

**Danish-Dutch workshop on LCA methods, held
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1. Introduction

At this moment, there are two extensive methodology projects going on in Europe: a Danish project focussing on methodology development for a number of key issues - for a further description see Appendix 1 -, and a Dutch project aiming to update the Guide and Backgrounds of Heijungs *et al.* (1992) – for a further description see Appendix 2.

From 16-17 September 1999 a workshop has been held on LCA methodology issues as currently debated within the Dutch and the Danish LCA methodology projects. The workshop was held at CML in Leiden (The Netherlands) and was jointly organised by the coordinator of the Dutch and the coordinator of the Danish LCA project. The workshop has been financed by the Dutch Ministry of Housing, Physical Planning and the Environment and the Danish Environmental Protection Agency.

The workshop focussed on the following goals:

- Information exchange on ideas and work done within the two project in three areas,
 - Marginal-average in relation to the allocation issue;
 - Impact assessment;
 - Interpretation;
- To avoid, where possible, any unnecessary differences between the two projects;
- To make clear and explain the remaining differences;
- To recommend research that could overcome these differences in due time.

These goals were to be achieved by presentations of both projects on the different subjects; comments from three invited critical observers (Anne-Marie Tillman, Konrad Saur and Roland Clift); and extensive discussions. The critical observers made critical, independent observations to the presentations made and thus gave input to the discussion, widening the discussions to developments taking place in Sweden, Germany and the United Kingdom with respect to the areas mentioned above.

The workshop was a closed workshop for a very limited number of invited people only: a limited number of researchers from the Danish project, a limited number of researchers from the Dutch project and threecritical observers. The workshop programme can be found in Appendix 3 and a list of participants is contained in Appendix 4.

In advance of the actual workshop, researchers from both projects wrote papers on the several subjects discussed. These papers were written as an input for the discussion, and thus are not the result of the discussions. They have also not been adapted anymore as a result of the discussions. The papers written are attached to this report as appendices 5 to 11. The following papers were written for the three subjects:

Marginal- average including allocation issues

- Bo Weidema, 1999. Some important aspects of market-based system delimitation in LCA – with a special view to avoiding allocation.
- Reinout Heijungs and Gjal Huppes, 1999. Inventory modelling in LCA with a focus on marginal versus average analysis and solutions for the allocation problem.

Impact assessment

- Michael Hauschild, Heidi K. Stranddorf, and José Potting, 1999. Life cycle impact assessment – Danish recommendations.
- Anders Schmidt and Pia Brunn Rasmussen, 1999. LCA and the working environment - Danish recommendations.
- Leif Hoffmann and Heidi K. Stranddorf, 1999. Estimate for an average world citizen contribution to regional and local impacts
- Marieke Gorree and Jeroen Guinée, 1999. LCIA in the Dutch methodology project.

Interpretation

- René Kleijn, 1999: Interpretation in the Dutch methodology project.

This report is an as good as possible and as comprehensive as useful reflection of the discussions that took place during the workshop. In chapter 2 to 4 the remarks from the critical observers and the discussion that took place, will be reported for each subject discussed.

2. Marginal-average and allocation

Participants: Roland Clift, Jeroen Guinée, Helias Udo de Haes, Erik Hansen, Michael Hauschild, Reinout Heijungs, Mariane Hounum, Gjalt Huppes, Erwin Lindeijer, Christian Poll, Konrad Saur, Anders Schmidt, Heidi Stranddorf, Anne-Marie Tillman, Bo Weidema, Henk Wijnen

The input papers for this session (see appendix 3 and 4) were presented by Bo Weidema and Reinout Heijungs respectively. Both presenters largely followed the papers of the appendices and added some examples or other material.

After these presentations the critical observers were asked to give their comments and observations.

Comments Roland Clift:

- The subjects that we discussed, are very important especially when knowing that ISO Guidelines show shortcomings on a number of points. So ISO is only a document to refer to in this respect, and not more than that.
- It is very important to get the Danish and Dutch methodology project in one line, since it would be terrible to have two different Guides. If these two main projects would set the right track, it is very likely that others will follow this track.
- Wording matters. The problem is that LCA has been developed in isolation, and that words used in LCA mean different things elsewhere. E.g. inventory means measuring stocks in other disciplines, but in LCA it is used for measuring flows.
- Do not bring in the term 'guilt' and responsibility in justifying allocation methods; we are dealing with analysis.
- One should make a distinction between complexity (which refers to the structure) and complication (which refers to the detail). One should first try to agree on the structure and not on the detail, while all arguments in the presentations made are on the level of the details. LCA is not complex, but only complicated.
- Essential requirements for a structure include:
 - It should have ground in the literature. State where you do agree with literature and where you do not, and give the references.
 - It should be consistent, i.e. if the structure for handling change-oriented questions is not applicable to descriptive questions, then something is wrong.
 - The defaults advised must be generally consistent with the structure proposed, but the application of other approaches (non-defaults) should always be possible. Note that the term default is very confusing and actually implies that a method is universally applicable, which is not what is strived for in the Dutch project. So please use another term.
 - Keep the structure simple stupid, or better worded: keep it simple, clever people.
- With respect to structure, I could agree with the paper of Heijungs & Huppes nearly fully, but I disagree with the presentation made by Heijungs.
- The general reasoning for doing this in one situation and that in another situation is different between the method for handling allocation in the Danish and the Dutch project, but the general reasoning behind is the same.
- The general structure is something like the following. For system A with economic outputs $x_1 - x_i$, the burden B takes the form:
 $B_A = f_{n_A}(x_1, x_2, \dots, x_i, t)$.
Similarly for a different system C:
 $B_C = f_{n_C}(x_1, x_2, \dots, x_i, t)$.
System extension is a way of adding or subtracting systems to limit the differences to the change modelled. For example, if system C delivers x_2, \dots, x_i but not x_1 , then keep x_2, \dots, x_i the same for the two systems so that
 $B' = B_A - B_C = f_{n_A}(x_1)$
but at the one value of t only.
The next question then is, what is the kind of comparison at stake? Is it a marginal, incremental or average/complete change. The problem with default presented by the

Heijungs is that the allocation method proposed is not what one expects for a change-oriented LCA. The default presented for the change-oriented allocation case is exactly the same as applied in cost *accounting*. One would have expected an allocation based on how does B change with all the functional outputs?

For a marginal change, it is always true that (provided the x_i can be varied independently):

$$dB = \left(\frac{\partial B}{\partial x_1} \right)_{x_2, \dots, x_i, t} dx_1 + \left(\frac{\partial B}{\partial x_2} \right)_{x_j (j \neq 2), t} dx_2 + \dots + \left(\frac{\partial B}{\partial t} \right)_{x_j} dt$$

so that there is always complete allocation. [Usually the t term is omitted, of course, in short-term analysis].

Over the area where the system is linear or linearisable, the same approach applies:

$$\Delta B = \frac{\partial B}{\partial x_1} \Delta x_1 + \frac{\partial B}{\partial x_2} \Delta x_2 + \dots$$

However, this equation only applies with complete generality if the system is linear and homogeneous, i.e. "linear through origin" (in which case the coefficients are identical to the coefficients in the input/output matrix).

- Any default should be broadly consistent with the universal structure of a full analysis.
- Be consistent on how the general structure relates to different questions asked in LCA.

Comments Konrad Saur:

- These two important projects are being followed closely by the international LCA community, and they will influence the international discussion significantly.
- ISO is a sort of cook-book and not a bible; as taste changes, cook-books must change too and they must certainly not hold back further developments.
- Harmonisation cannot be enforced since there are too many applications. This is not solved by defaults, it depends on the application and this is a key difference between the Dutch and the Danish project.
- LCA cannot solve everything, and it should not be over- or underestimated. LCA should not be made too complex, otherwise it will be ruined and we are already contributing to that.
- The Danish and Dutch project are also different because cultures and backgrounds are different. The Danish project follows a case-by-case approach, where the Dutch more follow a general approach working with general databases (specific versus general approach).
- Both projects use the same general requirements as starting points for their methodological proposals – it must be consistent, applicable and understandable – but they use it in different sequences.
- There should not come 3 or 4 approaches, there should be one approach which is applicable to all situations.
- Then some general observation and specific questions:
 - It would be useful to include a discussion in the papers presented on whether the proposed allocation methods are generally applicable or whether they are strongly dependent on the goal and the scope of a study.
 - LCA has been developed independent from other tools. There is pressure from industry and other users to use information which is already available due to other tools. It is thus important to move closer to what is there with respect to data than to move further away from that and demand extra data. Furthermore, economic calculation methods should not be re-invented. Shouldn't we use as far as possible the same rules as the economists, even if the economists would not always do it right?
 - Is there a difference between descriptive and change-oriented studies? Shouldn't the same defaults, methods and data be used?
 - Fixed variables do not exactly describe reality. Non-linear process models should be allowed now. In the past we allowed only linear models, but various software packages already have options for non-linear process modelling (Note: non-linearity here refers relation between process inputs and outputs and not to economic non-linearities).

- There is no correct allocation rule. If reasonable methods really differ sensitivity analyses should be a mandatory element in the Guides.
- Are we looking for a general LCA-method with defaults and arguments to deviate from, or is e.g. Weidema's decision tree the default and should we argue to deviate from that?
- We need to be practical. I have no fundamental criticism to Weidema's in depth process approach, but industry people will probably have difficulties to apply it.

Comments Anne-Marie Tillman:

- It is good to see that both papers present a structure with a distinction between change-oriented and descriptive analysis, a development which was initiated by Chalmers.
- Starting from the questions being asked is also a good point and is the only possible way (based on goal definition and application) to solve these debates.
- It is a good to see that CML is now taking a more less normative position than in the Guide of '92, and doesn't advise on one correct method anymore.
- The CML defaults presented perfectly fit into a descriptive LCA (average data, prices etc.), but they are given for change-oriented LCAs. A change oriented study is usually concerned with changes only in some parts of the system and the consequences of those changes, which implies that a change-oriented approach may be used for those parts of the system and a descriptive approach for other parts.
- In both presentations the scale of change was not referred to, although this is an absolutely important aspect. Wordings as long term strategic have something to do with scale but not everything changes fully. Although studying a complete change that may affect some surrounding systems, changing my process completely may still leave the system's electricity demand unaltered.
- Then some comments on a more detailed level:
 - Rule no. 4 as presented by Weidema ("product being a waste"). Who is the judge to determine what is a waste or not, what is the criterion here? The only indicator for this is whether someone is willing to pay for it (=economic basis).
 - The distinction between structural and occasional choices as presented by Heijungs. I really cannot see how LCA can support occasional choices?

Two clarifications were made after the critical observers stated their comments and observations:

- Weidema's approach is meant as a "default" for a change-oriented LCA in structural choices, as is CML's allocation method.
- The Göteborg waste management model is an example of how an LCA type of analysis can support occasional choices (see paper Heijungs and Huppes).

From these remarks the following points were extracted for plenary discussion:

- The distinction between descriptive (retrospective) and change-oriented (prospective):
 - why is descriptive no subject in both methodology projects?
 - Is it possible to use the same overall approach for descriptive as well as change-oriented LCA?
- Default and universal applicability:
 - Who is going to use that default and for what purpose?
 - Is there a better term for default?
- What is the role of ISO in these discussions on marginal-average and allocation? Is the ISO allocation preference order still useful?
- Responsibility (guilt) versus analytic in justifying allocation methods.
- A listing of agreements, as far as possible and useful at this moment.

Distinction between descriptive and change-oriented

The distinction between descriptive and change-oriented is important since it made us aware of average-marginal discussion. Although the discussion today focusses on change-oriented or prospective LCA, the descriptive or retrospective LCA still also has useful purposes.

Descriptive LCAs might be used for question like: "if I look at the world as it is running now, what does car driving contribute to environmental problems". Or: "what would have been the

effect if we would have decided that X years ago". Or they are used to compile environmental performance reports for companies. Prospective LCAs indicate the effect of choices. Retrospective (including current) LCAs may come in two types:

1. Indicating the effects of past choices
2. Describing past performance.

The method for 1. is fully similar to the method for prospective. For avoiding confusion and differing outcomes, it was suggested to apply the same method also to 2., as also there the analysis should link to prospective actions.

The following purposes of descriptive LCAs were identified:

- Before you can formulate a question, you first have to determine your system, the alternatives etc. For this you need a descriptive analysis (there is something before the change).
- Descriptive LCAs are good for learning purposes
- LCA is an iterative process. Descriptive is very good starting point using whatever data we have, afterwards you could do a market based LCA. Descriptive LCA is an eye-opener for people that would have otherwise not seen certain things. Starting with a descriptive analysis is useful even though we know that the question determines the answer.

Also some problems related to descriptive LCA were identified:

- With respect to prospective analysis there seems to be agreement that this deals with effects of choices. With retrospective a specific question has to be posed too, otherwise you don't know what you are answering.
- It is a waste of time to collect first data in one way for e.g. a descriptive analysis, then throw away everything and collect data in another way for e.g. a prospective LCA. Why then not gather the right data right away.

On the one hand it was argued by several participants that descriptive and change-oriented LCA would give different results as they answer different questions. On the other hand it was argued that a descriptive, or accounting type of LCA should not give different results from a prospective LCA. They should start from a universal structure and the effect of changes should come up in the accounting approach. This would imply that they are the same! Finally it was concluded that there is a need for a solid general structure offering room for different LCA types, including prospective and retrospective LCAs. The different LCA types should be related to different applications, if possible. General structure implies that one should be able to use the same LCA structure or meta-methodology, although different choices are made on steps within the methodology such as on system boundaries, data, allocation, impact assessment methods etc.

It was argued that practitioners nowadays often do a very practical sort of change-oriented LCA. Then first a descriptive LCA is performed mapping the current environmental impact of a given product. Then, improvement proposals are generated, and the effects of these proposals (= change-oriented LCA) are calculated through scenario analyses.

Related to this, it was stated that industry is not interested in the effects of changes in their product designs on other products. For socially broader-scope LCA (called "strategic choices" in paper of Heijungs and Huppes) a market-based approach as proposed by Weidema might be more appropriate. The choice is thus application dependent.

There seemed to be agreement on the following:

- One cannot base decisions on descriptive analysis.
- One cannot compare current performances with future performances.
- Descriptive and change-oriented analyses should be consistent with each other in relation to different applications
- Only those processes should be modeled in a market-based way, which are really affected by the change at stake.

- How changes should be modeled depends on the time-perspective and the scale of the change (e.g., descriptive analysis really is proportional, while in change-oriented analysis the difference between 1 unit or 1 million units more may significantly matter).
- In prospective LCAs marginal processes should be selected, which are the ones that indicate future performance of the system. On how exactly these marginal processes are to be selected, the Dutch and Danish projects differ only slightly, basically as the marginal process selected depends on the time horizon taken into account.
- In medium and long term applications, the average type of functioning should be taken into account.
- It would be very useful to have standard lists of marginal processes for main products like electricity for the year 2000, 2010, 2020, etc.

Universal versus default

The term default caused quite some confusion. For some the word default suggested that you should actually do something better, or in other words, default is something you should do if you don't have better options.

CML explained the rationale behind the use of the term default. Default is not the approach one should always apply. For scanning/screening LCAs simpler approaches will be advised than the default. However, many choices have to be made in LCA default choices will be offered which are for the different choices mutually as consistent as possible. Default is not prescriptively meant but as do-able within the limits of the resources time and money. Depending on the application, numerous non-defaults should be analysed in the interpretation.

This explanation solved a lot of problems.

Alternative terms and wordings suggested during the workshop to replace the term default, include:

- best practical approach
- baseline approach
- proxy
- easy applicable
- recommended practice
- recommend "best available practice" for which in some situation a proxy is needed

CML will reconsider the term default within its project, and make it more clear that, and how, the use of "default" depends on the applications. Sometimes, the goal and scope of a specific study requires deviating from the "default" (during the workshop the term default was held on to for pragmatic reasons).

One may either specify a 'full' LCA, with a more coarse proxy both in methods and in data for some applications, or one can specify a 'proxy' and indicate extras for increasing quality and assess sensitivities. The latter approach is followed by CML.

At a recently held Danish workshop, it was questioned whether a market-based allocation could always be performed for time and money reasons. It was suggested that market-based allocation was only important for a minor part of the co-product situations in which the results would be significantly different from those of other allocation procedures.

Not everybody could agree to this since some felt that it would be misleading to apply the correct method just to some processes and the less correct method for the remaining largest part of the processes.

Furthermore it was felt that it was not possible to determine which method is the correct one since all of them have advantages and disadvantages, both practical and theoretical.

One of the main disadvantages of the market-based approach, for example, is its practicability. According to Weidema, however, getting the marginal technologies is very easy by just phoning companies and asking some specific questions; in this way "default" marginal technologies can be given for quite a number of processes. However, it was felt by several participants that this way of working puts an awful lot of trust in company data, and only works for the short term and for specific company LCAs. What to do in case of changes on the scale of a whole society; long term strategic question cannot be solved by phoning company X.

Weidema replied to this that one should base the delimitation on interviews with a representative section of the market, and for future market situations, 10-year forecasts of the

EU are available, and the MARKAL-MATTER model includes 50-years forecasts including technology shifts.

Another disadvantage of the market-based approach is that although there is a lot of necessity and logic attached to the market-based approach, it was doubted that data etc. would be available to do it in practice. Furthermore, the market is often not that stable, in which case it is difficult to apply the market-based approach.

A disadvantage for both approaches is that a number of existing databases would have to be adapted, while the unallocated data, which are needed for that, are not available, such as in the case of e.g. the PWMI database. Therefore, both are not the best *practicable* approaches now, but that may not be a good argument to withhold these approaches since this will be valid for any new methodological proposal, at least in the area of allocation. If a clear method exists, databases can be adapted.

Since market-based and economic allocation both deal with prospective studies, both assume linearity in process data and both address marginal technologies, the question was asked whether the two approaches were really that different, or if they do, will they still look that different when further details have been worked out on how to apply both approaches properly. Answer on this cannot be given yet now, but maybe time will learn that both approaches are closer than they look now. As a first exercise, it could be investigated on a number of cases the results are mutually robust and point in the same (right?) direction. This part of the discussion was finalized by concluding that it would be useful to take five well-known process examples and then compare the results and type of reasoning of two approaches.

Next the following question was posed: are the Dutch and Danish national projects aiming for BATNEEC (best available technology no entailing excessive costs) or CATNIP (cheapest available technology not incurring prosecution)? This might clarify the differences between both projects. The question more or less remained unanswered.

The next question addressed was: are the methods proposed by Weidema and Heijungs & Huppes maybe related to different applications?

According to the authors, this is clearly so for the proposal of Heijungs & Huppes. They propose a distinction between occasional, structural and strategic decisions incurring different choices such as in the case of marginal process data for (short term) occasional decision. For different applications the general LCA body is the same in their proposal, but the details with respect to different choices differ.

Then Huppes discussed a sort of layered structure in which the approaches presented today and also the approach proposed by Ekvall in his thesis would fit in:

1. Ekvall's approach takes full account of market-mechanisms, in recycling only, by modelling elasticities. This is scientifically the most appropriate way to do it, but in practice it is unfeasible for all processes.
2. Weidema makes a simplification to Ekvall's approach by only taking 0 and 1 elasticities into account. This approach is feasible in practice, although maybe not for all applications. Several participants think, however, that this approach will require extra time and money, while Weidema argues that compared to the average approach, the market-based system delimitation is time-saving.
3. Heijungs and Huppes make a further simplification by not taking elasticities into account, but only the price mechanism. This makes the approach easily applicable in practice, although even this is often argued.

For the Heijungs & Huppes allocation method, it was proposed to perform an obligatory sensitivity analysis with the market-based approach in case a co-product is fully utilized and the co-product flow is important.

Furthermore, CML stated that the market-based allocation method will be included in the Guide as a non-default method with, if possible, some clear Guidelines in which situation it would especially be important to perform market-based allocation as a sensitivity analysis. Since there were no principal objections against neither of the two approaches discussed today, Huppes and Weidema will discuss further about putting both approaches in a meta-framework, about detailed comments and about how to refer and deal with each other's methods within the two national methodology projects.

Finally, as many practitioners will probably keep applying the “old” allocation methods, it was advised to include statement in the LCA-Guides being developed advising not only on which different methods can be applied, but also which ones should better not be used.

ISO

Some things in the ISO standards might support what we discussing here, but there is no clear reference to this kind of debate. However, it was generally felt that ISO should not hold up further developments and debates and that it should not be considered a “Bible”.

However, one should also not unnecessarily deviate from difficult consensus processes as ISO. It is necessary to give justification for deviations, but that is also exactly what is aimed for and done in the papers of Weidema and Heijungs & Huppes.

A listing of agreements, as far as possible and useful at this moment

In the paper of Heijungs & Huppes there was a list of choices included as made for a number of LCA methodological steps (see appendix 6, pp. 53-55). At the end of the discussion on “marginal-average with special focus on allocation issues”, this list was taken as a starting point to see on which choices the workshop participants could agree. The following notes were taken:

- All participants agreed that for long-term large-scale questions, steady state equilibrium modelling is the most appropriate approach. However, the models are likely to include constraints. Where the model relationships and constraints are linear, it is convenient to develop the system models in the Linear Programming form.
- In LCA temporal aspects are only included to a very limited extent.
- Spatial specification of processes is also included in only a limited way; the Danish project will, e.g., include proposals for site-dependent impact assessment. Site-specific impact assessment was concluded to be outside the scope of LCA.
- In a very limited way, LCA includes a number of economic market-mechanisms. Full demand-supply relations will probably never be included.
- Distinguish between product – and process – related emissions, for example dioxins from incineration of materials containing chlorine. However the emissions need to be fully allocated to the relevant parameters describing product throughput and process operation.
- Mathematical form. Most of us go for linear homogeneous inventory process models. Linear homogeneous process models should be used wherever possible for inventory analysis, recognising that a linearised model is usually only applicable over a limited range of parameters. Where the system is subject to constraints (e.g. in short term analysis when capital goods are fixed but capacity is variable to a certain limit), they should be included in the model (for example, by Linear Programming). In these cases, the burdens will be allocated in part to the constraints.
- The procedures for selecting the relevant technologies in change-oriented LCAs are very similar: modal modern (see Heijungs & Huppes in appendix 6) is quite similar to marginal technology (always on unconstrained process) except in a shrinking market.
- On allocation there is no general agreement on which methodology to apply, but different options are feasible and reasonable. The practitioners will have to choose themselves. It might be relevant to further distinguish here between short-term and long-term decision, but this has to be sorted out further.
- It was agreed that it might be useful to have an explicit list in the Guides being developed of approaches not to be used anymore, such as an allocation on mass basis. As this is also a non-recommended approach in ISO 14040, the practitioners should be advised not to use this approach and they should be warned that thus all former databases are wrong!

Finally, the issue of combined versus joint allocation was discussed. It was concluded that the method specified by Weidema for joint situations is also applicable for combined, as similar reasoning on elasticities of supply and demand are applicable there. Weidema will expand his text on this issue to show this. As also in economic allocation, there is no difference between joint and combined, the distinction loses its relevance in this context. It was considered a research issue whether both approaches give different results or not.

The final conclusion of the chairman was that this workshop day appeared to have been a very fruitful day, with constructive discussion in a good scientific atmosphere. There even appeared to be quite some agreements:

- The distinction between retrospective and prospective is significant.
- Retrospective analysis is important for e.g. educational purposes, but not for decision support.
- Prospective analysis is important for decision support and some kind of market-based approach (be it Ekvall, Weidema or Heijungs & Huppel) should be followed.
- In a prospective analysis, it is important to identify the marginal technologies, if these are not stable we can fall back on some kind of average technology.

In the discussion of the list of choices above, it appeared that there were no really big disagreements, although there is also no general consensus on what to do preferably in e.g. prospective analysis. There seemed to be general agreement on the principles of change-oriented versus descriptive analysis and related principles for allocation. On further details, opinions start to differ. However, it should be possible to work out a meta-framework (for which a start was given during the workshop by Huppel) of the approaches discussed in relation to different applications and/or different levels of sophistication in modelling economic mechanisms. For this, further discussions must take place between people involved from both national projects, and examples should be worked out as mentioned before.

Then, in the end it might be possible to distinguish between the following categories of methods:

- ultimate practice (the practice to strive for through further research, but not feasible now);
- best available practice ('second' best solutions);
- acceptable practice ('third' best solutions);
- unacceptable practice.

3. Impact assessment

Participants: Marieke Gorree, Jeroen Guinée, Helias Udo de Haes, Erik Hansen, Michael Hauschild, Mariane Hounum, Gjalt Huppes, René Kleijn, Christian Poll, Konrad Saur, Anders Schmidt, Heidi Stranddorf, Anne-Marie Tillman

The input papers for this session (see appendix 5, 6, 7 and 8) were presented by Michael Hauschild, Anders Schmidt, Heidi Stranddorf, Marieke Gorree and Jeroen Guinée. All presenters largely followed the papers of the appendices and added some examples or other material.

After these presentations the critical observers were asked to give their comments and observations.

Questions and comments by Anne-Marie Tillman:

- Is it possible to make a better connection in the LCIA discussion with the inventory discussions on marginal-average from yesterday?
- The trend to develop spatial approaches is good, but location data need to be collected in the inventory and the inventory data should also not be aggregated anymore for a spatial LCIA. The Dutch default doesn't fit with this development since then all inventory emissions will be aggregated.
- There should be clear Guidelines for practitioners how chemicals from the inventory results should be interpreted in impact assessment terms. This deals with the problem of chemical groups such as VOC and C_xH_y etc. And also with questions like: is there a difference between SO_x and SO_2 or can they be added applying the same impact factor, or if not, then what is the difference? Etc.
- Has spatial differentiation already been applied or tested in case studies, and is there experience with collecting geographical data? Answer of Hauschild: No, it has not been applied yet, but there will be a case study on this in the further course of the Danish project. Hauschild emphasises that the spatial differentiation guidelines in the Danish project will be voluntary: only when one wants to do it, then.....
- With respect to weighting, it is clear that there are different approaches and that there is not one preferred or correct option here. However, is it possible to state what kind of info is contained in a specific weighting method, and is it possible to recommend a method depending on the application? Magnus Bengtsson, student at Chalmers, is working on this.

Questions and comments by Konrad Saur:

- By the exclusion of non-European contributions in Europe-based spatial LCIA methods, an important part of the burdens is potentially shifted to the developing countries. We should be concerned about this.
- We should also be concerned about the fact that there is a trend to base the normalisation only on European data, while a significant part of the total global emissions takes place outside Europe. This should at least be mentioned in the Guides.
- Be transparent. The users of the models should understand the models and the limitations and possibilities of these models. Normalisation figures are often misused, since practitioners often don't realise that these figures are only valid for a specific characterisation method and for a limited amount of chemicals (if new characterisation factors are added, the normalisation figures should be updated too!).
- Although the proposal for work environment (WE) presented by Anders Schmidt looks good, I would not apply WE in LCA but do it separately. It is a different method and has a different scope. Or we should redefine LCA as a toolbox (cf. CHAINET) out of which different methods can be chosen depending on the application etc.
- Define the role of sensitivity and uncertainty analyses for the use of the different models, and advise practitioners that these analyses should be performed as a "default".

- The inventory data collection needs to be steered by demands from LCIA. Inventory data should be collected for those chemicals for which we have characterisation factors. So, please include a data collecting list in the Guides, and explain that SO_x is something different in mass terms than SO₂. Practitioners often don't know this. Furthermore, I support the comments on this point of Anne-Marie Tillman. One cannot calculate with BOD, AOX etc. These are water quality parameters, and for LCIA better and more adequate inventory data are needed.
- None of the presenters today described the inclusion of inventory parameters, like water and solid waste, in the LCIA results.
- Advice should also be given on how to present results, e.g., don't show only the weighting results but also show the impact scores, the underlying inventory results, and the results of sensitivity analyses. Saur recently wrote a paper about this subject which he will distribute among the participants of the workshop.

After these questions and comments of the critical observers, an inventory of the main discussion points was made. The following issues were identified:

- How to deal with categories not modelled to the system boundary, such as waste, and how should these be normalised and weighted?
- Which reference for normalisation is appropriate: person equivalent (per capita) or per area?
- How to deal with working environment? Is there an overlap with other toxicity categories?
- Which time perspective should be taken in LCIA (infinite, 100 years) or is this category dependent?
- How far can the choice of specific category indicators be harmonised between the two national projects, and is co-operation possible on toxicity impact indicators as to solve the problem of the remaining uncharacterised 100,000 chemicals (PTB profiles as first data estimate for multi-media modelling)? It was concluded here that this should be discussed further between the two projects aiming to avoid unnecessary differences and to justify clearly where both projects deviate. It was noted with particular emphasis here that harmonisation *and* continuous developments are both needed both; harmonisation should never withhold further developments. It was even suggested that it still was too early for harmonisation and that a competition of ideas was firstly needed now.
- Connection of LCIA to inventory in several respects (connection to marginal-average discussion; inventory data requirements from LCIA; and chemical groups and nomenclature problems).
- Is a cross impact categories consistent regionalisation possible, e.g. distinguishing a limited number of regions which are useful for all impact categories?
- Is co-operation useful and possible between the Dutch and the Danish projects with respect to the collection of data for normalisation? This will be discussed further within the two national projects.

For a plenary discussion the following three subjects were selected:

- Work environment;
- Reference of normalisation;
- Time.

Work environment:

In the Danish project WE is an important category based on the viewpoint that shifting of problems from outside environment to inside work environment should be prevented. LCA gives the overall framework to deal with issues of problem shifting and therefore WE should be part of LCA. The ambition of the Danish project is to map this potential problem shifting. It is not the ambition of the Danish project to improve the WE quality by LCA. There are too many data problems for this (lacking data for numerous sectors and for developing countries etc.), and there are other, more specific, tools to analyse this.

The approach presented by Schmidt could become even more valuable if concrete situations could be included instead of an average database. However, for the short term it will practically not be possible to differentiate in detail between different products and technologies. Principally it is possible, see IVF, but thousands of processes all over the world would have to be checked which is unfeasible in the short run for time and money reasons.

So, there is more work to be done, but maybe then the LCA background will be lost, since for a process assessment other tools might be more appropriate according to WE experts. The method of Schmidt offers an overview to identify the most important sectors with respect to WE in an LCA and then one should go into more detail with other tools.

The overview function of the method presented by Schmidt was supported, but on the other hand it was argued that this remained an important limitation of including WE in the average LCA. Average WE data for plastics production are not representative for polyethylene production, if the WE data are, e.g., for 80% based on VC shopfloor emissions from PVC production. More specific data are really needed then. Furthermore, there is a potential problem of double counting in methodology and data if separate shopfloor inventory data would be gathered in future. Work environment might preferably be one of the exposure routes in multi-media models, as emissions at the shopfloor can become emissions to air by evaporation through the chimney; in future, shopfloor and air emissions might be counted twice. In the long run work environment could become one of the exposure routes in modelling the human toxicity category, with physical accidents as a separate category including non work environment accidents, but for now it should be dealt with in a separate category.

It was concluded that the inclusion of WE in LCA is an important issue. If included in LCA, it will have to be dealt with as a separate category at this moment, which may imply some double-counting and which certainly implies that for numerous processes specific data will be lacking. For the future, it should be strived for that double-counting is avoided by investigating the possibility of including WE as one of the exposure routes in e.g. multi-media modelling. If this is feasible in terms of data collection, remains to be seen.

Reference of normalisation

As a start of the discussion it was stated that normalisation is not only a preparatory step for weighting, but also has an independent value and meaning.

Next the use of capita in the Danish reference for normalisation was explained. The use of regional references for regional impacts (and global references for global impacts) may be relevant when values or perceptions of that region is applied as basis for the weighting. The use of political targets is thus just one way of expressing these regional value sets. All foreign impacts then also are weighted on the basis of regional policy aims.

It was argued that this makes the normalisation application dependent, since the normalisation reference depends on how the weighting is performed. Weighting by political target is only one weighting option. If another method is used, another normalisation reference becomes possible, or might even be necessary. Thus, sometimes the capita and sometimes the area reference is good and we need both. Don't strive for the one and only method, but please tell people what different methods mean. That is much more important.

Next it was argued that by dividing the total problem by a number of persons, one loses the view at the total problem. If weighting values are available at a person's level, then this is okay. But the weighting should represent the society's weight, and then the total problem should be quantified for the level of that society.

This argument was not shared by everybody, since no matter whether you divide by capita or not, the normalisation figures are based on the same figures. By adding a fixed factor, one cannot say that the view on the total problem is lost in the capita approach. In addition it was stated that the view on the total problem was already lost by not looking at total functional units.

Another argument for using the capita approach was that it puts responsibility on people and therefore it communicates very easily, it is very pedagogical.

A last point raised was on the consistency of a regionalised normalisation approach. It was stated that by normalising at the European level, a specific impact might be weighted lower or higher compared to a normalisation at the world level. This point was tackled by stating that weighting factors and normalisation factors need to be connected to each other but how this connection should look like, was not discussed anymore.

It was concluded that:

- There is a clear relationship between normalisation and weighting.
- There can be different sets of normalisation figures for different weighting methods.
- It should be made clear to practitioners what the different sets mean.
- The independent relevance of normalisation is a clear issue in itself.
- How to regionalise consistently in normalisation (and consistent with inventory analysis, characterisation and weighting) is not completely clear yet.

Time

An argument against the use of infinity as the time-frame for LCIA is that people don't bother about things that happen in infinity. This is an evaluation problem. Another argument against is that infinity might not be that relevant if future technologies would solve the problem.

However, we will never know this.

An argument in favour is that the infinity time-frame doesn't shift problems to future generations and doesn't give motives to say that, e.g., landfill is no problem.

This inventory of arguments against and arguments in favour lead to the conclusion that by taking time frames of, e.g., 100 years, 1000 years and infinity would cover the whole range of ethical standpoints that can be taken.

Another point raised concerned the consistency of choosing time-frames for different impact categories. It was argued that consistency should be taken into account here. Either model all impacts to infinity or all to 100 years, but don't model metal-toxicity to infinity and CO₂-global warming to 20 years.

Finally, it was noted that consistency might also be relevant over the choices of time-frame made in modelling the inventory analysis and modelling the impact assessment. The GWP 20 might politically be relevant, but is only a fraction of the landfill impacts over infinity or over 100 years, and may not be very consistent with steady state modelling (= infinity !) in the inventory.

In landfill one may specify emissions in the inventory for, e.g., 100 years. What then remains is "emitted" as well. Given the immobilised nature of these "emissions", they should be treated differently, e.g., in terms of 'non-usable volume of environment'.

It was concluded that:

- The time-frame should be chosen in the same consistent way over the different impact categories.
- Consistency in time-frame might also have to be watched over the different LCA phases inventory analysis and impact assessment.
- A time-frame of 100 years and infinity will cover the whole range of ethical standpoints that can be taken. Both should be taken into account, e.g., as a sensitivity analysis.

4. Interpretation

The input paper for this session (see appendix 9) was presented by René Kleijn. He largely followed his paper and added some examples or other material. There was no input paper from the Danish project for this session, as this subject is not addressed in the Danish project. After the presentation by Kleijn, the Danish participants and the critical observers were asked to give their comments and observations.

Comments and questions from the Danish delegation (these comments and questions do not represent the Danish opinion but just reflect personal opinions, since Interpretation as such has not been discussed yet in the Danish committee):

- The presentation has focussed on recommendations for a detailed LCA. What will the recommendation be for a scanning or screening LCA? This will be addressed in the plenary discussion (see below).
- Will you be elaborating examples? Yes, both for detailed and scanning/screening LCAs.
- How will be dealt with marginal-average difference? Since this difference will influence an entire LCA, people will have think about these issues before the study is actually undertaken. An LCA-result for one or the other analysis can be quite different and that is not a helpful result of Interpretation.
- Based on personal experience, Hansen makes the following comments:
 - He agrees with the way sensitivity analyses and data issues were addressed by Kleijn.
 - With respect to the whole set-up of a study and all model choices made, an addition should be made. Also the model's limitations should be made clear. Some models are biased, e.g., the modelling of heavy metals in waste in EDIP, for some decisions. Some recycling and weighting methods are also biased, e.g., the EPS system as to resources, and furthermore other tools such as MFA/SFA may give other priorities than LCA.
 - Furthermore it should also be checked whether product designs for which an LCA is performed are still realistic and can meet general technical and safety requirements
 - Finally, an open discussion is necessary on the requirements for critical review. The critical reviewer has a very important role and we should find a way of organising this review in a practical way.

Questions and comments by Konrad Saur:

- Interpretation by ISO was meant to be something different than presented by Kleijn. Interpretation was not meant as a scientific phase but as a sort of large check-list involving technical people addressing questions such as, are the system boundary and specification reasonable, is the product design reasonable etc. Sensitivity analysis should be performed in the preceding phases (inventory analysis and impact assessment) and the results of these analyses should be interpreted in interpretation. From the arguments of Kleijn it became, however, clear that one can only perform a comprehensive, integrated sensitivity analysis at the end of the study when all baseline results are available. Uncertainty data should be gathered during the whole LCA, but in order to assess the influence on the result of the study the final analysis is performed at the end. In the presentation the checks were being missed, although they are discussed in the paper. So, be aware of the importance of these mainly qualitative checks (e.g., if A and B are compared are the data valid etc.).
- Interpretation guidelines for screening LCAs could include typical things that are always dominant in LCAs and thus should be investigated in sensitivity analyses, like transportation distances, energy models, etc.
- Traditional error analysis will probably never be possible in LCA since 1) there is no normal (gaussian) distribution as processes are highly non-linear; and 2) there is also no normal distribution for the connecting flows between processes. The key information to be provided by the Interpretation phase is how good/stable are my assumptions, which determine the results. For this statistical tools and error analysis are not needed.

Questions and comments by Anne-Marie Tillman:

- The presentation was a quite negative way of interpreting interpretation: finding all the wrongs done. You might also want to put it in a more positive way: how to draw conclusions from the results produced; how to further analyse the results; how to find options for improvements. Furthermore, everything learned from the specific LCA could be discussed.
- The role of technical experts remains underexposed. Technologies are not the expertise of the average LCA expert. Then it is necessary that someone reviews those aspects of a study, and this is normally not the peer reviewer. Thus, a peer review shouldn't only be done by an LCA-expert, but also by a technical expert.
- Start with the really simple uncertain things (such as lifetime in functional unit definitions, etc.) before going to Monte-Carlo analyses. Don't make things more complicated than necessary.

The following points were selected for a plenary discussion:

- How should interpretation be dealt with in screening analysis?
- Real uncertainty analysis within LCA is impossible.
- Qualitative aspect of interpretation.
- Emphasize also the positive aspects of a study in the interpretation.
- Is there a need for a professional code for LCA practitioners?
- Peer review.

How in screening analysis?

For a detailed analysis, Kleijn proposed to start with a dominance analysis and a perturbation analysis. In a dominance analysis the largest contributors to the total result are identified, while the perturbation analysis will give information on parameters for which the total result is most sensitive; these are two analyses to be applied in parallel.

Only on the results of these analyses, a Monte-Carlo analysis could subsequently be applied. This is actually also the set-up of the paper of Kleijn. In a screening analysis¹ one would like to have even quicker and dirtier methods, such as sensitivity analysis on typically known determining parameters and methods (transport distances, energy models but also allocation methods etc.) as suggested by Saur. This has still to be further elaborated within the project.

If the LCA study performed has some inherent problems or debates, it should be possible to specify these problems and debates in the Interpretation (e.g. the open-loop recycling method is determining for the results and the method used is debatable). If the LCA study performed seems to give inadequate answers to the question posed, there are three options:

- To make a more detailed inventory analysis;
- To use other tools than the LCA tool; or
- To adapt the question.

Forget about the real uncertainty analysis

It was noted by Saur that one should better forget about full uncertainty analysis within LCA (which was also not proposed by Kleijn; see above). Some people even like to go further than that: by performing Monte-Carlo analysis, one adds false apparent certainty to the results. The various uncertain parameters and methods cannot be added as they are mutually dependent.

Instead of Monte Carlo analysis, sets of most probable combinations of choices should be determined and calculated through as sensitivity analysis.

On the other hand, it was argued that Monte-Carlo types of analysis could take co-variances between different parameters into account. If this is so, this problem might be solved to large extent. This needs to be investigated further.

¹ Screening analysis is called scanning analysis in the Dutch methodology project, since screening analysis has quite different meanings in different documents and in SETAC does not stand for a result in itself. A scanning analysis in the Dutch project is meant to produce a result in itself, another term was chosen in order to prevent a discussion on wordings. If this is exactly what is achieved now, the use of the term scanning will be reconsidered within the Dutch project.

Qualitative

Quantitative tools could never replace expert judgement. Quantitative tools should be made available for broad use, but the tools and the results they produce should be handled with prudence.

To determine the right issues for sensitivity analyses there are at least two options:

- Based on dominance and perturbation analyses;
- Based on expert judgement.

These are no or-or options, much more and-and options. This is one dimension of qualitative assessments that could be made in the Interpretation.

Another dimension could be a more or less full qualitative assessment of the results by drafting a comprehensive list of questions a practitioner should pose him- or herself after producing the LCA results. It might be advisable to have a separate section on this in the Guide, e.g.: "if you want to perform a qualitative analysis, proceed to page 5; if you want to perform a quantitative analysis, proceed to page 10".

Types of question that could be asked, include:

- Is it correct that I did not include spatial information related to the goal and scope of my study?
- Is the product-design that I ended up with still stable and solid in technical and safety sense?
- Did I perhaps compare a well-developed optimised alternative with a not fully optimised alternative?
- Do the compared product systems really perform the same functions?
- Have I identified the relevant impact categories for this product system?
- Do the model limitations allow the conclusions that I tend to draw?
- Etc. etc.; see also ISO 14041 document for possible other relevant questions.

Peer review

The workshop recommends that LCA studies should be *interactively* peer reviewed, whenever relevant, although ISO doesn't prescribe an interactive peer review.

Positive aspect of a study

Everybody agreed that also the lessons learned and other more positive interpretation issues should be taken into account in the Interpretation phase.

Professional code

Finally it was discussed whether there was a need for a professional code for LCA experts. The discussion remained unsolved: there were advocates and opponents. It was advised, however, to include in the Guide a statement on for whom this Guide is written: the experienced LCA practitioner or the layman. People, who are experienced in education, have noticed that many of the Guides have been written for experienced people and not for the laymen. The aim of the Dutch Guide is, however, to make different layers of sophistication, which will become more difficult for each layer and will thus need more experience for each layer.

The final recommendation that was made during this workshop was supported unanimously: harmonisation of method, how useful and needed it may be for very good reasons, should never withhold further methodological progress. There is not one absolutely and universally true LCA methodology.

Appendix 1: The Danish LCA-consensus project

The Danish LCA-Consensus Project

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Keywords: LCA, Consensus, Denmark

Introduction

Within the LCA-field in Denmark significant progress has been made in the recent years. A major step has been the EDIP-project, that has developed methodologies and data aimed at integrating environmental concerns into product development. The EDIP-project is furthermore unique by the methodologies (normalisation and weighting) that has been developed to compare different types of environmental impacts (e.g. global warming versus eutrofication). Among other significant steps in the methodology development in Denmark one should be aware of the MUP (the Development Programme on New Materials) from 1994 and the Nordic LCA-guideline from 1995.

Although the LCA-development in Denmark, due to the EDIP-project and the other projects mentioned above, have reached quite far, there is still a way to go with respect to methodology development. The experience from the recent years practical use of LCA for product development and other purposes has clearly shown, that on several issues, a significant need for an extra effort exists.

These needs have i.a. been carefully considered by the Danish EPA's Ad Hoc Committee on Methodology Issues within LCA. The present project is a major outcome of these considerations.

An important experience, which is one of the corner stones for this project is, that LCA may be used for many different purposes, and that the demands for selection of methodology, procedures, accuracy, etc. naturally will depend on the actual purpose. Thus the requirements for a LCA to be used for product development internally in a manufacturing company may differ considerably from the requirements for a LCA to be used for system-choices on the society level (beer bottles of glass versus beer cans of aluminium).

Project objectives and content

The project will improve EDIP and LCA on several topics, for which this is deemed essential for the general accept and use of LCA in Denmark.

As a very important element in the process of obtaining general accept of EDIP and LCA in Denmark, the project, furthermore, aims at developing consensus on LCA in Denmark. This consensus will be reached by, that all relevant stakeholders in the LCA-field in Denmark are involved in the project, either as active participants in the project work or by participating in a number of workshops open to all interested parties, that is arranged as part of the project.

The project is organised in the following sub-projects:

Sub-project 1: LCA-applications

This sub-project will develop a systematic analysis of LCA-applications. This analysis aims at dividing LCA-applications into categories, which may be considered different regarding system limitations, effect categories, methodologies, level of detail and accuracy. Thereby this analysis will form the fundament for the work to be carried out in the other sub-projects, which are aimed at developing recommendations for the different LCA-categories.

Sub-project 2: System decisions and delimitations

This sub-project is dealing with the choices to be made in the "Goal and Scope Definition"

phase of a LCA. This includes choices concerning definition of functional unit, geographical, technological, and time related issues as well as allocation. Experience shows, that the choices made in this phase of an LCA will be of fundamental importance for the outcome of a LCA. In order to make the right choices, it is often essential with a good understanding of the system/market, which is covered by the LCA. The choices to be made in a LCA do, however, often reflect a trade-off between different benefits/drawbacks (e.g. accuracy versus man power input). In this case a kind of methodologically related uncertainty is introduced, which may often be significant and in special situations may lead to misleading results. The sub-project is thus focused on investigating:

- Which kind of system- or market understanding it is necessary to develop before defining the functional unit and making the other choices to be made in the “Goal and Scope Definition” phase, and what kind of information, that should be compiled for different LCA-applications and how to interpret this information.
- The uncertainty related to different methodological choices, illustrated by examples.

Sub-project 3: The working environment in LCA

The working environment is seldom included as an impact category within LCA, which may be due to lack of knowledge of existing methodologies for assessment of working environment issues. Data on working environment in foreign companies may also be difficult to obtain. Working environment issues are beyond doubt relevant to consider in LCA, but there is a need of evaluating which methodologies should be utilised for different LCA-applications and how far the assessment should go. Furthermore, there is a need for case studies to illustrate, how working environment assessments can be carried out and how system decisions and limitations are decided. The sub-project will, based on relevant cases, test and evaluate existing methodologies inclusive the methodologies used by the EDIP-tool.

Sub-project 4: Impact categories, normalisation and weighting

Selection of impact categories, normalisation and weighting are also critical elements in LCA. International consensus exist for most of the impact categories today used by EDIP. These impact categories should, however, be regarded as the present categories operational. Other categories like land use and noise should also be considered, when these have been developed to a level, at which they are operational in a LCA context. On the other hand, one would likely not need in a screening LCA to consider all the impact categories considered in a full LCA. The sub-project will evaluate the present and potential impact categories and develop recommendations for which impact categories should be utilised for different LCA-applications.

In EDIP the normalisation is based on 1990-figures, which for regional and local impacts is based on Danish conditions only. The sub-project will develop normalisation factors for international regions like Europe, as Danish companies will have to take conditions on the export markets in account as well as the conditions in Denmark. The sub-project will, furthermore, estimate the uncertainties, which are related to the normalisation factors and identify ways of reducing these uncertainties. The outcome of this activity will thus be an important supplement to the EDIP-tool.

In EDIP the weighting factors are estimated based on Danish political decisions for the different impact categories. As for normalisation a need exists to develop weighting factors for international regions.

Sub-project 5: Actual impacts and site-characterisation

This sub-project will develop methods to improve impact assessment in LCA. In the present methodologies inclusive EDIP, the contribution is calculated as potential impacts, since no evaluation of whether the impacts are actually taking place is carried out. This approach may give misleading results. For example, emissions of NO_x from power plants may be taken to be the most important contribution to human toxicity despite the fact, that this emission with the typical height of chimneys will be decomposed in the atmosphere before humans are exposed to this emissions. The sub-project will identify those impact categories, for which it may be relevant to correct the calculations, and for these impact categories develop site-

characterisation factors, which take such corrections into account and can be used in the EDIP-tool or other LCA-tools. Site-characterisation factors will be developed for Denmark as well as for international regions like Europe. EDIP is already prepared for such site-characterisation factors.

Results

The project will develop a number of short guidelines on LCA, which with reference to the LCA-application in question will give guidance on selection of methods, assumptions and procedures. The content of these guidelines will be discussed at the workshops mentioned above and the guidelines will thus set the field for LCA-work in Denmark. The following guidelines have been planned:

1. A general guideline, that will act as introduction to the following technical guidelines, and is aimed to enable the reader to make the right choices based on a careful consideration of the goal and scope for the LCA in question.
2. Definition of functional unit
3. Geographical, technological, and time related issues
4. Allocation
5. Working environment issues
6. Effect categories, normalisation and weighting
7. Actual impacts and site-characterisation

Each of these guidelines will be prepared in both Danish and English.

Behind these guidelines (for guideline 2-6), technical reports discussing and presenting the arguments for the recommendations made in the guidelines, will be prepared. These reports will be prepared in English only.

It is envisaged, that these guidelines will be of significant value in ongoing efforts to promote the development of more environmentally friendly industrial products. The fact, that the guidelines will be based on the different LCA-applications, and thus will consider simple as well as complicated LCA's, means that the results of the project will be of interest also to small and medium sized companies in Denmark.

Organisation

The active participants in the project include the following Danish companies and institutions:

- COWI, Consulting Engineers and Planners
- Institute for Product Development, Technical University of Denmark
- dk-TEKNIK
- SBI (the Danish National Institute for Building and Construction Research)
- DTI (Danish Technological Institute)
- DTC (Danish toxicology Center)
- Carl Bro, Consulting Engineers and Planners
- Ramboll, Consulting Engineers and Planners
- VKI (Water Quality Institute)
- Econet
- Danish Working Environment Service
- Institute for Technology and Society, Technical University of Denmark.

As the project, furthermore, has reference to the Danish EPA's Ad Hoc Committee on LCA Methodology Issues, the project in reality brings together all stakeholders in the field of LCA in Denmark.

Erik Hansen, COWI, has the responsibility as project manager for the total project and is furthermore project leader for sub-project 1 (e-mail: ehn@cowi.dk; fax: 76426402; phone:: 76426424).

Bo Weidema, IPD, is project leader for sub-project 2 (e-mail: bow@ipt.dtu.dk; fax: 45935556; phone:: 45934441).

Anders Schmidt, dk-TEKNIK is project leader for sub-projects 3 and 4 (e-mail: aschmidt@dk-technik.dk; fax:39696002; phone:: 39555999).

Michael Hauschild, IPD, is project leader for sub-project 5 (e-mail: mic@ipt.dtu.dk; fax: 45935556; phone:: 45934441).

Time planning

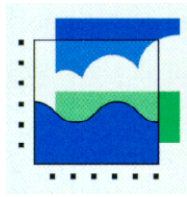
The project was initiated in October 1997 and will continue until summer 1999. As the general rule technical reports and guidelines will be ready in draft versions by the end of 1998, while the general guideline will not be ready before summer 1999.

Workshops for discussion of project progress will take place during May/June 1988, while workshops for discussion of draft guidelines will take place during November 1998 - January 1999.

International contacts

All international contacts are welcomed. Contact should be made directly to the relevant sub-project leader.

Appendix 2: The Dutch methodology update project



Centre of Environmental Science (CML)

Life Cycle Assessment in Environmental Policy

Update of LCA methodology Guide & Backgrounds documents of 1992 by Heijungs et al.

Project leader:

[Jeroen Guinée](#)

Centre of Environmental
Science, Leiden
University

In 1992 CML published, together with TNO and B&G, a Guide and Backgrounds document on LCA methodology (Heijungs *et al.*, 1992). Since then, a lot of methodological developments have taken place, and are still going on. Thus, it is useful to update these 1992 documents.

The project will be executed by CML with the support of a number of, as yet unknown, other institutes. The commissioners of the project are: Ministry of Housing, Spatial Planning and Environment (VROM-DGM); Ministry of Economic Affairs (EZ); Ministry of Agriculture, Nature Management and Fisheries (LNV); Ministry of Transport, Public Works and Water Management (V&W). The final results of this project (Guide and Backgrounds) are scheduled to be published in spring 2000.

The aim of this project is to update the CML methodology reports of 1992 to the latest developments. Six subgoals have been defined:

1. to indicate the necessity of an LCA methodology for environmental policy in general, and product policy in particular
2. to stimulate a broad acceptance of the LCA methodology within The Netherlands through a Steering Committee and a "Thinktank"
3. to indicate the potential areas of application of LCA, including the conditions and starting points
4. to steer the LCA methodology development with respect to:
 1. integration of all developments, nationally and internationally, since the publication of the previous methodology reports in 1992
 2. to shape a simplified LCA methodology
 3. to indicate the gaps in the methodology
5. to elaborate in detail on a number of methodological issues
6. to write a new guide and backgrounds document.

Recently published discussion documents and preliminary results:

1. Questions in LCA and the goal definition; discussion note for the

- meeting of the Thinktank at 20 November 1997. Download as MSWORD/rtf file [304 kB](#) or as MSWORD 6.0 zipped file [48 kB](#)
2. Informative and change-oriented LCAs: repercussions for the inventory analysis; note for the Thinktank at 19 February 1998. Download as MSWORD/rtf file [347 kB](#) or as MSWORD 6.0 zipped file [54 kB](#)
 3. Goal & Scope Definition and Inventory Analysis, comparison between Guide of '92 and ISO/DIS 14040 and 14041; note for the Thinktank at 19 February 1998. Download as MSWORD/rtf file [603 kB](#) or as MSWORD 6.0 zipped file [79 kB](#)
 4. Life Cycle Impact Assessment, note for the Thinktank at 4 June 1998. Download as MSWORD/rtf file [595 kB](#) or as MSWORD 6.0 zipped file [110 kB](#)
 5. MODES OF LCA, foundations and guidelines for change-oriented and descriptive analyses. Download as MSWORD/rtf file [386 kB](#)
 6. A decision tree for specifying LCA methodology. Download as MSWORD/rtf file [65 kB](#)
 7. The first draft of the new Backgrounds, October 1998. Download as Acrobat/PDF file [603 kB](#).
 8. Partitioning economic in- and outputs to product systems (Follow-up of: Allocation in LCA. Version October 3rd 1998). Draft working document for Dutch LCA Guide update. Version January 31st 1999. Download as Acrobat/PDF file [104 kB](#)
 9. Priority assessment of toxic substances - development and application of the multi-media fate, exposure and effect model USES-LCA (Author: Mark A.J. Huijbregts]. Final report, May 1999 (corrected edition). Download main report [374 kB](#) and data appendix [215 kB](#) as Acrobat/PDF files and toxicity potentials [32 kB](#) and chemical data [114 kB](#) as MSEXCEL 5.0/7.0 zipped files. For those people who downloaded these files before 23 September 1999, there is an errata list available: download here as Acrobat/PDF file [177 kB](#)
 10. Ecotoxicological effect factors for the terrestrial environment in the frame of LCA (Author: Mark A.J. Huijbregts]. Final report, May 1999. Download main report [62 kB](#) and data appendix [288 kB](#) as Acrobat/PDF files

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Appendix 3: Workshop programme

Thursday, 16 September 1999 – Inventory Analysis

8.45 – 9.00 *Welcome with coffee and tea*
9.00 – 9.15 *Opening by Helias Udo de Haes*

8.45 – 17.00 *Marginal-average including allocation issues: presentations*
(Chairs: Helias Udo de Haes)

Input papers

- Bo Weidema, 1999. Some important aspects of market-based system delimitation in LCA – with a special view to avoiding allocation.
- Reinout Heijungs and Gjalte Huppes, 1999. Inventory modelling in LCA with a focus on marginal versus average analysis and solutions for the allocation problem.

09.15 – 10.15 *Danish proposals (Bo Weidema)*
– Marginal-average
– Allocation

10.15–10.30 *Coffee and tea break*

10.30 – 11.30 *Dutch proposals (Reinout Heijungs)*
– Marginal-average
– Allocation

11.30 – 12.30 *Reactions and views from critical observers*
Roland Clift
Konrad Saur
Anne-Marie Tillman

12.30 – 13.30 Lunch

13.30 – 17.00 *Discussion* (Chair: Erik Hansen)

13.30 – 14.00 *Clarifying questions and agenda setting for discussion*

14.00 – 15.15 *Discussion (part I)*

15.15 – 15.30 *Coffee and tea break*

15.30 – 16.30 *Discussion (part II)*

16.30 – 17.00 *Drawing conclusions*
– Differences and similarities
– Research perspectives and recommendations

18.30 *Drinks and dinner in Leiden town*

Friday, 17 September 1999 – Impact assessment and Interpretation

9.00 – 9.15 *Welcome with coffee and tea*

9.00 – 12.30 *Impact assessment (Chair: Helias Udo de Haes)*

Input papers

- Michael Hauschild, Heidi K. Stranddorf, and José Potting, 1999. Life cycle impact assessment – Danish recommendations.
- Anders Schmidt and Pia Brunn Rasmussen, 1999. LCA and the working environment - Danish recommendations.
- Leif Hoffmann and Heidi K. Stranddorf, 1999. Estimate for an average world citizen contribution to regional and local impacts.
- Marieke Gorree and Jeroen Guinée, 1999. LCIA in the Dutch methodology project.

9.15 – 10.15 *Danish proposals*
Michael Hauschild: General concepts and site-characterisation
Heidi Stranddorf: European/global normalisation and weighting factors
Anders Schmidt: Work environment

10.15–10.30 *Coffee and tea break*

10.30 – 11.15 *Dutch proposals*
Marieke Gorree: Characterisation factors
Jeroen Guinée: Normalisation and weighting in Dutch project

11.15 – 11.45 *Reactions and views from critical observers*
Konrad Saur
Anne-Marie Tillman

11.45 – 12.45 *Discussion and conclusions*

12.45 – 13.45 *Lunch*

13.45 – 16.30 *Interpretation (Chair: Helias Udo de Haes)*

Input paper

- René Kleijn, 1999: Interpretation in the Dutch methodology project.

13.45 – 14.15 *Dutch proposals for Interpretation (René Kleijn)*

14.15 – 14.45 *Danish reactions and views*

14.45 – 15.15 *Reactions and views from critical observers*
Konrad Saur
Anne-Marie Tillman

15.15 – 15.30 *Coffee and tea break*

15.30 – 16.30 *Discussion and conclusions*

16.30 *Drinks*

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Appendix 5: Input paper Bo Weidema

Some important aspects of market-based system delimitation in LCA - with a special view to avoiding allocation

Positioning paper for joint workshop of the Dutch and Danish LCA methodology projects, 1999.09.16-17, Leiden

© Bo P. Weidema, 1999.09.04, Institute for Product Development, Building 424, 2800 Lyngby, Denmark

1. The distinction between prospective and retrospective studies

Some applications of LCA (product life cycle assessment) are listed in the current standard ISO 14040:

- product development and improvement,
- strategic planning,
- public policy making,
- marketing,

all applications which have to do with supporting decision making by analysing the consequences of a choice between different alternatives.

To study the consequences of a decision requires a prospective, comparative analysis. This is often not properly understood. Even within the ISO standard, there seems to be a lack of acknowledgement of this prerequisite. For example, in ISO 14040, a product system is defined as a “collection of materially and energetically connected unit processes”. A very literal (mis)interpretation of this definition may lead to the understanding of LCA as a simple engineering exercise, listing the activities involved in the manufacture, use, and disposal of a product, linking the outflows of downstream activities with inflows of upstream activities, and summing up the flows from and to nature, to finally assess the environmental impact of these flows. This misunderstanding may be further confirmed when reading the description of unit processes in ISO 14041 (section 4.3): “Unit processes are linked to one another by flows...”.

The problem with this interpretation is that it describes a static analysis, which is very far from the practical applications of LCA as described above.

This misunderstanding can also be found in the majority of currently published LCA studies, which are typically static analyses, based on historical data, without any indication of the consequences of the decision that the LCA is supposed to support. Such retrospective life cycle assessments have typically been applied for hot-spot-identification and product declarations (Tillman 1998), but their relevance has been questioned (Weidema 1998), since the ultimate goal even of hot-spot-identification and product declarations is to improve the studied systems:

- If a retrospective hot-spot-identification identifies a number of improvement options, a prospective assessment is anyway needed to assess the consequences of implementing the improvements, so one might as well make a prospective study in the first place.
- If product declarations are used by the customer to make a choice between several products, this choice should ideally be based on the environmental consequences of this choice (i.e. a prospective study), not on the historical impact caused by the products.

Figure 1 can be used to illustrate the difference between a prospective, market-based system delimitation, and the more traditional system description based on an engineering or accountancy approach, where material and energy flows are followed mechanically from process to process. In the figure, it is shown how a change in volume of one process (process 1 to the right) leads to a change in the demand for one of the raw materials to this process. However, many different technologies or processes can meet the specifications for this raw material supply. This is illustrated by the fully drawn processes to the left, which together makes up the suppliers to the market. Now, the traditional system delimitation will either

include an average of all these processes, weighted by their respective production volumes, or just include that specific process, which represents the current supplier to process 1, here illustrated by the fat box.

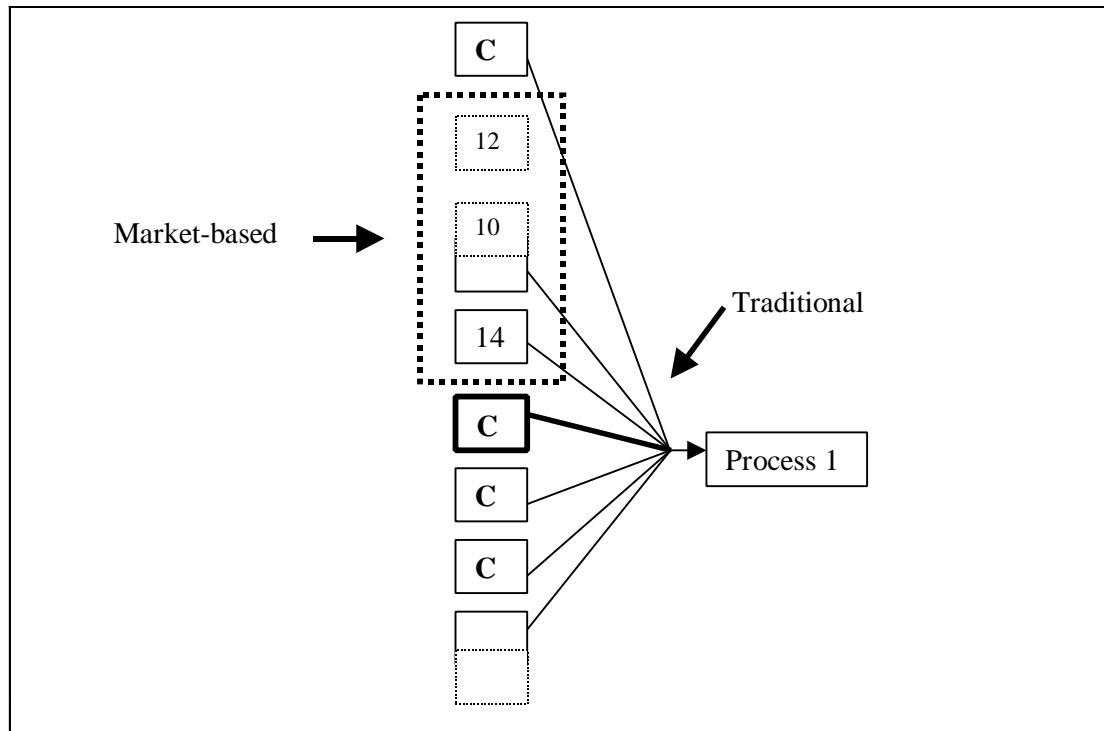


Figure 1. Theoretical illustration of the difference between market-based and traditional system delimitation in LCA

When applying an average, the result can be seriously affected by the delimitation of the market on which the average is taken. For example, it will make a large difference whether you regard the Nordic electricity market as one (relatively closed) market, so that a Danish electricity consumption is calculated as an average of Danish, Finnish, Swedish and Norwegian electricity production, or whether it is assumed that Denmark is a market in itself (which is often seen in life cycle assessments). If we choose to look at the average for Denmark, which is *not* a closed market, it is decisive whether the average is calculated from the Danish production alone or whether you take into account the exchanges with the neighbouring markets, and *how* you take this into account, e.g. whether you calculate with Danish production plus import-mix (in periods with much available water-power in Norway and Sweden), with Danish production plus import-mix minus export-mix (in periods with little water power available) or just Danish production plus net import/export (thus disregarding transit-trade). For Switzerland, having a large degree of transit-trade, Ménard et al. (1998) have shown how such different assumptions affect the average from 21 g CO₂ (Switzerland's own production) over 140 g CO₂ (Switzerland plus import minus export) to 500 g CO₂ (UCPTE average, in that UCPTE can be regarded as a relatively isolated electricity market like the Nordic). The recommendation of Ménard et al. (1998) is to use the model that disregards transit-trade (48 g CO₂) with the argument that this best reflects the actual market conditions. It should be clear from this example that averages can be highly debatable, and possible arguments for preferring one average over the other is actually often market-based. This may in itself be regarded as a serious argument for taking the full consequence, and use a truly market-based system delimitation instead of the average approach.

2. Market-based system delimitation

Contrary to considering averages, a market-based system delimitation will first investigate whether any of the processes delivering to the market are constrained in their capacity to change as a result of a change in demand from process 1 (figure 1). These constrained processes are marked with C's.

It should be noted, that also in a market-based system delimitation, the directly delivering process (the fat box) may well come into play. However, this requires that the change in demand overcome the constraints on the process, so that its production volume is actually affected. Thus, the change in demand must to some extent put the market forces out of play to ensure that a capacity adjustment is actually taking place in that specific process. This may especially be the case if the customer has a controlling influence on the supplier (possibly in the form of a monopoly position).

Next step in the market-based delimitation is to investigate whether the change is so large that it gives room for new technologies (illustrated by the perforated box in the upper end of figure 1) or that it can affect one or more of the identified constraints, so that a C-marked technology can anyway come into play.

Now, if the technologies/processes in figure 1 are arranged in such a way that the most economical are at the top (this is often also the newest and most efficient ones, but this depends also on the cost structure, including the wage level) and the least economical at the bottom (often the older, less efficient), it will typically be either the upper or the lower unconstrained process that is affected by a change in demand – depending on whether the market is expanding or shrinking. Contrary to the average, we are rather concerned with the extremes here.

Let us now focus on the situation with an expanding market, where the possible (non-C-marked) processes are found in the upper part of figure 1 inside the perforated box. We now look at the production costs of these technologies/processes (the figures in the boxes) and with adequate respect for non-monetarised aspects (flexibility, quality, knowledge) we can now point out the technology/process (marked with an arrow) that will be affected by the studied change.

When we identify the specific technology or process by the above procedure (originally published in Weidema et al. 1999), the relative uncertainty on our LCA-data will be quite limited compared to average data. However, it may be necessary to make sensitivity analyses with different technologies or processes – if more than one technology is plausible or if it changes over time. This is especially relevant if the market is unstable.

3. Avoiding co-product allocation

Co-product allocation has been one of the most controversial issues in the development of the methodology for life cycle assessments, as it may significantly influence or even determine the result of the assessments. It has been seen as so central a procedure that is often (and even in the ISO standard 14040) nick-named “allocation” as if it was the only allocation problem in life cycle assessments.

The idea that co-product allocation can be avoided by system expansion has been put forward by Tillman et al. (1991) and Vigon et al. (1993) in respect to waste incineration, and more generally by Heintz & Baisnee (1992). It was given a prominent place in the procedure of ISO 14041, where it reads: “Step 1: Wherever possible, allocation should be avoided by: 1) dividing the unit process to be allocated into two or more subprocesses and collecting the input and output data related to these subprocesses; 2) expanding the product system to include the additional functions related to the coproducts...”

Although avoiding allocation is seen as the preferable option, it has generally been regarded as impossible to expand the system in all cases. Therefore, other options have been maintained, especially the allocation according to economical revenue from the products, a procedure commonly applied in cost accounting (Huppes 1992). Older studies used simple physical allocation criteria such as e.g. the relative mass or exergy of the products, but these criteria have generally been discredited for lack of justification. However, in retrospective life cycle assessments, simple physical criteria may still be used as a proxy for economical revenue.

By applying the market-based approach outlined in the previous section, it can be shown that it is always possible, and seldom difficult, to identify the processes affected by a change in production volume, and therefore it can be concluded that allocation can (and shall) always be avoided in prospective life cycle assessments. In retrospective life cycle assessments, it is not possible to express an imperative regarding what allocation procedure to apply, but the preference for system expansion (as in the ISO procedure) still leads to a reasonable result:

- Either system expansion is regarded as irrelevant, because the retrospective study seeks to describe a status-quo situation, in which there are no changes in outputs, while system expansion relies on an analysis of relative changes in the output of co-products. In this case, allocation by economic relationships will be the only option left.
- Or system expansion is still regarded as relevant, because the retrospective study seeks to analyse hypothetical, historical changes like: What *would* have happened if this product had not been introduced or if this product had been produced instead of this? In this case, historical market data can be used to calculate hypothetical system expansions and to show what the results would have been of a prospective life cycle assessment if it had been produced at that historical moment.

All the different co-product situations can be covered by the same theoretical model and the same practical procedure, which are described below.

An important distinction is that between *joint production*, where the relative output volume of the co-products is fixed, and *combined production* with individually variable output volumes (Huppes 1992). For the latter type of production, allocation can be avoided simply by modelling directly the consequences of a change in the output of the co-product of interest (that which is used in the product system under study) without change in the output of the other co-products. This situation, which is more common than generally acknowledged, is dealt with in step 1 of the procedure (Figure 3). The remaining part of the procedure (steps 2 to 4) deals with the situation of joint production where allocation can only be avoided through system expansion:

Figure 2 shows how the co-producing process has one determining product (product A), i.e. the product that determines the production volume of that process. This is not necessarily the product used in the specific life cycle study. In figure 2, also just one co-product is shown, but in practice there may be any number of co-products, while at any given moment there can be only one determining product. How to identify the determining product is dealt with in step 2 of the procedure, see section 3.2 below.

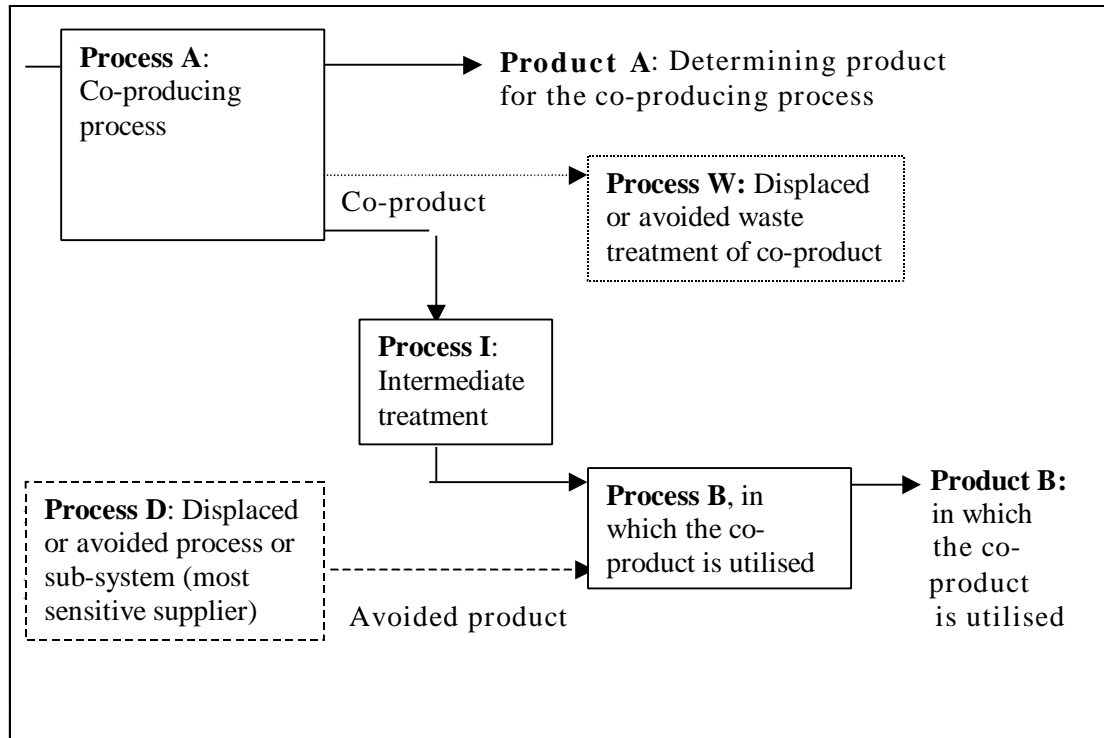


Figure 2. Model for describing system expansion and delimitation in relation to co-production

Performing a system expansion in relation to co-products is exactly to identify how the production volume of the processes in figure 2 will be affected by a change in demand for the product that is used by the life cycle study in question (whether this is the determining product for the co-producing process (A) or the product in which the co-product is utilised (B)). The answer to this question can be summarised in 4 simple rules:

- 1) *The co-producing process shall be ascribed fully (100%) to the determining product for this process (product A). This follows logically from product A per definition being the product, which alone causes the changes in production volume of the co-producing process.*
- 2) *Under the conditions that the non-determining co-products are fully utilised in other processes and actually displaces other products there, product A shall be credited for the processes, which are displaced by the other co-products, while the intermediate treatment (and other possible changes in the further life cycles in which the co-products are used, which are a consequence of differences in the co-products and the displaced products) shall be ascribed to product A. This follows – under the stated conditions - from the fact that both the volume of intermediate treatment and the amount of product which can be replaced, is determined by the amount of co-product produced, which again is determined by the change in production volume in the co-producing process, which is finally determined by the change in demand for product A. It follows from this, that product B is ascribed neither any part of the co-producing system, nor any part of the intermediate treatment.*

When studying a change in demand for product B, this product shall be ascribed the change at the most sensitive supplier (identified by the procedure described under system delimitation), i.e. the same process, which is displaced by a change in demand for product A (but see also rule no. 3).

If the two conditions stated in rule no. 2 are not fulfilled, rule no. 3 and 4 apply, respectively.

- 3) *When a non-determining co-product are not utilised fully (i.e. when part of it must be regarded as a waste), but at least partly displaces another product, the intermediate treatment*

shall be ascribed to product B, while product B is credited for the avoided waste treatment of the co-product. This follows from the volume of the intermediate treatment (and the displacement of waste treatment) in this situation being determined by how much is utilised in the receiving system, and not by how much is produced in the co-producing process. Another way of saying this, is that in this situation the intermediate treatment is the most sensitive supplier to process B.

4) *When a non-determining co-product is not displacing other products, all processes in the entire life cycle of the co-product shall be fully ascribed to product A.* This follows from the fact that the volume of these processes are determined solely by how much is produced in the co-producing process. In other words, all the processes can be regarded as belonging to an “intermediate treatment” or, since the co-product would otherwise have been a waste, they can be regarded as an “alternative waste treatment” for the co-producing process. Since the co-product does fulfil a function (else it would be a waste), although not a very essential function, the resulting product system is, strictly speaking, still multi-functional. In spite of this, it is comparable (equivalent) to another product system producing the determining product in isolation. This other product system does not require an expansion with the additional function (that of the co-product), since this function is being caused solely by the existence of the co-product and not by any external demand. To my knowledge, this situation has not been described before in relation to life cycle assessments. However, the situation (where a by-product does not displace another product) may occur rather seldom.

The application areas for the four rules are summarised in table 1, which at the same time shows for each situation, how the processes in figure 2 are to be ascribed to the different products.

Table 1. *System expansion in relation to co-products under different preconditions*

Displacement occurs	YES	YES	NO	NO
Co-product is utilised fully	YES	NO	YES or NO	
Use rule no.:	1+2	1+3	1+4	
Product A is ascribed process:	A+I-D	A+W	A+I+B	
Product B is ascribed process:	D+B	I+B-W		

Figure 3 summarises the 4 steps in the procedure in a decision tree, which also includes the 4 rules.

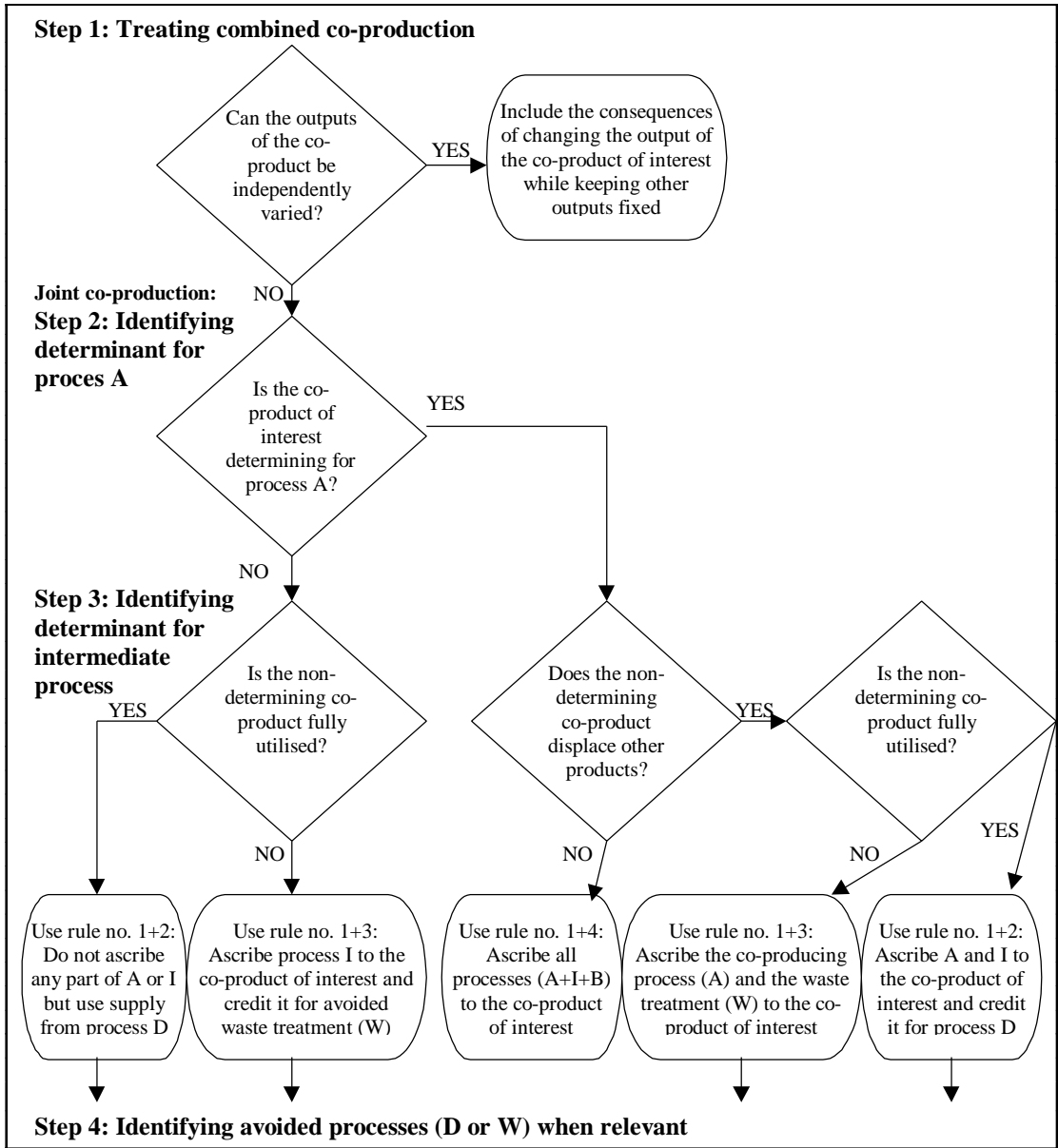


Figure 3. Decision tree showing the 4-step procedure

3.1. Treating co-products with individually variable output volumes (step 1)

If the output volume of the co-products can be individually varied, allocation can be avoided by modelling directly the consequences of a change in the output of the co-product of interest without change in the output of the other co-products. Rather than a modelling of the separate pure productions, what should be modelled is the consequence of the studied change in relative outputs. In this way, the benefits of co-production are inherent to the model and will be reflected in the outcome.

In general, a physical parameter can be identified, which - in a given situation – is the limiting parameter for the production. It is the contribution of the co-product of interest to this parameter, which determines the consequences of the studied change. The limiting production parameter may depend on the original situation. Therefore, it is essential to describe both:

- the original situation in terms of the relative outputs of the co-products before the studied change, and
- the production parameters which in this situation are determining for the changes in the exchanges of the combined production.

Example: Combined transport

Often, several items are transported by the same vehicle. The effect of adding another item to be transported depends on what physical parameter is limiting the transport capacity. In most cases, the transport capacity is limited by weight, which means that adding an item to be transported will increase the exchanges from the transport process in proportion to the weight of the transported items. However, when transporting lightweight goods, vehicles cannot be loaded at full weight capacity because of the space limit. For trucks, the weight capacity is typically utilised fully at a density of 250-300 kg/m³. If the density is lower than this limit, the transport capacity is limited by volume, which means that the amount of transport changes in proportion to the weight of the transported items.

Example: Combined waste treatment

The combined treatment of several wastes in the same treatment plant (landfill, incinerator etc.) is one of the classical examples of allocation problems. Many emissions depend on the composition of the incoming waste. For example, the emissions of cadmium will be in proportion to the amount of cadmium in the incoming waste. Thus, adding a cadmium-containing item will increase the emissions of cadmium with this amount. The same straightforward logic applies to the creation of incineration ashes, which depends on the ash content of the different incoming wastes. However, some emissions are not depending on the composition of the incoming waste. Classical examples from incineration are NO_x, which is formed in the combustion chamber, and dioxins, which are formed mainly in the "exhaust cleaning" processes. The formation of NO_x depends mainly on the combustion temperature, and while the formation of dioxins has some connection to the occurrence of elements like carbon and chlorine, a lot of other elements act as catalysts in the process. In principle, it is possible to add different kinds of waste and measuring the change in formation of NO_x and dioxins, thus reaching an understanding of the relations between the type of waste and the emissions. However, as long as the chemical reactions and their determining parameters are not fully understood it is most reasonable to assume that the emissions of NO_x and dioxins will change in proportion to the overall limiting parameter of the combustion process. Waste incinerator capacity is generally limited by the weight of incoming waste, which means that the emissions of NO_x and dioxins should change in proportion to the weight of the treated waste.

3.2. Identifying the product that determines the volume of the co-producing process (step 2)

Identifying a co-product as the determining product is the same as showing that the co-producing process will be affected by a specific change in demand for this product. Therefore, the procedure described in section 2 on system delimitation can also be used to derive a number of conditions that must be fulfilled for a co-product to be identified as the determining product. There are three such conditions, out of which the first two will already be fulfilled when the process has been identified (using the procedure described in section 2) as a relevant supplying process for the product system under study:

- 1) The volume of the co-producing process must not be constrained (e.g. by raw material availability, waste treatment capacity, or politically determined quotas on the process or any of its inputs or outputs). If such constraints occur, the process and its products are not relevant in a (prospective) study dealing with the effects of changes.
- 2) The co-product must be the preferred alternative to cover changes in demand, compared to the other products that it could substitute (which also requires that it is not otherwise constrained, see conditions 1 and 3). This is primarily determined on the basis of relative production costs, while also taking into account differences in flexibility, quality, stability or even more subjective aspects such as tradition and knowledge.
- 3) The co-product or a combination of co-products in which the co-product takes part must provide an economic revenue that is adequate reason for changing the production volume *and* have a *larger* market trend (change in overall demand) than any other co-product or combination of co-products that fulfil this condition (taking into account the relative outputs of the co-products). Note that in a combination, the co-product with the *lowest* market trend is determining the ability of the combination to influence the production volume.

See also box 1 for an illustration of condition 3.

It should be obvious that these conditions, and thus also which of the co-products that is the determining one, may change:

- over time,
- depending on location, and
- depending on the scale of change.

Thus, it is important always to note the preconditions under which a given co-product has been identified as determining. When in doubt, or when more than one co-product may be determining within the studied scale or geographical or temporal horizon, two or more alternative scenarios should be modelled.

Box 1: Illustration of condition 3

Assume a process with the four co-products A,B,C and D, with the following relative market trends and economic revenues:

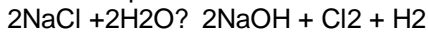
Co-product	Marginal economic revenue	Relative market trend
A	10	low
B	6	medium
C	5	high
D	1	high

Note that the stated market trends and economic revenues are relative to the normalised output volumes of the co-producing process, i.e. differences in the actual physical quantities do not play a role.

At a marginal production cost for the co-producing process of 9, only one co-product (A) can provide an adequate economic revenue to change the production volume alone. Product C cannot alone influence the production volume, in spite of the high market trend for this product. However, the combination B and C also fulfil the condition (of providing an adequate economic revenue). This combination can influence the production volume with the lowest of the trends in the combination. This is the medium trend of product B. Since this is still higher than the trend of product A, product B becomes the product that determines the production volume.

Example: Joint production of chlorine and sodium hydroxide I

The joint production of chlorine and sodium hydroxide is one of the classical examples of allocation problems. The chlor-alkali process yields three co-products:



Hydrogen is produced in relatively small quantities (27 g for every kg of chlorine) providing approximately 3% of the world market for hydrogen. The main production route is steam reforming of natural gas and this will probably also be the preferred process to cover a change in demand for hydrogen. As hydrogen does not fulfil condition 2, it cannot be the determining product. In addition, it can be noted that the value of the hydrogen is approximately 5% of the total income for the chlor-alkali process.

Chlorine and sodium hydroxide are produced in approximately equal quantities by the chlor-alkali process and their share in the total income for the process is approximately the same. Over the last 10 years, the price of chlorine has been fairly stable at 100-200 \$/Mg, whereas the prices for sodium hydroxide has been varying between 10 and 500 \$/Mg. Only in a short period from 1990-1991, the price of sodium hydroxide was so high that it could alone provide adequate economic revenue to change the production volume (Beal 1995).

In practice, the chlor-alkali process is the exclusive production route for chlorine, which cannot be easily stored and is typically sold locally. Sodium hydroxide is a more flexible product that can be stored and transported over long distances. Sodium hydroxide can be substituted by soda ash directly or by sodium hydroxide produced by causticisation of soda ash.

The fluctuating price of sodium hydroxide makes it difficult to base long-term decisions of capital investment on this product. Thus, a local, stable demand for chlorine is most often the basis for the decisions on capacity adjustment. This makes chlorine the determining product for the chlor-alkali process when applied in life cycle assessments with a long time horizon. Also in Kirk & Othmar (1978), the chlorine demand is pointed out as determining for the production capacity.

However, for some studies with a short time horizon, it may be relevant to regard sodium hydroxide as the determining product for the utilisation of the existing chlor-alkali capacity, in periods when the demand/price of sodium hydroxide is high. However, this situation is not likely to persist for longer periods, because of the existence of alternative production routes and substitutes for sodium hydroxide.

At one given moment, there is only one of the co-products that can be determining for the production volume. This follows from the condition 3 above: If more than one co-product or combination of co-products fulfil the condition to provide an adequate economic revenue to change the production volume, only that co-product or combination which has the relatively largest change in overall demand (market trend) is actually determining. However, it should also be clear that the determining product is not necessarily the only product of importance, since the combined economic revenue from several co-products may be necessary to change the production volume.

The illustration in Box 1 also shows that:

- the determining product is not necessarily the product, which yields the largest economic value to the process (although this will often be the case),
- the determining product is not necessarily the product, which is having the largest increase (or decrease) in demand.

3.3 Identifying the product that determines the volume of the intermediate processes (step 3)

The intermediate processes are those processes that take place between the split-off point where a non-determining co-product leaves the processing route of the determining product and the point of displacement where the co-product can displace another product (when this applies). While it is always relevant to determine the split-off point, it is only relevant to determine a point of displacement when the non-determining co-product is utilised fully in other processes and actually displaces other products there (i.e. when rule no. 2 applies).

The determining product for the intermediate processes is identified by investigating whether the two conditions of rule no. 2 are fulfilled or not, i.e. whether:

- a) the non-determining co-product is utilised fully in other processes,
 - b) the non-determining co-product actually displaces other products there
- (see also the decision tree in figure 3).

Whether a product is utilised fully and whether it displaces other products, depends on market conditions that - as for the co-producing process - may change:

- over time,
- depending on location, and
- depending on the scale of change.

Thus, it is important always to note the conditions under which the determinant for the intermediate processes has been identified.

3.4 Recycling

Recycling has been regarded as presenting distinct allocation problems needing a separate treatment. In the procedure presented here, the same procedure is applicable for recycling as for any other situation where the same processes are shared by several products. In figure 4 the recycling situation is presented, re-using the layout and lettering of figure 2.

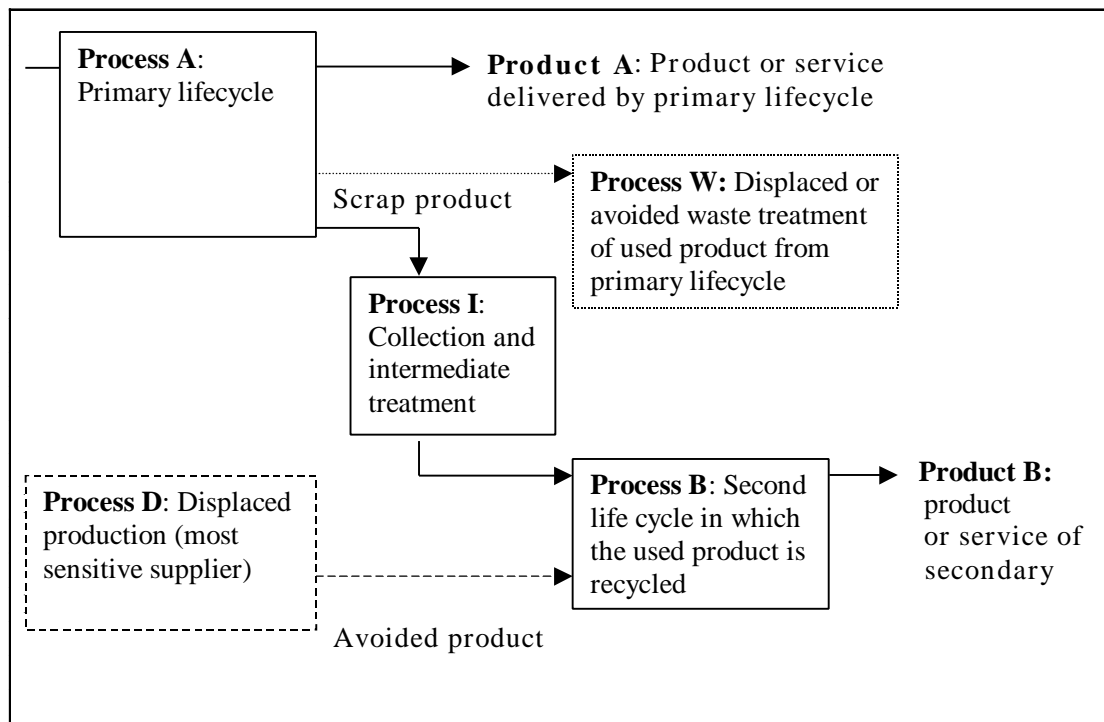


Figure 4. Model for describing system expansion and delimitation in relation to recycling

In this situation, it is no problem to identify the determining process for the primary life cycle. This is obviously the product of this life cycle, not the scrap.

The central issue is what determines the collection rate and thus the degree to which the scrap is utilised in the secondary life cycle.

In an expanding market for the scrap product, as is the case e.g. for most metals, all scrap collected will be used, and - provided a free market - the collection rate will be determined at the volume where the marginal cost of collection equals the marginal cost of the “virgin” production. In this situation, a change in the volume of the primary life cycle will lead to: a change in the amount of scrap available for collection, and a change in the amount collected (determined by the cost of collection of the specific scrap, which may be influenced by e.g. the existence of specific take-back facilities, the ease of disassembly, etc.), a change in the amount of scrap utilised in secondary life cycles, and thus in the displacement of “virgin” production (i.e. following rule no. 2).

A change in the volume of the secondary life cycle will not be able to influence the amount of scrap utilised, since it is already utilised fully. Thus, the change in the volume of the secondary life cycle must be covered by a change in “virgin” production (i.e. still following rule no. 2).

In a shrinking market, as we can see for cadmium and some other heavy metals, some of the available material is being deposited, since there is not an adequate demand. A change in volume of the primary life cycle will only lead to a change in the amount of material to be deposited, while a change in the volume of the secondary life cycle will lead to a change in the amount being recycled, and thus indirectly also to a change in the amount being deposited (i.e. following rule no. 3). It is interesting to note that in the case of cadmium (and possibly other heavy metals) the amount of recycling is fixed by environmental regulation, which means that it is “virgin” cadmium (as a by-product from zinc production) that is being deposited, while in other situations it can be expected that it is the scrap material that would not be collected.

It may be argued that the studied changes in either the primary or secondary life cycle may also have a secondary effect on the market prices, and when operating on a free market where the marginal cost of collection equals the marginal cost of the “virgin” production, this would affect equally the primary production and the collection of scrap. This was the background for the so-called 50/50-rule suggested by Ekvall (1994) under the assumption that the price elasticities of the “virgin” production and collection were equal (i.e. that they would react to a price change with the same change in volume). Actually, the price elasticities are not equal (Ekvall 1999), and at the high collection rates which exist in a free market, the resulting volume change in collection is likely to be much less (probably often negligible) compared to the change in “virgin” production. This would support the above conclusion of applying rule no. 2 in the situation of expanding markets. Also in the case of a moderately shrinking market, where the supply from “virgin” production still plays a role, the difference in price elasticities would imply that the “virgin” production is affected most. However, in a rapidly shrinking market, the scrap can cover the entire demand and virgin supply would not be relevant. In this situation, a small change in volume of the secondary life cycle would only be able to affect the scrap collection, which is in line with our above conclusion of applying rule no. 3 in case of shrinking markets.

3.4 Complex situations

The situation described by figure 2 (and 4) is a simplification, in that there is only one non-determining co-product shown (i.e. only two products coming out of process A) and none of the other processes have co-products. However, the more complex situations:

- where process A has more than two co-products (a situation that is rather the rule than the exception),
- where the intermediate process has multiple products (e.g. different grades of recycled building wastes),
- where the avoided process has multiple products (e.g. where an oil seed crop produces both oil and protein that displaces another oil seed crop with the same products but in a different proportion, or the co-products ethylene and propylene, where the same situation occurs, which one might fear could lead to an unending regression),
- where process B has multiple products (especially the situation of downcycling/cascading e.g. of paper and steel),

can all be handled by successive applications of the above procedure. Space does not allow a detailed treatment of all these situations. This will be done orally at the workshop and a more detailed presentation will be available in a forthcoming publication. Here, it may suffice to say that the problem of unending regression is eliminated by the clear cut-off criteria (either a process is included or excluded from the studied system) provided by the presented procedure.

3.5 Waste or co-product?

In previously presented allocation procedures, it was important to distinguish between wastes and co-products, since the exchanges of the co-producing process should be allocated over the co-products, but not over the wastes and emissions.

In the procedure presented here, the distinction between wastes and co-products is not important. If in doubt whether an output is a waste or a co-product, the output can be regarded as a non-determining co-product and passed through the procedure. It will typically fall under rule no. 3 (for “near-to-wastes” that are not fully utilised) or rule no. 4 (for true wastes that do not displace any other products). If a waste in the economic sense, i.e. an output without economic value to the process that produces it, displaces another product, the “waste treatment” is in fact a recycling, and rule no. 3 should therefore be applied in order to model correctly the consequences of this “waste treatment”.

Thus, from the procedure presented here, a novel definition of waste may therefore be derived: *A waste is an output that does not displace any other product.*

4. Acknowledgements

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Appendix 6: Input paper Reinout Heijungs and Gjalt Huppes

Inventory modelling in the Dutch LCA methodology project

With a focus on:

- marginal versus average analysis and**
- options for solving the allocation problem**

**Discussion paper for the
Danish-Dutch workshop on LCA methods
Leiden, 16-17 September 1999**

**30 August 1999
Reinout Heijungs & Gjalt Huppes
CML, Leiden University**

1 Introduction

LCA is a tool for supporting decisions regarding different options for fulfilling functions. Change oriented (or effect oriented) LCA inventory analysis specifies and compares the changes in environmental interventions patterns associated with the choice.² Ideally, this comparison is based on the real effects as would occur in the course of time, different for the different options or alternatives. In practice, only simplified models can make the analysis operational. The way LCA-models may adequately simplify reality depends on the choice to be supported. For the optimisation of a given system, a steady state model is not very useful. A steady state model leaves out options for short term variation but investigates structural changes we may consider, while the optimisation analysis takes the structure as given and analyses the short term variations possible within these constraints.

The questions to be asked and the type of modelling chosen set the scene for subsequent analysis of a number of discussions which have ravaged in LCA for a long time. One group of discussions centres around the marginal - average dichotomy, see chapter 4. Main topic is what exactly are we indicating as "the change" brought about by the alternatives considered. We think the principles to be quite straightforward but the answers to be quite complex and intricately related to the questions asked and the modelling set-up chosen. Another discussion area is that of allocation, see chapter 5. Here it seems that the principles are not established and can only be defined properly in the context of specific questions and models chosen for answering them. Thus, the main questions asked and the set-up of modelling chosen are a prerequisite for precisely answering the questions in this area of LCA dispute.

In this paper our aim is not to arrive at a single rule for the proper type of marginal analysis and the proper solution to the allocation problem. Our primary aim is to clarify the situation and investigate different modelling choices, each with its advantages and disadvantages. A combination of choices defines the default LCA we intend to develop in the Dutch LCA project. The default set is sensible in a number of situations. In other situations, other choices or other default sets may be more relevant.

In treating these subjects we will come in areas not usually seen as belonging to LCA, like economic equilibrium models or linear programming models used for optimisation. We do not want to go into discussions if only steady state models are 'real' LCA, e.g. because we think these other models are indispensable tools for some main questions. Even for a given question there may not be one clear and simple answer in methods choice. In our view, different models may give different insights in real world mechanisms. In working out one specific method, the sole criterion for methods improvement and comparison is if new real world effects are added, without compromising on others already present. For instance, we feel that incorporating dynamic emission patterns does not add much value to an LCA for a structural choice, while it may introduce a host of new uncertainties. We tend to be cautious in this respect, e.g. avoiding complexity in unrealistic assumptions. That is part of our strategy, however. It is definitely not what we consider the only "true" approach. Taking this broader view, some central assets of current LCA do not seem to be essential for decision support. For instance, the arbitrary size of the functional unit is needed in a certain type of simplified analysis, but not inherent in most real world questions. In this way we hope that LCA can more easily be linked to related types of analysis also for a structural choice aiming to support decisions in a sustainable direction.

² Throughout this document, we make choices that enables a more focussed discussion of subsequent items. Our first choice is already made at this point: we choose to elaborate in the Dutch update project change-oriented (or prospective) LCA, and not descriptive (or retrospective, or level 0) LCA. This does not mean that descriptive LCA is judged to be uninteresting or useless, but it rather fits in our general concept of a decision tree in which we follow one path, while only scanning some of the other branches.

2 Questions to be answered in LCA inventory modelling

CATEGORISATION OF QUESTIONS

Our starting point is a decision situation in which a choice between a number of alternatives is to be made. We distinguish between the questions to be answered and the way the answers can be produced. The questions are the starting points, and one or more, simple or complex models are the means for answering them. The questions are of the form:

“What are the environmental³ effects choosing option A as compared to option B”?

We limit the domain to choices related to products or functions. Restricting ourselves to the inventory, effects are in terms of environmental interventions⁴. We distinguish between three main types of questions, related to three main types of choice:⁵

- 1 Occasional choices, related to one-time functions
- 2 Structural choices, related to a function to be delivered regularly
- 3 Strategic choices, binding the choice on how to supply a function for a long, or even indefinite period of time.

Which specific questions are to be answered, per type? Without pretending to be systematic and complete we would consider the following questions to be relevant for developing a systematic approach to answering them.

OCCASIONAL CHOICES

This category of choices refers to choices by individual persons (mostly: consumers) that relate to singular decisions of which the influence on society is negligible. Examples of concrete choices and questions are:

- Travelling mode: Should I take the high speed train or the plane to my meeting in Paris next week?
- Drink containers: Should I use a china cup or a paper cup in the lunch facility I happen to be visiting today?
- Waste management: Should this piece of waste paper be put into the paper container or into the organic wastes container?

The time horizon of the decision and function fulfilment is short. In contrast, the time horizon of effects in the chain may be quite long. In specifying the effect chain, one may take into account simple or more complex mechanisms, simple or complex model forms, one may use one or several models, etc. A current choice does not influence the past, so capital investments as in building the aeroplane-to-be-used next week do not play a role in occasional choices. However, the extra passenger may lead to an earlier replacement of the aeroplane, which then leads to earlier and possibly larger environmental interventions. Similar types of reasoning can be set up for the other examples.

It should be noted that occasional choices may be repeated quite often, for instance when a business traveller chooses between train and plane for every business trip. The same applies to the manager of a waste treatment system who daily decides on the optimal operating conditions of his facilities, depending on the supply of waste that is to be treated.

STRUCTURAL CHOICES

This category of choices refers to choices by individual persons as well as firms that relate to decisions that affect society in a limited and easily reversible way. Examples are:

- Travelling mode: Should I take the high speed train or the plane to my weekly meetings in Paris?
- Drink containers: Should I use a china or paper cup in the lunch facility at my office, every working day?
- Waste management: Should I put my daily flow of old newspapers into the dustbin or into the paper recycling container?

³ We might add here “and other” to allow for the taking into account of effects of an economic and social kind.

⁴ Non-environmental effects may fit in the same framework.

⁵ This categorisation of questions is close to, but nevertheless differs in some respects from the categories short-term optimisation, mid-term improvements, and long-term societal change.

The time horizon for the function fulfilment may be long. The context for my decisions in terms of facilities is given in the short run but the constraints are eased each year, as investments and wear change the capacities of different technologies installed. For instance, even a small but continuous flow of extra discarded paper will lead to adjustments in investments of paper mills. The choices are formulated for consumers, but they may also apply to enterprises, for instance, when a company decides that its employees are supposed to make their business trips to Paris by train. Even the decision of a company between giving its employees a lease car or a free public transport card may belong to this category. The essential feature is that the choice is reversible, for instance that no large investments are involved. This puts limits on the scale of the decision. So, if a government decides that every citizen has a free public transport card, large investments of the railroad system may be required, which may be seen as practically irreversible; we then would categorise such a decision under "strategic choices".

STRATEGIC CHOICES

This category of choices refers to choices by individuals, firms and governments that relate to decisions that affect society in a substantial and practically irreversible way. Examples are:

- Travelling mode: Should the government invest in high speed railroads or in airports?
- Drink containers: Should society as a whole choose for re-usable china luncheon materials versus throw-away cups and plates?
- Waste management: Should cities introduce the splitting up of waste flows in different fractions, with a concomitant set of waste processing and recycling installations?

The time horizon of the activities for function fulfilment as influenced is longer for strategic choices than for occasional choices. Structural decisions have a similar or more limited time horizon. There may be a delay in the start of the activities, as for the investments required in the high speed train example. The time horizon of functioning may be limited to a few years, as with lunchroom kitchens, or may cover up to centuries, as with rail infrastructure. For the effects in the chain, one again may cover a shorter or longer period, as for recycling effects to fade out. Again, there may be one or several models, incorporating simple or complex mechanisms, with a simple linear or complex non-linear form. The essential feature is that the choice leads to extensive changes with a high degree of irreversibility, since the investments are so huge that it is very unlikely that such a decision will easily be turned back.

It may be difficult to categorise all choices in a proper way. Some choices may first appear to be structural decisions, but may be argued to be strategic decisions. For instance, if airline companies base their investment plans on the current use of aeroplanes, one weekly extra passenger may lead to more investments. Also, an occasional choice for a fluorescent lamp is a decision for 5 years, with possibly even repercussions for power plant investment plans. Therefore, it is not so much important in which category a certain concrete choice is placed. What is important, rather, is that the user of LCA is aware of the fact that every category question highlights certain aspects and ignores other aspects.

RELEVANT CHOICES IN DUTCH PROJECT

We tend to choose for concentrating our LCA guide to the structural choices. That does not mean that we consider the occasional and strategic choices as uninteresting, or as outside the domain of LCA. We rather think that these represent useful questions. But, they require a modelling set-up that deviates strongly from that needed to support structural choices. Therefore, we have chosen to leave the elaboration of this class of choices to other projects. We think that the approaches that have been developed by Clift and coworkers and by Weidema and coworkers may be useful for LCAs with occasional choices as a starting point. Strategic choices, on the other hand, call for an approach that could contain elements of scenario analysis and partial or general equilibrium modelling.

Before going into the details of marginal and average discussion and allocation methods, we now first deal with the general set-up of modelling, stating the framework for dealing more precisely with these questions. From hereon, we restrict the text to structural choices.

3. General concept of the inventory model

THE NEED FOR A MODEL

In some of the earlier documents, LCA was conceived as a method to manipulate data on emissions of pollutants and extractions of natural resources in a more or less mechanical way. However, ideas as those on “whole system modelling” have stimulated the transition of this picture to one in which the modelling exercise plays a central role. LCA, at least in its “prospective” or “change-oriented” mode (ref) as discussed here, deals with the prediction of which environmental interventions will occur. And prediction is a procedure for which a model is to be used. Therefore, this paper will put a large emphasis on the foundations of the model for LCA, with a bias towards the model for life cycle inventory analysis.

THE REALITY BEHIND THE MODEL

It is useful to get a clearer picture of what type of reality is supposed to be reflected by the model for inventory analysis. When studying the change in environmental burdens, it is necessary to specify:

- a time pattern, distinguishing between short-term effects and effects on the longer term;
 - a reference situation in which the effects of the alternative investigated do not take place.
- Figure 1 illustrates what is involved in a change-oriented analysis. We see a time pattern of emissions.⁶ There is an autonomous pattern (e_0), governed by a complex pattern of economic cycles, environmental regulation, population growth, cultural influences, natural disasters, civil wars, and so forth. At a certain moment in time (t_0) an economic actor has the power to decide on implementing a choice. This may be a producer redesigning his production process, a consumer buying a certain product, an authority granting a permit, etc. Figure 1 shows from t_0 on two lines: one with some alternative being implemented (e_2), and one with the reference alternative (e_1). It is assumed here that there is an immediate effect at t_0 , and that there is a complicated difference between the two lines at later stages. This complicated difference is due to upstream and downstream consequences that are introduced with a time-lag.

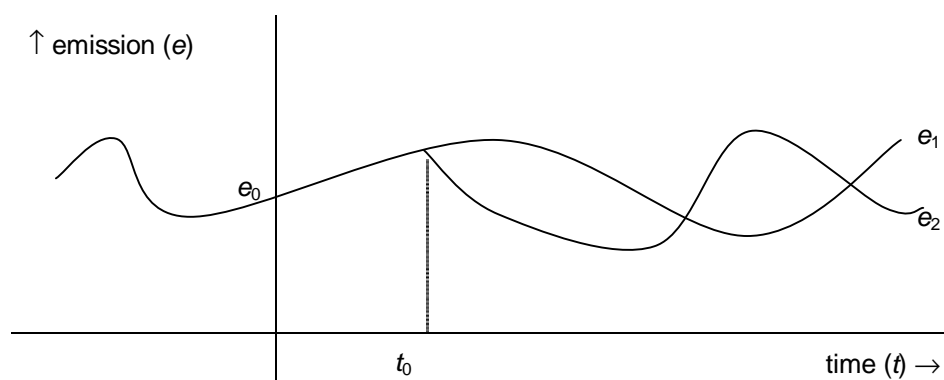


FIGURE 1. Time pattern of the emission before a choice (e_0 , left of t_0), after the choice not being implemented (e_1) and after the choice being implemented (e_2).

An example may clarify this further. A consumer that decides to drink one extra cup of coffee, buying it from a coffee machine, first causes an increase in electricity and water demand. With a delay of a few hours, he will use the toilet, again using electricity and water, but now also involving the waste-water treatment plant. With a delay of a few days, filling of the coffee machine will take place, where some extra filling of coffee (and perhaps sugar and milk) and the cup reservoir needs to be done. The same applies to the disposed cup. After days to weeks, the signal of extra coffee consumption will have reached the producers of coffee, milk, sugar and cups, and the waste treatment facilities. These will presumably produce extra coffee, milk, etc. to compensate for the extra use. Next they may also be induced by this and similar signals to adjust their production and/or investment plans. This latter indirect effect

⁶ This is a one-dimensional concept, which may stand for emission of CO₂, for damage to the ozone layer, or for an aggregated environmental index. The generalisation to a multi-dimensional set of environmental consequences, including resource use, is straightforward.

may also reach the producers of electricity and water, the firm that maintains the coffee machines, and the firm that collects the waste bins. For instance, it may be that there is an extra waste bin already one day later. We may even extend this example with bizarre consequences, analogous to the image that is used to illustrate chaos theory: the butterfly in Peking which causes a storm in New York. For instance, my coffee consumption may cause that import exceeds the threshold for constructing a new freight airport.

Examples like this one may be written down for any choice: product design, packaging material, mode of transport, etc. We see that there may be all types of primary, secondary, etc. effects which may be invoked at quite different moments of time. If we decide to concentrate on the very short-term, say one hour, the only effects of the coffee consumption will be due to electricity and water use by the coffee machine. Even production of coffee is then left out. If we, on the other hand, decide to analyse the effect at a point in time that is farther away, say three weeks, than we may have included some "indirect" effects, like the extra waste bin. But we then surely miss the short-term effects, like the production of electricity for running the coffee machine. If we want to cover instantaneous effects, effects on the time scale of hours, of days, and of years, we have to switch from one moment in time to an integration over an interval of time. In that case, it is necessary to specify the integration boundaries.⁷ It seems natural to opt for a full time-integration when we are speaking about consequences throughout the life cycle. Ultimately, one may choose a specific variant of time-integration, namely based on a constructed long-term equilibrium situation.

THE NEED FOR A SIMPLIFIED MODEL

A model is a simplified representation of a part of reality. In the case of LCA, there are two aspects worth mentioning.

- LCA deals with complex interwoven networks of industrial, agricultural, household and waste management activities. The pattern of activities is dispersed over many locations and may span decades. The mechanisms that govern the behaviour of these activities are of a technical, economic, cultural and political nature. The mathematical relationships that describe these mechanisms are non-linear, dynamic and may show hysteresis. The model of LCA should introduce crude simplifications in very many directions.
- LCA concentrates on one product life cycle, although it is well known that economy and technology are such that any two products are connected through a common process at some stage. The model of LCA should therefore possess the property that it is able to cut out a product life cycle from the interconnected complex. In particular, the setting of system boundaries and the allocation procedure are needed to enable this process of isolating one product life cycle. Another option is to incorporate "all other processes" in a more aggregate way, e.g. using input-output tables (Lave et al., 1995).

In an ideal situation, one would like to know the environmental interventions (and/or effects) of a certain choice specified per location and per time. This is extremely difficult, if not impossible for theoretical reasons. Practitioners of LCA are happy if they can overcome the difficulties in predicting with reasonable accuracy the total environmental interventions, integrated over all locations and infinite time in an assumed steady-state. There has not been much attention for aspects of spatial differentiation or specification of dynamic patterns in time, of the form "emission in Dublin at 16th of June". This has made that LCA is sometimes said to *a priori* exclude specifications of space and time, and that spatially differentiated LCA or dynamic LCA is almost a *contradictio in terminis*. In this paper, we take a more liberal position. Space-integration and time-integration are seen as two possible steps in the inevitable process of constructing a feasible model for LCA. There are more steps. Some of these steps involve the model structure (e.g., linearisation of process characteristics and aggregation of individual companies into a sectoral set-up), and others involve the mechanisms involved (e.g., ignoring demand elasticities or changes in use patterns by consumers). Again, we stress that, although these simplifying steps facilitate the modelling exercise and may be very normal in LCA practice, the explicit incorporation of, say, non-linear relationships and economic mechanisms, is by no means in contradiction with the aim or principles of LCA. Hence, if this paper proposes certain simplifying steps in the construction of

⁷ When choosing for time-integration, one should think about whether or not to discount future effects to their present value.

an LCA model, some further research effort may be invested so as to omit one or more of these simplifications. It may well be argued that certain simplifications are simply too crude for particular situations.

MAIN MODEL SIMPLIFICATIONS

The construction of a model is always an interplay between a number of limiting factors and a couple of demanding requirements: availability of data, availability of dedicated software, availability of time and availability of expertise on the one hand, and quality (measured in terms of accuracy, reliability, robustness of ranking of alternatives) and representativeness on the other hand. The omission of economic mechanisms or spatial detail leads to a great simplification, but it certainly reduces the quality of the analysis. Below, we will sketch some proposed simplifications for the model of life cycle inventory analysis for supporting structural choices. It should be understood as a default, in the sense that it is only one step towards a generic method, and that deviations from these simplifications are perfectly legitimate.

Some main lines of simplification are:

- An almost complete omission of spatial detail. Thus, amongst other, emissions in the vicinity of different types of ecosystems are not distinguished from one another. This, by the way, does not mean that the distances between unit processes is put to zero: transport is just taken into account. It also does not mean that all unit processes are assumed to operate according to the technological state that is representative for one region. We may still distinguish between different emission characteristics for electricity production at different places, we only do not specify where the emission occurs. The only default spatial details that are kept are those along a short list of environmental media: air, surface water, soil, and perhaps sea and sediment.
- A complete omission of temporal detail. This means, amongst others, that emissions are specified as total (infinite) time-integrated emissions. This, by the way, does not mean that operations like storage⁸ are left out. It also does not mean that all unit processes are assumed to operate according to the technological state at one point in time. We may still use different emission characteristics for electricity production needed for the construction of factory buildings and that for recycling 50 years later.
- A complete omission of non-linearities. This means, for example, that when the production of 1 kg steel is associated with an emission of 5 kg, the production of 2 kg steel is assumed to be associated with an emission of 10 kg.
- An omission or extreme form of simplification of most economic, socio-cultural and technological mechanisms that influence the operation of the processes that are considered in the inventory analysis. For instance, when product A is more expensive than product B, switching to B will make that the consumer has more money to spend on new (polluting) activities. This is normally not taken into account.⁹ The same applies to the phenomenon that people use to light more lamps when these are energy-efficient is normally left out. There are numerous examples of this type of simplifications. Some mechanisms are just ignored (like the two above), and others are taken into account in a simplified way. An example of this latter category is the economic substitution of certain materials by coproduced materials, where a sophisticated economic model would apply cross-elasticities, while some LCA-analysts assume a full, or zero, substitution in an allocation procedure. As a default line, we propose to leave out all mechanisms except those that are related to changes in volume, and (see above) to simplify that mechanism to a linear approximation. This has, amongst others, important consequences for allocation; see chapter 4.

Figure 2 shows the model that is supposed to reflect the reality depicted in Figure 1 under some of the simplifications that were discussed above.

⁸ To purport the analogy with space: Transport is the process which carries an item from location A to location B, while storage is the process which “carries” an item from day A to day B. Both transport and storage are economic processes which may need fuel, electricity, cleaning, and which may emit pollutants.

⁹ Unless, e.g., the functional unit is expressed in monetary units.

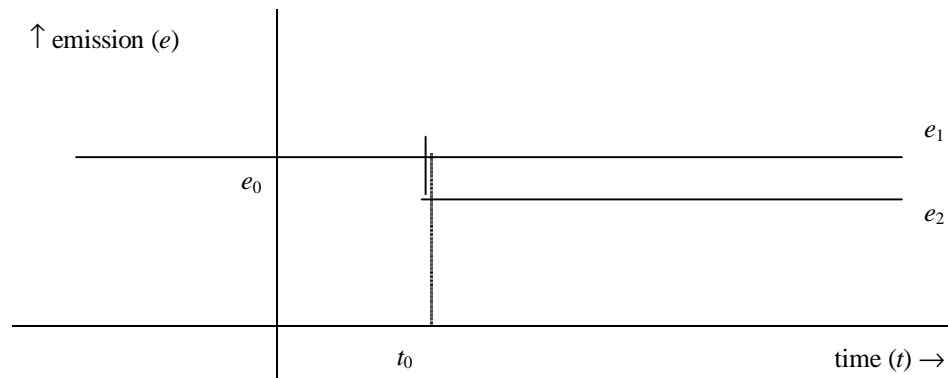


FIGURE 2. Simplified time pattern of the situation of Figure 1.

Notice that some of the complexities of economy-environment relationships are maintained. For instance, there is usually no aggregation of pollutants into substance groups (like “heavy metals” or “organic compounds”). Another example is the detailed micro-look at the economy (like treating “rolling of steel” or “bleaching of paper” as separate activities. One is of course perfectly allowed to make simplifications along these dimensions. They facilitate the computations, but on the expense of producing a less reliable answer.

RELEVANT CHOICES IN DUTCH PROJECT

Following the main model simplifications outlined above, and in connection with the previous choice for focussing on structural decisions, we tend to concentrate the default modelling exercises to steady-state modelling without the specification of patterns in time and space. Furthermore, we limit the modelling mechanisms to fixed input-output relations of the Leontief-type, with linear homogeneous functional forms.

3. Average and marginal processes and average and marginal process data

BASIC CONCEPTS

The basic mathematical meaning of the terms average and marginal is clear and is summarised below. Applying the in itself clear concepts still may cause difficulties. Implied in an LCA relevant choice is the (exogenous) change in the volume of some product as produced by some unit process (plant, facility, etc.). How can we now describe the resulting changes in the other inputs and outputs of that process? Let us simplify the situation to a process that produces one functional output (x , say, electricity) and that has one other flow (y , say, input of fuel). A change in the demand for electricity will induce a change of the production volume of the generation process.¹⁰ This can be considered as a shift from the reference value of x (which we will denote by x_0) to the value of x implied in the choice for alternative 1 (for which we use x_1). We will call this an incremental change. The associated incremental change in fuel need (y) is one from y_0 to y_1 .

The relationship between x and y is known in economics and engineering as the production function.¹¹ It is a result of the interplay between physics, chemistry, technology and economics. The relationship can be symbolised as a function f which maps any value of x onto a value of y (or the other way around). The production function is thus

¹⁰ For simplicity, we concentrate here on the direct (short-term) change. Such a change will in the longer term lead to changes in maintenance, replacement, investments, and so on. A later paragraph will expand on this issue.

¹¹ In agreement with the previous note, there exist short-term production functions and long-term production functions.

$$y = f(x)$$

In general it is a non-linear function, involving many variables, and it is often not exactly known. We here treat the case of two variables with known relations.

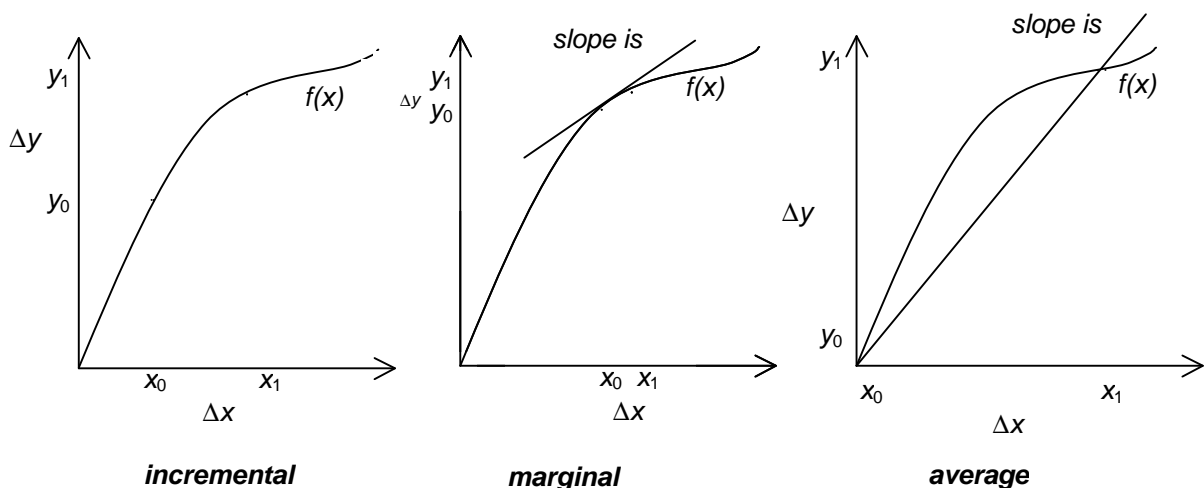
In the case of an incremental change of electricity need Δx (from x_0 to x_1) we need to calculate Δy (from y_0 to y_1). This means that we have to calculate

$$\Delta y = f(x_1) - f(x_0)$$

Our general ignorance of knowledge of the production function f makes this calculation problematic. A second problem is that we cannot simply rewrite this equation as a function of the change in x , like $\Delta y = g(\Delta x)$, even if $f(x)$ is known.

There are, however, two situations which lead to important simplifications. One is referred to as a marginal change, the other as a change for which average data may be appropriate. See Figure 1.

FIGURE 1 INCREMENTAL, MARGINAL AND AVERAGE ANALYSIS OF A RELATION BETWEEN TWO VARIABLES



When the change is quite small (such as when needing 40 W extra from a large power plant), we may make a linear approximation to the non-linear production function. In that case, we use

$$\Delta y = MF \times \Delta x$$

where MF is the marginal factor (the “slope”) for the input of fuel.¹² This formulation is known as using marginal data, because the data apply to a marginal change. It has the big advantage that one value (namely MF) suffices to calculate the change in the fuel input for any change in the electricity production, as long as that change is small enough to justify linearization.

When, on the other hand, the change is “revolutionary” in the sense of resulting in a complete shut-down of a facility ($x_1 = 0$) or a complete start-up of it ($x_0 = 0$), a different approximation may be used:

$$\Delta y = AF \times \Delta x$$

where AF is the average factor for the input of fuel.¹³ This formulation is known as using average data. In this case, there is no such thing as a corresponding average change. Its

¹² More precisely: it is the first derivative of f with respect to x , evaluated at $x = x_0$. There is one formal requirement for this approximation: f must be differentiable, which means that it must be continuous. In practice, AF may be recorded in a database, even without full knowledge of the function f . AF is then obtained through a small but non-zero change around the typical working point of the process.

¹³ More precisely, in the case of start-up it is the ratio y_1/x_1 and in the case of shut-down it is the ratio y_0/x_0 . When the non-closed working point of the production characteristic is the typical working point of the unit process, the two cases start-up and shut-down will yield the same average factor. There is

name derives from the fact that at the non-closed working point, the average fuel need per unit of generated electricity coincides with the average factor. Using the average factor has again the big advantage that one value (namely AF) suffices to calculate the change in the fuel input for any change in the electricity production, as long as that change is “revolutionary” enough to justify complete start-up or shut-down.

DIFFERENT MEANINGS OF AVERAGE

In the above, we introduced the term average as a way of dealing with process data in “revolutionary” changes. We did not mention it with respect to incremental or marginal changes. However, it may be argued that using marginal data for ascribing interventions to activities may introduce an unfairness. If a train is running with 100 passengers, one may calculate the average electricity use per passenger. If one extra passenger enters the train, the train's electricity use will increase marginally. Now, one can follow two different principles for assigning electricity use to the extra passenger:

- the “factual” approach: the marginal change in electricity use is assigned to the extra passenger,
- the “fair” approach: the new electricity use is distributed evenly among all 101 passengers.

The second approach has the advantage that historical facts (like who was the last passenger) do not matter: every passenger is treated in the same way and “responsible” for a proportional¹⁴ amount of electricity use and associated environmental interventions. This also makes that this approach is not susceptible to “strategic abuse”, like when someone argues that the aeroplane was flying anyhow, forgetting that structural changes may be induced by occasional choices of many persons. But it also has disadvantages. A disadvantage of a practical kind is that one could envisage different methods to establish the partitioning. On the basis of number (every passenger 1/101th), on the basis of mass (with or without luggage), on the basis of share in sales (first class versus second class passengers), etc. But there is also a more fundamental disadvantage: it is to some extent with the idea the original idea that LCA is supposed to provide a model of what is factually happening. Anyhow, whether one prefers either of the two approaches, an important lesson here is that even marginal data may be used for an average (= proportional) assignment. Fortunately, the dichotomy between factual and fair partitioning is not important for the remainder of this paper; see our recommendations at the end of this chapter.

DIFFERENT MEANINGS OF MARGINAL

Next, there is the problem what exactly is on the axes. First, let it be clear that a production function is normally more than a relation between one input and one output. It may be a whole vector of inputs that is related to a whole vector of outputs. Some pairs of inputs or outputs may be directly coupled (like the case of burned fuel and generated electricity), while other pairs of inputs and outputs may be only related in a longer time perspective (like the case of replaced generators and generated electricity). A marginal change, as the effect resulting of changing one unit, may thus be modelled with different time frames in mind. In economics, eg, the short term marginal effect of increasing production equals the change in variable costs, like the extra petrol needed for getting an extra passenger into the air each flight. In the somewhat longer run, an extra passenger will lead to extra food on board, extra maintenance of the cabin etc. In the still longer run, the number of flights will go up, as planned flights are related to the occupancy percentage. Therefore, the marginal costs will now include those of the extra aeroplanes built to adapt to the increased demand. Effectively these long term marginal costs are equal to the average costs. The lesson here is to be precise in the uniqueness of the decisions studied. In the aeroplane costs example there was a subtle change from one time one passenger extra, to short term effects of on each flight one passenger extra, to longer term effects of one passenger extra on each flight. Each shift makes that a different meaning of the adjective marginal is to be read.

one formal requirement here: the closed working point should have coordinates $(0, 0)$, which means a real closure. A boiler that is switched on but not used still needs some energy, but a boiler that is switched off doesn't. We do not preclude any choice in the treatment of capital goods here.

¹⁴ This is one reason to prefer the term proportional to average.

Finally, we must distinguish between the marginal process and the marginal data of a process. There may be one (or more) unconstrained process(es), which may be identified as the process(es) that will be used to produce the extra demand of a certain product. This process is the marginal process in a process mix. Next, one may determine how the emissions, fuel needs, etc. will change when one marginal unit of output is needed. These changes then reflect the marginal process data. It is perfectly possible to treat the marginal process with average data, so the two concepts should be clearly distinguished.

In change-oriented LCA, the analysis is about incremental changes, not about averages. However, incremental changes, like marginal changes, may coincide with average effects under the assumptions as stated above.

In situations where a simplified model is used, these analytic differences disappear. With linear relation not through the origin, marginal and incremental effects coincide, but differ from average effects. With linear relations through the origin, marginal, incremental and average effects are all equal.

CONCLUSIONS FOR DUTCH LCA PROJECT

In connection with the previously stated modelling principles, we focus on fixed technology mixes, i.e. on an average technology that is representative for the location and time of the proposed choice. These average technologies are then treated using average data including capital goods.

4 Defining and solving the allocation problem: options

DEFINING THE ALLOCATION PROBLEM

As indicated in the previous chapter on modelling, the allocation question arises and is defined by the set-up of the modelling chosen. This relation is so fundamental that it does not seem useful to treat the subject of allocation separately. Even the distinction between modelling and allocation is not sharp and a matter of terminological convention. The marginal analysis of given installed capacity systems as described by Azapagic and Cliff may be seen as part of the still multifunction inventory model, leading to an outcome which still may require some allocation, as in the situation of joint production. Alternatively, it may be seen as a main step in allocation itself.

For the allocation problem to occur, it is necessary but not sufficient that one or more processes have multiple functional outputs (Heijungs & Frischknecht). If these outputs can be varied independently, the process is 'combined'; if they cannot be varied independently, they are joint. The previously stated choice for using fixed input-output coefficients per process, makes that all multiple processes are regarded as joint. The available information does not specify the options for short term changes of capacity use within a given installed capacity. In the long term, a single process can be varied in its relative outputs by technical adjustments; the process changes. Also, process mixes can have an adjusted pattern of functional outputs. An example is single sodium production and joint sodium-chlorine production. By shifting between them, which requires investments, a broad range of sodium and chlorine mixes can be produced. It seems best to reserve scenario analyses if one really wants to include these mechanisms. This may be seen as a substitution solution to the allocation problem, although it is incompatible with the starting point of fixed coefficients.

One main assumption sometimes made is that final demand remains constant. For global LCA inventory analysis, the *ceteris paribus* assumption means that final demand by consumers is constant. This assumption simplifies the analysis at the costs of artificial effects. E.g. for extra PVC, an expansion of a joint production facility for sodium/chlorine is necessary. The sodium then cannot be used and may be left out of consideration. All inputs and outputs of the facility then are allocated to the chlorine and the sodium may even be treated as a waste. This solves the allocation problem but can hardly be seen as contributing to a realistic causal analysis. A related assumption is that elasticities of demand are either zero or infinite, while we know that in reality their usual range is around 1, say between +/- 0.1 to 10. A related but less extreme assumption is that of constant final demand (e.g. Ekvall 1999), in the

comparison between alternatives. This also is a not realistic assumption, being equivalent to the assumption that all substitution is perfect, i.e., that consumers are indifferent as to co-product and substitute. It has as an ultimate consequence that some intermediate demand types have a zero elasticity, implying that extra supply is just not being used.

The substitution method, in which the production of a co-product is supposed to “avoid” the production of an equivalent product by another product system, is an example of a method that relies on economic mechanisms. These have been excluded as a default in our modelling simplifications. It is also quite data-intensive to incorporate substitution phenomena for all co-products, and, worse, for the co-products of the substitute (= avoided) processes. The impossibility of a systematic application is one important reason to choose a different default option.

Models differ in their option for treating arbitrary functional units. All models that are not strictly linear (or more precisely: not homogeneous to degree one) require the specification of absolute amounts, as incremental and marginal amounts depend on them. The effects of one functional unit then differ from the next and also the size of the functional unit influences effects. Allocation results then also will be size dependent.

OPTIONS FOR SOLVING THE ALLOCATION PROBLEM

In line with the ISO recommendations, we think that one should first try to zoom in on the multiple processes, to see if a further detailing into more refined unit processes resolves part of the allocation problems.¹⁵ There will surely remain allocation problems at certain points. Consistent with our previous choice for excluding economic mechanisms as a default, we do not recommend to follow the substitution approach (“avoided burdens”). Then remains the partitioning-based methods, which perform a true allocation. A real causal analysis, in the sense of being based on an interplay of thermodynamics, stoichiometry, market mechanisms and even legislation, is, in line with the exclusion of technological and economic mechanisms, outside our default scope. We thus fall back to economic allocation¹⁶ on the basis of the relative shares of the use-values. Nevertheless, it may be that for certain combined processes, e.g., waste incineration, reasonable causality-based models exist, which deserve replacing the generic default solution. For multiple outputs, application of causality-based physico-chemical models as a non-default seems to be much more problematic.

In promoting the shares in the use values of the multiple functions of a process as a basis for allocation, several practical problems occur. We mention: taxes and subsidies, differences in currencies, fluctuations in prices, inflation, market failures, and the absence of prices. Lindeijer & Huppes (1999) discuss possible solutions for most of these problems at length.

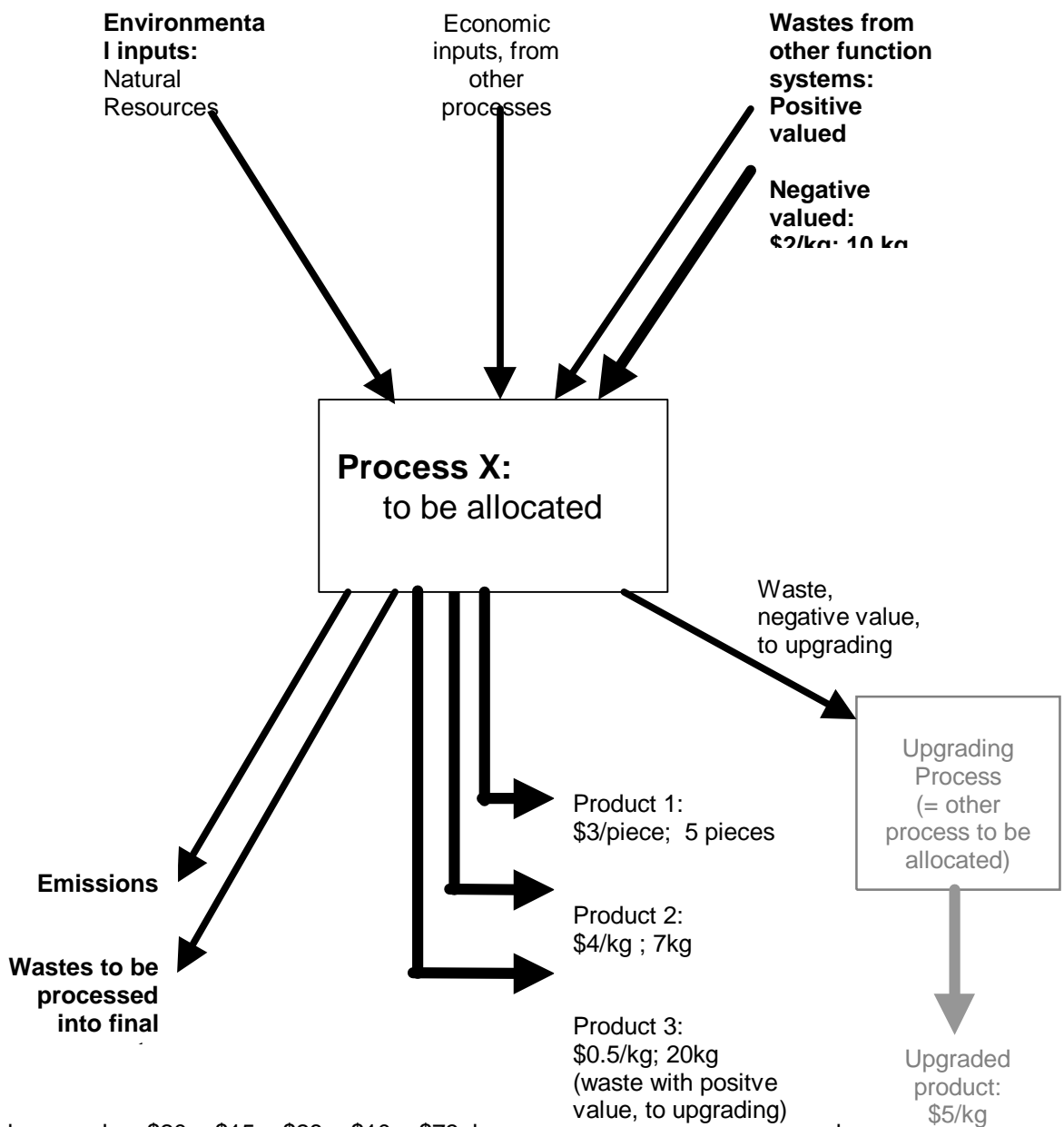
¹⁵ Note that this is in fact no allocation step; it is merely a closer investigation of the situation.

¹⁶ Using these shares does by no means imply that economic mechanisms are included, just like using emission factor does not imply that technological mechanisms are included.

Consider a process with

1. a set of inputs of products, materials and services (price > 0);
2. a set of input waste flows (price < 0);
3. a set of environmental inputs;
4. a set of outputs of products, materials and services (price > 0);
5. a set of output waste flows (price < 0);
6. a set of environmental outputs.

The flows in the sets numbered 2 and 4 represent the functional flows. The other flows in sets 1, 3, 5, and 6 are to be allocated to the different functional flows. In the default line, we collect figures about the share of each flow in set 2 and 4 in the total proceeds of the process. These shares add to 1 (or 100%). They serve as multiplication factors for each of the flows in 1, 3, 5, and 6. The figure illustrates this.



Total proceeds = \$20 + \$15 + \$28 + \$10 = \$73, hence each input should be allocated with a factor 20/73 to the waste inflow, 15/73 to product 1, 28/73 to product 2, and 10/73 to product 3.

CONCLUSIONS FOR DUTCH LCA PROJECT

Consistent with the previously motivated default modelling, and consistent with ISO's recommendations on allocation, we propose to use the relative share of the use value of the functional flows of a process (measured by their relative share in the process' proceeds) as the default basis for allocating the other flows to the functional flows.

5 Summary and conclusions

One central conclusion from this analysis is that there are good reasons to have different models for different types of questions. Even for the same type of question, different models may be used, each with advantages and disadvantages. Only within the realm of specific models is it sensible to go into the details of questions on marginal and average data and processes and pro and cons of different solutions for the allocation problem.

The output of this paper is input in the coming discussion. To facilitate an orderly discussion, main options for methods choices in the inventory have been brought together in the table on the next pages. It is clear that choices on each item cannot be made independently from each other. Sometimes logic forbids combinations. Dynamic models cannot be linear through the origin models. Sometimes combinations are not so sensible, as specifying processes dynamically for a steady state analysis. When discussing specifics, the place in the table should be clear. There is some order in the table in that it starts with higher order aspects. The hierarchical aim we had in mind is too much for this still muddled piece of theory, however.

In the table, the intended default line in the Dutch LCA project, for specifying standard LCA, has been underlined. This is not to say that this always is the best approach. The most appropriate approach for a specific decision depends on questions to be answered and on the resources available. For larger decisions as on the energy systems society should invest in, the steady state model we set as default surely is not good enough. There we would like to see a dynamic analysis for main parts of the system. For some simple checks, our simple model may still be too complicated, and scanning methods could be needed.

Table 1 **Open choices in inventory modelling surveyed**
underlined: proposed default choices for Dutch LCA project

1 Questions:

- ***descriptive***
- ***change-oriented***
 - * single
 - * structural
 - * strategic

2 Model types

- ***time aspects in model relations***
 - * comparative-static
 - > equilibrium (steady state)
 - > non-equilibrium
 - * dynamic
 - * optimisation
- ***time specification of inventory results***
 - * yes
 - * limited
 - * no
- ***locational specification of processes***
 - * yes
 - * limited (?)

- * no (but media specified)
- **mechanisms included**
 - * fixed input-output relations (black box technical coefficients including behaviour)
 - * technical production function
 - * market mechanisms
 - > *supply relations*
 - > *demand relations*
- **mathematical form**
 - * homogeneous to degree one
 - > *linear through origin*
 - > *non-linear (eg CES/Cobb-Douglas)*
 - * linear not through origin
 - * exponential
 - * [all other non-linear: not used?]
- **additional assumptions 1**
 - * all other functions constant
 - * other functions may vary

3 Marginal - average

- **data per process**
 - * marginal
 - > *short*
 - > *medium*
 - > *long*
 - * average
 - > *excluding capital goods*
 - > *including capital goods*
- **technology choice in time**
 - * fixed mix
 - > *short term (eg current)*
 - > *medium term (eg modal-modern)*
 - > *long term (future scenario)*
 - * unconstrained processes
 - > *short term*
 - > *medium term*
 - > *long term*
 - * dynamical process specification
 - > *per process*
 - > *process mix*
 - * future state process mix/scenario
- **technology specification spatially**
 - * spatial specification for all processes
 - * spatial specification for some processes
 - * spatial specification for foreground not background ('behind markets') processes
 - * specified spatial distribution per process type
 - > *short term (eg current)*
 - > *medium term (as developing in trend)*
 - > *long term (future scenario)*
 - * specified spatial distribution for process mix
 - > *short term (eg current)*
 - > *medium term (as developing in trend)*
 - > *long term (future scenario)*

4 Allocation

- **system boundary definition**
 - * full world (as in IOA)
 - * including processes as influenced through market mechanisms
 - * smallest system as needed for function investigated, expanded till flow has function for other system, or flow touches environment
 - * till main materials have become final wastes (cascade systems)

- **problem definition**
 - * equal for all types of multi-functionality
 - * different for: open loop recycling; co-production; waste processing

- **options for solution of allocation problem**
 - * per process
 - > allocation-as-splitting
 - > allocation-as-splitting, for boundary processes only
 - . mass
 - . direct energy content
 - . use-value shares in total functional output
 - . social value
 - . etc ?
 - * for system
 - > [accepting unequal functions in comparison]
 - > system value
 - > adding processes till functional equality between alternatives
 - . only as really expected, (= iff supply elastic and demand inelastic)
 - . as artificial solution to allocation problem ("better than none")
 - > subtracting processes till only function investigated remains
 - > [adding market model = new system boundary definition, go back]

Appendix 7: Input paper of Michael Hauschild, Heidi K. Stranddorf, and José Potting

Life cycle impact assessment – Danish recommendations

Position paper for the
Joint workshop of the Dutch and Danish LCA methodology projects
Leiden, 16-17 September 1999

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The starting-point of the work on impact assessment in the Danish method development and consensus project is the methodology developed under the EDIP programme 1992-1996 and documented in Wenzel et al., 1997 and Hauschild and Wenzel 1998. In accordance with ISO/DIS 14043 (1997), the EDIP methodology distinguishes four phases in the impact assessment component: Classification (assignment of inventory results, mandatory), Characterisation (calculation of category indicator results, mandatory), Normalisation (calculating the magnitude of the category indicator results, optional) and Weighting (optional). Three classes of impacts are identified as assessment parameters: Resources, Environment and Working environment. The EDIP methodology for impact assessment is documented in detail in Hauschild and Wenzel (1998).

The development in the Danish LCIA method after the EDIP programme has primarily taken place under the EUREKA programme (LCAGAPS), the TMR-program from the European Commission and recently the Danish method development and consensus project. The activities have predominantly been focused on spatial differentiation in characterisation (Potting and Hauschild in preparation), and updating of normalisation references and weighing factors (Stranddorf in preparation).

For each phase of the impact assessment component, this document will give a brief presentation of the methodology as presented in detail in Hauschild and Wenzel (1998), followed by a summary of the modifications resulting from the method development and consensus project as presented in Potting and Hauschild (in preparation). Where relevant, main differences and similarities with the Dutch methodology project will be indicated. The document concludes with a presentation of future research areas.

Environmental impacts

Like in the Dutch approach, the EDIP methodology treats impacts on the environment by an environmental theme method considering the following impact categories: Global warming, stratospheric ozone depletion, photochemical ozone formation, acidification, nutrient enrichment, ecotoxicity, human toxicity, and dumping of waste. Compared to the original EDIP approach, the development of spatial characterisation will involve redefinition of some of the impact categories, notably acidification, nutrient enrichment and tropospheric ozone formation. A short description per impact category of current state and proposed modifications of the methodology will be given later in this document.

Spatial aspects in characterisation

Already during the EDIP programme it was found that for the non-global impact categories, the omission of any type of spatial information sometimes lead to obviously misleading results. EDIP

was therefore prepared for modification of the site-independent impact potentials by a site factor. The site-factor expresses the extent to which the full impact potential is realised as determined by the spatial conditions of the emission.

Currently, site factors are being developed for characterisation of all the non-global impact categories covering the Danish and European situation. In some cases, new site-generic

factors that represent a global default and a range for a global default will be established to replace the site-generic factors currently used in EDIP.

The work involves a quantification of the possible spatial variation underlying the current site-generic characterisation factors for each of the impact categories. This variation is for some impact categories expressed in integrated spatially differentiated characterisation factors, and for other impact categories in site factors to be combined with the existing site-generic factors. Site characterisation can replace the traditional characterisation. The spatially differentiated characterisation factors can also be applied in retrospective as a part of the sensitivity analysis to quantify the possible error in the most important impact potentials due to lack of consideration of spatial aspects. The preferred way of using the site factors will amongst others depend on the intended application of the LCA results. The Danish method development and consensus project will therefore offer both possibilities, and leave it open to the user in what way to use the spatial characterisation factors. Where site-generic characterisation factors are preferred over the spatially differentiated characterisation factors, the spatially differentiated ones at least provide the ranges for the uncertainty posed by refraining from spatial differentiation.

Three levels of site characterisation are distinguished:

- *Site-generic characterisation* applying site-generic factors (or global default factors) in the cases where nothing is known about the location of emission or where the inclusion of spatial information in the impact assessment is unwanted.
- *Site-dependent characterisation* applying either spatially differentiated characterisation factors or site-factors together with the site-generic factors. Site-dependent assessment requires a rough indication of the geographical location as the only data additional to current life-cycle inventory. This information is available in most current life cycle inventories. For some of the impact categories, information about the type of the source can be used to get additional spatial differentiation.
- *Site-specific characterisation* which requires detailed spatial information about location and type of emission source. Site-specific characterisation will typically be beyond LCA, but may in particular applications be required. Site-specific characterisation was not covered by the Danish method development and consensus project.

In addition to spatially differentiated characterisation factors, also spatially differentiated normalisation references are provided. These normalisation references must be used together with the characterisation factors but are not further elaborated in this document.

Similar to the Dutch approach, the EDIP methodology aims on characterisation of the incremental increase of impact (i.e. marginal analysis). Some impact indicators will be defined further along the causality chain than what is intended in the Dutch project.

Global warming (global impact)

Where the Dutch methodology advises to use all three time horizons, current EDIP methodology applies IPCC's GWP factors for direct impacts over a 100 years time horizon except for CH₄ where IPCC's own modelling allows all the indirect impact contributions to be included as well. In addition GWPs are calculated for VOCs and CO of petrochemical origin representing their stoichiometric conversion to CO₂ (and hence considering them as indirect CO₂-emissions). As an optional feature, the EDIP method also provides GWPs that represent the indirect contribution from VOCs to radiative forcing through their photochemical oxidation leading to the formation of the strong greenhouse gas ozone. The method development and consensus project will in similarity with the Dutch project provide an update of the current GWP factors. In addition, the global normalisation reference will be updated, based on 1994 figures.

Stratospheric ozone depletion (global impact)

WMO/UNEP's ODP values for an infinite time horizon are used in current EDIP methodology. In addition, ODP values for shorter time horizons (5, 20 and 100 years) are provided as an option, considering the fact that the already adopted schemes for abolishing the strong ozone depleting substances will cause the impact to decline some decades ahead in time. The method development and consensus project will provide an update of the current ODP factors as well as an update of the global normalisation reference based on 1994 figures.

Consumption of ozone depleting substances are used as an estimate of the emission. This methodology may overestimate the actual emissions as recycling or destruction of ozone depleting substances become ever more widespread.

Photochemical ozone formation (non-global impact)

The current EDIP methodology applies POCP values as determined by

- using the longest time perspective (5-9 days) in the British UK AEA Harwell trajectory model for emissions taking place in areas with a high background level of NO_x
- using the longest time perspective (4 days) in the Swedish IVL trajectory model for emissions taking place in areas with a low background level of NO_x

Weighted average POCP-values are provided for VOC mixtures from different types of man-made sources. In addition, regression expressions are provided for estimating missing POCP values from knowledge of the substance's reaction rate constant with hydroxyl radical for a wide range of organic chemicals. The method development and consensus project will present new site-generic and spatially differentiated factors that integrate the spatial variation caused by differences in background levels of NO_x and VOCs, atmospheric dispersion and conversion, population and ecosystem density, and exceeding of the relevant thresholds. Characterisation factors will be provided also for NO_x emissions, and the impact indicator will be defined closer to the endpoint compared to current EDIP methodology. Normalisation references are developed as person equivalents for Denmark and EU-15 based on 1994 figures and for the world based on a global 1990-inventory assuming these figures also to be valid for 1994.

Acidification (non-global impact)

Current EDIP methodology defines acidification at the level of mineralisation and release of protons providing acidification factors that reflect by the potential for hydrogen ion release. It includes the possibility for reducing the acidification potential according to the fraction of anions not leached from the system (due to e.g. plant-uptake, fixation or degradation). The method development and consensus project will present new characterisation factors, as well site-generic as spatially differentiated, that integrate the spatial variation caused by differences in emission levels and background concentration of acidifying compounds, atmospheric dispersion and conversion, ecosystem density and sensitivity. The acidification factors will be defined as contribution to exceeding of the critical load of terrestrial or aquatic ecosystems. This measure differs substantially from the hydrogen potentials maintained in the Dutch project. Normalisation references are developed as person equivalents for Denmark and EU-15 based on 1994 figures and for the world by extrapolation from EU-15 to global level (Hoffmann and Stranddorf - in preparation)

Nutrient enrichment (non-global impact)

Nutrient enrichment is in the current EDIP methodology defined at the level of increasing concentrations in the receiving environment of the nutrients N and P similar to the proposal maintained in the Dutch project. The impact category may be treated as consisting of two sub categories – N-enrichment (expressed as N-equivalents calculated from the substances stoichiometric content of N) and P-enrichment (expressed as P-equivalents) allowing distinction of situations where the emitted nutrient is limiting in the receiving environment. This opens for a kind of spatial differentiation e.g. between fresh water systems (most of the time P-limited) from salt water systems which are generally N-limited. The method development and consensus project elaborates on the division into a terrestrial and an aquatic sub-category reflecting the differences in sources, the related nutrient emissions and their impact. The new characterisation factors for the terrestrial impact from atmospheric emissions, both the site-generic and the spatially differentiated, are closely related to the characterisation factors for acidification. The factors for terrestrial nutrient enrichment will be defined as contribution to exceeding of the critical load of terrestrial ecosystems. For aquatic eutrophication, site factors will be developed that modify the site-generic factors in the current EDIP methodology. The details are not yet available. Normalisation references are developed as person equivalents for Denmark and EU-15 based on 1994 figures and for the world applying the extrapolation methodology developed for acidification.

Ecotoxicity (non-global impact)

Current EDIP methodology defines ecotoxicity at the level of ecosystem function and treats it as four separate sub categories according to the environmental compartment where the effects occur:

- acute aquatic ecotoxicity
- chronic aquatic ecotoxicity
- chronic terrestrial ecotoxicity
- toxicity towards waste water treatment plant

The substance's effect characteristics is represented by its PNEC value determined from single-species laboratory test results using application factors. The substance's fate characteristics is represented in a rather simplified modular approach through discrete factors for

- redistribution among the environmental compartments (determined by its Henry's law constant and its photochemical oxidation half life in air)
- biodegradability as determined in OECD tests

The method development and consensus project will provide site factors for ecotoxicity for emissions reaching the soil and water compartments as well as normalisation references for Denmark, EU-15 and world-wide based on 1994 figures. The basis of data has been scarce and therefore extrapolation from specific European countries like The Netherlands, to Denmark and EU-15 as well as from EU-15 to the world has been applied.

The effect modelling is in principle the same as proposed by the Dutch guideline but the fate modelling for the ecotoxicity as well as the human toxicity impact category differs from the full integrated fate-modelling based on the EUSES risk characterisation tool that is applied in the Dutch approach.

Human toxicity (non-global impact)

The impact category is defined at the level of toxic effects in humans and treated as four separate sub categories according to the route of exposure:

- human toxicity via air
- human toxicity via water
- human toxicity via soil
- human toxicity via ground water

The effect characteristics of the substance is represented by a human reference dose (HRD) or a human reference concentration (HRC) in air. Reference doses and reference concentrations are extrapolated from laboratory data by using application factors in an approach similar to that applied for determination of the PNEC values for ecotoxicity with the important difference that for human toxicity it is the effect towards the individual and not the population that is studied. The fate of the substance is modelled by a modular approach similar to that used for ecotoxicity. Since the effect parameter is an ingested dose for three of the four exposure routes, however, the fate model is combined with exposure modules representing the human exposure through food chains in soil or water. The method development and consensus project will provide site factors for human toxicity from air emissions. These factors modify the site-generic approach in the current EDIP methodology by accounting for spatial differentiation in exposure. Factors are provided for two substances: the short-lived hydrogen chloride and the long-lived benzene. These two substances represent the lower and upper boundary in between which the exposure increase from most toxic substances will lie. The site factors integrate the spatial variation in exposure posed by differences in atmospheric dispersion and population densities. Normalisation references are developed for as person equivalents for Denmark, EU-15 and the world. The world-wide normalisation reference has been estimated by extrapolation from EU-15.

Deposition of waste in landfills

Waste deposition processes are life cycle processes and as such they should be analysed and the product-specific inputs and outputs quantified as part of the inventory analysis. Due to the complex and dynamic conditions of waste deposits, this task was not solved by the EDIP programme. As an intermediary solution, the EDIP methodology includes deposition of waste in landfills as impact categories to represent those emissions that we are presently not able to estimate in a product-specific manner. The landfilled waste is classified in four categories:

- volume waste
- hazardous waste

- radioactive waste
- slags and ashes

There is no characterisation, the impact potential is simply represented by the weight of the deposited waste within each category.

Under the EUREKA programme LCAGAPS, models have been developed to allow estimation of the product-specific emissions from municipal landfills (which although gradually being abolished still constitute an important disposal technology in large parts of Europe, not to mention the rest of the world). The output of the model is emissions occurring during the first 70-100 years (the methanogen phase) and residuals in the landfill after that period. The model is documented in Nielsen and Hauschild, 1998 and Nielsen et al., 1998.

Noise

Noise is not included as an impact category in the EDIP methodology but under the method development and consensus project, a methodology is being developed (Potting and Hauschild, in preparation). The characterisation represents the perceived nuisance from noise expressed through the sound pressure and including spatial aspects like the population density in the area impacted by the noise source.

Resources

Resources are non-renewable resources as well as renewable resources. No characterisation is performed. For non-renewable resources, the normalisation applies the annual consumption of an average world citizen assuming that the resources are traded on a common open world market. For renewable resources, the normalisation reference represents the average person's annual consumption for the region within which the resource is typically being extracted and traded.

Following the normalisation a resource consumption is weighted using the reciprocal value of the current supply horizon (the known extractable reserve divided by the annual consumption). For renewable resources, the supply horizon is infinite and the weighting factor zero unless the use rate exceeds the rate of regeneration (unsustainable use of the resource).

Applying the concepts defined in ISO 14042, the normalisation and weighting steps of EDIP programme should be considered as two consecutive normalisation steps applying respectively the current annual consumption and the total known extractable reserve as normalisation references.

Working environment

For working environment the EDIP methodology considers seven impact categories:

- Cancer due to exposure to chemicals
- Reproductive damage due to exposure to chemicals
- Allergenic impacts due to exposure to chemicals
- Neurotoxic damage due to exposure to chemicals
- Hearing impairments due to exposure to noise
- Musculoskeletal injuries due to monotonous repetitive work
- Injuries due to accidents

The Danish Method Development and Consensus Building project involves further development of the methodology for assessment of working environment impacts and reference is made to the paper on this topic to be presented at the workshop (Schmidt and Brunn Rasmussen, 1999),

Normalisation

The normalisation step is common for all three classes of impact categories (resources, environment and working environment) in that an impact score for the product system is divided by the corresponding annual impact score from an average person in a chosen

reference year. Hereby, all impacts are expressed in a common unit as person equivalents and a comparison across the three classes is in principle possible ("is the product particularly heavy in its impact on resources, environment or work environment compared to the background activities of society, and is this in accordance with our expectations?").

The normalisation reference

The impact used as reference for normalisation is determined for the total man-made activities within the region that is relevant considering the scale over which the impact mechanism works. The implication of this is that a global impact has to be related to the contribution of an average global citizen to the specific impact. Accordingly, a regional impact is related to the contribution of an average citizen contributing to that impact for the relevant region. In the original EDIP-method, this is implemented through a global person equivalent for the global impact categories and a Danish person equivalent for the regional and more local impact categories. This differentiation serves to make the normalisation references reflect the level of impact which actually contributes to the current state of the environment. This is fundamental since the current perceived state of the environment is decisive for the environmental policy measures and the reduction targets that are used as value basis in the consecutive weighting (see below). The approach is different from the Dutch one where normalisation factors for all impact categories refer to the same region.

In the method development and consensus project, the basic concept of EDIP is maintained but for all the non-global impact categories normalisation references are now represented Denmark or Europe (EU-15). When studying different environmental impact it is obvious that the borders of a specific impact will not follow country or continental borders, generally speaking. However, for practical reasons, and because the error due to import and export of pollutants will be minor when a region like Europe is considered, the data collection has been based on existing geographical borders.

Estimate of the contribution of an average world citizen to regional and local impacts – the world proxy

In the updated version of the EDIP an estimate of the contribution from an average world citizen is estimated even for the regional impacts (world proxy). A methodological framework is developed for this. The method is easily applicable for energy-related impacts while impacts like nutrient enrichment and ecotoxicity may need another approach. This is currently being discussed (Hoffmann and Stranddorf, in preparation).

Fundamentally, the idea of the world proxy for non-global impacts is in discrepancy with the EDIP-principle. Nonetheless, world proxies are being developed for pragmatic reasons:

- for users who are reluctant to include regional and local differences into their LCIA
- to serve as proxies for regional normalisation references for those geographical regions of the world where data are not obtainable or regional normalisation references have not yet been developed.

The world proxy is discussed in a separate paper submitted to this workshop (Hoffmann and Stranddorf, in preparation).

Weighting

The EDIP weighting factors are distance-to-target factors derived for the Danish (for regional impact categories) or global (for global impact categories) politically determined reduction targets for the period 1990-2000. The EDIP method is open to the use of use of other weighting factors as long as the reporting is transparent about this (the background for sustainability and carrying capacity-based distance-to-target weighting factors is also provided for several impact categories).

In the method development and consensus project, the focus has been on two issues; firstly, improvement on the methodology and secondly, collection of new data. The update focuses on the period 1994 - 2004. An important implication of this is that the distance - to - target is

approximately zero for the substances contributing to the stratospheric ozone depletion, since the goal is almost achieved. The implication of this is that the weighting factor for ozone depletion approach infinity while other weighting factors are around 1- 3. This impact (ozone depletion) has major concern in the world society. However, applying an infinite weighting factor gives to this specific topic more focus than it actually needs. As an amendment to the EDIP weighting methodology it is proposed to use 20 as the maximum factor for any impact category. This ensures that the topic will receive the attention it needs without the focus being exaggerated.

Future method development

A number of different Danish LCIA method development activities can be foreseen for the nearest future. A brief review is given here.

Ecotoxicity and human toxicity methodology

The Danish EPA has announced a major project focused on handling of chemicals in LCA (the product approach as supplementing the other regulatory strategies reaching all the non priority chemicals)

- screening and full-fledged methods – handling of missing data problem
- prediction of e.g. energy consumption in production of specific chemicals
- updating the EDIP approach

Proposals have been called for a pilot project that will start late 1999.

Waste disposal processes

The Danish EPA also has announced a project on quantification of product-specific in- and output from waste disposal processes. The paradigm developed for municipal landfills under LCAGAPS will be applied to other solid waste disposal processes (slags and ashes, mine tailings, chemical waste, nuclear waste). A pilot project was finished spring 1999 and the full project will probably be initiated in 2000.

In addition, there are plans for continuation of the activities on site characterisation and further development of the modular approach for fate modelling for ecotoxicity and human toxicity.

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Appendix 8: Input paper of Anders Schmidt and Pia Brunn Rasmussen

LCA and the working environment - Danish recommendations

Paper for the joint workshop of the Dutch and Danish methodology projects,
Leiden 16-17/9-1999

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Introduction

Whether or not the working environment (WE) shall be included in LCA has been a much debated issue during the development of LCA during the last ten years, at least when Scandinavian LCA practitioners were discussing with colleagues from other countries.

WE has been included in most Danish and Swedish methodology proposals, either as an integrated element (Christiansen (1991), Schmidt (1994), Hauschild (1996)), or as a supplement to LCA of the natural environment (Antonsson (1999), Bengtson (1997)). In opposition to this, other European countries have not considered the working environment in the development of LCA.

The main reason for including WE in LCA is that suboptimisation should be avoided, i.e. products with a smaller environmental impacts should not be produced on the expense of an increased impact in the working environment.

There may be good reasons for not including WE in LCA. A discussion of this is outside the scope of this paper, which has the main objective of drawing attention to a "new" and operational approach to WE-LCA that has been developed in the new Danish method development and consensus project.

Existing methodologies

Methods for WE-LCA can roughly be divided into three groups with different approaches:

- **Chemical screening** methods (Schmidt (1994), Hauschild (1996)), in which the main substance flows in the processes in the life cycle are examined with respect to their potential health impacts
- **Sector assessment** methods (Hauschild (1996), Antonsson (1999)), in which the average impacts on the working environment in different economic sectors are examined by using readily available statistical information
- **Process assessment** methods (Hauschild (1996), Bengtsson (1997)), in which the single processes in the life cycle are examined with respect to their potential impacts on the working force.

The pros and cons of each of these approaches are discussed in the technical report from the project. Some basic characteristics of the three groups are shown in Table 1.

Method group	Required time	Number of impact categories	Level of precision	Aggregation possibility	Data availability
Chemical screening	Low	Low	Medium	Low	Medium
Sector assessment	Low	High	Medium	High	High
Process assessment	High	Medium/High	High	High	Low

Table 1. Basic characteristics of methods for impact assessment of the working environment.

As indicated in the table, the process assessment method is judged to give the most precise assessment, but at the expense of the time required to make the assessment. Given the rela-

tively low status of WE-LCA this may be prohibitive for a general inclusion of the working environment in LCA.

Chemical screening methods on the other hands are fairly quick and easy to include, provided the practitioner has a good knowledge of classification of chemicals. The methods does, however, only consider a limited number of impacts and does not give the possibility of aggregation of impacts over the life cycle.

The sector assessment methods have their main advantage in a broad selection of impacts categories in combination with an relatively easy access to the basic data. The disadvantage is that the level of precision often is relatively poor because average data for large sectors is used for the assessment of many different processes.

Seen in a broad perspective, a combination of the three methods seems to be able to give the most useful results. Chemical screening methods can quickly identify the chemical hot spots in the life cycle, while the sector and/or process assessment methods can be used to make a quantitative assessment of a broad range of impacts.

A description of the framework for an integration of the three methods may become available through the work in SETAC WG "Working Environment". Until this is accomplished, the recommendations from the Danish method development and consensus project is that a sector assessment method can be used to create an overview of the working environmental impacts in the life cycle. In order to facilitate the inclusion of WE in LCA, the methodology described in EDIP has been improved and an open database with information on a large number of sectors developed.

The methodology

The basic requirement of the method is that it shall to give information on the working environmental impacts per functional unit, along with similar information on other impact categories concerning the natural environment. This requirement is met by using statistical information from two main sources.

Working environmental statistics

The Danish Labour Inspectorate annually publishes the number of accidents and reported damages for a large number of economic sectors. The publication addresses the following impacts which give a broad - but not complete - overview of the potential impacts in the working environment:

- Fatal accidents
- Total number of accidents
- Reported injuries, diseases and damages
 - Hearing damages
 - Cancer
 - Musculo-skeletal disorders
 - Airway diseases (allergic)
 - Airway diseases (non-allergic)
 - Skin diseases
 - Psycho-social diseases

It should be noticed that the impacts are measured in category endpoint already at the inventory stage of the LCA. No further impact assessment is therefore necessary.

Using this kind of statistics causes some uncertainties. Some of these are addressed in the following paragraphs:

- *Inter-annual variation.* For some of the more infrequent impacts like fatal accidents and cancer there may be a large variation in the number reported from one year to another. This type of uncertainty is dealt with in two ways:
 - an average is made using information from the most recent three years, and

- information from subsectors (4- or 5-digit NACE-code) with a small number of accidents and injuries is aggregated on a 3-digit NACE-code level
- *Under-reporting in some sectors.* The tradition of reporting accidents and diseases vary between sectors which may cause an underestimation of the impacts. This type of uncertainty is not dealt with in the methodology but is an obvious target for future improvements of the method.
- *Latency time.* For some impacts, especially cancer, the effect is often seen many years after the exposure took place. For other impacts like hearing damages and musculo-skeletal diseases, the effects will only be seen after many years of continuous exposure. This uncertainty cannot be dealt with quantitatively, but should be addressed in the interpretation of the results.

Produced amounts

While the impacts in a given sector can be calculated without problems, calculation of the amount produced in the same sector requires some extra work. Production statistics including import and export was suggested as the basis in the classical EDIP method, but proved to be very difficult to use in heterogeneous sectors.

The goods statistics, however, can be used to calculate the outputs from a given sector. All countries produce goods statistics using an international set of guidelines, giving the possibility of exchanging comparable information. The Danish goods statistics are published four times a year with an aggregation for the whole year in the last report.

The basic information in the goods statistics is the value of the goods produced within about 15.000 product groups. Each product group is identified by an 8-digit code which is unequivocally related to an economic sector. For many of the product groups, the statistics also contain information on the amount produced, most often given as the weight of the products. The two types of information makes it possible to calculate the total weight of the products being produced in an economic sector in a two step procedure: first calculating the average price per kilo of product (for those products where information on both weight and value is available) and subsequently divide the total value of the products with the average price.

The basic statistical material is very comprehensive, but with kind assistance from the Danish Statistical Agency (DSA) the requested data were developed in a few weeks. Having the DSA to perform the calculations also made it possible to include information which is otherwise kept as confidential and use supplemental information on value from foreign trade statistics.

The major uncertainties associated with this approach are summarised below:

- *Inter-annual variation:* Averages for three years were used, primarily in order to make the information on produced amounts match the information on work-related damages, but also to handle temporal variations.
- *Differences in the level of detail in different sectors.* Some sectors produce goods which are relatively homogenous in comparison with other sectors. An example of a homogenous sector is "production of iron and steel", producing iron and steel bars and plates as the main product. An example of a heterogeneous sector is "production of plastics packaging", producing large and small products by using a large variety of materials and processes. The uncertainty in the heterogeneous sectors cannot be avoided, and LCA practitioners must be aware of this, especially when dealing with speciality products, i.e. products that require special working conditions.
- *Raw material production.* Raw materials are often produced in homogenous sectors. However, production of most metals and minerals takes place outside of Denmark, which made it difficult for the current methodology project to compile and process the necessary statistical information. In the project it was chosen to use data from single companies instead of national or international averages. This is not fully satisfactory, especially because the format of the information on work-related injuries and diseases differed from the format reported to the Danish labour authorities. Again, the uncertainty must be dealt with in the interpretation of the results until better information can be achieved.

The database

The database developed in the Danish methodology and consensus project contain information on more than 80 economic activities (equal to 80 unit processes, broadly defined). The database is divided into 4 categories:

- **Production of raw materials**, e.g. oil and gas, sand, paper and cardboard, steel and iron, cement, aluminium, lead, etc
- **Processing/manufacturing of final goods**, e.g. MDF-plates, wood for buildings, basic chemicals, rubber products, plastic components and products
- **Manufacturing of final goods**, e.g. glass, ceramics, steel tubes, concrete building elements, tin cans, screws, nails, etc
- **Manufacturing of final goods/mounting**, e.g. radios, TVs, refrigerators, chairs, vacuum cleaners

With a few exceptions (e.g. transportation, electricity) the working environmental impacts have been calculated per kilo of produced goods for each of the economic activities. The database is not complete, but it should be possible for most products to identify the main economic activities and use the information for the calculations. If the exact sector is not found in the database, it is suggested to use information from a related sector, e.g. by using information on "mounting of refrigerators" to describe the impacts from "mounting of freezers".

The most significant drawback of the database is perhaps that it is not possible to establish data for the use phase of a product. One reason for this is that the output from the use phase most often is immaterial products, e.g. service functions, which cannot be measured in "normal" units like kilos. Another reason is that a direct link between the use of the product and the resulting working environmental impacts cannot be established.

The developed database is almost exclusively based on Danish statistics. The practitioner and the commissioner must thus know that the results reflect the impacts, as if all unit processes had taken place in Denmark. It is however possible to establish similar databases for other countries, whereby the geographical and technological coverage may be improved significantly. Due to differences in working environmental statistics between countries, some co-ordination will be necessary before an broad international database can be used.

The procedure

The procedure in making LCAs including working environmental impacts does not differ from other LCAs. Until the developed database has been integrated in e.g. the EDIP PC-tool, it is suggested that the list of parts in a given product is used for calculations of the impacts in a spreadsheet.

The first step is to specify the economic activities that each of the parts goes through before entering the final product. To facilitate the calculations, it is suggested that materials and processes are grouped into relevant economic activities. An example is that all plastic packaging is placed in the same group, simply because the database does not distinguish between different materials or production processes.

When the grouping has been performed and the resulting material flows are entered in the spreadsheet, the appropriate links to the database are made. At the moment, no specific recommendations on how to present the results are given. It is thus up to the single practitioner to extract the most relevant information and conclusions from the calculations.

The impacts can subsequently be normalised. This is done by relating each of the impacts to the average annual impact on a Danish Worker. The resulting figure is expressed in person-equivalents, i.e. the same unit as the other impacts in the EDIP-methodology. No weighting is performed due to the lack of quantitative political targets for the impact categories.

Discussion

The recommendation from the Danish method development and consensus project is that the sector assessment method is used to assess the working environmental impacts. The virtues of the method is that it has a high degree of objectivity, the database is fairly extensive and can at the same time easily be extended with information from other countries and processes

and last, but not least, the time required to make the assessment is modest in comparison to many of the other activities in making LCAs.

The methodology follows the standards in the ISO 14040-series closely and the technical report gives a characterisation of the methodology with respect to the main headings in the standards like geographical and time coverage, representativeness, etc. As mentioned earlier, one deviation is that the impacts assessment step is not divided into classification and characterisation. Instead, the results from the inventory phase are used directly as this step measures the impacts directly in category endpoint.

The level of detail in assessment of the working environment is comparable to that of local environmental impacts like toxicity and ecotoxicity. This is not fully satisfactory, but the main objective for including the working environment in LCA, i.e. securing that products with a smaller environmental impact are not produced on the expense of an increased impact in the working environment, can be fulfilled.

For LCAs where the working environment is the primary focus, more precise methods are needed. The process assessments methods described by both Hauschild *et al.* and Bengtsson *et al.* may prove sufficient to cover the needs. One drawback, however, is that the methods are relatively time consuming and that exchange of inventory results is difficult.

On the longer term, it is recommended that the development work addresses the possibility for an objective and operational integration of the sector and process assessment methods, e.g. by using the sector assessment to create the first overview of the potential life cycle impacts and the process assessment to give a more detailed assessment of the most important activities and/or activities where the sector method cannot distinguish between alternatives. In addition to this, development or refinement of screening methods for chemical as well as other impacts could prove to be a very valuable tool for product designers and developers.

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Appendix 9: Input paper of Leif Hoffmann and Heidi K. Stranddorf

Estimate for an average world citizen contribution to regional and local impacts.

Position paper for the joint work shop of the Dutch and Danish LCA methodology projects 16. - 17. September 1999

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Introduction

The aim of this paper is to propose a method to predict normalisation factors from one geographical area to another. The specific challenge is to estimate a world value/"world proxy" (or certain other specified areas) for the following local and regional normalisation factors: acidification, eutrofication (nutrient enrichment), photochemical ozone formation, ecotoxicity and human toxicity. The extrapolation is necessary due to lack of world wide emission data for the year 1994.

A general extrapolation method is described by using normalisation references for acidification covering approximately 40 European countries. The present data have been used to identify relations between available acidification data and different technical and economical factors. The applicability of the proposed methodology is discussed for the local and regional normalisation factors: acidification, eutrofication (nutrient enrichment), photochemical ozone formation, ecotoxicity and human toxicity. Global warming and stratospheric ozone depletion are global effects and the normalisation factors are therefore based on available global emission/estimate data.

A global emission database called EDGAR (Emission Database for Global Atmospheric Research) (Olivier *et al.*, 1996) contains estimates for 1990. The useability of these data will be discussed in relation to photochemical ozone formation. Extrapolation from countries/groups of countries to EU-15/the world has been discussed in other LCA methodology projects e.g. the Dutch project, and the conclusion is that all extrapolation methods will be based on general assumptions and therefore never generally valid (Guinée, 1999).

General considerations

Normalisation factors for different impact categories are expected to be available for Denmark, EU-15 and if possible a larger group of European countries (EU-15 + approx. 25). The extrapolation from a given region to the whole world can be made with normalisation factors covering EU-15, Europe (approx. 40 countries) or countries in groups based on income as baseline. The proposed methodology will also be used for extrapolation of emissions from one or more European countries to total EU-15.

The proposed methodology has to be as simple as possible e.g. based on as few factors as possible and preferable one method for all impact categories. This is due to limited resources for data collection but also to reduce the introduced uncertainties. The expectation is that almost all collected data will represent some uncertainty and by adding, multiplying etc. the uncertainty will increase. However, it is quite obvious that not all impact categories can be described equally qualified by the same parameters

The extrapolation can either be based on using one set of factors or by a combination of different factors. The uncertainties of the different methods will be discussed.

The extrapolation has to be based on easy available quantitative or qualitative data i.e. data that are available for the whole world in one source (in order to reduce uncertainties) if possible (e.g. World Bank reports, United Nations reports, OECD reports, EUROSTAT reports etc.). Examples on available data are:

- GDP - gross domestic¹⁷ product [US dollars]
- GNP - gross national¹⁸ product [US dollars]
- Population
- Sector contribution to GDP (agriculture, industry, services) [%]
- Total energy consumption [million tons of oil equivalent (Mtoe)]
- Energy consumption (coal, oil, gas, nuclear energy, hydro power) [Mtoe]
- Carbon dioxide emissions [million metric tons]
- Energy efficiency [1987 \$ per kg oil equivalent]
- Energy intensity [total primary energy supply (Mtoe) divided by GDP (in constant prices; 1990 dollars)]

Examples on advantages and disadvantages with the different data are presented in the Table 1.

¹⁷ Gross domestic product (GDP) measures the total output of goods and services for final use occurring within the domestic territory of a given country, regardless of the allocation to domestic and foreign claims.

¹⁸ Gross national product (GNP) measures the total domestic and foreign income claimed by the residents of the economy.

Table 1*Advantages and disadvantages with different statistical data.*

	+	–
GDP (Gross Domestic product)	available for approx. 200 countries and groups of countries; World Bank/United Nations statistics	depend on financial, industrial and agricultural activity; the financial activity that is part of the GDP e.g. banking does not influence on the emissions
GDP/capita	same as above	same as above
GNP (Gross National product)	available for approx. 200 countries and groups of countries; World Bank/United Nations statistics	depend on financial, industrial and agricultural activity; the financial activity that is part of the GNP e.g. banking does not influence on the emissions
GNP/capita	same as above	same as above
Total energy consumption (per capita)	available in World Bank statistics	potential emissions depend on distribution on energy sources
Commercial energy use (per capita) in oil equivalents	available in World Bank statistics	
Energy consumption/distribution on sources	emissions to air depend on distribution of energy sources	consumption of specific sources only known for the most developed countries (OECD, European)
Energy efficiency	available in World Bank statistics	
Energy intensity	emissions to air depend on distribution of energy sources	only known for the most developed countries (OECD, European)
Sector contribution to GDP (agriculture, industry, services)	available in World Bank statistics	
Agricultural activity	available in World Bank statistics	
Technological level	information on technological level necessary for estimation of potential emissions	no statistics; qualitative estimates
Industrial activity	World Bank statistics	only known for the most developed countries (OECD, European)
Cleaning technology (overall)	possible to estimate using knowledge of industrialisation	no quantitative data
Cleaning technology (flue gas cleaning)	information on cleaning technology necessary for estimation of the total emissions to air	only known for the most developed countries (OECD, European)
Wastewater treatment	information on wastewater treatment technology necessary for estimation of the total emissions to water	only known for the most developed countries (OECD, European)

General extrapolation method

Acidification depend on the emissions of NH₃, NO_x and SO₂; for a detailed description of the impact category see the section on acidification. According to the CORINAIR 94 summary report (Ritter, 1997) the distribution between the above

mentioned substances is 24%, 32% and 44%. The sectors responsible for the acidification in Europe is shown in Table 2.

Table 2

Distribution of emission acidifying substances from industrial sectors (Ritter, 1997).

Sector	Distribution %
Combustion in energy and transformation processes	34
Agriculture and forestry, land use and wood stock change	23
Road transport	17
Combustion in manufacturing industry	11
Other mobile sources and machinery	6
Non-industrial combustion plants	5
Production processes	3
Waste treatment and disposal	1
Extraction and distribution of fossil fuels/geothermal energy	0.4
Solvent and other product use	~ 0

Mentioned in descending order of importance in relation to acidification, the most important sector is seen to be combustion in energy and transformation processes, agriculture and forestry, land use and wood stock change, road transport and combustion in manufacturing industry. Information on the activity in these sectors is not available in statistical material covering the whole world.

Economical activity and energy consumption are parameters that can be used as approximation for the activity in the different sectors and information is available in UN or World Bank statistics.

The relation between acidification and a number of selected parameters (Acidification = function (x)) has been tested by linear regression analysis. The parameters tested are:

- GDP/capita [US\$/capita]
- GNP/capita [US\$/capita]
- fossil fuel/total energy
- GDP/unit of energy use (energy efficiency [US\$ per kg oil equivalent])

Economical activity is measured as “gross domestic product” (GDP) and as “gross national product” (GNP). GDP measures the output of goods and services occurring within the domestic territory of a given country whereas GNP also includes foreign income. GDP is therefore supposed to be the best parameter to describe the activity in the above mentioned sectors.

Figure 1 and Figure 2 show potential acidification potential expressed as sulfur dioxide equivalents i.e. kg SO₂-eq./year/capita versus GDP/capita for EU-15 respectively Europe including European part of Asia and Balkan (note: countries with zero values for acidification equivalents or GDP/capita are omitted in the plot and the regression line). Both figures show very low correlation. The correlation coefficient R² is determined to 0.1767 and 0.0052 respectively. The very low correlation with GDP/capita for Europe might be explained by lack of industrial activity or at least lack of reported activity in some of the middle and low income countries.

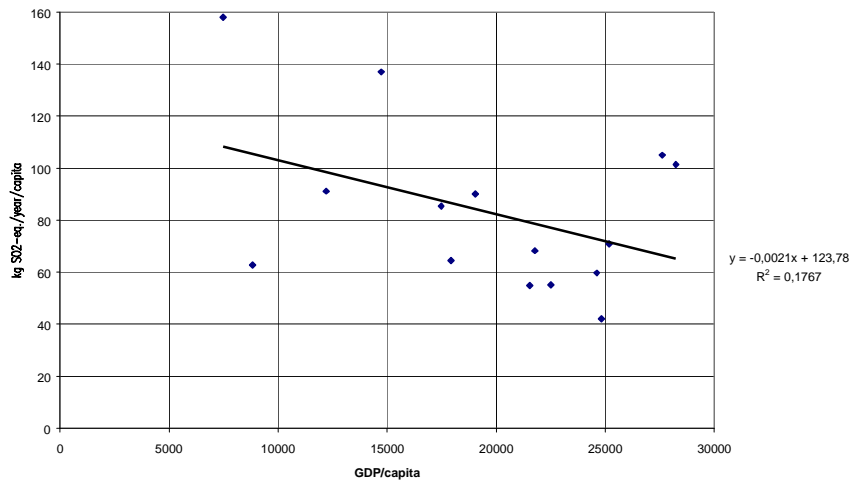


Figure 1
Acidification (SO₂-eq./year/capita) vs. GDP/capita (1994) for 15 European countries (EU-15).

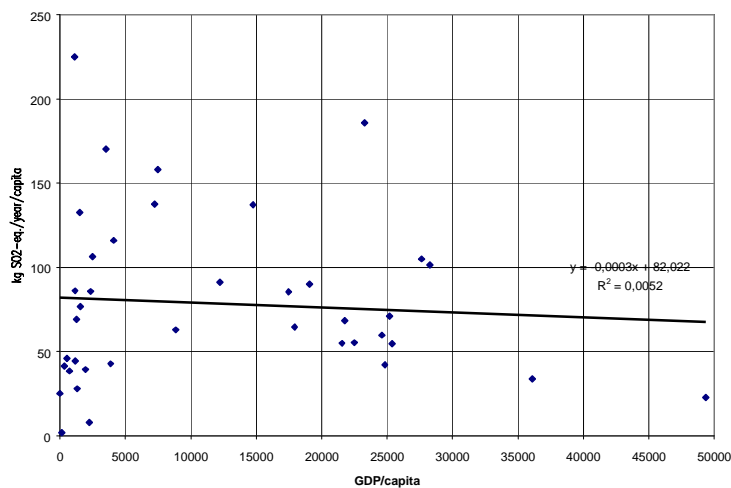


Figure 2
Acidification (SO₂-eq./year/capita) vs. GDP/capita (1994) for 38 European countries.

By this method the weighting of the single countries is set equal i.e. the acidification potentials for Luxembourg or Liechtenstein counts as high as the acidification potential for Germany. An alternative method is to calculate the acidification potential for groups of countries where the grouping can be based on income¹⁹. The alternative method is weighting the acidification potential in relation to the population in the group.

¹⁹ High income economies: EU-15 + Iceland, Liechtenstein, Norway, Slovenia and Switzerland

Middle income economies:

- Upper middle economies: Croatia, Czech Rep., Estonia, Hungary, Poland, Slovak Rep., Turkey

- Lower middle: Belarus, Bulgaria, FYROM (Macadonia), Latvia, Lithuania, Romania, Russian Fed., Ukraine

Low income economies: Albania, Armenia, Bosnia & Herzegovina

The World Bank statistical material is using a grouping based on income expressed as *GNP/capita* resulting in four groups: *high income*, *upper middle income*, *lower middle income* and *low income economies*; see page 88 for a general description of the different income groups.

One argument for using *GNP/capita* is that the level of economy might reflect the industrial activity (e.g. the consumption of fossil fuels). Another argument can be that the World Bank statistics include average values for a number of other parameters for the income groups.

Figure 3 and Figure 4 show the acidification versus *GDP/capita* and *GNP/capita* respectively. The European countries are divided in groups according the grouping made by the World Bank based on *GNP/capita* in 1997. Average *GDP/capita* is also calculated for groups based on the above mentioned grouping in order to maintain consistency in the grouping. The average *GDP/capita* for the different groupings is based on *GDP* for the European countries actually assigned to the different income groups.

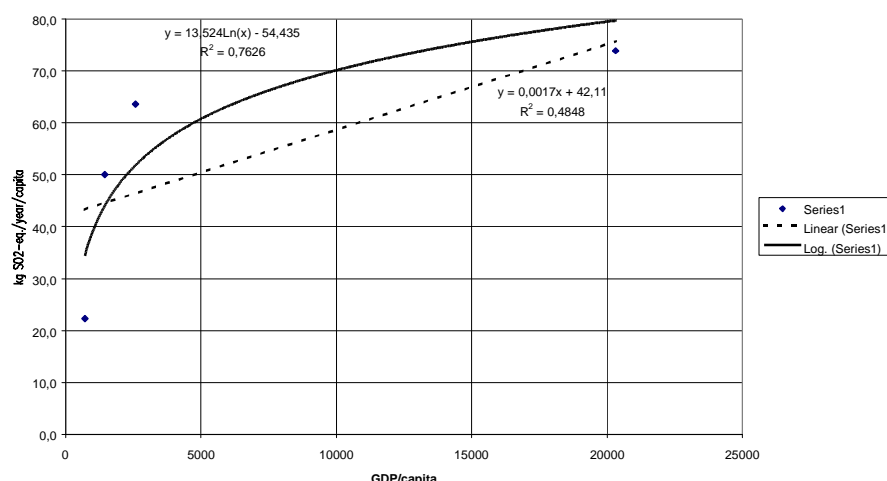


Figure 3
Acidification (SO_2 -eq./year/capita) vs. *GDP/capita* for 38 European countries in four income groups (*high income*, *upper middle income*, *lower middle income* and *low income*). The income groups are based on *GNP/capita* in 1997.

The relation between acidification versus *GDP/capita* and *GNP/capita* is tested by regression analysis. The results are presented in Table 3.

Table 3
Correlations between acidification and *GDP/capita* and *GNP/capita*.

Acidification vs.	Relation	Correlation line	Correlation coefficient (R^2)
<i>GDP/capita</i>	Linear	$y = 0.0017x + 42,11$	0.4848
	Logarithmic	$y = 13.524\ln(x) - 54.435$	0.7626
<i>GNP/capita</i>	Linear	$y = 0.0014x + 41.624$	0.5351
	Logarithmic	$y = 11.593\ln(x) - 38.937$	0.9092

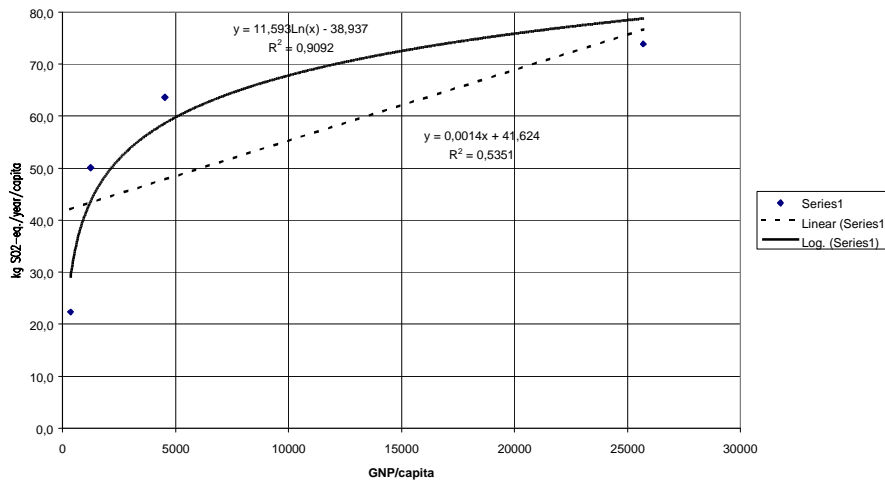


Figure 4
Acidification (SO₂-eq./year/capita) vs. GNP/capita (1997) for 38 European countries in four income groups (high income, upper middle income, lower middle income and low income).

The methodology using grouping of countries according to their GNP/capita has one disadvantage as the representation of countries in the different groups are unequal. The number of countries is 20, 7, 8 and 3 in the high income, upper middle income, lower middle income and low income countries respectively. The average GNP/capita and GDP/capita are both slightly above the average in upper middle income countries.

The statistical data of the regression analysis are compared in Table 4.

Table 4
Overview of relations between acidification and selected parameters.

	Geographical area	Correlation	Corr. coef. R ²	Comments
GDP/capita	EU-15	negative	0.1767	Figure 1
GDP/capita	EU-15 + 23	negative	0.0052	Figure 2
GDP/capita ln(GDP/capita)	38; income groups ¹	positive, linear positive, logarithmic	0.4848 0.7626	Figure 3
GNP/capita ² ln(GNP/capita)	38; income groups ¹	positive, linear positive, logarithmic	0.5351 0.9092	Figure 4
Fossil/total energy	EU-15	positive	0.1895	
Energy efficiency	EU-13 ³	negative	0.1029	
Energy efficiency	EU-13 + 6	negative	0.4574	

For definition of income groups see World Bank statistics; 0.

GNP data for 1997.

EU-15 except Germany and Luxembourg.

Conclusion

The overview shown in Table 4 reveals a correlation coefficient, R², equals 0.9092 in the situation kg SO₂-eq./year/capita versus ln(GNP/capita) and a correlation coefficient equals 0.7626 in the situation kg SO₂-eq./year/capita versus ln(GDP/capita) based on data from European countries.

Based on world population and average income in GDP/capita²⁰ at 4,515 US\$/capita the world normalisation reference for acidification can be calculated to:

59 kg SO₂-eq./year/capita

Based on average GNP/capita at 5,130 US\$/capita (1997) (World Bank, 1998) for the world the similar value can be calculated to:

60 kg SO₂-eq./year/capita

Both methods results in a world normalisation factor at approximately 60 kg SO₂-eq./year/capita.

The presented method result in the normalisation factors for the different areas and the world as shown in Table 5.

Table 5
Summary

Geographical area ¹	Average income GDP/capita	Acidification potential kg SO ₂ -eq./year/- capita	Notes
Denmark	28,245	101	Calculated
EU-15	19,992	74	Calculated as weighted average
High income economies	20,323	74	Weighted average; 20 countries
Upper middle income economies	2,588	64	Weighted average; 7 countries
Lower middle income economies	1,447	50	Weighted average; 8 countries
Low income economies	711	22	Weighted average; 3 countries
World	4,515 5,130 ²	59 60	GDP/capita, logarithmic GNP/capita, logarithmic

¹ High income economies: EU-15 + Iceland, Liechtenstein, Norway, Slovenia and Switzerland

Middle income economies:

- Upper middle economies: Croatia, Czech Rep., Estonia, Hungary, Poland, Slovak Rep., Turkey

- Lower middle: Belarus, Bulgaria, FYROM (Macadonia), Latvia, Lithuania, Romania, Russian Fed., Ukraine

Low income economies: Albania, Armenia, Bosnia & Herzegovina.

² GNP/capita

Based on the results of the acidification scenario a general extrapolation methodology can be outlined. The general methodology will be based on the following assumptions:

²⁰ The total GDP is calculated to 25.284×10^{12} \$ (UN, 1996) and a midyear world population at 5,609,678,819 in 1994 (USBC, 1996). The average GDP/capita equals to *4,515 US\$/capita*.

- linear relationship between normalisation factor and $\ln(\text{GDP/capita})$
- the normalisation factor is zero when the average income expressed as GDP/capita is zero

The proposed extrapolation methodology can be expressed as:

$$\text{Norm. fact}_{\text{Imp. cat., World}} = \text{Extrapolation fact.} \times \text{Norm. fact.}_{\text{Imp. cat. EU-15}}$$

Based on the assumptions and the results of the acidification scenario the mathematical relationship can be expressed as follows

$$\text{Norm. fact}_{\text{Imp. cat., World}} = \frac{\text{Norm. fact.}_{\text{Acid. World}}}{\text{Norm. fact.}_{\text{Acid. EU-15}}} \times \text{Norm. fact.}_{\text{Imp. cat. EU-15}}$$

$$\text{Norm. fact}_{\text{Impact cat., World}} = \frac{59}{74} \times \text{Norm. fact.}_{\text{Impact ca. EU-15}}$$

$$\text{Norm. fact}_{\text{Impact cat., World}} = 0,8 \times \text{Norm. fact.}_{\text{Impact ca. EU-15}}$$

Statistical sources

The World Bank

The statistical material published by the World Bank covers all countries in the world with a few exceptions for some of the parameters. Average values for the different parameters are presented for groups of countries based on income expressed as gross national product (1997; GNP/capita):

- High income economies [above \$ 9,656]
- Middle income economies
 - Upper middle economies [\$ 3,126 - \$ 9,655]
 - Lower middle [\$ 786 - \$ 3,125]
- Low income economies [below \$ 785]

In the World Bank statistics the following data is available: GDP, GNP, Population, Commercial energy use, GDP per unit of energy use (World Bank, 1998).

References

Guinée J (1999). Leiden University, The Netherlands, Personal communication, January 12, 1999.

Olivier JGJ, Bouwman AF, van der Maas CWM, Berdowski JJM, Veldt C, Bloos JPJ, Visschedijk AJH, Zandveld PYJ, Haverlag JL (1996). Description of EDGAR version 2.0: A set of global emission inventories of greenhouse gases and ozone-depleting substances for all anthropogenic and most natural sources on a per country basis and on $1^\circ \times 1^\circ$ grid. RIVM report nr. 771060 002/TNO-MEP report nr. R96/119.

Ritter M (1997). CORINAIR 94 - Summary Report - European Emission Inventory for Air Pollutants. Copenhagen: European Environment Agency.

USBC (1996). Midyear world population 1950 - 1995. United States Bureau of the Census, International Data base. (Available at <http://uastr1.math.umass.edu/>)

UN (1996). Statistical Yearbook 1994. Data available as of 31 March 1996. Forty-first issue. United Nations, Department for Economic and Social Information and Policy Analysis Statistics Division. New York.

World Bank (1998). World development indicators 1998. (Available at <http://www.worldbank.org/data/databytopic/databytopic.html>)

Appendix A: Data sources

Databases (paper)

UN (1996). Statistical Yearbook 1994. Data available as of 31 March 1996. Forty-first issue. United Nations, Department for Economic and Social Information and Policy Analysis Statistics Division. New York.

Databases (electronic)

OECD

World Bank

World Development Indicators 1998 (available at CD-rom; extracts are available at <http://www.worldbank.org/data/databytopic/databytopic.html>)

Organisations

- **Organisation for Economic Co-operation and Development (OECD)**
75775 Paris Cedex 16
FRANCE
Phone.
Fax
e-post
<http://www.oecd.org/>
- **United Nations Office of Geneva**
<http://www.unog.ch/>
United Nations
New York
U.S.A.
<http://www.un.org/>
- **World Bank Group**
The World Bank
Washington, DC 20433
U.S.A.
Phone: [1] 202 477-1234
Fax
e-post:
<http://www.worldbank.org>
- **EUROSTAT**

Appendix 10: Input paper of Gorree and Guinée

Impact Assessment in the Dutch LCA methodology project

**Discussion paper for the
Danish-Dutch workshop on LCA methods
Leiden, 16-17 September 1999**

**6 September, 1999
Jeroen Guinée & Marieke Gorree
CML, Leiden University**

Contents:

- 1 General introduction
- 2 Levels of sophistication
- 3 Starting points for impact assessment
- 4 Impact categories and concomitant characterisation factors proposed in the Guide
- 5 Normalisation
- 6 Evaluation
- 7 Topics for discussion
- 8 References

Impact Assessment in the Dutch LCA methodology project

Jeroen Guinée & Marieke Gorree (CML)
Leiden, 31-08-1999

1. General introduction and starting points

The Dutch methodology project aims for an update of the Guide and Backgrounds from 1992 (Heijungs *et al.*, 1992) taking into account all main LCA methodology developments, which have taken place since then. The Guide should instruct practitioners on the best practicable LCA methodology as available anno 1999. As illustrated in the paper of Heijungs and Huppes (1999), the new Guide will focus on guidelines for performing change-oriented (prospective) LCAs on structural choices.

In this paper we will present our ideas on the impact assessment phase as will be elaborated in the new Dutch Guide. For this, we will first draft the general levels of sophistication of LCAs that we will distinguish in the Guide. Then, we will discuss our starting points for elaborating the impact assessment phase, our proposals for impact categories and concomitant characterisation factors, normalisation and evaluation. Finally, we will some possible topics for discussion during the workshop.

2. Levels of sophistication

As LCAs can be performed to different levels of sophistication depending on the amount of time and money available and the specific goals of a study, guidelines will be given for three levels of sophistication²¹:

1. *Scanning (simplified or screening) LCA*. This is a quick and shortened LCA, not completely complying with ISO demands. Guidelines for this level will be very practical and simple, such as the advise to perform allocation on a mass basis – or a similar joint physical parameter (m^2 , m^3 , etc.) - as much as possible.
2. *Detailed LCA, only defaults*. This is a full LCA for socially and technically not too complex decisions, using default choices for all methodological steps. Guidelines for this level will comply with ISO demands, but will at the same time be as practical as possible although demanding more expertise and time spending from the practitioner, such as the advise to perform allocation on the basis of the ISO 14041 preference procedure.
3. *Detailed LCA, defaults and sensitivity analyses on non-defaults*. This level is similar to level 2, but meant for socially and technically complex applications. Therefore level 3 also includes guidelines to apply a number of other methods - more or less equally relevant and scientifically sound as the default methods - to give insight in the limitations of level 2. This is fully compatible with ISO, but it takes account of scientifically and practically similar methods and may also anticipate on a number of developments expected in the near future. For the Impact Assessment non-defaults will a.o. include examples of site-factors, examples of damage approaches and possibly a monetary effect assessment if available, or time can be spend on the development of lacking characterisation factors. In this way the practitioner gets insight in the robustness of the results for different existing methods and possible future developments. For complex decisions also other tools may be relevant, but these will not be elaborated in the new Guide.

3. Starting points for impact assessment

General starting point for the elaboration of the *Impact Assessment* in the Guide is ISO 14042(1999). In practice this implies that we follow the principles described in the report of the SETAC-Europe working group on life cycle impact assessment (WIA-2; Udo de Haes *et al.*, 1999). The aim of WIA-2 is to contribute to the establishment of best available practice regarding impact categories and concomitant characterisation factors to be used in LCIA. This aim is similar to the aim of the Guide, but in the Guide we have to go a little further: we also have to 'prescribe' the best available practice for *this* moment.

²¹ The precise definition of and distinction between these three levels of sophistication is currently being debated within the Thinktank of the Dutch methodology project, which will probably result in changes and additions.

Best available practice is in the new Guide to be used as default in level 1 and – probably for LCIA more or less the same defaults except maybe land-use methods if these are too time intensive - in level 2 LCAs. Deviation of this best available practice is always possible and may well be highly recommendable in specific situations. In a detailed LCA including non-defaults (level 3) also other valid indicators can be applied. In such an LCA it is also possible to focus further on a dominant impact category, or to elaborate on lacking factors.

Similar to the WIA-2 work, the defaults for some main aspects of category indicators and modelling of category indicators will be made in the following way in the new Dutch Guide:

- *Marginal or average approach.* We will advise in the Guide to work with the available characterisation factors as they are, without making any further distinction between marginal and average.
- *Thresholds.* We will advise to take all emissions into account in LCIA, without differentiating between below and above standard situations (= “less is better” approach).
- *Themes or endpoint (damage) approach.* In the new Guide we advise to apply the themes approach and we will propose characterisation factors for this. In general modelling up to the level of endpoints is still developing. There is still debate on aspect as usefulness and feasibility and the methods are not sufficiently comprehensively operational yet, thus they are not ready for default use now.
- *Time horizon.* With respect to the time horizon of impacts, we advise to choose for eternity if the model allows this, or otherwise for 100 years or more.
- *Fate, exposure and effect.* If practical (!) models allow this, all three dimensions should be taken into account in characterisation factors for emissions.
- *Regionalisation.* With respect to regionalisation, we feel that all indicators should at least be applicable on a global scale, since the regional dimension is often lacking in available data sets. If it can be shown that inclusion of regional information is clearly relevant and possible, we advise to use regionalised characterisation factors if available (under the condition that also sufficient spatial information is available at the inventory level), or to use zero as the characterisation factor for non-sensitive areas (accepting that transport to possible sensitive areas is then mistakenly not taken into account).
- *Serial²², indirect²³, combined²⁴ and parallel²⁵ impacts.* For serial and indirect impacts a substance is classified to all relevant impact categories to their full amount, unless there is insufficient information available to do so and unless there is an overlap between impact categories. For combined impacts the different substances may be classified separately, all to their full amount. Characterisation modelling has then to make assumptions on standard concentrations of the "other" substances. Real parallel impacts are probably rather scarce. In those cases where the contribution of the substance to one impact category substantially lessens the possible contribution to another, e.g. acidification or eutrophication of NH₃, it is advised to divide the interventions between the relevant impact categories. This should be based on the best available information, otherwise 100/100.

4. Impact categories and concomitant characterisation factors proposed in the Guide

ISO 14042 does not give a list of impact categories and characterisation factors. WIA-2 gives a list of impact categories but does not make choices with respect to characterisation factors. For the work on the Guide, such further choices need to be made too. See Table 1 for the choices that will probably be made in the new Guide.

²² E.g. heavy metals which first cause ecotoxicological impacts and then human health impacts.

²³ E.g. methane contributing to photochemical ozone creation of which the ozone created contributes in its turn to global warming which can contribute to stratospheric ozone depletion.

²⁴ E.g., synergistic or antagonistic impacts of toxic substances.

²⁵ E.g., the toxic and the acidifying impacts of sulphur dioxide.

Table 6: List of impact categories and concomitant default and non-default characterisation factors proposed in the new Guide (preliminary draft!).

Impact category		Characterisation factors	
		Default	Non-default
A. Input related categories			
Depletion of abiotic resources		<ul style="list-style-type: none"> ADP based on reserves and deaccumulation: o.a. Guinée (1995), Ekvall et al (1997) 	<ul style="list-style-type: none"> ADP based on the useful energy/exergy in the world: Finnveden (1996b). ADP based on the environmental effects of the harvesting of the resource now : no characterisation ADP based on the change in the environmental effects of the harvesting in the future: Müller-Wenk (1998a) for metals
Depletion of biotic resources		No method operational yet. In future a BDP based on reserves and/or rate of deaccumulation is advised: Guinée (1995) or Sas et al. (1996) (first formula only)	
Land use	depletion of land	none, land depletion = $a \times t$ ($m^2 \cdot yr$)	-
	loss of life support function	<ul style="list-style-type: none"> factor based on the fNNP: Lindeijer et al. (1998) ? 	<ul style="list-style-type: none"> factor base on the ability of the area to fulfil functions: Baitz (1998)?
	loss of biodiversity	<ul style="list-style-type: none"> factor based on the species density: Lindeijer et al. (1998) ? 	<ul style="list-style-type: none"> factor based on the relation between the total area of High Impact Land Use and the percentage of threatened vascular plant species: Müller-Wenk (1998b),
B. Output related categories			
Climate change		<ul style="list-style-type: none"> GWP₁₀₀: Houghton et al. (1994, 1995) 	<ul style="list-style-type: none"> GWP₂₀, GWP₅₀₀: Houghton et al. (1994, 1995)
Depletion of the stratospheric ozone		<ul style="list-style-type: none"> Steady state ODP: WMO (1992, 1995) 	-
Human toxicological impacts		<ul style="list-style-type: none"> HTP based on multi-media transport model EUSES: Huijbregts (1999) 	<ul style="list-style-type: none"> Ecoindicator '99 based on DALY-concept Hofstetter, 1998 (?)
Aquatic ecotoxicological impacts	water	<ul style="list-style-type: none"> AETP based on multi-media transport model EUSES: Huijbregts (1999) 	-
	sediment*	<ul style="list-style-type: none"> SETP based on multi-media transport model EUSES: Huijbregts (1999) 	-
Terrestrial ecotoxicological impacts		<ul style="list-style-type: none"> TETP based on multi-media transport model EUSES: Huijbregts (1999) 	-
Photo-oxidant formation		<ul style="list-style-type: none"> POCP: Derwent et al. (1998) 	<ul style="list-style-type: none"> MIR, EBIR or MOIR for short term effects: Carter (1997). MIR for high NO_x concentrations and EBIR and MOIR for lower NO_x concentrations. POCPs for low NO_x concentrations: Andersson-Sköld et al, 1992

Impact category	Characterisation factors	
	Default	Non-default
Acidification	<ul style="list-style-type: none"> AP (European average) based on RAINS-LCA model of Huijbregts (1999a) 	<ul style="list-style-type: none"> Site specific factors of Huijbregts 1999a. If emissions all take place in Europe and the inventory gives information about the country in which the emissions take place. Minimum scenario for the contribution of NO_x and NH₃: Lindfors (1996) for non-European sites ?
Eutrophication (incl. BOD)	<ul style="list-style-type: none"> EP Heijungs et al. (1992) 	<ul style="list-style-type: none"> distinction between: terrestrial nitrification (N to soil and air) and aquatic nitrification (N and P to water and air and organic matter to water, or when information about the limiting nutrient is available scenarios for N- or P-limited ecosystems) Site specific factors of Huijbregts 1999a for NH₃ en NO_x. If emissions all take place in Europe and the inventory gives information about the country in which the emissions take place.
Odour	<ul style="list-style-type: none"> OP_{air}=1/OTV_{air}: Heijungs et al. (1992) OP_{water}=1/OTV_{water}: Heijungs et al. (1992) 	-
Noise	none, noise = G (Pa ² ·s): Heijungs et al. (1992)	-
Radiation	<ul style="list-style-type: none"> RP based on the exposure pathways for, the committed dose per unit "intake" and the probability that effects like cancer or hereditary effects occur: Level 1 of Solberg-Johansen (1998) (or method Frischknecht/Hofstetter?) 	<ul style="list-style-type: none"> method Frischknecht/Hofstetter?
Casualties	none, casualties = C: Heijungs et al. (1992)	-
Waste heat	none, waste heat (water) = E (MJ): Heijungs et al. (1992)	-

*: additional to WIA-2

5. Normalisation

In the new Guide we will advise to use global normalisation factors (based on world data for resource consumption and emissions) as default. In contrast to the regional approach or the (Dutch) consumption approach, these reference values can be used as default in every LCA study. As non-defaults we will probably advice to use European and Dutch normalisation factors.

However, at this moment it is not yet certain that there will be financial means available to update currently available sets of normalisation factors for these three scale levels to the latest characterisation factors proposed in the new Guide, and to the latest emission and resource use inventories at these three scale levels. Since the Danish project is also doing some work in this area, it might be advisable to join our efforts here.

6. Evaluation

According to ISO this includes grouping and weighting.

- Grouping: We are not aware of any practical examples available for grouping and ranking methods in LCA, thus no approaches will be recommended for now in the Guide.
- Weighting: At a conceptual level, we will advise to use weighting factors related to the values of the community, which takes the decision at hand. At a practical level, three approaches seem to be available at this moment, consistent with the choice for the policy themes: the (authorised) social weighting, distance-to-target and the revealed preference approach. None of these lists includes weighting factors for all impact categories, and all of them lack a socio-political preferences based part. Therefore, no default will be advised in the Guide but several examples of weighting factors will be provided (cf. 1995 Nordic Guidelines), a.o. from Hauschild *et al.* (1998), Kortman *et al.*, (1994) and Kalisvaart & Remmerswaal (1994). The use of different available weighting sets will give the practitioner and the target group of the study insight in the influence of different weighting sets and into the strong and weak points of each set.

7. Topics for discussion

We expect the following topics to be interesting for a plenary debate during the workshop:

- 1) Characterisation factors.
 - a) Which characterisation factors do the new Dutch Guide and the EDIP books added with the new results from the current Danish methodology project propose for each impact category;
 - b) What are the differences?

In our view the main differences are to be found in the impact categories listed in table 2. Is this correct?

Table 2: Impact categories for which the characterisation factors (CF) differ between CML and EDIP.

	CML	EDIP
Acidification	European AP's based on RAINS	CF + site factor
Eutrophication	EP Heijungs (1992)	CF for N, CF for P , CF for both
Human- and ecotoxicity	HETP, AETP, TETP, SETP based on the multi-media transport model EUSES	CF including multi-media transport based on simple rules of thump
Abiotic depletion	Aggregation based on reserves and deaccumulation	no aggregation in the characterisation, weighting in the evaluation phase based on reserves and deaccumulation
Biotic depletion and land use	see table 1	no characterisation factors
Working environment	no characterisation factors	Separate method (not included in the characterisation phase of an LCA)?
Radiation	see tabel 1	no characterisation factors

For climate change ozone depletion and photo-oxidant formation the characterisation factors are more or less the same. Perhaps it is advisable to try to use the same, most recent version, of GWPs, ODPs and POCPs;

- c) What are the perspectives to overcome these differences in the future?
 - d) How does the choice for a change-oriented (prospective) analysis influence the choice for characterisation factors?
- 2) Levels of sophistication:
- a) What is the relation between the levels of sophistication as probably proposed in the new Dutch Guide and the distinction in the EDIP books between qualitative screening and quantitative detailed methodologies?
 - b) What are the consequences of the different level-distinctions for the choice of characterisation factors, assuming the latter are supplied as easy applicable lists of factors in quantitative LCA approaches?
- 3) Site characterisation:
- a) Does this always include fate and exposure analysis?
 - b) How practical is it yet?
 - c) What are the data needs?
 - d) Can it be included in the Dutch Guide as one of the (practically applicable) non-defaults?
 - e) How to deal with non-site specific (e.g. background) processes?
 - f) How to combine non-site specific results with site specific results for each impact category and in the evaluation?
- 4) Normalisation:
- a) Can we join effort as to our mutual work on normalisation, e.g. – if not both projects are using the same characterisation factors - on an update of the emission and resource data needed for a global and a European normalisation?

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Appendix 11: Input paper of Kleijn

Interpretation in the Dutch LCA Methodology Project

Discussion paper for the Danish-Dutch workshop on LCA methods Leiden, 16-17 September 1999

13 September-1999
René Kleijn
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IMPORTANT NOTE:

This is a first preliminary version of our ideas on Interpretation. Comments will be appreciated! The content is based on what is practically possible within the scope of this project.

1. Introduction

The Interpretation is the fourth and last phase of the LCA after Goal & Scope definition, Life Cycle Inventory Analysis and Life Cycle Impact Assessment. The main aim of the Interpretation is to reflect on the results of the previous phases of the LCA and on the choices that have been made during the entire process of generating these results.

This paper will start with a summary of the main points of ISO draft international standard on Interpretation followed by a description of our current ideas for operationalizing Interpretation the new Dutch Guide&Backgrounds.

2. Interpretation in ISO

The basic structure for the Chapter on Interpretation in the new Guide will be similar to that from ISO/DIS 14043. In the box below some of the main items from this document are summarised.

Short summary of the main topics in ISO/DIS 14043:

“Life cycle interpretation is a systematic technique to identify, qualify, check, and evaluate information from the results of the life cycle inventory (LCI) analysis and/or LCIA of a product system, and present them in order to meet the requirements of the application as described in the goal and scope of the study.

Life cycle interpretation includes communication to give credibility to the results of other LCA phases, namely the LCI and LCIA, in a form which is both comprehensible and useful to the decision maker.”

Elements:

1. **Identification of the significant issues** based on the results of the LCI and LCIA phases of LCA;
2. **Evaluation** which considers completeness, sensitivity and consistency check;
3. **Conclusions**, recommendations and reporting of the significant issues.

Ad 1.

objective: structure the results from the LCI/LCIA in order to determine the significant issues in accordance with the goal and scope definition, interactively with the evaluation element.

information: results LCI/LCIA; methodological choices; value choices; role & responsibilities interested parties.

significant issues: inventory parameters, impact category indicators, special (groups of) processes.

Ad 2.

objective: establish and enhance confidence and reliability in the result of the study.

completeness check ensure that all relevant data needed for the interpretation is available and complete.

sensitivity check: assess the variability of the results by assessing whether the uncertainty of the significant issues affect the conclusion.

consistency check: determine whether the assumptions, methods and data are consistent with the goal and scope.

Ad 3.

objective: draw conclusions and make recommendations for the intended audience of the LCA LCI study.

3. Interpretation in the new Dutch Guide

In the new guide the Interpretation will be divided into three elements which are similar to those in ISO 14043:

1. Analysis of the results (3.1)
2. Sensitivity and uncertainty analysis (3.2)
3. Conclusions & recommendations (3.3)

These three elements will be discussed in paragraphs below.

3.1 Analysis of the results (ISO element 1)

The first element is the analysis of the results “as they are” that is, without adapting the information that was used to generate these results. This element can be divided into two sub-elements:

- contribution analysis (or dominance analysis)
- anomaly assessment

3.1.1 Contribution analysis

In the contribution analysis the overall contribution to the total results are calculated e.g. by expressing the contribution in % of the total.

Examples are the calculation of the contribution to the results of:

- contribution of individual processes within the total (e.g. pasteurising within 1000 l of milk);
- contribution of a group of processes within the total (e.g. preserving within 1000 l of milk);
- contribution of a life-cycle stage within the total (e.g. production within 1000 l of milk);
- contribution of product within the total (e.g. the bottle within 1000 l of milk);
- contribution of an environmental flow within the total (e.g. SO₂ within 1000 l of milk)
- specific product properties e.g. the energy requirement of a refrigerator.

The contribution to the results can be calculated on different levels:

- on the level of the overall end results (results at the most aggregated level)
- on the level of impact category indicators
- on the level of inventory results e.g. emissions or extractions of (groups of) substances

3.1.2 Perturbation analysis²⁶²⁷

In a perturbation analysis one studies the effects of small changes on the results of an LCA (Heijungs, 1994; Heijungs, 1996). This result of such an analysis could be a list of processes or flows in order of decreasing importance for a specific type of end-result (e.g. CO₂emission, Global Warming score or Eco-Indicator). The perturbation analysis is very easy to implement when a matrix type of calculation method is used and can be used for an improvement

²⁶ This type of analysis is referred to as marginal analysis by Heijungs. Using this term here however would lead to confusion because of the use of the term ‘marginal’ in a different context in the Goal & Scope definition and Inventory modelling.

²⁷ One could discuss whether the perturbation analysis should be a part of the Analysis of the Results (3.1) or of the Sensitivity Analysis (3.2). One could argue that in the perturbation analysis the data used for describing the system are changed. However, these small changes are only used to assess which process or flow are most important in the system *as it is*. Thus one could state that a perturbation analysis is used to assess the *Intrinsic sensitivity* of the system and not the effects of the uncertainties in the variables or model choices.

analysis of a specific product system. However, more importantly for the interpretation, it can help to focus the sensitivity analysis to those variables and model choices which are most important for the end results. Thereby it can to a large extent reduce the effort that has to be put into the gathering of uncertainty data.

3.1.3 Anomaly Assessment

On basis of e.g. experience unusual or remarkable deviation from expected or normal results are determined or simply stated. Anomalies can be found by looking at the results of the LCA and the way in which these results were generated with an expert eye. The expert may have a look at the parameters describing the system, the methodology which was used in the different phases of the LCA, the data that was used and the results and conclusions of the analysis, all in relation to the goal & scope of the study. An expert might be able to locate unexpected or missing emissions or discover assumptions or methodological choices which are incompatible with the type of LCA.

Another way in which anomalies can be discovered is to compare the study with other, similar, studies. Again one should focus on at the parameters describing the system, the methodology which was used in the different phases of the LCA, the data that was used and the results and conclusions of the analysis, all in relation to the goal & scope of the study. When comparing two LCA studies great care should be taken that the goal & scope of the studies are truly similar.

3.2 Sensitivity and uncertainty analysis (ISO element 2)

In order to use LCA as tool for decision making information is needed on the robustness of the results. Therefore information is needed on the *validity* and the *reliability* of the results. It is important to make a distinction between these two:

- when discussing the **validity** the question should be answered whether the results are based on sound reasoning, or in LCA, whether the appropriate (e.g. correct representativeness in space, time, technology etc.) process data(sources) and models have been used and whether the appropriate methodological choices and assumptions have been made, all in relation to the goal&scope of the study. If any controversial choices have been made the influence of these choices on the end results of the study should be assessed. *Variability*, as introduced by others in the context of LCA (e.g. Huijbregts, 19xx, Hertwich, 1999), is regarded as a part of validity. When discussing the validity one should keep in mind that the assessment of the validity is closely linked to the choices that are made in the Inventory Model (see Discussion Paper Heijungs and Huppes);
- when discussing the **reliability** the question should be answered whether the parameters and data which are used are likely to be true or correct and can therefore be trusted or believed. The issue of reliability is closely linked to the item of data quality within the LCI (van den Berg et al., 1999; Wrisberg et al., 1999).

In principle the following items should be subjected to an analysis of the validity and reliability:

- data(sources)
- model

In every phase of the LCA models and data are used. Therefore, for every phase the validity and reliability of model and data should be discussed in the interpretation.

There are three major requirements for the models used in an LCA. First they should represent the "real world" as good as possible (correct formal description and formal description), second they should be complete and third they should be in line with the goal & scope of the study (thus fit in one of the following: Occasional Choices, Structural Choices Strategic Changes see Discussion Paper Heijungs and Huppes).

In the next paragraphs the sensitivity and uncertainty analyses for data(sources) and models will be discussed for every phase of the LCA except for the Interpretation. When Interpretation would be included we would have to discuss the uncertainties within the uncertainties which, at this moment, is a bridge to far. Another question which remains is the question whether the type of sensitivity and uncertainty analysis is representative.

3.2.1 Goal & scope definition

In the Goal & Scope definition the question which should be answered by the LCA is specified.). The validity and reliability of model and data should be assessed in the sensitivity and uncertainty analysis.

model

There is a number of important choices which is made in the Goal & Scope definition:

- appropriateness of the question in relation to the model choice;
- marginality of the functional unit;
- the choice of the functional unit;
- system boundaries;
- inclusion of mechanisms.

Appropriateness of the question in relation to the model choice;

Whether the question to be answered by the LCA is related to Occasional, Structural or Strategic Choices is of major importance for the choices of models and of data(sources) later on in the study (as is shown in the discussion paper of Heijungs and Huppel).

Marginality of the influence / effect of the decision

The model choice should be related to the effect of the decision which the LCA is supposed to support (see paper Heijungs and Huppel).

Choice of the functional unit

The following questions regarding to the validity of the choice of the FU should be answered in the Interpretation:

- is the function defined in accordance with goal&scope: e.g. in food products the question if the FU should be defined in terms of calories, protein content or "pleasure while eating"
- do the options which are being compared have the same performance: e.g. when comparing two types of paint a litre or kg might not be the right comparison measure because there could be a difference in the surface area that could be painted with one litre of each. Another example is the comparison between different bottles. If an LCA has been done for different one litre bottles the results are not automatically valid for similar 1.5 litre bottles.
- are the options which are being compared really functionally comparable ? for example both a train and a car will take you from A to B but when you carry a lot of luggage a car is functionally superior to a train. Other example are: the comparison between two "every day" shampoos of which one has a "anti dandruff" function added; the comparison between two televisions with different screen sizes etc.
- is consumer behaviour incorporated in the FU: although the amount of detergents needed to clean one load of cloths may be reduced consumers tend to stick to their old habits continue to use much more than is advised or needed.

system boundaries (see also paper Heijungs and Huppel):

- time aspects in model relations
- time specification of inventory results
- locational specification of processes

inclusion of mechanisms

- fixed input/output relations
- technical production function
- market mechanisms (substitution of one product with another)
- social (change spending patterns)

data

Although they are not often recognised as such there are some very important data issues within the goal & scope definition. In this phase the system is described both qualitatively and quantitatively. For example, in an LCA of “one-way” packaging vs returnable packaging the trip rate which is assumed for the returnable packaging is of major importance to outcome of the study. Therefore the validity and reliability of parameters describing the system is an important issue. Whether the value for the value of a system parameter is valid for a specific LCA is also dependent on the representativity of this parameter in time, space and technology. This of course, again in relation to the type of question to which the LCA should provide an answer (Occasional, Structural or Strategic Choices).

3.2.2 Inventory Analysis (see also Discussion paper Heijungs & Huppes)

In the Inventory Analysis the product system is described both qualitatively (process tree) and quantitatively (process data). The boundaries of the product system are defined, both with other product systems and with the environment. Furthermore, in order to prevent endless regression, process inputs outputs are cut-off if processes behind these inputs and outputs are thought to be of minor importance. The validity and reliability of data and methodological choices should be assessed in the sensitivity and uncertainty analysis.

model

System boundaries

One of the most important model choices within the Inventory Analysis are related to the system boundaries. The first system boundary is the one between **economy and environment**. This boundary is specifically important for LCAs in which agriculture, forestry or landfill play an important part. The validity of the following choices should be assessed in the sensitivity and uncertainty analysis (all in relation to the questions that the LCA should provide an answer for):

- in agriculture, forestry: is the soil regarded as a part of the environment or of the economy ? and what about (parts of) the crop ? this is especially important with regard to fertilisers and pesticides. Another question is how are health effects of pesticide residues on the crop handled.
- in landfill sites: is the site controlled and regarded as a part of the economy or is it just a dumpsite and regarded as a part of the environment ?

The next type of system boundaries is that between **the product system under study and other product systems**. This system boundary is reflected in the choice for a specific principle of allocation both per process as for the system as a whole. The validity of the choice should be assessed in the sensitivity and uncertainty analysis (all in relation to the questions that the LCA should provide an answer for).

The last type of system boundary is that between **relevant and not relevant processes** in order to prevent endless regression. This system boundary can be implemented via cut-off criteria which should reflect the environmental impact of the processes which are cut-off in some way. Criteria which are often used are mass and energy inputs of the concerning processes. However, cut-off rules can also be replaced by a rough assessment of the environmental impact of the process “behind” the cut-off point e.g. via the use data from IO-analysis (Carnegie Mellon). The validity of cutting off the processtree can only be assessed by a (rough) assessment of the importance of the part of the processtree which is cut off. For this data from the IO-analysis can be used.

Another important methodological choice is whether marginal or average data is used. Again, this choice should be in line with the type of question to which the LCA should provide an

answer for: Occasional, Structural or Strategic Choices (see table 1 Item 3 paper Heijungs and Huppes)

If landfill sites are regarded as a part of the economy one needs a time horizon to calculate the emissions from that these landfill sites. This time horizon may vary between zero and infinity. Zero means that there are no emissions at all, this could be the case when the site is completely sealed off from the environment. Infinity means that the emission is equal to the amount which is landfilled. The validity of the choice should be assessed in the sensitivity and uncertainty analysis (all in relation to the questions that the LCA should provide an answer for)

Calculation method

In LCA software two calculation methods are normally used: sequential and matrix calculation. When there are internal loops within the system e.g. with closed loop recycling, a sequential calculation method may give erroneous results or no results at all. In that case matrix calculation is the only valid calculation method.

data

In the inventory the data issue focuses on data on environmental and economic inputs and outputs of processes within the economy. The influence of the choice of data(source) can be huge (Copius Peereboom et al., 1999, etc.. The validity of the data can be assessed by determining whether the time, space and technology which the data represents is in line with the questions to which the LCA should provide an answer (as defined in Goal & Scope). Next to that the reliability of the data should be assessed. First of all the completeness of the inflows and outflows of the processes should be checked, e.g. are there any emissions missing? Next to that the uncertainties in the amounts of inflow and outflow should be considered. This process can both be quantitatively with the aid of uncertainty analysis and qualitatively with some type of data quality indicators (e.g. Weidema et al.).

3.2.3 Impact Assessment

In the Impact Assessment the environmental impacts of the sum of the inflows to and outflows from the environment are assessed. In order to do this models are used to relate these flows to environmental impacts. Within these models parameters are used for which should be valid for the type of questions that should be answered by LCA and of which the uncertainty should be assessed. Currently there is a number of conceptually different, but equally valid, Impact Assessment methodologies. Still the choice for a certain methodology can of course be important for the end results. In order to assess the influence of this choice different methodologies should be used.

model

Within the different Impact Assessment methodologies certain model choices are made. Most important are:

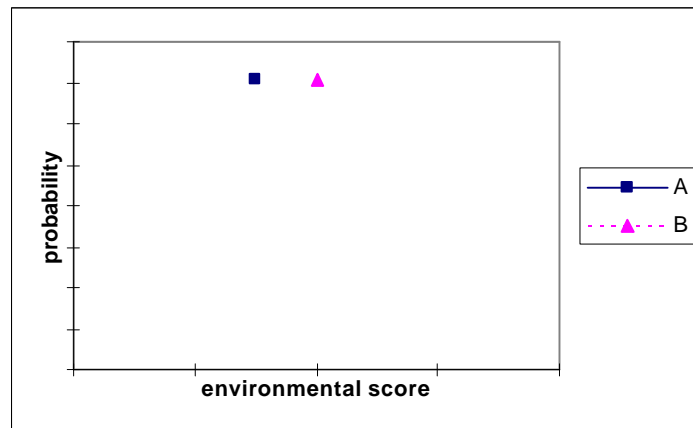
- validity Steady State modelling / Time horizon
- validity of neglecting of site specific impacts
- validity of neglecting additivity of impacts
- validity of assuming marginality of impacts

data

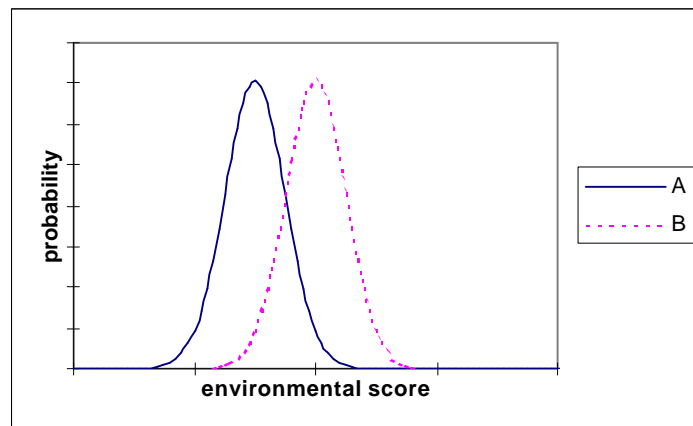
In the impact assessment there are two types of data, model parameters e.g. in multi-media models concentration of particles in different environmental compartments, amounts of air water and soil etc. and data related to specific flows e.g. in multi-media models degradation rates, solubility but also toxicity etc. The validity of both the model parameters and the data related to specific flows should be assessed on the basis of representativeness in time and location in relation to questions to which the LCA should give an answer. Furthermore the uncertainty in the data should be assessed.

3.2.4 Practical guidelines to handle validity and reliability issues in LCA

In the most general terms the question that has to be answered by an LCA is whether two product systems are significantly different from one another in respect to e.g. emissions, environmental scores or eco-indicator scores. When an LCA is performed without any uncertainty or sensitivity analysis the results are two points: one for product system A and one for B. When e.g. the emission of CO₂ of the two systems is compared, the emission of A is bigger than that of B or the other way around and the conclusion could be drawn that B, from an environmental point of view, is better than A .



However, the question should be whether the CO₂ emissions of both product systems are *significantly* different from one another or that the difference is a mere artefact of the uncertainties of the values of the parameters within the systems and model choices. As can be seen in the above the robustness of the end results of an LCA is subject to a large number of validity and reliability issues and the value of the result is not a single point but some kind of probability distribution.



Thus, in order to judge this robustness, insight is needed in the influence of the combination of all the issues mentioned above. Several methods have been proposed to gain this insight of which three are discussed here:

- calculation of extreme values;
- formal statistics: uncertainty propagation;
- empirical statistics: Monte Carlo simulation.

Calculation of extreme values

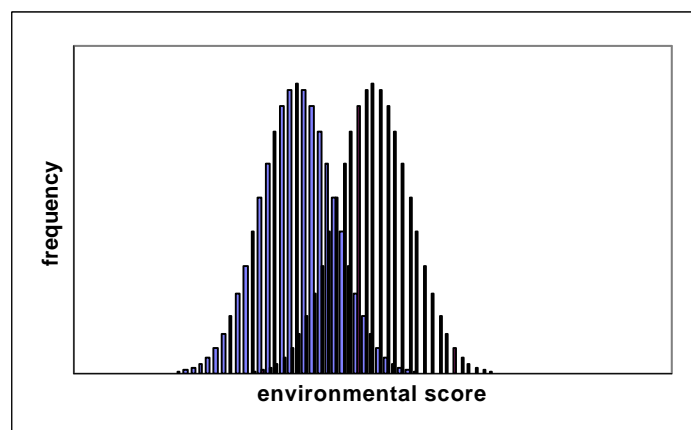
One approach that seems very simple is calculating the extreme values. In this calculation the upper and lower values of every parameter are combined to find the upper and lower value of the end result. Heijungs (1996) shows that due to the complexity of an LCA (e.g. the presence of feedback loops) the extremes of the result can not be predicted by intuition. He also shows that this implies that this means that all combinations of upper and lower values would have to be tried and that this procedure, for an average LCA, would take an modern PC more calculation time than the current age of the universe. Therefore this type of uncertainty analysis is not of much use for most LCAs.

Formal statistics: uncertainty propagation

Heijungs (1996) proposes a formal solution via a regular statistical method: propagation of uncertainties. In this case one starts not with determining the upper and lower value of a parameter but by assuming a particular distribution of the values for the parameters. When a normal distribution is used the mean and standard deviation of the parameters would have to be determined. Although the mathematics involved are complicated the method in itself is relatively simple to implement in automated calculation procedures, that is, when matrix calculation is used. With this formal statistical approach one will be able to make statements like: with a 95% certainty interval the emission of CO₂ of product system A is bigger than that of product system B.

Empirical statistics: Monte Carlo simulation

Another technique that can be used to avoid the problems connected to calculation of the extreme values is stochastic modelling. This technique can be performed with the aid of a Monte Carlo or Latin Hypercube simulation (Huijbregts, 1998a and 1998b). In both types of simulation a predefined, limited number of combinations (typically 10,000) of random parameters, restricted by their uncertainty distribution, is used to calculate the results. The only difference between a Monte Carlo and a Latin Hypercube simulation is that in a Monte Carlo simulation for each parameter the uncertainty distribution has to be specified while a Latin Hypercube simulation works with an uncertainty distribution which is segmented into a number of non-overlapping intervals, each having equal probability. An advantage of the stochastic modelling is that, in contrary to the formal statistic methods, it is relatively easy to use various parameter distributions, such as uniform, triangular, normal and log normal. The result of this type of analysis is a frequency chart of possible outcomes.



Once a frequency chart has been generated the same statistical methods as with the above mentioned formal statistics approach can be used to assess whether two product systems are significantly different from one another.

In all three methods described above information is needed on the uncertainties in parameter values. In LCA practice one of the most time consuming tasks is to collect the appropriate data let alone collect the information of the uncertainties in the data. As already proposed by Heijungs (1996) and Huijbregts (1999), focussing on key parameters would simplify matters to

a large extent. One way to rank parameters in order of importance for the end results of the study is the use of a perturbation analysis (see 3.1.2). This could greatly reduce the amount of information needed for a sensitivity analysis.

For model choices the approaches sketched above are in principle possible. However, current LCA-software will not always allow the procedures needed. This is for instance the case with choices regarding to the allocation. In order to assess the influence of a certain chosen allocation procedure it should be possible to make this change without having to reorganise the whole data set.

3.3 Conclusions and recommendations (ISO element 3)

Performing sensitivity analysis and uncertainty analyses on data and models is one thing, processing the results of these analyses in the conclusions of a study is another thing. There are examples of studies where sensitivity analyses have been performed, but where the outcomes of these analyses have not been processed in the results at all. First guideline for drawing conclusion thus would be:

Take the results of the sensitivity and uncertainty analysis on data and models into account in the conclusions.

The next question then is how should one taken these results into account?

The most simple but not so elegant solution is to determine for the most dominant data the uncertainty and to add the results of these analyses (see section 3.2.5) to a maximum uncertainty range for data. In a similar way the uncertainty could be determined of the most important model choices (e.g. allocation models and characterisation models for some impact categories) and the results of these analyses could be added again to a maximum uncertainty range for models. After that, the further interpretation is to the practitioner and/or the decision maker.

A more elegant, but not yet practically available solution is to formulate both data and model uncertainties as input uncertainties (e.g. data: $5 \pm 0,5$ and models as the probability, say 0,333, on model A, B or C) into a Monte Carlo analysis. In this way all model and data uncertainties are aggregated into a total frequency distribution of the end results of a study. In the work on the Guide we will have to take a closer look into what is feasible at this moment and for this we will consult some experts in the field.

Whatever the precise Guidelines will be, they are necessary especially for comparative assertions (e.g. LCA applications within the Dutch Packaging Covenant, long term waste strategies, ..) in order to minimise opportunistic use of results ('hired gun' effect).

Finally, it will have to be determined in a comparative LCA, which differences in results are significant to be able to conclude that a certain product alternative is environmentally more sound than another alternative. For the simple solution, it will not be possible to provide any further guidelines here, as far as we can foresee now. For the Monte Carlo solution, it will be investigated if ordinary statistical analysis can be applied to its results.

With respect to validity, the conclusions must be formulated in compliance with the limitations of the scope and main data and model choices made, and in compliance the limitations of the LCA tool itself. This implies that the conclusions are only valid for the systems analysed and thus not, automatically, for other similar system which have not been analysed. For example, the results for 1 litre packaging alternatives for a certain liquid are not valid for similar 1,5 litre packaging alternatives. Separate justification is needed if the conclusions are expanded to other similar systems.

It also implies that the conclusions are valid for the main data and model choices made. If, e.g., the system boundary is expanded to include more processes earlier in the chain it is in principle possible that the conclusions would not be valid anymore. A list of main choices that should be reported here, will be drafted in the new Guide.

Finally, formulating conclusions in compliance with the limitations of the tool implies that a conclusion that a certain installation better be situated at location A instead of location B cannot be drawn on the singular basis of an LCA.

It is our conviction that even a waterproof Interpretation cannot prevent misuse of LCAs, it can only minimise it. It will always be possible to manipulate results or use results to answer the wrong questions. By giving guidelines or check-lists, the Guide will try to minimise possible misuse. Besides these guidelines, the peer review process is of crucial importance here but this and other procedures will be described in separate procedural section in the new Guide (cf. Van Duin en de Bruijn, 1998a+b).

4. Conclusions and Research recommendations

In this paper we have drafted our preliminary ideas for elaborating the Interpretation phase. ISO 14043 on Interpretation is still in progress and doesn't contain many practical guidelines. The key issue of the interpretation is the quality and the validity of the study's results. With respect to the validity aspect, it is mainly a matter of communication of the results as to what they do indicate and what they don't. This has to do with the limitations of the goal and scope of the study (e.g. which product alternatives have been included and which not), and with the limitations of LCA as a tool (LCA is one tool, RA is another giving other results). Guidelines for this can be worked out, and but then have to be tested in practice. In the new Guide we can give first guidelines and further research is necessary to test these guidelines and to make them more comprehensive.

With respect to reliability, there is much more hurdles to take. In the first place reliability data on models and data used are largely lacking. But also practical and comprehensive methods are lacking to deal with data quality and to enable aggregation of quality indications of individual parameters to a judgement of the total quality of the results of a specific LCA study. Further research is needed here, building on expertise on uncertainty handling in science for policy (see Functowitz & Ravetz; van den Berg et al., 1999; Wrisberg et al., 1999).

5. References

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