A review of three textbooks for LCA have been published as Weidema B P, Brandão M. (2019): Book Review. Journal of Industrial Ecology. This file provides more detailed comments for one of the textbooks:

Detailed comments for the ILCA assessment criteria for a good beginner's LCA textbooks for Jolliet O, Saadé-Sbeih M, Shaked S, Jolliet A, Crettaz P. (2016). *Environmental Life Cycle Assessment.* Boca Raton: CRC Press

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General requirements

Low (or no) price
£57.40, $83.97 (Electronic version; January 2017)

Up-to-date
An example of the importance of choosing the right functional unit, using a case study on popcorn as packaging material, clearly misses one of its most important messages because the case study used was published in 1994, before land use became an interesting issue for LCA. The recent version 3 of the ecoinvent database is described in section 4.3, which nevertheless includes outdated statements on energy modelling that are only true for version 2. In section 4.2.1 also reproduces data from ecoinvent version 2. Table 5.1 reproduces the IPCC 2007 values for global warming potentials (somewhat outdated for a 2016 textbook). Chapter 6.7 provides a review of LCA software which will quickly be outdated and may not really be relevant for a textbook. More interesting would be to understand what calculations are involved and why different software give different results.

Readability (Numerical score: Flesch–Kincaid test, using word length and sentence length, applied to textbook introduction)
Use of terms are unsystematic at times. For example, a descriptive list (om p. 7) is introduced as a list of definitions. The term "accurately" is used on p. 48, where the right terms would have been "precisely". Renewable energy is said to "require" the use of non-renewable energy on p. 51. Flesch–Kincaid score: 29 (Very difficult)

All new topic-specific terms explained when introduced and/or in glossary
There is a glossary, but it does not include core terms such as "Environment", "Attributional" or "Consequential". The latter two terms are introduced with the definitions provided by Finnveden et al. (2009) and Curran (2005), respectively, that describe the "focus" and "aim" of these methods, rather than their nature, as in the more recent and authoritative definition by UNEP/SETAC (2011). Electricity "mix" is used in Section 4.2.2.1 on energy modelling, but the idea of a mix (system boundaries, average or marginal) was not been introduced in the text previously. The term "intrinsic uncertainty" is introduced (in section 6.5.1.2.3) without any definition being provided.

Mentions alternative terms used in practice, to provide the student with an appropriate vocabulary to comprehend the general literature that use these alternative terms
Alternative terms used in practice are seldom mentioned. In Section 3.5 on system boundaries, the inconsistent definition of ISO 14044 (that the system boundary is the set of criteria to define the boundary) is uncritically repeated and even highlighted without alternatives.

Does not introduce unnecessary terms or use terms in other ways than usual, unless clearly justified and announced
LCA is introduced (on p. 10) as concerned with impacts of "products and services" while normal (and ISO 14040-series) usage is that the term "products" covers goods and services. On the same page, it is stated that "A partial LCA can also be conducted", which would not be an LCA according to ISO 14040. On the same page, LCA is introduced as a "decision-making tool", where probably "decision-supporting" would be more correct. In Chapter 3 on goal a system definition, the term "scenarios" is used, without justification, for what ISO 14040 calls "product systems" having the same functional unit in a comparative LCA, while the term scenario is normally used to signify alternative macro-economic futures. A distinction between primary and secondary functions of a system is introduced, without any clear definition nor indication of the purpose of this distinction. Final energy is given a thermodynamically unclear definition ("Energy provided and purchased by user"). Internalization (section 6.8.2) is presented as the measurement and expression of the external costs, while it should more correctly be described as the process of adjusting the prices to include the external costs.

Logical structure, avoiding repetition and avoiding introducing topics that later turn out to be unnecessary
Section 3.5 introduces the problems of cut-offs, but also “Note that the input–output method of LCA avoids many of these issues associated with cutting off the supply chain”. However, the introduction of this method is delayed till Section 4.4.4. In Chapter 4 "The inventory simply combines the previously calculated reference flows of unit processes in the system with emissions and extractions for each unit process". However, there was no previous calculation mentioned for the reference flows, nor is the combination "simple" unless the unit processes have first been provided with additional information required for the linking. A general observation on the differences between databases appears unexpectedly, hidden within an example, in the description in Section 4.2.2.1 on how to calculate primary energy. In secion 4.3 on inventory databases, it is unexpectedly said that "During goal setting, the system boundaries are defined and all processes included within these boundaries are listed and quantified", a quantification that was not mentioned explicitly in the Chapter 2 on goal and system boundaries, and which leaves it unclear where the boundary between scoping and inventory is intended to be. In the description of the ecoinvent database, the different system models are described, and a recommendation is made of using the cut-off model. For the reader, that is yet uninitiated to allocation, this recommendation comes without rationale. Likewise, marginal modelling is suddenly introduced in a discussion on electricity mixes, without having been mentioned at all before. In Chapter 5.4 a listing of impact assessment methods is given, with a quick description of each. In the next section 5.5 these methods are again mentioned but in more detail. It would have been preferable if these two lists had been integrated. Discounting is introduced under LCC (section 6.8.1) without any separate heading although the topic is also highly relevant for “environmental” and social impacts. A section on Cost Internalization is placed under life cycle costing, although it appears to belong better in the Chapter on LCIA. Rebound effects, which really belongs in the inventory chapter

(and/or with system boundaries under goal and scope) is treated in Section 6.8.4 (the Chapter on interpretation).

Contextualizing LCA within its broader field
In Chapter 2.3.2 a comparison to other tools for environmental assessments is attempted, but the explanations of these other tools do not capture the core differences between the tools. In section 7.3.4, LCA is mentioned as a "mandatory basis for the environmental declaration of products and the definition of ecolabel criteria". However, it is not mentioned that these applications only use reviews of LCA results and do not - or only in a limited way - apply the LCA technique itself. In section 7.3.6 LCA is described as being "part of the larger framework of life cycle thinking", while the logical conceptual order would be that both belong to the larger field of Environmental Management.

Clear relationship to Life Cycle Costing and Life Cycle Sustainability Assessment
The concepts are introduced at the end of Section 2.3, but a clear delimitation of environment (term not defined in textbook) from sustainability is still missing. A third term "technical analysis (life cycle engineering)" is added as a component of sustainability aspects, without further explanation. Economic analysis is further treated in Section 6.8.1, and social LCA in Section 6.8.5.

Basic concepts are introduced
Some basic principles of system modelling are introduced in Section 3.4.1, which includes a useful Figure 3.3. that shows that the (physical) inputs to a product system from the rest of the economy is zero (a more problematic issue in this Figure is the sharp division between economy and environment - as is the question of the missing labour input…).

Introduces basic quantitative skills required
Somewhat out of place (in Section 6.4.1.9 in the interpretation chapter), there is some useful advice on the use of spreadsheets.

Clear relation to ISO standards
The textbook follows the ISO 14044 standard in structure, but not in all definitions and details. In Chapter 3 on goal and scope definition, the authors rename this to "goal and system definition" "to highlight to the reader the importance of clearly delineating and describing a system" – an important issue, but still a narrowing of the scope as described in ISO 14040. Furthermore, the new name is not applied consistently throughout the book (not even in the glossary), which still features "goal and scope" in many places. Chapter 5 on LCIA is introduced with the question "how do we interpret this inventory data?", which may be confusing, since LCIA and interpretation are separate phases in LCA. With reference to Heijungs et al. (1992) it is stated (in Chapter 6) that "the goal of interpretation is to examine various ways of reducing environmental impacts and then identify priorities for taking action." It is not explained why this is the sole goal and no reference is given to the ISO definition and the issues of assessing which conclusions are valid, i.e., the study quality issues.

Provides additional detail and explanations relative to ISO
The text provides additional detail, explanations, and examples. In Section 3.2 on the functional unit, an additional (unjustified and unnecessary) requirement is added that the FU functional unit must be "additive, such that the impact of two FUs is double that of one FU".

In Section 3.4.2, a new requirement is introduced that each scenario (i.e. product system) “being compared in the LCA must have its own flowchart”.

Quantitative uncertainty and data quality clearly stressed throughout in an operational manner
Uncertainty is mentioned several places in the book, and separately discussed in section 6.5.

Rigour and prudence throughout the text, and providing rationales for any normative statements
In the Chapter on principles (on p. 10), LCA is said to be characterised by "Quantified balances are made over the entire life cycle" without explanation of what it is that is balanced, nor explaining how this should be understood in relation to the lack of mass and energy balances in traditional attributional LCA. In the same list, it is stated that "LCA accounts for all major environmental issues known today", which is not true if the ISO 14001 definition of the environment is applied (Environment is not defined in the textbook, neither in the glossary nor in the text). For the function of a product system (Section 3.2), the term "select" is used, and in section 6.5.1.2.2 the functional unit, the system boundaries, and the allocation are presented as normative choices, rather than as something to be empirically identified. Chapter 4 on inventory analysis talk of flows crossing the system boundary (singular) while the analysed scenarios (product systems) are stated in plural. It is unclear of the implication is that the calculation is done for the difference between the scenarios. In Chapter 4.3.3 on data quality and uncertainty, the availability of uncertainty information in ecoinvent and use of Monte Carlo simulation is described, without mention of the serious unaccounted incompleteness issue in the database.

Providing rationales and practicable procedures for all recommendations
In Chapter 6, the interpretation phase is described as “particularly useful for discussing and analyzing the results of the complete inventory before moving on to the impact assessment” and it is recommended that “the contributions of each stage of the life cycle should be compared” and "the contributions of each system component should be reviewed". Rationale is missing for why this should be particularly interesting. Although a bit more logical, a rationale would also have been good for the recommendation that "the respective contributions of each pollutant and extracted substance should be analyzed, identifying which emissions and extractions generate the most impact for each impact category". In section 6.8.2 it is recommended that "care must be taken when summing and comparing different types of costs to ensure that adding them is legitimate", but no procedure to judge legitimacy are provided.

Text and calculations checked for errors
In Chapter 3 it is stated that “When comparing environmental impacts of different modes of transport (rail, road, and air), the time to travel a given distance … cannot be directly included in the FU”, which is incorrect, since the total behaviour during the longest time can be used as functional unit, thus including any rebound effects. In Figure 3.5 something has gone wrong with the mass and energy balances, while the accompanying text reads "Since this is a physical system, mass and energy balances can be carried out to check that unit processes and the global system respect conservation of mass and energy." Maybe a hidden student exercise? It is incorrectly stated (on p. 71) that for transportation, the ecoinvent database "provides average data assuming an empty truck on the return trip". In section 6.6.5, as a significant limitation of Taylor series expansion for uncertainty propagation, it is stated that it is "being confined to lognormal distributions for all input and output variables" which

is however not the case, as explained by Heijungs (2009) in his article "Sensitivity coefficients for matrix-based LCA" in Int. J. of LCA. The Internal Rate of Return (IRR) is presented as "a useful metric and well suited for decision-making purposes. The higher the IRR of a scenario, the more profitable it is." However, when comparing mutually exclusive projects, and especially projects with different time profiles, Net Present Value (NPV) is the appropriate measure, not IRR. Profitability is measured by the ratio between profit and income. NPV measures the relative VALUE of an investment, while IRR measures the RATE of yield, i.e. the rate of pay-back on an investment and is thus only relevant as an additional measure in capital constrained situations. In relation to Table 6.8, the values 0.7 and 8 are said to be in same order of magnitude. Eco-efficiency is introduced in section 6.8.3, as a way to achieve the greatest reduction of environmental impact per monetary unit. An example is provided that is announced as illustrating the four quadrants of an ecoefficiency graph. However, the example only includes options 1 and 3. It is also theoretically impossible to determine which of the options 2 and 4 is the socially optimal one, since that depends on the weight given to the two axes of the graph, i.e. the monetary value of the environmental impact. When specifying the axes, an implicit weighting is done, and then one may as well add the external and internal costs (=NPV) instead of studying their ratio (as suggested in formula 6.7) since this does not tell you which one is socially optimal, only what rate (yield) you obtain for the given cost for each solution. A socially optimal solution (the one with the lowest sum) can have the lowest eco-efficiency. The attribute approach of Norris (2006) for accounting for social impacts is wrongly named "the attributional LCA approach".

Real-life examples throughout, illustrating good practice and the points made in the text
As an example of a simple application, a comparison of single-use and multiple-use cups is provided in Chapter 2.4. However, in the goal and scope definition of the example, unjustified exclusions are made: "The production and use of detergent for washing the cup are not considered here" and "the infrastructure for cup production are excluded because their impact ... is considered negligible". A table provides an excerpt of the inventory, which comes without introduction, and without explanation for why these specific emissions (or why all of these) were chosen to be shown, and without uncertainty? In the impact assessment, it is revealed that "the relative ranking of scenarios is identical in all three damage categories" and the remaining discussion therefore just uses the total aggregated impact. In the conclusions of the example, it is stated that for a sporting event, "the impact of the cups is relatively small compared with that of the transportation of people to the location of the event". A better example would have been on a more important issue, have had a wider scope, possibly with justified exclusions, and would have shown differences in results between impact categories, so that the student would see what to do in such a case. In Section 3.1.1 on goal definition, some examples are given to demonstrate how "The intent of a given LCA should be clearly specified to avoid ambiguity among the potential applications and audiences". However, this importance is not clear from the examples, and it is unclear how the LCAs would have been performed differently with a different goal definition. In Section 3.2. on system functions, the primary function of a car door is given as "Help to ensure safe use of the car" (should it not rather have been something to do with access?), with secondary functions of "Protection from theft" (not a function of the door as such, but rather of the lock) and "Sealing the car shut" (for which you really do not need a door). Examples of secondary functions of "potatoes" is "Maintenance of arable land" and "Protection of the landscape and environment", for which it is really not obvious that you would need potatoes. An example of the importance of choosing the right functional unit, using a case study on popcorn as packaging material, clearly misses one of its most important messages because the case study used was published in 1994, before land use became an interesting issue for LCA. An

example on the functional unit of light bulbs introduces price differences between the compared options, but does not mention the rebound effect, although "behavioral factors" are mentioned at the end of the example as important for "the social dimension" (rather than being an integrated and crucial part of the procedure). In Section 3.3.5 on multifunctional systems, it is stated that "the function chosen for analysis is important to identify" and an example is given for a system of wheat crop production, where number of options are discussed. However, the reader is left without a clue on how to make this choice. It seems to be said that one can make a choice for any of the options and thus get any result you like. The relation to the goal is completely missing. In the section 3.5 on system boundaries, an example is given of a comparison of a fast-food restaurant with a traditional one, noting that "The first flaw with this study is that the system boundaries are chosen as the walls of the restaurant, only accounting for the processes that occur within the restaurant", without noting that this means that the study is not an LCA at all. Furthermore, two different LCIA methods are used for the two alternatives, obscuring the comparison of the system boundaries. And finally, there is no explanation given for the large change in the "use" stage, a stage that is not mentioned anywhere in the example. A strange example is introducing Section 4.1.3 on aggregation over time and space: "If a product leads to a total emission of 5 kg of SO2 into air, this may consist of 1 kg emitted in India in 2000, 0.1 kg emitted in Switzerland in 1995, 3 kg emitted in Brazil in 2010, and 0.9 kg emitted on the "world market" (without geographical specification) in 2014", apparently involving causality backwards in time? In section 4.2.3 an example of the front-end panel of a car is given, where the LCI result (here called "the emission and extraction matrix") appears out of the blue, without any explanation of the calculations. In Chapter 6 on interpretation an example is given of a comparison of a desktop and a lap-top computer. Besides being a somewhat outdated issue, this would be an excellent example if the purpose is for the students to find errors or problems in the presented study, but presented here without criticism, the use of problematic examples does not fulfil the educational purpose. Section 6.4.1 and most of the following sections seem very theoretical. It would be good with one or more examples throughout this part of the book. In section 7.3.2 on application to ecodesign, a number of design principles are suggested as being defined with basis is LCA. However, all of these principles could be identified with life cycle thinking alone. A more appropriate example would be one where LCA gave a surprising counterintuitive result (i.e., counterintuitive to life cycle thinking).

Relevant and tested exercises provided
Each Chapter ends with exercises. In the exercises for Chapter 2, the student is asked to decide which assessment method "is most appropriate for the following situations" and to list "key reasons for using this method". A better question would have been: "What can each of these methods contribute in this specific situation?" (although the prior text does not provide sufficient information to answer either of these questions).

Additional resources provided for download
No

References to relevant further reading
Yes

Option for providing feedback to authors (and having responses)
No

Specific content requirements

Introduces setting of goal and scope, including the core distinctions of average versus marginal modelling
Goal and scope is described in Chapter 3 (although under a different name), and shortly introduces attributional and consequential modelling (without a fulfilling definition) and simply provides the programmatic statement that "In this book, we will help the reader to pragmatically consider the question...: "How can a model, or a combination of models, best be used to answer a question recognizing both strengths and weaknesses of different modeling frameworks and available data?"" Marginal modelling is suddenly introduced in a discussion on electricity mixes in the ecoinvent database in Chapter 4.3, without having been mentioned at all before, and not being explained here either. Non-linear modelling is introduced in section 6.6.3.1 with this example: "If an LCA predicts such high impacts that, for example, all species will disappear, a nonlinear consequential approach could suggest that decreasing the load slightly yields no improvement. In such a case, a simpler linear relationship yields the more realistic result that decreasing the load leads to the long-term reduction of impacts." However, it is not explained why the linear relationship should be more realistic for modelling marginal changes, considering that if all species have already disappeared, a slight decrease in dose will not make them come back.

Introduces the concept of a functional unit, including the conditions for substitution
In section 3.3, but without mention of substitution.

Introduces procedures to ensure all relevant impacts are included in an LCA study, including social issues
"Traditional LCA" (undefined term) is said to exclude social issues, and only to include environmental (also undefined term). It is not mentioned that already Fava et al. (1991) described LCA as including broad social aspects.

Basic introduction to unit processes and data collection for these
In section 4.2.1. a Step 2 simply states that data for unit processes "can be found (a) in databases, (b) by measurements, or (c) by direct contact with companies", not mentioning estimation and calculation, and not specifying whether there is any preference order or principle. It is really not very helpful for the uninitiated student to describe how "data of the highest quality" can be collected as: "This can be by extrapolation, adapting a similar (but not representative) process to match the considered process, or by simply using a similar process as a proxy" (p. 49).

Introduces the construction of linked databases from unit processes, introducing also the parallel between matrix and flow chart notations
Section 3.4.2, entitled "Flowchart" begins "The flowchart or flow diagram or process tree (such as the one depicted in Figure 3.6) provides a clear overview of the processes and their relationships"; yet in Figure 3.6 does not show how much natural gas flows into the different activities supplied by natural gas, and while there were 8 inputs to the central process In Fig. 3.5, there are only 6 in the corresponding flowchart 3.6. Maybe a hidden student exercise to find the missing flows? In Chapter 4 "The inventory simply combines the previously calculated reference flows of unit processes in the system with emissions and extractions for

each unit process". However, there was no previous calculation mentioned for the reference flows, nor is the combination "simple" unless the unit processes have first been provided with additional information required for the linking. In section 4.2.1. a Step 1 introduces an unexplained "association" between a reference flow and intermediary flows and an unexplained concept of "core unit processes", and Step 4 suggests to "Calculate emissions of each unit process by multiplying the amount of each unit process per FU by its emission factors" without any indication of how to obtain the amounts (scaling factors) of each unit process to be used for this calculation. In the example aggregated inventory of extractions and emissions for liquid primary aluminium at plant, taken from ecoinvent 2.2 (somewhat outdated for a 2016 publication), there is no mass balance and it is not very obvious how these data were arrived at. Thankfully, a reference is provided that "Sonnemann and Vigon (2011) provide additional guidance on how to collect data for a given unit process"; and even a much clearer (and even free) source of guidance than what the textbook provides on this topic.

Basic introduction to the inventory calculus, explaining also the similarity of process LCA and Input-Output calculus
Section 3.4.1 ends with a statement that "All processes required to fulfill the system function should be part of the system. In practice, this is often not possible, either because of a lack of data or time to carry out the LCA." It would have been helpful with a reference here to the global input-output databases that provide the desired completeness. Chapter 4 on inventory analysis talk of flows crossing the system boundary (singular) while the analysed scenarios (product systems) are stated in plural. It is unclear of the implication is that the calculation is done for the difference between the scenarios. In the introduction to Chapter 4, IO tables are mentioned, but without clearly distinguishing physical and monetary IO tables. "For the process approach" it is stated that "inventory is calculated by "multiplying the reference flows and corresponding intermediary flows" by the direct emissions of each unit process, without information what "corresponding" means, and why this is procedure is only relevant in the process approach, since later the same is repeated for the IO approach, except for an additional procedure "using economic data to first relate the direct demand for a good or service to the total demand in the entire economy", the rationale behind which is not explained.

Introduces the options for combining process-based and IO LCA, highlighting the options for taking the best from both approaches and avoiding cut-offs
Yes, in section 4.4.5 after first having introduced the two approaches. Two IO databases are compared (in section 4.4.2.2), but no explanation is provided for the observation that Open-LC emission factors are smaller than the CEDA factors for the majority of sectors. A strange statement of "extraction of uranium often not considered" (p. 80) is not further explained. In a comparison with process based LCA, it is just stated that it is "important to be aware of differences in the approaches and to carefully verify the compatibility of I/O and process data if they are ever combined in a single study", but nothing more specific on what to do. It is said that "I/O data are generally relatively old due to the lag time between data gathering and publication" without any comparison to the similar (or worse) situation for most process-based data. In Figure 7.1 (System boundaries; Rule 2), it is recommended to cut-off already available information, in spite of IO-data being part of the same Figure.

Introduces the concepts of markets
Not introduced.

Introduces alternative procedures for handling of co-production, including the distinction between combined and joint production
Substitution is suddenly introduced in an example in Section 4.2.2.2, without prior introduction (e.g. in section 3.3 on, where it would have been natural). Co-production is discussed in section 4.5, but without mentioning the distinction between combined and joint production.

Introduces the concept and procedures for handling rebound effects
An example on the functional unit of light bulbs introduces price differences between the compared options, but does not mention the rebound effect, although "behavioral factors" are mentioned at the end of the example as important for "the social dimension" (rather than being an integrated and crucial part of the procedure). Rebound effects are not introduced until Section 6.8.4 (in the Chapter on interpretation).

Introduces the relevance of temporality of emissions (e.g. the often erroneous assumption of neutrality of biogenic CO2-emissions)
Not introduced.

Introduces Life Cycle Impact Assessment and the impact pathways (cause-effect chain, environmental mechanism) concept
Yes, in Chapter 5. A very useful explanation of what LCIA is all about is given here: "How can you compare lead emissions in water with chlorofluorocarbon (CFC) emissions in air? How can you compare increases in human toxicity with contributions to climate change? In other words, how can you compare apples and oranges? Some would say that it is not apples and oranges, but apples and elephants—their impacts are so different! These elements cannot be directly added, and an apple plus an elephant does not equal two apple-elephants (Figure 5.1). But it is still possible to compare an apple and an elephant by considering criteria to which they can both be related. If you are concerned about the resistance of a floor, the weight or the weight per square meter is a good criterion. In the case of an apple weighing about 0.2 kg and an 8 t elephant, the elephant is equivalent to about 40,000 apples! Other equivalencies can be defined from other perspectives and criteria, such as their nutritional potential (in the unlikely case that an elephant is eaten) and the emissions of aromas if we focus on odors!"

Figure 5.2 is presented as being reproduced from ISO 14040 as showing an impact pathway. However, the figure does not show an impact pathway, but only a single impact category within such a pathway. Also, it does not appear in ISO 14040. The closest is Figure 3 in ISO 14044, but it is different (does not have more than one endpoint). Also, the text in ISO 14044 provides quite a different picture than what is presented in the text here.

Explains the implicit weighting that may occur when choosing and normalising impact categories
In the section on normalization, only one specific way of doing normalisation is described and there is no discussion of the purpose, need and dangers of normalisation. In the example on p. 155, normalised damages are being compared, without mentioning that this is a misuse of normalised data. A few pages further on, it is nevertheless stated that "For example, although the normalized scores for human health and ecosystems are both expressed in

person-years per FU, they cannot be summed directly without implicitly or explicitly assuming weighting factors for the total normalized impacts of these two categories."

Introduces the procedural aspects of weighting, objectivity-criteria, the role of science in soliciting values, and democratic and consensus-based approaches to weighting

Not mentioned.

Introduces mass balancing as quality assessment tool in both inventory and impact assessment

In Chapter 4 it is nicely mentioned that "When possible, we perform the mass balance of each substance in the studied process to verify that the utilized data and calculated elementary flows still conserve mass" but this is not followed in any of the examples later, e.g. for the aggregated inventory in Figure 4.1.