Impact assessment within the framework of life-cycle assessment of products

The Society for Environmental Toxicology and Chemistry (SETAC) has organized several workshops offering a discussion platform for methodological problems related to lca. Recently, a first version of a so-called »Code of Practice« has been drafted by a committee of international lca-experts under the auspices of SETAC (1). One of the main elements of this Code of Practice has been the development of a methodological framework. Within this framework four components are distinguished: goal definition and scoping, inventory analysis, impact assessment and improvement assessment. In this short paper we discuss the state of the art of the impact assessment component. For a more detailed theoretical description of cml's ideas about methodology for lca, we here refer to a number of English papers and reports which can be obtained from cml (2 – 7).

Impact Assessment

The impact assessment is concerned primarily with the interpretation of the inventory table, which is the result of the inventory analysis. This table is a long list of quantified extractions of resources and emissions of chemicals (and other outputs if known). Moreover, it provides a way to aggregate this long list into a limited number of scores representing the contribution of the product system studied to a number of environmental problems. In the »Code of Practice« three steps are distinguished within the impact assessment:

1. classification;
2. characterization;
3. valuation.

This division in steps is fundamentally different from previously applied methods such as the »the critical volumes approach« (8,9). In this approach emissions are weighted by politically determined environmental standards and aggregated per medium (water, air, soil). In the impact assessment as defined in the Code of Practice environmental and socio-political aspects are distinguished as rigidly as possible for transparency reasons. In the classification/characterization extractions and emissions are aggregated per type of environmental problem, applying as much as possible scientific knowledge about environmental processes and effects. In the valuation different problem types are weighted against each other based on social values and preferences. Below we will shortly discuss the contents of these three steps according to our ideas and end with a general discussion of further needs.

Classification

The main issue of the classification step is the definition of the relevant impact categories for the impact assessment. A list of generally recognized environmental problems in terms of assessment endpoints for the classification should be defined. For a particular case, one may deviate from this list if there are reasons to do so. In December 1991 at a setac-workshop in Leiden, a first discussion took place about environmental problems that should preferably be included in an lca (9). During this workshop an as complete as possible list of generally recognized environmental problems was divided into three groups: depletion including all problem types related to inputs from the environment (extractions), pollution including all problem types related to outputs to the environment (all kinds of emissions), and disturbances including all problem types causing changes of structure within the environment (without associated inputs or outputs). This list is adopted here with some small changes and supplements, see Table 1.

We will not discuss this list extensively as to why certain problem types are included or excluded. For this we here refer to our previous work (2, 4). The classification/characterization according to the problem types mentioned in Table 1 results in 18 effect scores. Whether this maximum will also be reached in current case studies depends on the question whether equivalency factors can be developed for all these problem types and whether all inventory analysis data needed are available. Of course, effect scores of problem types can also be zero if the inventory table does not contain any input or output contributing to that particular problem type.

Characterization

The next step is to find a way to translate the extractions and emissions of the inventory table into contributions to the problem types defined in the classification. Aim of the characterization is to perform this translation as scientific and as objective as possible leaving out socio-economic and political in fact all non-environmental considerations. Thus, the translation is based on the best currently available scientific knowledge of environmental processes and effects.

The translation is performed by multiplying extractions and emissions by a so-called equivalency factor. This equivalency factor is defined per type of extraction resp. emission and per type of environmental problem. In this way the relevant extractions and emissions are aggregated per type of environmental problem (resource depletion, global warming, acidification etc). In a general formula (see formula 1):

Formula 1:

$$\text{effect score}_{\text{problem}} = \sum_{\text{emission / extraction}} \text{equivalency factor}_{\text{problem, emission/extraction}} \times \text{amount}_{\text{emission / extraction}}$$

We proposed the list of factors shown in Table 2. Notice that radiation and occupational health have not yet been operationalized at all. Moreover, some problems have been operationalized more satisfactory than others.

An optional step within the characterization is the normalization of effect scores. The effect scores obtained after the previous two steps denote the contributions to well-known environmental problems. The meaning of the resulting numbers, however, is far from obvious. The effect scores become more meaningful by converting them to a relative contribution to the different problem types by means of a normalization (cf. 1, 2, 4, 11). To this end, we propose to divide the effect scores by the total extent of the same effect scores for a certain area and a certain period of time. The result of this step may be called the normalized environmental profile.

Table 1: Generally recognized environmental problems.

depletion	pollution	disturbances
depletion of abiotic resources	– enhancement of the greenhouse effect	desiccation
depletion of biotic resources	– depletion of the ozone layer	physical ecosystem degradation & landscape degradation
	– human toxicity	human victims
	– ecotoxicity	
	– photochemical oxidant formation	
	– acidification	
	– nutrification	
	– radiation	
	– dispersion of heat	
	– noise	
	– odour	
	– occupational health	

All normalized effect scores have the same dimension: that of a time. In a general formula:

Formula 2:

$$\text{normalized effect score}_{\text{problem}} = \frac{\text{effect score}_{\text{problem}}}{\text{effect score}_{\text{area, time, problem}}}$$

The total extent should be calculated using empirical data about extractions and emissions, and applying the same characterization models as proposed above. Since these are generic characterization models at a global scale, data on extractions and emissions for the normalization should be gathered on a global scale for a certain time period, for example a year. A very first attempt to arrive at such world annual effect scores has recently been made (7).

Valuation

Final step of the impact assessment is the valuation. The valuation starts where environmental science can give no further answers anymore about the further aggregation of data. Up till now this border line is drawn after the normalization, but in future this could change due to an increased knowledge of environmental problems.

Also after the characterization one product alternative will seldom be preferred to another one in all environmental aspects in practice. Then in some cases a further valuation may be necessary, in which the relative importance of each of the environmental problems is assessed. The valuation facilitates a decision on the choice between product alternatives, or on the subject of product improvement. Important however is that a valuation which assigns one single environmental number to a product should be used with care. A second aspect of the valuation is an analysis of the reliability and the validity of the entire analysis, giving rise for instance lead to confidence intervals. A last remark with respect to valuation: lca helps you to make decisions, it does not decide for you.

Discussion

It seems possible to define equivalency factors for quite a broad spectrum of problem types. However, there are some points that need further attention:

- inventories are not specific enough;
- equivalency factors need further improvement and values need updating.

Group parameters such as hydrocarbons (hc), cfcs/halons, heavy metals or volatile organic compounds (voc) are difficult to include in this type of characterization because there are only equivalency factors available for specific chemicals. If the individual emission data are not available, one can of course work with group values which can be derived as the arithmetical average of the individual species within that group. If, for example, only emission data on hc is known, average pocps could be derived from pocps of individual vocs. These average pocps can be calculated based on arithmetic averages of pocp values for individual vocs. This average is of some value if pocp-values of the individual vocs are only varying within a »reasonable« range. However, arithmetical averages for, for example, heavy metals and vocs have little meaning as the variation between the data of their individual species is extremely large, e. g. the hca for metals varies between 0.017 for tin and 47000 for chromium(vi). In fact, for a characterization as described above a specification of these group parameters is needed. Even incomplete, any specification is better than none. With respect to the second point, it will be clear that the state of elaboration of the different factors is quite different. odps, gwps and pocps are (quite) well-known and (more or less) accepted ones, while the aps and nps are much less accepted. One of the reasons for this difference in status is that the first ones have their own scientific discussion panels, such as the »Scientific Assessment Panel« under the auspices of the *World Meteorological Organization* (wmo) for ozone depletion, the »Intergovernmental Panel on Climate Change« (ipcc) under the auspices of wmo and *United Nations Environment Programme* (unep) for global warming, and the *Working Group on Volatile Organic Compounds* under the auspices of *United Nations Economic Commission for Europe*. Transportation, degradation and other relevant environmental processes are not included in the ap and the np for example. Similar to the gwp, odp and pocp these processes should be included in the ap and the np. This is not so easy, because in the case of acidification and nutrification these processes are much more area-dependent.

One way or another, a solution has to be found for this problem. To coordinate and authorize this process, it is vital to have a scientific discussion panel for each of these problem types. For many problem types such panels are still lacking. These panels could also provide updates of equivalency factors if new scientific knowledge becomes available. For example, the ipcc releases updates of gwps every one or two years. lca-studies should include these updates. We suggest to follow only the updates released by the international scientific panels, and not also the updates from publications of individual scientists as the latter have not been discussed yet in a broad scientific forum such as the ipcc.

The development of valuation methods is still at a starting point. An overview of different possibilities to arrive at formalized weighing factors is given in (2), and an overview of currently available methods in (12). A comparison of two competing methods, socially determined factors versus sustainability factors, is described in (13). This report presents preliminary figures. A first attempt to design a procedure for a social inquiry is in (14). Clearly, further work is needed in this field.

An impact assessment as proposed above, distinguishing an environmental science based assessment (classification and characterization) and a social preferences and values based assessment (valuation) is certainly more objectified compared to, for example, the earlier mentioned critical volumes approach applying political-environmental standards. Often heard arguments against impact assessment are that there are too many uncertainties attached to this component to include it at all and that you loose your basic information from the inventory. In our opinion these criticism is hardly (or not) valid for an impact assessment as discussed in this paper. Of course, there are uncertainties attached to any method for impact assessment, but assuming that you have to make a valuation one

Table 2: Equivalency factors to characterize the various problem types defined in the classification.

problem	unit of effect score	equivalency factor
depletion of abiotic resources	–	1/reserves
depletion of biotic resources	yr^{-1}	BDF
enhancement of the greenhouse effect	kg CO_2-equivalent	GWP
depletion of the ozone layer	kg CFC-11-equivalent	ODP
human toxicity	kg body weight	HCA RESP. HCW resp. HCS
ecotoxicity (aquatic resp. terrestrial)	m^3 water resp. kg soil	ECA resp. ect
photochemical oxidant formation	kg C_2H_4-equivalent	POCP
acidification	kg SO_2-equivalent	AP
nutrification	kg PO_4^{3-}-equivalent	NP
waste heat	MJ	1
odour	m^3 air	1/OTV
noise	$Pa^2 \times s$	1
desiccation	kg (or l) water	1
damage to ecosystems and landscapes	$m^2 \times s$	1
victims		1

way or another, it is then the question how to deal with these uncertainties. This is why we propose to make the assessment as transparent as possible and distinguish environmental aspects from other aspects, strive to apply the best authorized scientific knowledge available and advice to perform sensitivity analyses in order to see to what extent uncertainties influence the final results. With respect to the loss of information, we think that is precisely the other way around. Information can be gained by performing an impact assessment. The inventory table data have not disappeared but they are interpreted which can give new (and not less) point of views. An impact assessment can also be performed per process and not only for the entire product system which enables a new range of analysis techniques, particularly with respect to the identification of improvement options (cf. 6).

Last but not least, lca as we described it in this paper only deals with the environmental aspects of a product without mixing these with other aspects such as financial, technical and macro-political aspects (e.g. third world issues). This does not mean that we think these aspects are not important. On the contrary, these are very important too, but we think for a transparent overall valuation it is much more appropriate to distinguish these different issues clearly. A pilot study distinguishing between the assessment of environmental and micro-economic aspects of investments in a joint framework has just been published (15).

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Standardisierung von Produkt-Ökobilanzen

Zur Begründung von Konventionen und Standardisierungen

Die Ergebnisse der bisher vorgelegten Ökobilanzen weichen – national und international – stark voneinander ab, je nach der gewählten Methodik, dem zugrundegelegten Bilanzraum und den angewandten Daten. Beispielhaft soll auf Ökobilanzen für Fensterrahmen, Windelanwendungen und Verpackungen verwiesen werden.

Um Ergebnisse von Ökobilanzen für gesamtgesellschaftlich bedeutsame umweltorientierte Bewertungen und Entscheidungen zu nutzen, müssen sie auf konsensfähigen und tragfähigen Methoden basieren. Diese Arbeiten können nur als »Gemeinschaftsarbeit« aller beteiligten Kreise organisiert werden, zumal die Festlegung des Bilanzraumes und insbesondere die Bewertung nicht auf objektiven, wissenschaftlich ermittelten Wahrheiten sondern auf Konventionen beruhen werden. Sie werden daher zugleich von dem »Wollen« der Beteiligten getragen, sich unabhängig oder unter Zurückstellung von Einzelinteressen zu einigen. Dies ist zugleich die Begründung, diese Arbeiten aufgrund des dort geltenden Konsensprinzips im Rahmen der Normung zu organisieren.

Aufgrund der immer stärkeren europäischen und auch internationalen Ausrichtung des produktbezogenen Umweltschutzes (Europäischer Binnenmarkt, globale Umweltthemen) sollten zudem international gültige Konventionen unter Berücksichtigung nationaler Besonderheiten angestrebt werden, zumal die wissenschaftliche Methodendiskussion bereits sehr stark internationalisiert ist (SETAC-Aktivitäten).

Stand der Institutionalisierung der Arbeiten

1993 konnten sowohl international als auch national wichtige Weichen für den Aufbau von Strukturen zur Erarbeitung entsprechender Konventionen gestellt werden. Im Rahmen der ISO (Internationale Normungsorganisation) wurde das Sub-Committee 5 »Life Cycle Assessment« im ISO-TC 207 Environmental Management (Sekretariat: Frankreich, Vorsitz: Deutschland, Dr. Marsmann, Bayer AG) eingerichtet. Die Aufgabenstellung lautet: »Standardization in the field of life cycle assessment as a tool for environmental management of product and service systems. It encompasses the assessment of impacts on the environment from the extraction of raw material to the final disposal of waste« (Resolution 6/1993 ISO/TC 207/SC 5). Wie bei entsprechenden Arbeiten üblich, hat man sich hier in Anlehnung an das Standardmodell produktbezogener Ökobilanzen in Arbeitsgruppen aufgeteilt:

- *WG 1 »Life cycle assessment – general working principles and procedures«* (USA); Scope: The ISO WG 1 (...) is committed to develop principles and guidelines to harmonize the practice for undertaking and reporting LCA studies in a responsible transparent and consistent manner. (...) (cooperation with other WG's) (Resolution 7/1993).
- *WG 2 »Life cycle inventory analysis – general«* (Deutschland)