Int J Life Cycle Assess (2016) 21:293–296
DOI 10.1007/s11367-015-1026-0

COMMENTARY AND DISCUSSION ARTICLE

# Attributional and consequential LCA in the ILCD handbook

**Tomas Ekvall[1] · Adisa Azapagic[2] · Göran Finnveden[3] · Tomas Rydberg[1] · Bo P. Weidema[4] · Alessandra Zamagni[5]**

Received: 4 December 2015 / Accepted: 28 December 2015 / Published online: 11 January 2016


**Abstract**
*Purpose* This discussion article aims to highlight two problematic aspects in the International Reference Life Cycle Data System (ILCD) Handbook: its guidance to the choice between attributional and consequential modeling and to the choice between average and marginal data as input to the life cycle inventory (LCI) analysis.
*Methods* We analyze the ILCD guidance by comparing different statements in the handbook with each other and with previous research in this area.
*Results and discussion* We find that the ILCD handbook is internally inconsistent when it comes to recommendations on how to choose between attributional and consequential modeling. We also find that the handbook is inconsistent with much of previous research in this matter, and also in the recommendations on how to choose between average and marginal data in the LCI.
*Conclusions* Because of the inconsistencies in the ILCD handbook, we recommend that the handbook be revised.

**Keywords** Attributional LCA · Average data · Consequential LCA · ILCD handbook · Life cycle inventory analysis · Marginal data · Review

Responsible editor: Mary Ann Curran

✉ Tomas Ekvall
tomas.ekvall@ivl.se

1 IVL Swedish Environmental Research Institute, PO Box 5302, 400 14 Göteborg, Sweden

2 The University of Manchester, Manchester M13 9PL, UK

3 KTH Royal Institute of Technology, 100 44 Stockholm, Sweden

4 Aalborg University, Skibbrogade 5, 9000 Aalborg, Denmark

5 Ecoinnovazione, Via Guido Rossa 26, 35020 Ponte San Nicolò, Italy

## 1 Introduction

The International Reference Life Cycle Data System (ILCD) Handbook (JRC-IEA 2010) was developed by the European Joint Research Centre (JRC). The ILCD handbook comprises several volumes and was produced in a major effort by researchers at JRC in collaboration with external researchers. The handbook was reviewed by an international panel of LCA experts but not revised after the review. It has been required for use in several EU projects (e.g., European Commission 2015a, b) and is referred to as a guideline for good life cycle assessment (LCA) practice (e.g., Laurent et al. 2014) and as a starting point for further methodological choices (e.g., Ahlgren et al. 2015).

Because of the significance of the ILCD handbook in the LCA community and in the environmental policy initiatives that followed—among which the Single Market for Green Products (European Commission 2013a, b)—and because it was not revised in response to the external review, we feel it is important to discuss the limitations of the document. The aim of this discussion article is not to review the full handbook, but only to highlight a couple of problematic aspects in the way the detailed general guide (JRC-IEA 2010) deals with attributional and consequential LCA. The choice between and application of attributional and consequential LCA is important, since this has a strong influence on the LCA results. The use of attributional and consequential LCA for decision-making has also recently received significant attention by other authors (e.g., Anex and Lifset 2014; Brandão et al. 2014;

Dale and Kim 2014; Hertwich 2014; Plevin et al. 2014a, b, c; Suh and Yang 2014).

We analyze the ILCD guidance on attributional and consequential LCA by comparing different statements in the ILCD handbook with each other and with previous research.

## 2 Analysis

### 2.1 Attributional or consequential LCA

The ILCD handbook states that the modeling in the life cycle inventory (LCI) analysis relates to the concepts of attributional and consequential modeling (JRC-IEA 2010 p. 36). The distinction between attributional and consequential LCI was originally made at an international workshop on electricity data in 2001, although similar distinctions had been made earlier by several authors, using different terminologies and slightly different definitions (for a review of early works, see Ekvall 1999). The 2001 workshop stated that attributional and consequential LCI respond to different types of questions (Curran et al. 2005):

- Attributional LCI considers the flows in the environment within a chosen temporal window.
- Consequential LCI considers how the flows may change in response to decisions.

The outcome of the 2001 workshop has been interpreted differently and/or been slightly revised by other authors. For example, Finnveden et al. (2009) state that:

- Attributional LCA is defined by its aim to describe the environmentally relevant physical flows to and from a life cycle and its subsystems.
- Consequential LCA is defined by its aim to describe how environmentally relevant physical flows will change in response to possible decisions.

The glossary in the Shonan database guidelines (Sonnemann and Vigon 2011) defines the terms as:

- Attributional approach: System modeling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.
- Consequential approach: System modeling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.

The ILCD handbook itself states (p. 71) that:

- The attributional LCI model describes its actual or forecasted specific or average supply chain plus its use and end-of-life value chain, all embedded into a static technosphere.
- The consequential LCI model describes the supply chain as it is theoretically expected in consequence of the analyzed decision, embedded in a dynamic technosphere that reacts to a change in the demand for different products.

The ILCD handbook also identifies three archetypical situations in which LCA can be used:

A. Micro-level decisions (products)

   – Improvements, comparisons, procurement
   – Labeling: type 1 criteria, EPD, carbon footprint

B. Meso-macro level decisions (policy)

   – Identifying improvement potentials
   – Policy development

C. Accounting (products and policy)

   – Monitoring and reporting at all levels

The handbook uses this structure to provide methodological guidance and provisions linked to each situation. One such example is the choice between attributional and consequential LCA.

According to all of the definitions above, consequential LCI should be used for situations A and B in the ILCD handbook, since it states (p. 37) that, when LCA is used as decision-support, the LCI model should reflect the consequences of the decision. Apparently inconsistently, the ILCD handbook explicitly recommends attributional modeling for micro-level decisions (p. 82) and for most of the life cycle when meso- and macro-scale decisions are investigated (p.85). One exception is processes where the decision causes big changes (p. 41; p. 85). Changes are judged to be big if they correspond to more than 5 % of the total production capacity of the production system or to more than the annual replacement of production capacity in the system (p. 42). The only other exception given (p. 13) is sensitivity analyses, where attributional modeling can be displaced by consequential modeling to evaluate the robustness of the study results and conclusions.

### 2.2 Average or marginal data

Attributional and consequential modeling are different in terms of, for example, the choice of input data. Finnveden et al. (2009) state that attributional LCI is based on average data

**Table 1** The choice of input data in LCI models aiming to assess decisions according to Azapagic and Clift (1999) and the ILCD handbook

| Data to model | Azapagic and Clift (1999) | ILCD handbook |
|---|---|---|
| Small changes in production volume | Marginal | Average |
| Significant changes in production volume | Incremental | Marginal |
| Complete change of production system | Average | ?* |

*Not clearly specified

that represent the actual physical flows. The ILCD handbook (p. 71) basically agrees with this, but it is more specific and states that producer-specific data should ideally be used for modeling the production of goods and services for which the supplier is known.

For consequential LCI, Finnveden et al. (2009) state that marginal data are used when relevant to model consequences. Marginal data represent changes that are small enough to be approximated as infinitesimal. Azapagic and Clift (1999) state that such changes “are in effect very small and do not cause a change in the way the system is operated”. Ekvall (1999) suggests that marginal data can be used to model the effects of many actions on the production of bulk materials, energy carriers, and services for which the total production volume is very high.

It is often useful to distinguish between short-term and long-term marginal changes. Short-term effects are changes in the utilization of the existing production capacity in existing production plants, while long-term effects involve changes in the production capacity and/or production technology. Weidema et al. (1999) state that most LCAs involve choices that directly or eventually affects the capacity of the production systems in the life cycle. Ekvall and Weidema (2004) argue that any change can be expected to have both short-term and long-term effects; however, they add that long-term effects are likely to be more relevant to model in environmental studies because they are driven by a concern for the long-term situation.

The ILCD handbook (p. 85) requires long-term marginal data to be used to model production systems where the decision causes big changes. Hence, it agrees with previous authors that long-term marginal data are adequate to model certain consequences. However, it disagrees on whether marginal data should be used to model small or large changes (see Table 1).

The previous authors are not a homogenous group, but most of them would agree with the view of Azapagic and Clift (1999) that small changes should be modeled using marginal data (c.f. Brandão et al. 2014). Average data of the new system should be used when the change involves a complete elimination or change of a production system. This is reasonable because average data describe the production system as a whole. Azapagic and Clift also argue that changes that do not affect the full production system but a significant share of the production volume should be modeled using scale-dependent, incremental data.

The ILCD handbook, in contrast, requires that average data are used to model small changes. Marginal data are used only to model changes that are big enough to have a direct, large-scale effect on the production capacity of the system (p. 42; p. 170) and in these situations the handbook does not specify any upper limit to the use of marginal data.

It has been argued that the uncertainty in the marginal data is often large (e.g., Finnveden 2008; Mathiesen et al. 2009) and that significant time and effort are required to understand and reduce this uncertainty (e.g., Ekvall et al. 2005; Zamagni et al. 2012). On the other hand, other authors (e.g., Weidema 2009) argue that the error is greater in attributional LCA compared to consequential LCA due to low accuracy. Therefore, we would argue that the recommendation should not be to use average data when the change is small and marginal data when the changes are big enough to have a direct, large-scale effect on the production capacity of the system. Instead, it would be better to recommend, for consequential LCA, the use of marginal or incremental data to model changes when the accuracy is important, i.e., when the choice of data is important for the results and conclusions of the study.

## 3 Conclusions

The recommendations on attributional and consequential LCI in the ILCD handbook are in part inconsistent with much of previous research on attributional and consequential LCA. If the ILCD handbook is regarded as a scientific document, this not necessarily a problem: as science evolves, new findings and new methods need not be consistent with the old ones if the old ones are proven wrong or outdated. If regarded as a scientific document, the main problems are that it is not internally consistent and that it does not convincingly show that the earlier published methods are wrong or outdated.

However, the ILCD handbook is not primarily a scientific document but a guide for LCA practitioners in academia, industry and policy. As such, it ought to be not only internally consistent but also consistent with established research findings and methods widely agreed upon and used in the LCA community. Therefore, we recommend that the handbook be revised in accordance to the discussion in this paper as well as the recommendations of the expert review panel.

**Acknowledgments** Tomas Ekvall and Tomas Ryberg acknowledge the financial support provided for the writing of this article by the Swedish Research Council Formas and the Swedish Environmental Protection Agency through the Foundation for IVL Swedish Environmental Research Institute (SIVL).

## References

Ahlgren S, Björklund A, Ekman A, Karlsson H, Berlin J, Börjesson P, Ekvall T, Finnveden G, Janssen M, Strid I (2015) Review of methodological choices in LCA of biorefinery systems—key issues and recommendations. Biofuels Bioprod Biorefin 9(5):606–619

Anex R, Lifset R (2014) Life cycle assessment: different models for different purposes. J Ind Ecol 18(3):321–323

Azapagic A, Clift R (1999) Allocation of environmental burdens in multiple-function systems. J Clean Prod 7(2):101–119

Brandão M, Clift R, Cowie A, Greenhalgh S (2014) The use of life cycle assessment in the support of robust (climate) policy making: comment on "using attributional life cycle assessment to estimate climate-change mitigation…". J Ind Ecol 18(3):461–463

Curran MA, Mann M, Norris G (2005) The international workshop on electricity data for life cycle inventories. J Clean Prod 13(8):853–862

Dale BE, Kim S (2014) Can the predictions of consequential life cycle assessment be tested in the real world? Comment on "using attributional life cycle assessment to estimate climate-change mitigation…". J Ind Ecol 18(3):466–467

Ekvall T (1999) System expansion and allocation in life cycle assessment—with implications for wastepaper management. PhD thesis. Dept. Technical Environmental Planning, Chalmers University of Technology, Gothenburg, Sweden

Ekvall T, Weidema B (2004) System boundaries and input data in consequential life cycle inventory analysis. Int J Life Cycle Assess 9(3):161–171

Ekvall T, Tillman A-M, Molander S (2005) Normative ethics and methodology for life cycle assessment. J Clean Prod 13(13-14):1225–1234

European Commission (2013a) Building the single market for green products. Facilitating better information on the environmental performance of products and organisations. COM(2013) 196 final, Brussels, 9.4.2013

European Commission (2013b) Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. 2013/179/EU

European Commission (2015a) EEB-01-2016: Highly efficient insulation materials with improved properties. In: Horizon 2020 Work Programme 2016–2017: 5.ii. Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing. European Commission Decision C (2015)6776 of 13 October 2015

European Commission (2015b) NMBP-06-2017: Improved material durability in buildings and infrastructures, including offshore. In: Horizon 2020 Work Programme 2016–2017: 5.ii. Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing. European Commission Decision C (2015)6776 of 13 October 2015

Finnveden G (2008) A world with $CO_2$-caps. Electricity production in consequential assessments. Int J Life Cycle Assess 13(5):365–367

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S (2009) Recent developments in life cycle assessment. J Environ Manag 91(1):1–21

Hertwich E (2014) Understanding the climate mitigation benefits of product systems: comment on "using attributional life cycle assessment to estimate climate-change mitigation…". J Ind Ecol 18(3):464–465

JRC-IEA (2010) International Reference Life Cycle Data System (ILCD) Handbook—General guide for Life Cycle Assessment—Detailed guidance. First edition March 2010. Publications Office of the European Union, Luxembourg. Available at http://lct.jrc.ec.europa.eu/

Laurent A, Clavreul J, Bernstad A, Bakas I, Niero M, Gentil E, Christensen TH, Hauschild MZ (2014) Review of LCA studies of solid waste management systems—Part II: methodological guidance for a better practice. Waste Manag 34(3):589–606

Mathiesen BV, Münster M, Fruergard T (2009) Uncertainties related to the identification of the marginal energy technology in consequential life cycle assessment. J Clean Prod 17(15):1331–1338

Plevin RJ, Delucchi MA, Creutzig F (2014a) Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers. J Ind Ecol 18(1):73–83

Plevin R, Delucchi M, Creutzig F (2014b) Response to comments on "using attributional life cycle assessment to estimate climate-change mitigation…". J Ind Ecol 18(3):468–470

Plevin RJ, Delucchi MA, Creutzig F (2014c) Response to "On the uncanny capabilities of consequential LCA" by Sangwon Suh and Yi Yang. Int J Life Cycle Assess 19(8):1559–1560. doi:10.1007/s11367-014-0739-9

Sonnemann G, Vigon B (2011) Global guidance principles for life cycle assessment databases. UNEP/SETAC Life Cycle Initiative, Paris/Pensacola

Suh S, Yang Y (2014) On the uncanny capabilities of consequential LCA. Int J Life Cycle Assess 19(6):1179–1184

Weidema BP (2009) Avoiding or ignoring uncertainty. J Ind Ecol 13(3):354–356

Weidema BP, Frees N, Nielsen A-M (1999) Marginal production technologies for life cycle inventories. Int J Life Cycle Assess 4:448–456

Zamagni A, Guinée J, Heijungs R, Masoni P, Raggi A (2012) Lights and shadows in consequential LCA. Int J Life Cycle Assess 17(7):904–918