NEW DEVELOPMENTS IN THE METHODOLOGY FOR LCA

Expanded handout version

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Abstract

Many methodological choices in a life cycle assessment (LCA) depend on the goal of the study, i.e. its application area. A better definition of the application areas and especially a clear distinction between retrospective and prospective applications allows a more unambiguous description of the methodology to apply for different applications.

Keywords

Application areas / Prospective, comparative life cycle assessments / Product substitution / Functional unit / Choice of technologies / System expansion / Co-product allocation / Future forecasting / Site dependent impact assessment / Uncertainty

Introduction

In a paper, which I presented to the RITE International Workshop on Total Ecobalance held in Tokyo (Weidema 1996), several areas of methodological choices were outlined, which all depend on the goal of the study, i.e. its application area. The choices affected by the goal of the study are:

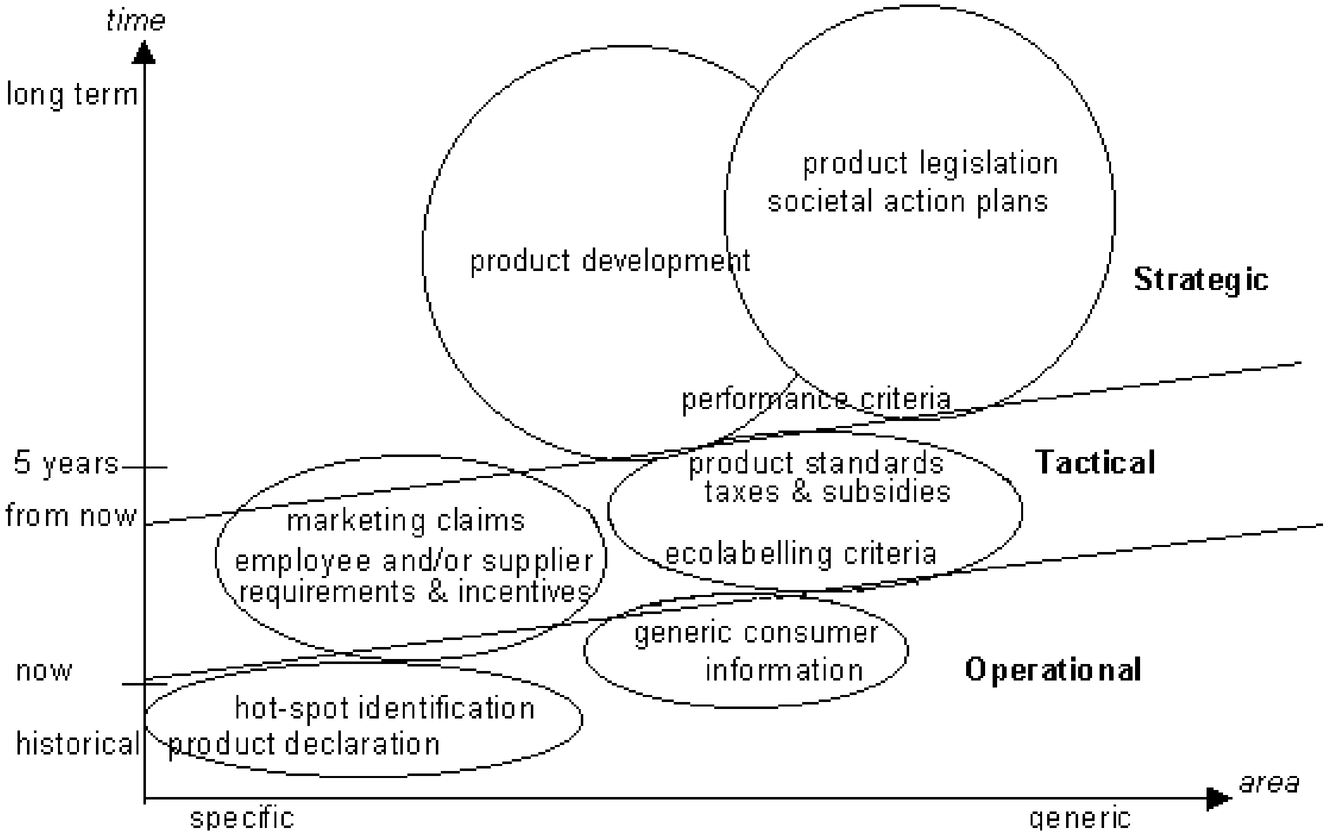
- The definition of the functional unit.
- The choice of technologies for which data are to be collected (including geographical aspects).
- The method for handling co-products.
- The use of future forecasts.
- The model for impact assessment.

I pointed out that there was, however, "no clear understanding of how the goal influences the methodological choices, i.e. what methodological adaptations are necessary in relation to a certain purpose," and that more research in this area was needed.

It is a pleasure for me to be able to present to you here, less than 3 years later, the first results of our research on this topic. These results show that it is indeed possible to reduce the ambiguity and uncertainty from these methodological choices, through a more clear understanding of their relationships to the application areas.

Application areas

The methodological choices outlined above are fundamentally determined by the products and interest groups affected and the temporal and spatial aspects of the studied systems. On this basis, six clearly defined application areas can be distinguished (Weidema 1998) (see figure 1).



With respect to methodological choices, the most important distinction is that between the retrospective life cycle assessments of the accountancy type (typically applied for hot-spot-identification and product declarations) and the prospective, comparative life cycle assessments, which study possible future changes between alternative product systems (typically applied in product development and in public policy making) (Tillman 1998). As the ultimate goal of most applications (even hot- spot-identification and product declarations) is to improve the studied systems, the relevance of retrospective life cycle assessments may be questioned:

- 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.

In the following, I shall therefore focus mainly on the methodology for prospective, comparative life cycle assessments.

Foreground and background processes

For prospective, comparative life cycle assessments, it has been suggested that a distinction between foreground and background processes can be useful (Clift et al. 1998, Tillman et al. 1998). However, to apply this distinction in the following analysis, we have found it necessary to define these terms more strictly, so that:

- a foreground process is a process whose production volume will be affected directly by the studied change,
- a background process is a process whose production volumes will not be affected or be affected only indirectly (i.e. only through the market) as a consequence of the increase or decrease in demand as a result of the studied change.

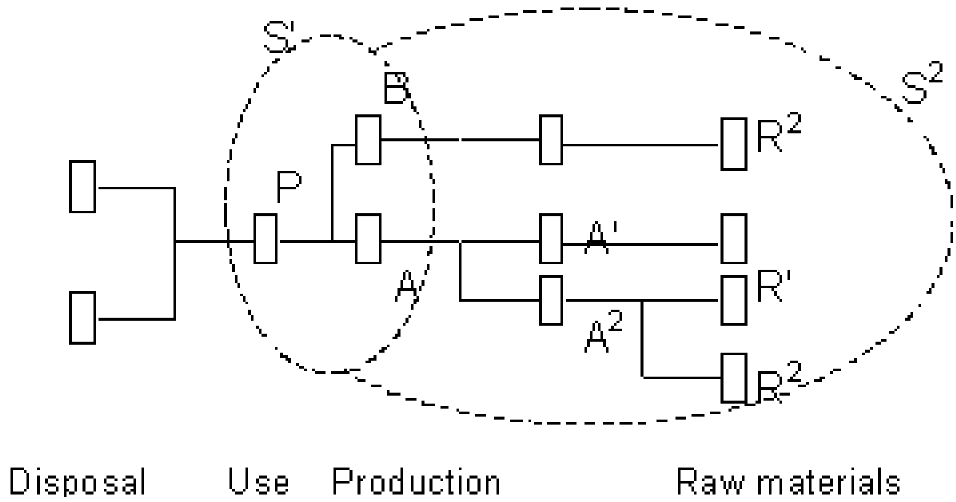
Product substitution

In a prospective, comparative life cycle assessment, the object of study is the environmental impacts of a potential product substitution. Product substitutions may occur anywhere in the life cycle, from raw material substitutions, over substitutions in the production and use stages, to substitutions between alternative waste handling options. However, life cycle assessments are typically limited to study the effects of substitutions at one specific stage in the life cycle, the range of possible substitutions at that stage being delimited by the functional unit (i.e. the functional unit typically does not specify what choices to make at other stages). The reason for this is that life cycle assessments are typically aimed at situations where the influence of the decision-maker is limited to the specific substitution studied (i.e. most processes are in the background).

However, if the decision-maker is able to affect substitutions at different stages in the life cycle (i.e. using foreground processes for these), these substitutions may - both in principle and in practice - be specified by the functional unit, thus including all possible choices simultaneously in the study. Even when the decision-maker is not able to influence directly any substitutions elsewhere in the life cycle (i.e. when most processes are in the background), the studied substitution at one stage in a life cycle (the foreground) may still lead indirectly to product substitutions in other life cycle stages (in the background). These substitutions are then not included in the functional unit, but the expected result of the substitutions (in terms of affected processes and their technologies) is simply included when modelling the product systems.

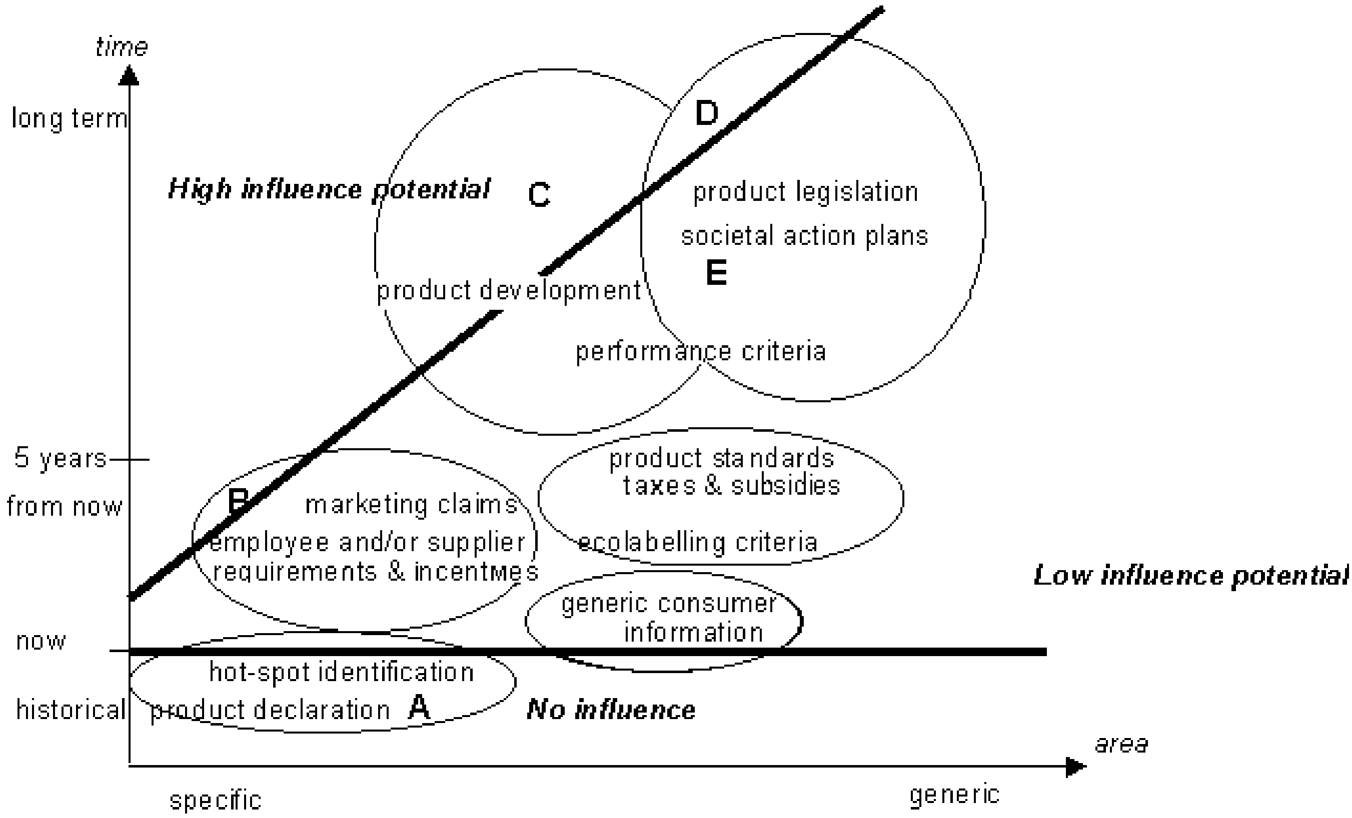
Put very briefly, using the terminology of foreground and background processes: Product substitutions in foreground processes may be included in the definition of the functional unit, while substitutions in background processes are simply accounted for by including the affected processes and technologies when modelling the product system. See also figure 2 and the explanatory text to this figure.

Relating this to the application areas in figure 1, it can be seen that the conditions for a large area of influence (S' in figure 2) is limited to the upper left-hand corner of figure 1 (see figure 3), namely for long-term, strategic applications involving relatively well-defined products of enterprises with relatively large (expected) influence on the different actors in the life cycle.



Explanations for figure 2: The substitution studied may be at the use stage (to use product A or Product B for the function P), at the production stage (to produce product A by route A' or A2), at the raw material stage (to use raw material R' or R2) or at the disposal stage. However, the choice of a specific product (say B) will typically imply a choice of production route and raw materials (R2) that is not put into question. It is only when the decision maker (in the case of the choice A or B, the user is the decision maker) has an influence on the choice of production and/or disposal route and/or raw materials use, that the other choices (e.g. A' or A2 and R' or R2) can be included by the definition of the functional unit (e.g. specifying: "P produced using raw material R2", or the more conditional specification: "P produced with optimal raw material choice," which allows a comparative investigation of different raw materials). This is illustrated by the sphere of influence S2. Usually, the influence of the decision-maker is more limited, typically to the choice between different products at the previous stage in the product chain (S'). In this case, the functional unit is simply specified as "P" without indication of any specific conditions of production or disposal. Nevertheless, these choices will still be made by other decision-makers in the chain. So, what will be included in the life cycle study, is the expected result of these choices, i.e. the expected route of production and disposal as chosen by the decision-makers for these stages of the life cycle.

Figure 3. *The influence of the decision-maker in relation to the application area*



Explanations for figure 3: The decision-maker's potential influence on the different processes in the product system increases towards the top left of the diagram, i.e. as the decision horizon becomes more long-term and as the decision relates to more specific products and geographical areas. For retrospective studies (area A), there is no choice to influence (thus, all processes are background processes). For medium-term, tactical studies, high influence on specific processes throughout the life cycle (i.e. a high degree of foreground processes in the product systems) is limited to studies, where the product system is very well-defined and where the decision-maker already at present has a high influence on the other actors in the life cycle (illustrated by area B in the figure). Tactical aspects (i.e. contacts to be made in the product chain) may also be part of the considerations in product development, and the more long-term the development, the more ambitious one may be with respect to obtaining influence (area C). Even on a societal level, it may be possible to influence specific choices (foreground processes) throughout the life cycle, when the products are relatively well-defined and have well-defined interest groups (including producers and users), and when the time horizon is long enough to allow the necessary regulative and technical infrastructure to be developed (area D). For the rest of the applications (area E in the figure), the products are either too generic (i.e. includes several products or a group of products) or involve too many interest groups to allow a decision-maker to influence specific choices throughout the life cycle (i.e. most of the product systems will be background processes).

For a thorough understanding of a specific product substitution, information is required on:

- The market segment affected, as determined by the obligatory product properties ("must have"), necessary for a user in that segment to accept the products as comparable and thus substitutable.
- The extent of the studied substitution, where:
    - small, short-term substitutions affect only capacity utilisation, but not capacity itself,
    - small, long-term substitutions affect also capital investment (installation of new machinery or phasing out of old machinery),
    - large substitutions affect also the determining parameters for the overall technology development, i.e. the constraints on the possible technologies, the overall trends in the market volume, or the production costs of the involved technologies, so that the studied substitution in itself may lead to new technologies being brought into focus.
- Product availability, i.e. whether the market situation actually allows a choice between the products to be made (in this respect, markets may be differentiated geographically, be more or less regulated, more or less monopolised, and more or less transparent).
- The positioning properties of the products ("nice to have"), as well as price and information, which influences the degree to which a potential product substitution will actually be realised.

It should be noted that in the first part of the life cycle (e.g. in relation to raw material substitution), price tends to play a larger role and product quality is often less complex, more easy to define precisely, more dominated by technical aspects, and more stable over time than later in the life cycle (consumer products) where complexity increases, preferences change more quickly, and qualitative aspects and irrational behaviour may have larger influence.

Also, the market aspects may change over time:

- Markets tend to become more transparent and geographically homogenous, but at the same time more segmented with regard to quality requirements.
- There is a tendency for positioning properties to become obligatory with time.

Definition of the functional unit

When defining the functional unit of a comparative study, the obligatory product properties must always be taken into account. To obtain a precise and indisputable definition, it has proven useful to analyse in detail the actual obligatory product properties required by the relevant geographical markets and market segments. Whether the other aspects of product substitution (availability, positioning product properties, price, and information) should also be taken into account depends on the time horizon of the study. In studies with a long time horizon (e.g. product development or strategic management), it may be reasonable to compare two products, for which substitution cannot be immediately realised, but where it is assumed that substitution will be realised under specific, future conditions of availability, price and product information. The shorter the time horizon of the study, the less relevant it is to include product alternatives, for which substitution is not likely to be realised under the present conditions.

Two products may be compared even when they differ with respect to positioning properties. If these positioning properties can be determined to fulfil specific functions, equivalence between the compared products must be ensured by treating these functions as co-products (see below).

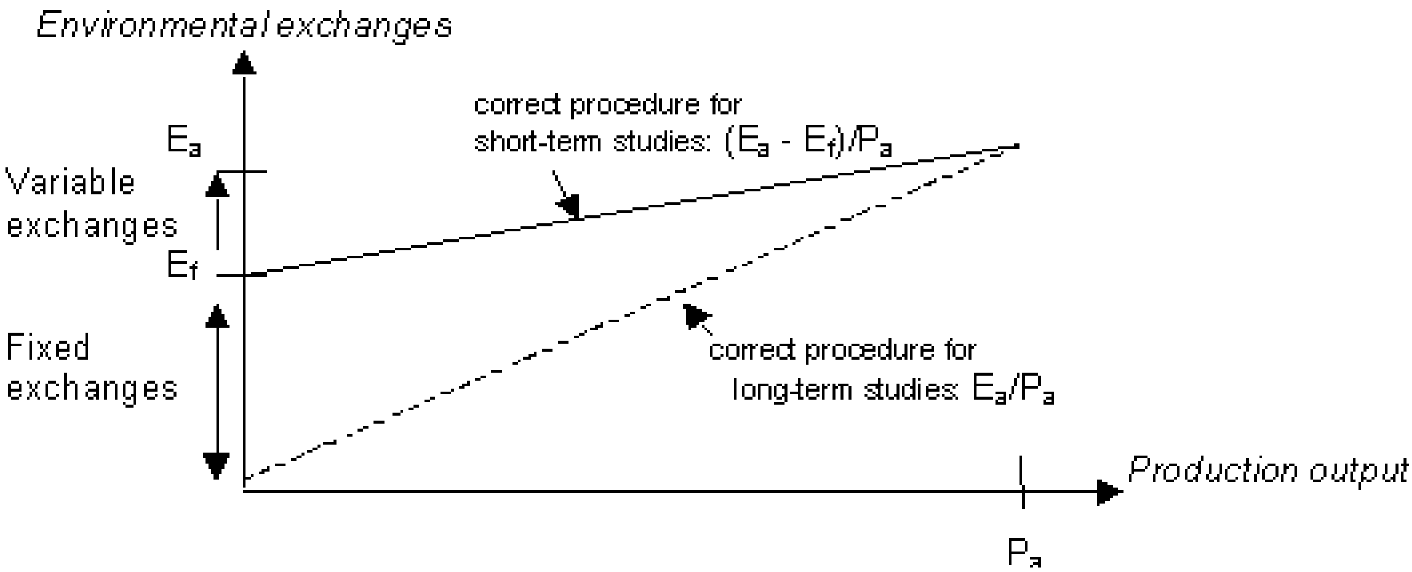
Choice of technologies

As mentioned above, the processes to include in a prospective, comparative life cycle study - and the technologies of these processes - are identified as the processes and technologies actually affected by the studied product substitution (as defined by the functional unit). To identify the processes affected, all four types of information on product substitution mentioned above are relevant. We have formalised the treatment of the last three types of information in a step-wise procedure for identifying the affected processes, see Weidema et al. (1998).

When the processes to include in a study cannot be precisely identified in terms of technology or geography, or if substitute data have to be used when the desired data are not available, this will add to the total uncertainty of the result. From our initial investigations, it seems clear that the largest cause of such uncertainty is inadequate identification of the technology to apply (for example, if the modal choice is unknown for a transport process, or if the fuel choice is unknown for a combustion process). Another major cause of uncertainty is inadequate specification of the geographical location (since a large part of the variations between processes are related to geographical differences). Such knowledge on the relative importance of the causes of uncertainty can be applied in the data collection strategies for life cycle studies, thus minimising this source of uncertainty.

In most life cycle studies, environmental exchanges are calculated for the total production (including the fixed environmental exchanges related to capital goods and general maintenance of the production capacity), and then divided by the production output to yield a value expressed per functional unit (the dotted line in figure 4).

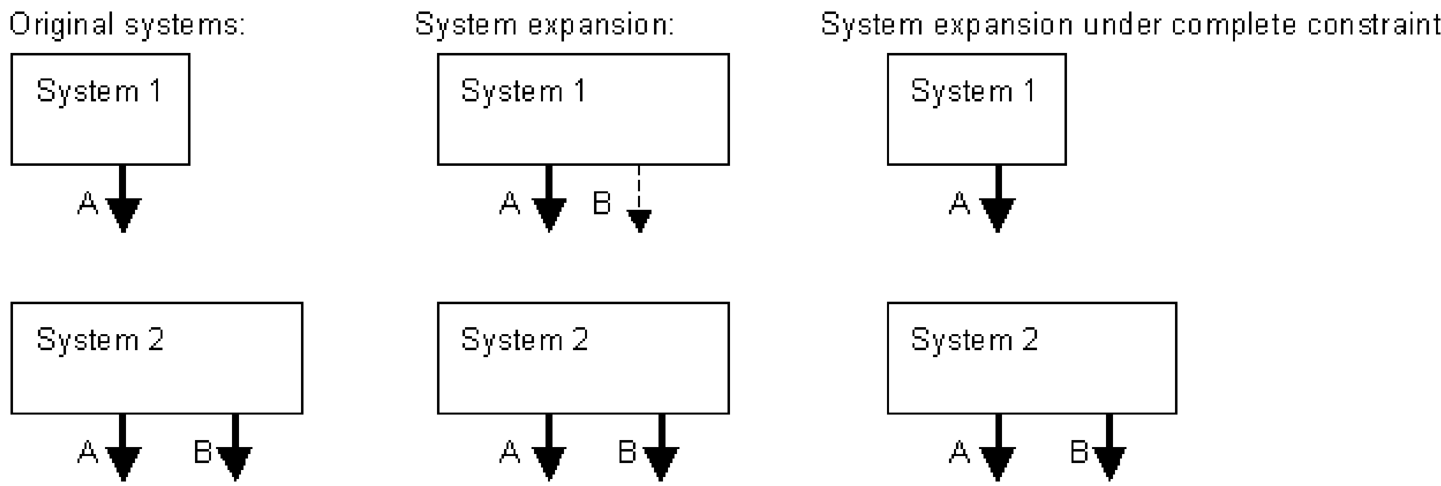
Figure 4. *Fixed and variable environmental exchanges*



However, for short-term product substitutions (i.e. not involving changes in production capacity), it is necessary to limit the study to those environmental exchanges, which are variable with the individual product. This means that the fixed environmental exchanges should be eliminated from the study (for example, in a coal mine, most of the emissions and energy expenditures have a fixed relation to the size of the mine, not to the variable production output). By providing more information on capacity utilisation and fixed environmental exchanges of different processes, we seek to improve the accuracy of data relating to short-term product substitutions.

Method for handling co-products

If a co-product does not appear in similar quantity in all studied systems of a prospective, comparative study, it is necessary to expand the studied systems, so that they all yield comparable product outputs. The processes to include when making such system expansions must be those processes actually affected by an increase or decrease in output of the by-product from the studied systems (see figure 5).



Explanations for figure 5: The two original systems to the left are producing product A either without by-products (system 1) or with the by-product B. System expansion (illustrated in the middle of figure 5) is performed with the following rationale:

If system 2 substitutes system 1, more B is being produced for the same quantity of A. This additional amount of B will substitute another existing production of B, which must then be added to system 1 to take this effect into account. Here, the difficult task is to identify which existing production of B is being substituted. If system 2 is being substituted by system 1, less B is being produced, thus requiring a new substitute production to be added to system 1. Here, the difficult task is to identify which production of B is the substitute. If the substitutions can be expected to be small (marginal), the affected production processes for B are the same in the two situations. If the substitutions are large, the existing production of B being substituted (when output from system 2 is increasing) and the new substitute production (when output from system 2 is decreasing) may be different.

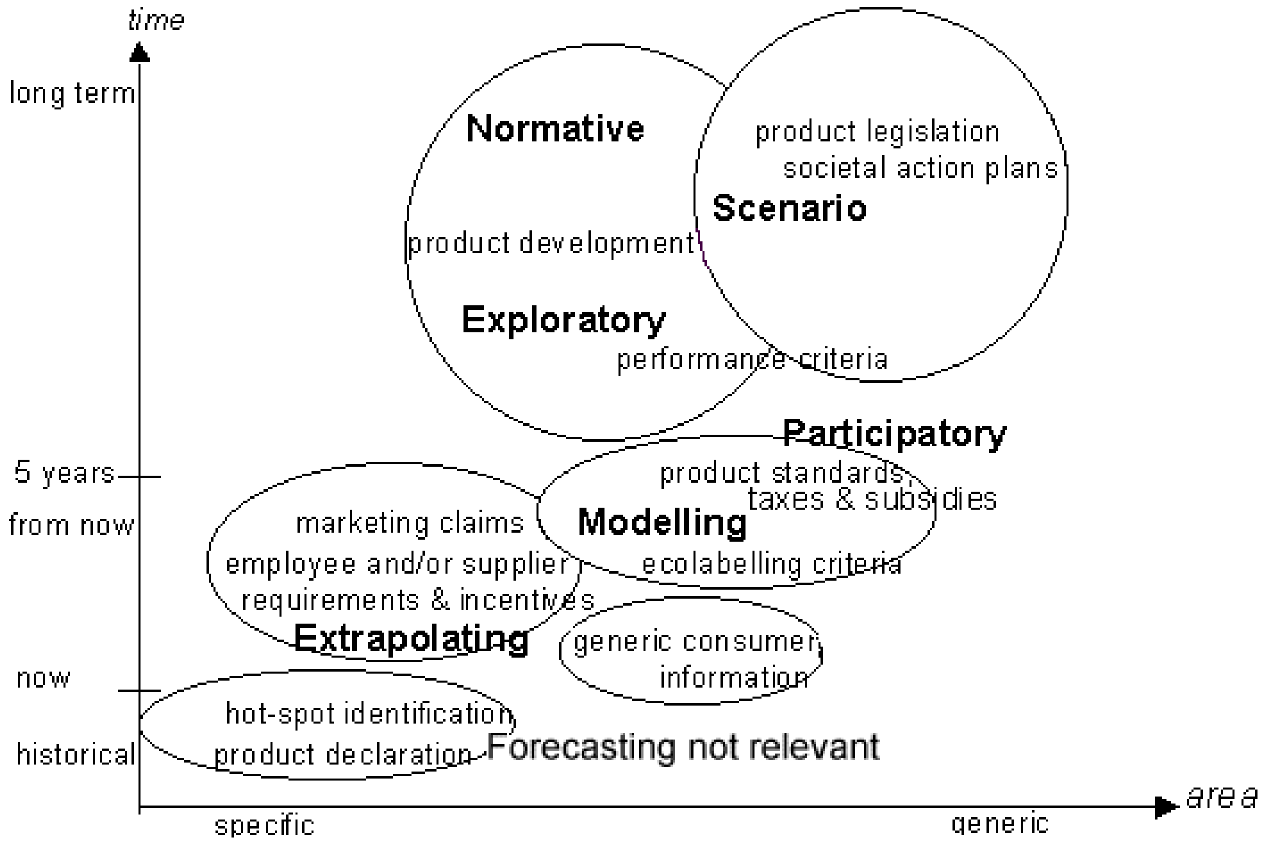
A special situation (illustrated to the right in figure 5) occurs when all possibilities for substitution are constrained, in which case a change in output of product B from system 2 can only lead to a change in consumption of B (possibly via a change in the price of B). In this situation, where a change in output of B does not lead to any substitution, all environmental burdens of system 2 is carried by product A and no system producing B is added to system 1. Thus, the product systems are comparable in spite of not having identical product outputs (system 1 with product A compares to system 2 with products A and B).

Thus, to identify the processes for a system expansion, one may apply the above-mentioned procedure for identifying the processes and technologies actually affected by a product substitution (Weidema et al. 1998). When applying this formal procedure we have found that system expansion is always possible, i.e. that it is always possible to identify those processes, which will be affected by a shift between the studied systems. Obviously, the identification can be made with more or less precision, but we have found that even an uncertain identification of the affected processes yield more useful results than an arbitrary allocation according to e.g. economic relationships between the co-products.

It should be noted that for life cycle assessments of the retrospective type, where no system expansion is possible and a full (100%) allocation of the environmental inputs and outputs is required, co-product allocation by economic relationships is the only possibility.

From the observation that system expansion is always possible for prospective studies, and never for retrospective (leaving only the option of economic allocation for such studies), we obtain a much simpler description of the procedure for co-product handling than the description in ISO 14041, although leading to the same result as when following the ISO procedure. In between system expansion and economic allocation, the ISO text has an option of using physical relationships. However, a closer analysis of this option shows that it simply encompasses some specific cases of system expansion and some specific cases of avoiding allocation through sub-division of the process.

Figure 6. Relevance of different methods for future forecasting in relation to the application areas of life cycle assessment.



The use of future forecast

For prospective studies, the data to be applied should reflect the relevant time horizon. For the short and medium term (1-5 years) forecasts for single processes (e.g. primary steel manufacture) may be based on simple extrapolation of trends and historical data (Futures Group 1994). For long term (5-25 years) forecasts, and forecasts for processes and systems, which are less specific (e.g. the general disposal system of society) and of larger importance for the life cycle assessment result, it becomes increasingly relevant to use modelling methods, such as trend impact analysis, which adjusts the extrapolations with the expected impact of mechanisms analogous to those determining past events (Gordon 1994). For generic studies, aimed at influencing many stakeholders (e.g. ecolabelling), it may be relevant to use participatory methods incorporating the insight and opinions of experts and stakeholders. Scenario methods, incorporating several parallel forecasts, are most relevant for system forecasts used in long-term, strategic studies for both societal decisions and product development. The product development process may also benefit from the systematic creativity in exploratory methods, which combine analytic techniques dividing a broad topic or development into increasingly smaller subtopics or consequences, and imaginative techniques aimed at filling all gaps in the analytical structure. For long-term, strategic applications, involving relatively well-defined products of enterprises where the decision maker is expected to have a large degree of control over the future and the different stakeholders involved, it may be relevant to apply normative forecasting, which investigates how we want the future to be and how to obtain this goal (Coates 1994). See also figure 6.

The model for impact assessment

The absence of spatial and temporal information in the data from typical life cycle inventories put constraints on the possibilities of subsequent life cycle impact assessment to predict actual impacts.

As I already mentioned in my earlier presentation referred to above (Weidema 1996), our method and software for life cycle assessment includes the possibility for adding "site factors" with which one may characterise the local conditions under which the emissions occur and the sensitivity of the actual recipients of the emission. Until recently, this possibility was seldom used in practice, since the actual site factors to use had not been developed. We have been working intensively on this subject, and have now demonstrated that it is indeed possible to develop such general site factors for different emission types. As a result of this, we now also know more about how large the variation is for some values used in impact assessment and thus how large the additional uncertainty is, when the location is unknown (Potting et al. 1998a).

The use of site factors is most relevant in enterprise specific studies, historical studies and studies with a short to medium time horizon where the geographical location is typically better specified, than in long-term, strategic and generic studies where the actual locations of the product systems are not yet determined. However, even when the precise geographical location is unspecified, some general site aspects of a process can be known (such as the typical stack height or location of a process: indoors/outdoors, marine/landbased, mobile/stationary), allowing a more precise impact assessment (Potting et al. 1998b).

A note on terminology

Above, I introduced the distinction of foreground and background processes. However, it is worth noticing that I have not relied on these terms in the methodological explanations, but only used them in brackets to show the places where these terms could have been used. My point in doing this is to show that the terms are not necessary, and since they are often used without a precise definition, they may be more misleading than guiding. I therefore suggest that these terms should not be used in general for systems descriptions.

Similarly, I have avoided the term "marginal" in the description of the procedure to identify the affected processes or technologies, although I have used this term extensively elsewhere (Weidema et al. 1998). This term is also used in many different meanings and may therefore give rise to confusion. I suggest to use it only to distinguish between small (marginal) substitutions, where an increase and a decrease will affect the same process, and large substitutions where this may not be the case.

Conclusion

To summarise, specific relationships between application area and methodology have been demonstrated on the following areas:

- the influence of the decision maker determines the amount of simultaneously studied substitutions defined by the functional unit, and the time horizon determines the scope of product alternatives to include in the study,

- the distinction between retrospective and prospective applications determine whether the processes to include are those which have (retrospectively) contributed to an existing product or those affected by a (prospective) product substitution, and whether to handle co-products by (retrospective) economic allocation or (prospective) system expansion,
- the distinction between small/large and short-term/long-term changes determine the technologies to consider and whether to consider capital goods, maintenance etc.,
- the time horizon and complexity of the studied system determines whether forecasts should be made by extrapolation, modelling or scenario methods; the amount of stakeholders affected determine whether participatory forecasting is relevant, and for specific applications in product development, exploratory and normative forecasting may be relevant.

The methodological improvements described above all work towards reducing the uncertainty of LCA results. However, it must be acknowledged that applications aimed at predicting future consequences of a choice will always have an inherent uncertainty simply because their area of study is an uncertain future. This uncertainty cannot be removed, but it may become more acceptable if generally agreed standard scenarios are developed and applied.

We are presently investigating the relative importance of the uncertainties related to the above mentioned methodological improvements, with the aim of giving advice on how best to reduce the uncertainties in a given application.

Acknowledgements

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