Chapter 12
Life Cycle Interpretation

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Abstract The interpretation is the final phase of an LCA where the results of the other phases are considered together and analysed in the light of the uncertainties of the applied data and the assumptions that have been made and documented throughout the study. This chapter teaches how to perform an interpretation. The process of interpretation starts with identification of potentially significant issues in the previous stages of goal and scope definition, inventory analysis and impact assessment, and examples of potential significant issues are given for each phase. The significance is then determined by checking completeness, sensitivity and consistency for each of these identified issues. The outcome is used to inform previous phases on the needs for strengthening the data basis of the study, and where this is not possible to reconsider the goal and scope definition of the study. Finally, guidance is given on how to draw conclusions based on the previous steps of the interpretation, qualify the conclusions in terms of their robustness, and develop recommendations based on the results of the study.

Learning objectives After studying this chapter, the reader should be able to:

- Explain the purpose of interpretation and its relationships to the other phases of the LCA.
- Explain what is meant by "significant issues" and give examples of potential significant issues from each of the methodological phases.
- Describe procedures to identify significant issues.
- Explain how sensitivity analysis and uncertainty information is used in combination to focus the data collection in previous phases of the LCA and to qualify the conclusions that are drawn from the results of the study.

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12.1 Introduction

Interpretation is the phase of the LCA where the results of the other phases are considered together and analysed in the light of the uncertainties of the applied data and the assumptions that have been made and documented throughout the study. The outcome of the interpretation should be conclusions or recommendations that (1) respect the intentions of the goal definition and the restrictions that this imposes on the study through the scope definition and (2) take into account the appropriateness of the functional unit and system boundaries. The interpretation should present the conclusions of the LCA in an understandable way and help the users of the study appraise their robustness and potential weaknesses in light of any identified studylimitations.

Central elements of the interpretation phase such as sensitivity analysis and uncertainty analysis are also applied throughout the LCA process together with impact assessment tools as part of the iterative loops which are used in the drawing of boundaries and the collection of inventory and impact assessment data (see Chaps. 8–10). A more detailed presentation of these elements is given in Chap. 11.

The interpretation proceeds through three steps as illustrated in Fig. 12.1.

1. The significant issues (key processes and assumptions, most important elementary flows) from the other phases of the LCA are identified (see Sect. 12.2).

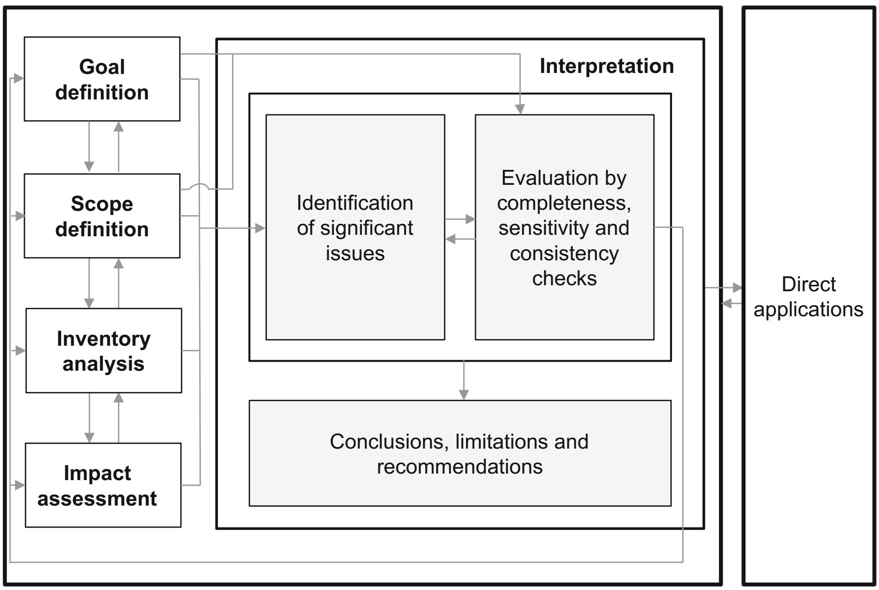

Fig. 12.1 The elements of the interpretation phase and their relations to each other and to the other phases of the LCA (revised from ISO 2006a, b)

2. These issues are evaluated with regard to their influence on overall results of the LCA and the completeness and consistency with which they have been handled in the study (see Sect. 12.3).
3. The results of the evaluation are used in the formulation of conclusions and recommendations from the study (Sect. 12.4).

In cases where the study involves comparison of two or more systems, there are additional considerations to be included in the interpretation (Sect. 12.5).

12.2 Identification of Significant Issues

The purpose of the first element of the life cycle interpretation is to analyse the results of earlier phases of the LCA in order to determine the most environmentally important issues, i.e. those issues that have the potential to change the final results of the LCA. The significant issues can be methodological choices and assumptions, inventory data for important life cycle processes, and/or characterisation, normalisation or weighting factors used in the impact assessment. The practitioner is encouraged to prepare a list of such choices during the practical execution of the LCA, the definition of goal and scope, the modelling of the product system and the impact assessment, to help with their identification (see for example reporting recommendations for life cycle inventory phase in Sect. 9.7). Table 12.1 provides examples of such influential issues.

As discussed in Chap. 11, sensitivity analysis can be performed as a contribution analysis where the contribution from each process or stage to the total results for an impact category is quantified and expressed. It can also be done as a dominance analysis, where the processes or stages are ranked according to their relative share in the total impact.

The identification of significant issues draws on the sensitivity analysis activities in the evaluation element of the interpretation phase in combination with information about potential key assumptions and uncertainty ranges for potential key numbers in inventory analysis and impact assessment. At the same time, the evaluation element takes the identified significant issues as an important input. The two elements are thus performed in iteration.

In the illustrative case on window frames in Chap. 39, life cycle impacts are dominated by the use stage in all impact categories for all four window frame designs. Parameters related to the use stage, such as the modelled heat loss, the assumed mix of heating sources, the LCI processes used to represent each heat conversion technology in the heat mix, and the relevant characterisation factors and normalisation references involved in the impact assessment were thus identified as significant issues.

Table 12.1 Examples of significant issues

What to look for	How to identify significant issues
Goal and Scope definition—methodological choices and assumptions	
Functional unit	Choice of functional unit, system expansion (assumption of alternative/replaced technologies), allocation model and setting of system boundaries are discrete choices that can be checked by running the different possibilities as scenarios and comparing the results to determine their influence on the final outcome and conclusions
Handling of multifunctional processes – System expansion – Allocation criteria	
Cut-off decisions and boundary settings	
Inventory analysis—data for product system processes	
Data for activities occurring in many parts of the product system, e.g. transportation or energy transformation processes	Sensitivity analysis is performed by varying the single issue, or in case of interdependency by joint variation of the concerned issues, and analysing their influence on the outcome of the study The range of variation applied for a given issue should reflect the uncertainty by which it is accompanied
Data for key processes: processes that contribute substantially to the environmental impact of the product system in one or more impact categories	
Data for key elementary flows: processes that contribute substantially to the overall results for an impact category	
Impact categories that dominate the total impacts from the product system	
Impact assessment factors	
Characterisation or normalisation factors used in the impact assessment	Sensitivity analysis is performed by varying the single issue, or in case of interdependency by joint variation of the concerned issues, and analysing their influence on the outcome of the study The range of variation applied for a given issue should reflect the uncertainty by which it is accompanied
Choice of impact assessment method and selection of impact categories	Other impact assessment methods and potentially omitted impact categories may be tested to see if they give different outcomes of the study

12.3 Evaluation

The evaluation element establishes the basis for the conclusions and recommendations that can be formulated in the final element of the interpretation (see Sect. 12.4). It is performed in an iterative interaction with the identification of key issues in order to determine the reliability and stability of the results from the identification element.

Like the identification of key issues, the evaluation covers the results from the earlier phases of the LCA, the inventory analysis and the impact assessment, in accordance with the goal and scope of the study, with focus on the significant issues identified among methodological choices and data.

The outcome of the evaluation is crucial to determine the strength of the conclusions and recommendations from the study, and it must therefore be presented in a way that gives the commissioner and user of the study a clear understanding of the outcome.

The evaluation involves:

- Completeness check.
- Sensitivity analysis in combination with uncertainty analysis.
- Consistency check.

12.3.1 Completeness Check

Completeness checks are performed for the inventory and the impact assessment in order to determine the degree to which the available data is complete for the processes and impacts, which were identified as significant issues. If relevant information is found to be missing or incomplete for some of the key processes or the most important elementary flows or impact categories, the necessity of such information for satisfying the goal and scope of the LCA must be investigated. If deemed necessary, the inventory and impact assessment phases must be revisited in order to fill the identified gaps. Alternatively, the goal and scope definition may have to be adjusted to accommodate the lack of completeness. If an important data deficiency cannot be remediated, this should be considered when formulating the limitations in the conclusions from the study (see Sect. 12.4). If the missing information is found to be of little importance, this should be documented in the reporting of the completeness check.

Taking the completeness check of the illustrative case on window frames (see Chap. 39) as an example, several gaps were identified. In relation to LCI, the applied heat mix was thus only representative for district heating (and hence not appropriate for situations with local heating sources), and the LCI unit processes used to model the energy technologies applied in the heat mix were geographically representative for Norway and Switzerland and hence not fully representative for Denmark. With regard to LCIA, the use of site-generic characterisation factors for some impact categories may not be fully representative for the specific impact pathways of environmental flows released in or close to Denmark. Once identified, those gaps therefore underwent the procedure described in Fig. 12.2 to be addressed in the study.

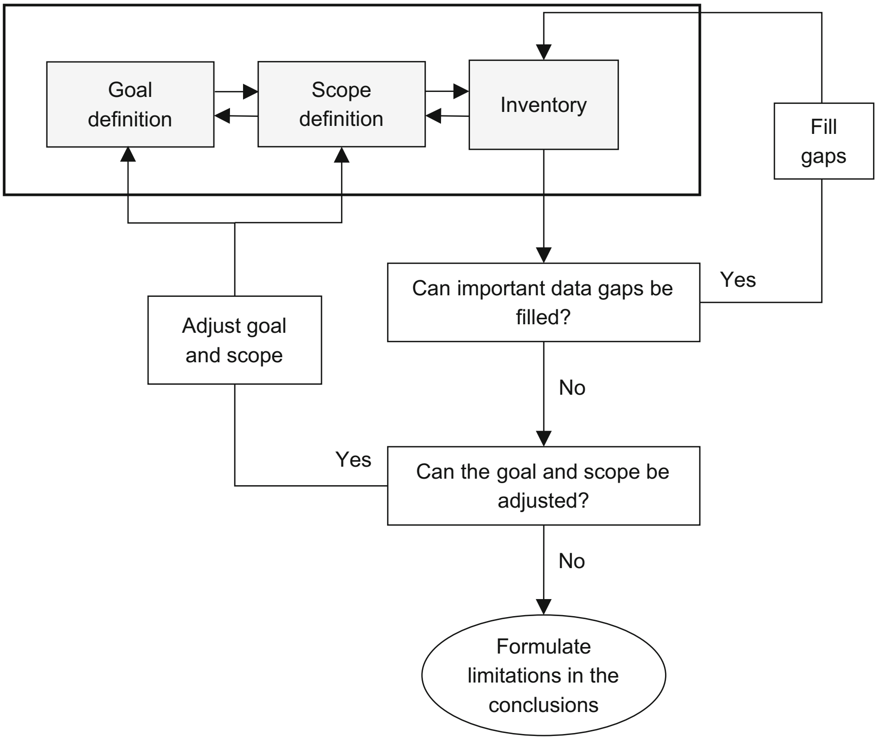

Fig. 12.2 Iterative interaction between completeness check and the earlier phases of the LCA

12.3.2 Sensitivity Check

Sensitivity check has the purpose of identifying the key processes and most important elementary flows as those elements that contribute most to the overall impacts from the product system. Sensitivity analysis can be performed and presented as a contribution analysis (which activities contribute to which environmental impact scores, by how much and through which elementary flows?) or a dominance analysis (which activities contribute most to which impacts or flows?). See Chap. 11 for a more detailed discussion of sensitivity analysis and how it is performed.

In the illustrative case on window frames, not all significant issues were covered in the sensitivity analysis due to lack of sufficient data and knowledge to construct sensitivity scenarios in some of the cases. A sensitivity scenario reflecting the EU27 heat mix was established and results showed that impacts for a few impact categories (mainly related to toxicity) were lower than in the baseline scenario, while most impacts were higher due to a larger share of oil and natural gas in the EU27 heat mix.

In support of the iterative approach applied in LCA, sensitivity analysis is also used as a steering activity in the iteration loops that are performed throughout the LCA in support of boundary setting for the product system, inventory data collection and impact assessment. The findings from these earlier sensitivity analyses are brought into the sensitivity check of the interpretation phase.

In the interpretation phase, sensitivity analysis is used together with information about the uncertainties of significant issues among inventory data, impact assessment data and methodological assumptions and choices to assess the reliability of the final results and the conclusions and recommendations which are based on them (Sect. 12.3) (Table 12.2).

Table 12.2 *Tools for sensitivity analysis*

Factors checked for sensitivity	Tools for sensitivity analysis
Data uncertainty	The influence of data uncertainty for key issues can be checked by allowing the data to vary within the limits given by the uncertainty estimates while modelling the product system and checking the results. If the information about the (stochastic) uncertainties of the individual elementary flows and characterisation factors allows it, it is also possible to calculate the uncertainty of the final results in terms of inventory and environmental impacts (e.g. simulating it using Monte Carlo techniques). See Chap. 11 for a more detailed discussion of uncertainty analysis and how it is performed
Methodological uncertainty	The influence of methodological (systematic) uncertainties can be checked by analysing different possible choices (e.g. of applied allocation principle) as scenarios and reporting the influence on the final results. Methodological choices which may be relevant to include in a sensitivity analysis include: handling of multifunctional processes (system expansion assumptions or allocation rules), cut-off criteria, boundary setting and system definition, and judgements and assumptions concerning data in the inventory; and for the impact assessment: selection of impact categories, assignment of inventory results (classification), calculation of category indicator results (characterisation), and normalisation and weighting of impact scores

The combination of sensitivity analysis and uncertainty analysis helps identify focus points for improved inventory data collection or impact assessment.

As illustrated in Fig. 12.3, data with a high uncertainty need not be a focus point for improvement if the sensitivity to this data is very low. In the same way, data which has a strong influence on the final results of the study may also not require further data collection effort if the representativeness of the data is high and its uncertainty negligible. The focus point for improvement of data quality should be data with a strong influence on the overall results and a high uncertainty or questionable. If such data cannot be improved, the result is a low precision which must be reported. If the precision is insufficient to meet the requirements from the intended application of the results, it may be necessary to revise the goal of the study. Figure 12.4 provides a decision tree for handling the sensitivity check.

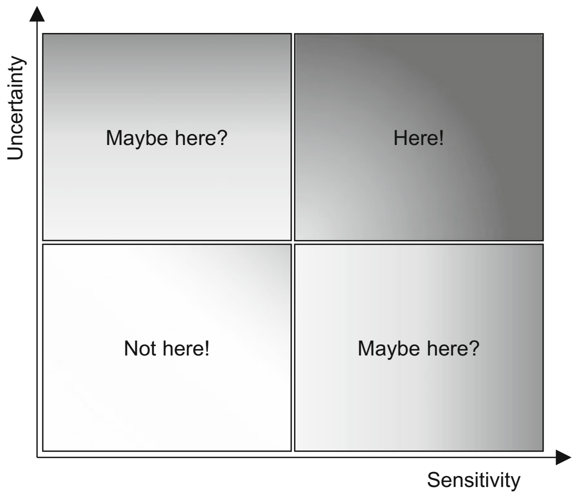

Fig. 12.3 Focusing collection of improved data by combining sensitivity and uncertainty information

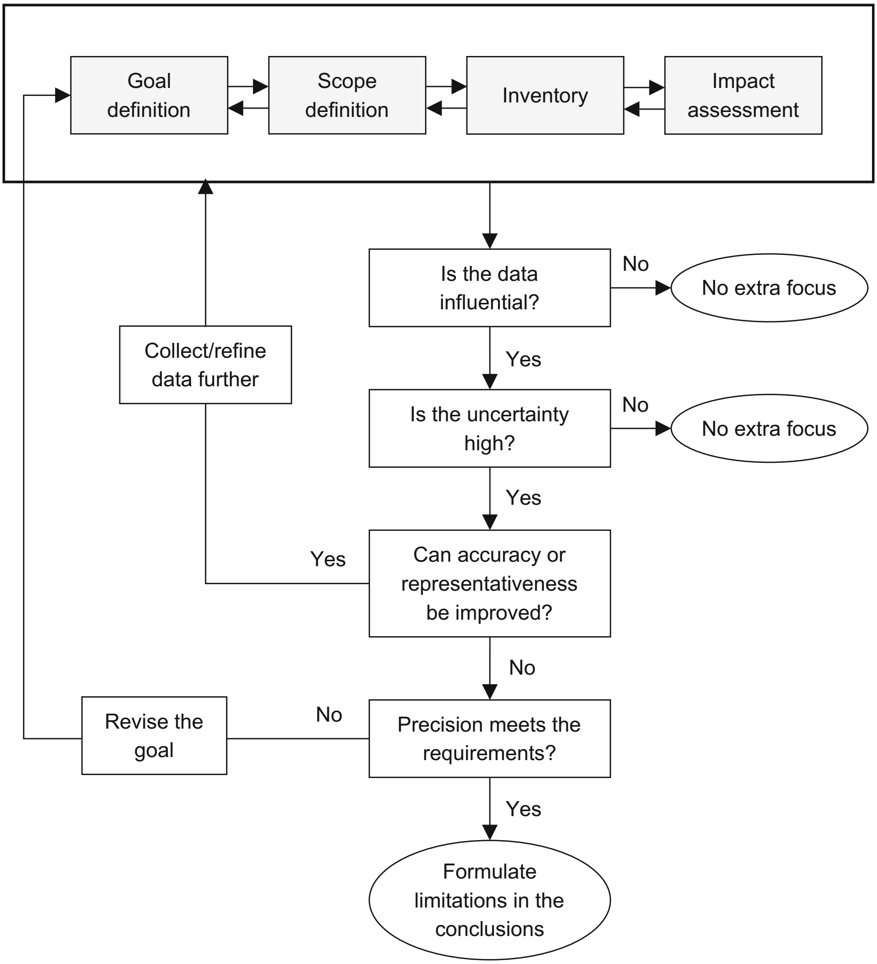

Fig. 12.4 Combination of sensitivity analysis and uncertainty information to focus improvement of the LCA data

12.3.3 Consistency Check

The consistency check is performed to investigate whether the assumptions, methods, and data, which have been applied in the study, are consistent with the goal and scope.

Are differences in the quality of inventory data along a product life cycle and between different product systems consistent with the significance of the processes, which the data represent and with the goal and scope of the study? Inventory data quality concerns both the time-related, the geographical, and the technological representativeness of the data, the appropriateness of the chosen unit process to represent the process of the product system, and the uncertainty of the data.

In case of comparison between different product systems, the consistency check also investigates whether allocation rules and system boundary setting as well as impact assessment have been consistently applied to all compared product systems.

When inconsistencies are identified, their influence on the results of the study is evaluated and considered to draw conclusions from the results.

Taking the window frame case as example again, the main identified inconsistency is between the goal and scope and the interpretation of the results which does not give due consideration to changes that may occur in particular in the background system within the time frame of the study (at least 20 years). Important changes are the Danish heat mix (for which the share of fossil fuels is expected to decrease) and the technological development in the heat supply technologies (see Chap. 39 for further details).

12.4 Conclusions, Limitations and Recommendations

Building on the outcome of the other elements of the interpretation, and drawing on the main findings from the earlier phases of the LCA, the final element of the interpretation has to draw conclusions and identify limitations of the study, and develop recommendations to the intended audience in accordance with the goal definition and the intended applications of the results.

The conclusions should be drawn in an iterative way: based on the identification of significant issues (Sect. 12.2) and the evaluation of these for completeness, sensitivity and consistency (Sect. 12.3), preliminary conclusions can be drawn. It is then checked whether these preliminary conclusions are in accordance with the requirements of the scope definition of the study (in particular data quality requirements, predefined assumptions and values, and limitations in methodology and study). If the conclusions are aligned with the requirements, they can be reported as final conclusions, otherwise they must be re-formulated and checked again.

Recommendations based on the final conclusions of the study should be logical and reasonable consequences of the conclusions. They should only be based on significant findings and relate to the intended application of the study as defined in the goal definition.

In the illustrative case on window frames (Chap. 39) it was concluded for example that the wood composite (W/C) window has the lowest impact among the four compared windows in all impact categories, and that impacts occurring in the use stage are generally dominating the total impacts and are caused by the demand for heat to compensate the heat losses that occur through the window. Albeit not visible in the results, due to the disregard of technological changes related to heat supply over the time frame of the study (likely going towards lower impacts), the dominance of the use stage impacts is likely to decrease with time, depending on what technological improvements are introduced in the other stages of the window life cycle, but it is still expected to remain significant in a foreseeable future. A follow-up study is recommended to further address these dynamics.

12.5 Interpretation for Comparative Studies

In studies that involve a comparison of product systems, the interpretation has to consider a number of additional points to ensure fair and relevant conclusions from the study.

- Significant issues must be determined for each of the systems, and special attention should be given to issues that differ between the systems and which have the potential to change the balance of the comparison.
- The completeness check must have specific focus on differences in the completeness of the treatment of some of the significant issues between the product systems. If there are differences that could influence the comparison results, these should be eliminated if possible and otherwise kept in mind in the formulation of conclusions.
- If an uncertainty analysis is performed to investigate whether the difference between two systems is statistically significant, the analysis should be performed on the difference between the systems (one system minus the other), which should be checked for a statistically significant difference from zero taking into account potential co-variation between processes of the two systems (e.g. processes which are the same). See the discussion of this point in Chap. 11.
- When an LCA is intended to be used in comparative assertions intended to be disclosed to the public, the ISO 14044 standard requires that the evaluation element include interpretative statements based on detailed sensitivity analyses. It is emphasised in the standard, that the inability of a statistical analysis to find significant differences between different studied alternatives does not automatically lead to the conclusion that such differences do not exist, rather that the study is not able to show them in a significant way.
- A consistency check must be performed of the treatment of the key assumptions and methodological choices in the different systems to avoid a bias and ensure a fair comparison.

  – Are differences in the quality of inventory data between the compared product systems acceptable, considering the relative importance of the processes in the product systems, and are the differences consistent with the goal and scope of the study? For example, if one study is based on specific and recent data with a high degree of representativeness for all the key processes while the other uses extrapolation from literature data, there is a bias in the inventory data that can make a comparison invalid.
  – Have allocation rules and system boundary setting been consistently applied to all product systems?

– Has the impact assessment been performed consistently for the systems, have the relevant impact categories been included for all systems, and have the impacts been calculated in the same way and with the same coverage of elementary flows for all the systems?

The influence of any identified inconsistencies on the outcome of the comparison should be evaluated, and taken into consideration when conclusions are drawn from the results.

References

This chapter is to a large extent based on the ILCD handbook and the ISO standards 14040 and 14044. Due to the scope of this chapter, some details have been omitted, and some procedures have been rephrased to make the text more relevant to students. For more details, the reader may refer to these texts:

EC-JRC: European Commission—Joint Research Centre—Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook—General guide for Life Cycle Assessment—Detailed guidance, 1st edn. March 2010. EUR 24708 EN, Luxembourg, Publications Office of the European Union (2010)

ISO: Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040). ISO, the International Organization for Standardization, Geneva (2006a)

ISO: Environmental Management—Life Cycle Assessment—Requirements and Guidelines (ISO 14044). ISO, the International Organization for Standardization, Geneva (2006b)

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