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Life Cycle Assessment (LCA)

A guide to approaches, experiences and information sources

European Environment Agency

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Note

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Preface

Life-cycle assessment (LCA) – a guide to approaches, experiences and information sources

There are great expectations for LCA.

At the European level, the Parliament has suggested that the Commission develop a framework for an integrated life-cycle-oriented product policy. In the work for the next framework research programme, LCA also has a prominent role in promoting competitive and sustainable growth.

The design and production of new products and materials should be based on a life-cycle assessment concept. LCA is also a necessary basis for eco-labelling requested by consumers, NGOs and international and national authorities. Business and industry sectors are aware of the requests from customers, and recognise the possibilities for LCA in saving natural resources and energy and in minimising pollution and waste. LCA is not only a tool to improve the environment, but also an instrument for industry implying cost-savings and competitive advantages.

In addition, the interest in developing environmental management systems and tools as a basis for decision making is expressed in the work with Agenda 21 and ISO 14 000.

The European Environment Agency (EEA) has the mandate 'to provide the Community and the Member States with objective, reliable and comparable information at the European level'. Among its goals, the EEA shall provide information for environmental policy development and implementation and ensure broad dissemination and accessibility. Important principles in this context are pooling existing information and know-how and facilitating data harmonisation.

The main advantage of LCAs is in supporting decision making with scientific data and competence, and thereby in distinguishing between scientific facts (as far as possible) and sets of values. In this context, its ambition is very close to the mandate of the EEA.

By balancing science and simplicity, LCA implies that there can be many limitations that should be addressed in LCA studies and development work, for example:

- the type of information provided, especially by life-cycle impact assessment, is merely an indicator;
- LCA should not be misunderstood as a comprehensive or a complete assessment;
- LCA is different and distinct in approach from other management tools;
- LCA uses subjective judgement extensively, and the lack of scientific or technical data is sometimes obvious.

It is also a challenge to take the step from LCA as a communication tool to an operational tool in environmental management. LCA-based environmental management should become part of good business management heading towards the eco-efficiency concept 'producing more quality with less resources'.

LCA should be used together with other established techniques, such as environmental impact assessment and environmental risk assessment. These approaches complement each other, but are not interchangeable and cannot be substituted for each other.

Creating this publication the Agency hopes to guide the readers through this information and provide links to external sources. The Internet version and the supplementary database have been developed as complementing products to give greater access to the information.

The production has involved many contributors other than the authors. The report has been reviewed by the Scientific Committee of the EEA and the National Focal Points, for which EEA is grateful. The Society for Promotion of Life Cycle Development (SPOLD) has contributed to the project with advice and constructive criticism. A critical review of the draft publication was made by Dr Dennis Postlethwaite, UK, past-Chairman of the SETAC-Europe LCA Steering Committee and member of the UK Delegation to ISO / TC207 / SC5 on Life Cycle Assessment.

The EEA hopes that this publication together with the prepared meta-database containing information sources will prove valuable to its readers. We have tried to target different parts of the publication to different users. It is our intention to continue our efforts to make these tools operational.

Domingo Jiménez-Beltrán
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Content

About this guide to LCA

What is LCA?

Life cycle assessment (LCA) involves the evaluation of some aspects - often the environmental aspects - of a product system through all stages of its life cycle. Sometimes also called “life cycle analysis”, “life cycle approach”, “cradle to grave analysis” or “Ecobalance”, it represents a rapidly emerging family of tools and techniques designed to help in environmental management and, longer term, in sustainable development.

This publication, developed for the European Environment Agency (EEA), aims to help business and other readers to find their way through the LCA maze to the right tools for the application they have in mind. The early chapters are written in such a way as to be easily accessible to environmental managers in companies and other similar professionals, whereas the methodology sections may require some LCA background of the reader.

Where did LCA come from?

Like all good ideas, LCA probably started in a number of different places, in a variety of different ways. We provide a brief history of LCA in chapter 1.

Concept or tool?

Some people find LCA useful as a conceptual framework, others as a set of practical tools: both views are correct, depending on the context. Even scientists and engineers can find “life cycle thinking”, a tremendous spur to their creativity and ability to see the wider dimensions of a problem. An explanation of the different levels or styles of LCA can be found in chapter 3.1.

A growing need

Sustainable development is now on the national and international agendas. It requires many things, but above all it requires rapid improvements in eco-efficiency, or in the efficiency with which we use energy and a wide range of materials taken from nature, and how we minimise waste. This builds on the long-running international interest in so-called “cleaner technology”. Even more demanding, however, sustainable development calls for eco-efficient improvements throughout the life cycle of a given product or system. This challenge is further described in chapter 2.

What is a product’s life cycle?

Simply stated, the life cycle of a product embraces all of the activities that go into making, transporting, using and disposing of that product. The typical life cycle consists of a series of stages running from extraction of raw materials, through design and formulation, processing, manufacturing, packaging, distribution, use, re-use, recycling and, ultimately, waste disposal. Further information on this aspect of the debate can be found in chapter 4.4.

The producer’s responsibility

Once, a manufacturer simply handed a product over to a distributor or customer, and that was the end of the story. No longer. These days it is widely recognised that any producer works with “chains” of suppliers “upstream”, and chains of customers “downstream”. The producer’s responsibility no longer ends - if it ever did - at the factory gate. Increasingly, industry accepts that product stewardship is the way forward. Governments, too, are beginning to impose “take back” requirements, to make producers take their wastes back and reprocess at least a proportion. These responsibilities are described in more detail in chapter 2.

Life cycle management

Among the newer concepts in LCA is “Life cycle management” (LCM), which is an integrated approach to minimising environmental burdens throughout the life cycle of a product, system or service. In some forms, LCM can provide a simplified set of LCA procedures suitable for small- and medium-sized enterprises (SMEs). LCM is further explained in chapter 3.2.4

The LCA tool

A typical LCA-study consists of the following stages:

1. Goal and scope definition.

2. A detailed life cycle inventory (LCI) analysis, with compilation of data both about energy and resource use and on emissions to the environment, through out the life cycle.

3. An assessment of the potential impacts associated with the identified forms of resource use and environmental emissions.

4. The interpretation of the results from the previous phases of the study in relation to the objectives of the study.

An account of the relevant LCA methodological framework based on the ISO 14040 standard can be found in Chapter 4.

Energy and resources

Many different forms of resources, renewable or non-renewable, mineral, water, land, plant or animal may need to be included in an LCA study. So, for example, energy may include process energy, heat or electricity produced from such energy sources as fossil fuels (e.g. coal, oil, natural gas), nuclear power, or a range of renewable sources, among them biofuels (e.g. wood, straw, waste), and solar, wind or water power. All of these energy sources have different environmental characteristics, bringing with the different benefits - and very different problems. These issues are further explored in appendix 4.2.

Environmental emissions

If we take the entire product life cycle as our focus, it is clear that it is very likely to be a complicated picture - with environmentally significant inputs and outputs to air, water and soil at every life cycle stage; see also chapter 4.4, table 4-2. Some unexpected impacts - or benefits - may turn out to be associated with some of the co-products or by-products which are produced by a given process. These will need to be tracked through. And of course there is always at least a chance that some new form of pollution will suddenly be discovered, such as by endocrine disrupters. See also appendix 4.2 for further description of impact categories.

Can computers help?

Computers, as in every area of life, can make things much better - or, if mismanaged, much worse. We can be helped to cut through the data to the real issues, or we can be drowned in data. Where computers help to turn data into information and information into knowledge, as they often do, they are a hugely valuable part of the LCA process. A range of PC-based software programmes, often linked to large databases, have been developed and are now coming into the market. This software is of variable quality, but is rapidly improving. Further details may be found in chapter 5.3.

Is LCA expensive?

A full LCA will normally require a great deal of data, and as a result will be time-consuming and expensive. In extreme cases a study can take several years and cost millions of ECU. Full LCA studies give the best background for decisions, but they are often only relevant for important intermediates and other large-selling products - which are not often changed. In practice, a simplified form of LCA is often used, tailored to the product and the purpose. In such cases the time and cost may be much lower, from about 10,000 ECU. Further development of LCA software may help to further cut costs. More information on this area can be found in chapter 5.3.

What can LCA do for my business?

LCA is a *decision support* tool. Used in the right way, it can help to ensure that a company's choices are environmentally sound, whether in the design, manufacture or use of a product or system. On the financial side, experience shows that companies using LCA can discover important product improvements, new approaches to process optimisation and even, in some cases, radically new ways of meeting the same need - but with a new product, or with a service. You may not want to hear about new ways of doing what your business does, but it may be less painful than, if your competitors find out first. See also chapter 3.2.1..

Suppliers will have to report

Even the largest companies cannot drive their industries or market towards sustainable development targets without the support of their value chain. As a result, we are seeing major companies beginning to challenge their suppliers on their environmental targets and performance. In some cases, proper systems and targets may even be a condition of supply. A growing numbers of companies start to produce their own LCAs, their suppliers will be called upon to provide much of the data needed. This trend is explained in chapter 3.2.2.

Can LCA help in product comparisons?

LCA cannot - or at least should not - be used to claim that a particular product is environmentally *friendly*. At best it is only possible to say, using a specified set of criteria, that one product is better than another in certain aspects of its performance.

Such data, however, may legitimately be used in comparative product marketing - even if experience shows that many manufacturers or retailers are tempted to over-claim. This problem, coupled with biased information and lack of quality control, can do more than anything else to undermine the authority of LCA methods. These issues are discussed in chapter 4.3.

Is LCA mandatory?

In a word, no. LCA is currently an option for companies, but it is an option which growing numbers of customer companies are beginning to encourage their suppliers and partners to at least think about. In some countries, for example Denmark, new environmental accounting and reporting requirements are likely to encourage the further spread of LCA thinking, if not always of LCA tools. The links to other environmental management tools are explored in chapter 3.2.

Green procurement

No longer it is simply a question of a few green-minded companies insisting on green specifications, where suppliers could meet them at little or no additional cost. Increasingly, too, we see local and national government agencies beginning to develop product policies and to explore ways in which they can use their procurements systems to help drive eco-efficiency through the economy. Life cycle thinking is essential in developing the criteria for green procurement. The trend is discussed in chapter 3.3.2.

Ecolabelling

For some product categories the products with the best environmental performance may get a ecolabel. The use of environmental labelling has proceeded less fast in many parts of the European Union than was originally expected, but where it has been used there has been an almost automatic requirement for LCA inputs. In the EU ecolabel regulation LCA is required for the development of ecolabel criteria. For obtaining the label, only some selected LCA-data may be required.

Ecolabelling has been hugely controversial in some countries, and in relation to some products in particular, but the ecolabelling challenge is not going to go away. Moreover, it is likely to spread into new areas, among them electric power supply. More information can be found in chapter 3.3.1.

Environmental declarations

Environmental declarations may not have the same ring as “eco-labelling”, but this special kind of environmental labelling (approved by ISO as type III labelling) may prove rather more popular in some quarters, since it includes more information and all products can get the label. The output tends to be a selection of LCA data printed out as a set of columns or profile. See chapter 3.2.2.

Stakeholder views

In the end, however, how much we do to make LCA useful, it will not really help unless the world believes that it is useful. SustainAbility surveyed a range of external stakeholders during the project to find out what they thought of LCA. Highlights of the results can be found in chapter 1.4.

Where can I get more information?

This is getting easier all the time. A new LCA journal has appeared, and many scientific papers and reports on LCA have been

published in recent years. In addition, a growing number of Internet homepages on LCA can be found on the World Wide Web. A selection of this information sources is presented in chapter 5.

Who's Who in LCA?

A growing numbers of institutes, universities, governmental agencies, industries, trade associations and consultants are involved in LCA as experts or users. The main players in Europe are included in the database available on http://www.eea.eu.int

What will happens next?

Forecasting, they say, is always hard - but particularly when you are thinking about the future! To give a small taste, however, we look at some possible trends in LCA, based on nine major transitions towards sustainability, in chapter 2.3.

1. A Brief History of LCA

1.1 The Early Years

The first studies to look at life cycle aspects of products and materials date from the late sixties and early seventies, and focused on issues such as energy efficiency, the consumption of raw materials and, to some extent, waste disposal. In 1969, for example, the Coca Cola Company funded a study to compare resource consumption and environmental releases associated with beverage containers. Meanwhile, in Europe, a similar inventory approach was being developed, later known as the 'Ecobalance'. In 1972, in the UK, Ian Boustead[1] calculated the total energy used in the production of various types of beverage containers, including glass, plastic, steel, and aluminium. Over the next few years, Boustead consolidated his methodology to make it applicable to a variety of materials, and in 1979, published the *Handbook of Industrial Energy Analysis*.

Initially, energy use was considered a higher priority than waste and outputs. Because of this, there was little distinction, at the time, between inventory development (resources going into a product) and the interpretation of total associated impacts. But after the oil crisis subsided, energy issues declined in prominence. While interest in LCA continued, , thinking progressed a bit more slowly. It was not until the mid eighties and early nineties that a real wave of interest in LCA swept over a much broader range of industries, design establishments and retailers - taking many of them by surprise.

1.2 Rapid Growth and Adolescence

Despite almost three decades of development, one practitioner in our survey (see Appendix 1.1) said: "LCA is still a young tool." The rapid surge of interest in 'cradle to grave' assessments of materials and products through the late 1980s and early 1990s meant that by the 1992 UN Earth Summit there was a ground-swell of opinion that life-cycle assessment methodologies were among the most promising new tools for a wide range of environmental management tasks.

The most comprehensive international survey of LCA activity to date, *The LCA Sourcebook*, was published in 1993[2]. At the time, LCA was of limited interest "outside a very small community of scientists, mostly based in Europe or North America. But then," the *Sourcebook* noted, "their work escaped from the laboratory and into the real world."

Some countries took an early lead. "In the UK," said David Cockburn of PIRA, "it has been surprisingly fast. Ten years ago there was only one main practitioner [in the UK], Ian Boustead. Now there are many more academics, consultancies and companies with an in-house capability."

While the field continued to progress, the pace has been sporadic. According to a recent report by IMSA and SPOLD[3], the chief barriers to greater progress in the LCA field have been a low level of experience with LCA, coupled with undue expectations and "over-advertisement". This led to a period of disillusionment with LCA, aggravated by a strong sense that many of those using LCA were simply doing so to buttress existing positions, rather than to fully understand and respond to the real issues.

1.3 Towards Maturity

So, where are we now? Although the pace of development is slowing, the methodology is beginning to consolidate - moving the field toward a long-awaited maturity. Yet the usefulness of the technique to practitioners is still very much in debate. In the past couple of years, however, there has been a growing confidence in the LCA community that the emerging tools have a real future. For example, Procter & Gamble's Peter Hindle sees "enormous progress" and is optimistic about the future for life-cycle inventories (LCIs) and about the take-up of life-cycle thinking by management generally.

Others take a very different view. "LCA is a million miles away from the man in the street," said Dr Mike Jeffs of ICI Polyurethanes. Part of the difficulty in making the technique more accessible comes down to the competing needs of simplicity (or at least clarity) to aid practitioners and credibility, to

[1] LCA - How it Came About, The Beginning in the UK, *Ian Boustead in the International Journal of Life cycle Assessment 1 (3) 1996*

[2] The LCA Sourcebook: A European Guide to Life Cycle Assessment, *SustainAbility, SPOLD and Business in the Environment, 1993*

[3] Synthesis Report on the Social Value of LCA *carried out by IMSA on behalf of the Society for the Promotion of LCA Development (SPOLD), 1995.*

enable decision-makers to have faith in the robustness of the results. As Mariane Hounum of the Danish Environmental Protection Agency put it: "We need to find a simple way of communicating the results of LCA, because most people have neither the time nor the interest to read entire documents. But if the answers are simple, then again the question of credibility arises - because there is no way for [stakeholders] to check the validity of the results."

Back in 1992-1993, SustainAbility coined the term 'laptop LCA', pointing out that until LCA as a tool becomes truly user-friendly and accessible, it is unlikely to take off in a comprehensive way. Over the years, software designers have been responding to the challenge, and as the final section of this Guide demonstrates, there has been a proliferation of LCA software on the market. These should be carefully checked before use, however, since this field is still in its infancy - and the available products are of variable quality. One of the key concerns is that it is often very hard indeed to verify the quality of the data used.

Overall, the LCA community is now able to offer a growing range of useful management tools. But it continues to struggle a number of key issues, some of which are strongly linked to the nature of the discipline itself. These include:

- the complexity of many of the methodologies and processes;
- the high cost and long time-scales, although much progress has been made in this area;
- the necessity of making value judgments in the course of the work, judgments which are not always identified in the final report;
- the lack of accepted international standards (although the SPOLD LCA format initiative has been useful, and an ISO standard is under way);
- the continuing invisibility of much LCA work, compounded by the above factors.

But the lack of a real market pull for LCA data is perhaps the most important factor. Companies have simply not, by and large, felt the need for LCA in their regular decision-making.

That said, however, and given the cooling of public opinion on most environmental issues through the mid-1990s during the second great environmental downwave, it is astonishing how much interest there has been in some sectors of industry. LCA results have played a key role in procurement decisions, for example, as companies have sought to assess the relative performance of competing suppliers. This activity, in many cases, has been driven by a recognition that while public opinion may move in great surgetides, the underlying trend on most environmental issues is still moving steadily upwards.

A series of issues in 1995 and 1996, most particularly the controversy surrounding the planned disposal of the Brent Spar oil buoy and the massive economic and social dislocations caused by public reactions to 'mad cow' disease or BSE, helped to re-ignite interest in life-cycle thinking, if not necessarily always in LCA methodologies proper.

The Brent Spar debate highlighted the need to use LCA not only to fast moving consumer goods like detergents, or consumer durables like washing machines, but also to major structures and installations. Although Shell has conducted work on the 'shadow pricing' of the disposal options, many observers wondered why life cycle thinking had not been built into the design and operation at a much earlier stage. The BSE controversy, in turn, raised the life-cycle issue for a wide range of industries and for consumers, by illustrating how vulnerable agricultural and food chains are to new forms of contamination.

1.4 Stakeholder Views

LCA has traditionally been written about and discussed by experts behind closed doors, or in the R&D laboratory, with little in the way of public communication, let alone consultation. But as practitioners see the need for increased credibility of the tool and greater acceptance by the public, the mood is changing. As a result, there is now a greater curiosity about what other people think about the discipline, and about the implications for the future.

In order to develop an introduction which was topical and well-founded, SustainAbility conducted a sample survey of industry practitioners, standard setting organisations, ecolabelling boards, industry associations, research institutes, consultants, non-govern-

mental organisations (NGOs), students, the environmental media and financial institutions. Their views inform the sections which follow.

The sample was in no sense statistically valid, but the conclusions drawn and the recommendations made by the different stakeholders fall into a very clear pattern. A list of the respondents in the EEA / SustainAbility survey can be found in Appendix 1.1. We have also drawn on the conclusions of the IMSA study, *Synthesis Report on the Social Value of LCA*.

The findings of the survey can be summarised as follows:

- LCA, in its various forms, is now seen by all stakeholders as a necessary, integral part of the environmental management tool-kit;
- Practitioners see value in using this family of tools not only for established areas like new product development but also, increasingly, in the process of corporate strategy formulation;
- Although the period of "maximum hype" is over, LCA remains in the early stages of development, with a good deal of further development needed;
- The level of knowledge of LCA remains worryingly low in the public domain;
- Among those who are aware of LCA, there is still a clear divide between those who focus on LCA as a set of tools and those who consider LCA thinking as a paradigm through which to think and prioritise;
- The level of progress differs between countries, but overall the pace of development in the LCA field is slowing as consolidation of methodologies begins;
- The credibility of the tools - and of the users of LCA data - is critical if the LCA community is to gain sufficient authority and LCA is to be useful in the long term;
- A major concern - expressed by a high proportion of practitioners - is that quality control mechanisms remain relatively weak;
- The involvement of external stakeholders in defining study boundaries and stimulating 'out-of-the-box' thinking is seen to be increasingly important.

Appendix 1.1:

A Spectrum of Stakeholder Views

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Major Findings

The sample was in no sense statistically valid, but the conclusions drawn and the recommendations made by the different stakeholders fall into a very clear pattern. We have also drawn on the conclusions of the IMSA study *Synthesis Report on the Social Value of LCA*. The findings of the survey can be summarised as follows:

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Some Stakeholder Perspectives

Consultants

Among the practitioners, the consultants were probably the most optimistic about the future for LCA. Nick Turner of ERM noted that "the number of practitioners has grown, the use of LCA has changed [towards more practical applications such as ecolabelling], the number of actively involved research groups is increasing (e.g. SPOLD, ISO, CEN and SETAC) and LCA has also gained a more important role in education. Ten years ago, LCA wasn't taught; now it is a much more focused part of courses and students are aware of it."

It is probably worth noting, however, that this was the most positive assessment provided by any of our respondents. Our Battelle Europe respondent, M. Porta, noted that the interest in LCA has been very mixed. One factor at work here is that the potential benefits of LCA vary considerably between industry sectors, markets and countries. But all the consultants agreed that a key challenge for the future is to enhance the credibility of LCA.

Consumer Associations
Consumers often have the ultimate say in which products survive and which do not. Some respondents were optimistic that consumers would play an increasingly important role in this area. "We should not underestimate the ability of consumers to make environmental choices even in the absence of ecolabels," as David Monsma of the US Council on Economic Priorities (CEP) put it.

To date, however, most consumer associations and campaigners have paid little attention to LCA. Many have also paid surprisingly little attention to ecolabelling. But at least one of the national ecolabelling bodies felt that their role could grow, indeed would need to grow. "I see the role of consumer associations evolving," said Ing. Raffaele Scialdoni of Italy's Angenzia Nazionale Per L'Ambiente (ANPA). "This is particularly likely as more final consumer goods are affected."

Ecolabelling Boards
The link between ecolabelling and LCA is often assumed to be close and automatic. The response from leading individuals in the field, however, suggests that the links are much looser - and that ecolabelling is very unlikely to drive the LCA debate - or improve LCA credibility - in most countries.

There was widespread scepticism among most respondents about the progress to date - and value - of ecolabelling. Many saw the link between ecolabelling and LCA as weak. And some argued that this was appropriate. "I think that ecolabelling should not be based on a full LCA," argued Paolo Frankl of Istituto Ambiente Italia. But there was a sense that if ecolabelling could be made to work, LCA would inevitably benefit.

"There is a lot of scepticism about ecolabels," was the way Martin Wright of *Tomorrow* Magazine summed up the challenge, but added: "if people come to accept the ecolabelling approach, then it is likely that they will accept LCA too." Among the optimists, on the other hand, was Professor Roland Clift of the University of Surrey and the UK Ecolabelling Board. He said that "ecolabelling could be useful in improving the credibility of LCA," but he also accepted that "there are still problems in its implementation."

Financial institutions
A key problem in LCA, as Anne-Maree O'Connor of the National Provident Institution (NPI) put it, is that "the leaders have been ahead of consumer demand, and haven't had the response in the market place which they might have hoped for." On the other hand, Sarita Bartlett of Norway's Storebrand commented that her impression is that "the use of LCA has spread to more industries and applications - and will continue to do so."

Ideally, the financial institutions and analysts would like to be able to compare and benchmark. That is a key feature of their business. In the USA, for example, Kristin Haldeman of the Investor Responsibility Research Center (IRRC) stressed that "comparability would be very useful when making evaluations" for investment purposes, but Anne-Maree O'Connor accepted that such comparisons would be difficult for the foreseeable future.

The analysts agreed that raw data were generally not helpful in their work. What was needed was processed data, as long as the assumptions and methodologies were transparent, intelligible and credible. They also inclined to the view that guidelines for LCA were essential and that, on the credibility front, verification would be helpful. "We definitely need verification," said Anne Marie O'Connor, "to prevent dubious claims - and prevent them from undermining the credibility of the whole LCA process."

As far as ecolabelling is concerned, they felt that it could be useful "if all the wrangling ever settles down", but Sarita Bartlett noted that ecolabels only meet the needs of certain stakeholders - and certainly not of financial analysts or the insurance industry.

Governments
Through regulations and ecolabelling initiatives, governments clearly have an important role to play. Increasingly, too, some government agencies will require LCA data in support of their decision-making processes. But, while the Danish EPA felt it could handle LCA processes competently without external verification, there were some reservations about government's overall capacity to do LCAs in-house.

So how do people who tackle LCA on a pan-European basis feel about the usefulness of LCA in policy decisions? "Government is not expert enough - and regional situations vary too much - for it to be sensible to base pan-European policy on LCA," argued Nancy

Russotto of APME. There were also reservations about LCA as a policy-making tool: "LCA is not yet water-tight enough to be used as a policy making tool," said Gareth Rice of the University of Surrey. On the other hand, Anne-Maree O'Connor of NPI argued that governments can play a useful role by providing financial incentives for LCA and by improving access to data on public registers of emissions, so that emissions and impacts can be linked back to companies and their products. In short, although it is still easier to see LCA as a tool for assessing products, it is very likely that it will be used for government and industry policy making.

Industry Associations

Surprisingly, some industry LCA practitioners were highly sceptical about the contribution of industry associations to the debate. One even went so far as to say that "they will continue to protect their corporate members from calls to divulge real information which might be useful to customers and consumers."

More positively, most respondents felt that industry associations would "come up the curve", playing an increasingly important role with respect to the provision of sectoral data. Several industry association respondents forecast that there would be growing pressures for benchmarking against industry averages. Many companies are much happier to supply data when they know they will be aggregated, and industry associations will increasingly be required to supply aggregated data - both to member companies and to client industries and regulators.

Overall, the associations were expected to play a central role. "Industry associations will help industry to understand the true value of LCA," was the way Anders Linde of EUROPEN put it. Some of the respondents also felt that such associations will have an important role to play in assisting small and medium-sized enterprises (SMEs).

NGOs

Although, perhaps not surprisingly, there were reservations ("NGOs are not objective; they support political or other lobbying agendas"), most practitioners saw non-governmental organisations (NGOs) as potentially having a critical role in relation to LCA. "NGOs have credibility," was the way Anders Linde of EUROPEN summed it up.

Most respondents saw the NGOs as playing more of a representative, challenging role than a direct contribution to such areas as the formulation of corporate strategy. But even this position may well change as some of the transitions outlined in the latter part of this introduction take hold.

Among the benefits the involvement of NGOs can bring are the following:

- Greater corporate transparency through demanding more data;
- Making LCA practitioners think again by challenging the assumptions of those commissioning and carrying out LCA work;
- Adding weight to the public acceptability of the results of LCA work.

But there were concerns that many NGOs would decide not to play the game, either because of political differences or because they lacked the necessary skills and other resources. One respondent noted that NGOs typically fall into two categories: (1) those that understand the complexity of environmental issues and trade-offs, who will work in LCA processes; and (2) those who are single issue campaigners, and cannot afford to admit complexity - who will usually turn down invitations to participate.

In the US, Kate Victory of *Business and Environment* noted, "if NGOs are at all wise, they will become involved. Not, perhaps, with the methodology, but helping technical experts to understand and communicate that technical analysis will not answer all questions. And NGOs can help with value judgements." Among the consultants, Nick Turner of ERM argued that the role of NGOs could go in a number of directions. "I can't see them commissioning LCAs," he said, "but could see them involved in peer review. NGOs are listened to and have weight in society."

The NGO respondents themselves displayed an interesting mixture of scepticism and hope. "This is still not something that the average man in the street knows anything about," said Sally Nicholson of WWF. Rick Heede and Chris Lotspeath at the US Rocky Mountain Institute agreed: "There has been slow take-up in the context of little or no public awareness," they reported. And some NGO respondents were more critical. "LCA has been a justification for products, rather than an objective analysis," argued Tim Jenkins of Friends of the Earth (FoE).

More hopefully, Ann Link of the Women's Environment Network (WEN) noted: "Some environmental groups have started to take LCA seriously, not just as an industry greenwash, which maybe it was at the beginning. I suppose (and hope) that LCA will become a more involving and accessible tool in the future." Several NGOs saw LCA and ecolabelling playing a potentially important role in public education on key issues and the options for action.

This group of respondents were most wary about the misuses of LCA. "LCA should not be used as the basis of green labelling or ecomarketing claims," said one, arguing that this would be "a complete bastardisation of LCA." To be useful, all NGO respondents agreed, LCA projects would need to afford greater transparency and result in data that are both comparable and benchmarkable. "This is a set of tools for continuous improvement," said one NGO, "not for selling products."

Research Institutes and Universities

Overall, this category of respondents was fairly upbeat about the future prospects for LCA. "We see an accelerating take-up of LCA," reported Dan Francis of Brunel University.

An interesting distinction made by a number of respondents was between LCA tools and life-cycle thinking. As Professor Roland Clift of the University of Surrey put it, "life cycle thinking has been fairly widely adopted across industry and government bodies, while LCA proper has had a more limited take-up, due to time and money requirements. Interest in LCA is gaining ground," he said, "but in practice it is still difficult to persuade designers and engineers to use even abridged forms of LCA."

2. What Role for LCA in Sustainable Development?

2.1 Life Cycle Thinking and Sustainability

Sustainable development is now on the political and business agendas. In Germany, Professor Schmidt Bleek of the Wuppertal Institute expressed forceful views about the significance of LCA in sustainable development. He argued that LCA would be essential in the transition to more sustainable lifestyles and products - and noted: "Firms that are not well on the way to developing and selling sustainable products will be cut out of the market over the next 10 to 20 years."

When companies and practitioners were asked about the most important applications for LCA, the most popular response in the SustainAbility survey was *new product development*. "New product development is the ultimate goal," as Rolf Bretz of Ciba put it.

The second most important area for the business respondents was *corporate strategy*. This was explained on the basis that LCA introduces the notion of a corporation's responsibility for the whole life cycle, encouraging and assisting the process of strategy review. Supporting this view, practitioners and researchers alike agreed that the future of life cycle thinking is bright.

In the UK, Professor Roland Clift argued that "it is key that life-cycle thinking be fostered throughout organisations, and be adopted as part and parcel of the organisation's philosophy, mission and day-to-day operations. This makes it essential that life-cycle thinking also be applied to corporate educational processes."

2.2 Some Ground-Rules for a Credible LCA

There have been a number of key shifts in the business and environment debate since *The LCA Sourcebook* was published. Some of these are specific to the LCA field, others related to much wider changes in the fields of environmental strategy, management and communication.

In order to explain some of the challenges that now face LCA practitioners - and users of LCA data - it is worth looking at some of the wider changes now impacting related areas of business- stakeholder relations.

Late in 1996, SustainAbility completed a major survey of corporate environmental reporting, alongside the United Nations Environment Programme (UNEP) and 16 international companies. The 2-volume

Table 2-1
Engaging stakeholders: 10 transitions.

	ESTABLISHED FOCUS ON		EMERGING FOCUS ON
1.	One-way, passive communication	ü	Multi-way, active dialogue
2.	Verification as option	ü	Verification as standard
3.	Single company progress reporting	ü	Benchmarkability
4.	Management systems	ü	Life-cycles, business design, strategy
5.	Inputs and outputs	ü	Impacts and outcomes
6.	Ad-hoc operating standards	ü	Global operating standards
7.	Public relations	ü	Corporate governance
8.	Voluntary reporting	ü	Mandatory reporting
9.	Company determines reporting boundaries	ü	Boundaries set through stakeholder dialogue
10.	Environmental performance	ü	'Triple bottom line' performance

report, *Engaging Stakeholders*, focuses both on the thinking of reporting companies and of the growing number of users of reported data and information. Ten transitions were identified for the reporting community (see Table 2-1).

The focus on openness, credibility and dialogue can also be seen to apply directly to rising trends in LCA. Below we consider some of the implications for LCA, taking each of these transitions in turn.

2.2.1 Dialogue

One-way, passive communication	Ü	Multi-way, active dialogue

There is worrying evidence of a growing 'credibility gap', and in some cases of a 'credibility crisis', both in the field of corporate environmental reporting and in relation to LCA, because some stakeholders feel that the tool has lost much of its acceptability through occasional misuse in the past.

A few companies have experimented with a degree of stakeholder dialogue around the issues related to LCA, Dow Chemical and Novo Nordisk among them, but these interactive processes remain the exception. In the meantime, the main issue which seems to be creating the current 'credibility crisis' in relation to reporting revolves around the fact that currently most companies decide how they should prepare their LCAs. They also define the boundaries of the exercise (see under Transition 9, below).

In effect, companies undertaking LCA control both the content of the communication and the communication channels. By contrast, there is a growing expectation that stakeholders should be involved much earlier in the process. Only if this happens will the next generation of LCA projects be credible and, ultimately, useful.

But it is worth asking to what extent the value of LCA depends on its public credibility? The consensus among practitioners was that, although much depends on the context and application, credibility is "critical". Some practitioners, among them Mike Richards of Tioxide, subscribed to the view that some people working on LCA "live in the belief that it is much more credible than it actually is." But all concerned warned that gaining the backing of the scientific community is the first priority, with public credibility coming later in the process. Some practitioners, including Giorgio Rowinski of Fiat, even questioned the value of LCA when used in public communication - arguing that the public is too easily influenced, constantly shifting its opinion on key issues.

When we asked practitioners to comment on the best ways of building and maintaining public confidence in LCA, they mentioned the following:

- The professionalism and training of those undertaking LCA work;
- Accepted standards and methodologies;
- Internal sensitivity analysis and data checks;
- Peer or critical review, including public questioning at seminars and conferences;
- Transparent reporting of processes and outcomes;
- Stakeholder dialogue;
- Verification.

2.2.2 Verification

Verification as option	Ü	Verification as standard

The verification of LCAs has not, to date, been a requirement. But NGO respondents were unanimous in calling for the external verification of LCAs. "External verification would help people to overcome the suspicions that inevitably arise when LCAs are carried out by companies with a vested interest in the outcome," as Sally Nicholson of WWF put it. Four out of five NGO respondents were unaware of the existence or

nature of existing LCA quality control mechanisms. It is also interesting that both the environmental media respondents "passed" on this issue, implying that they were equally confused about quality control mechanisms.

The LCA practitioners surveyed felt that there are currently few quality checks in place in the LCA field. Responses ranged from "not a lot" to "am not aware of any quality checks in particular". One practitioner explained, "I lack quality control myself when doing LCAs. The problem is that LCAs are very data-intensive. It is very easy to make a mistake - and much harder to find it." If this is more generally the case, this is an issue which should be addressed by the LCA community.

In this context, it is interesting to hear some practitioners - among them Dr Hans-Jurgen Klüppel of Henkel - saying that LCAs should never be published, or perhaps even made public, without a peer review. Asked whether there is a need for external *verification*, most practitioners agreed that, where the LCA data are for external consumption, verification by a third party can be a good idea. However, a proportion of these said that the distinction between peer review and verification is artificial. The key difference may simply be whether the external party or parties is / are paid for the work and formally sign off on it.

All the consultants surveyed mentioned peer review, or some form of external verification, as important. Marcel Bovy of IMSA added that his experience suggests that "peer reviews almost always result in major error corrections." Among the research institute respondents, all favoured some form of verification, with Paolo Frankl of the Istituto Ambiente Italia summarising the task as one of avoiding "mistakes and misuse". Several respondents said it was good practice, whether the data were for internal or external use, to adopt peer review techniques. "Perhaps data should be checked by a peer in a company even if it's only for internal use," as Dan Francis of Brunel University put it.

According to Kim Christiansen, who was involved in developing ISO 14040, the international LCA standard, verification is one of the themes which was discussed at some length by the ISO committee. It proved difficult to agree on how to verify whether or not an LCA study follows the text of the standard. Should the accredited certifier make judge the LCA study undertaken, the practitioner responsible or the organisation with which a practitioner works? Ultimately, it was agreed that if the results of an LCA are to be used externally, particularly if they are to be used to make a comparative assertion with another product, an external 'critical review' is necessary, whereby a more formal review process takes place than the usual journal review.

The key thing, as Martin Wright of *Tomorrow* Magazine noted, is that "independent third party verification is *available*, which doesn't mean that it has to be used every time." Among the practitioners, David Russell of Dow Europe argued that it could well be time to begin thinking about a body responsible for accrediting LCA practitioners and verifiers as a first step towards making LCAs more comparable.

2.2.3 Benchmarking

Single company progress reporting	Ü	Benchmarkability

One key contributor to the 'credibility gap' is the 'comparability paradox'. This runs as follows: to make Corporate Environmental Reports - or LCIs and LCAs - more useful to stakeholders, they need to be comparable; to be comparable they need to be developed within some sort of framework and with generally accepted indicators that make comparisons possible; and yet companies have so far largely resisted attempts to introduce common indicators, frameworks and benchmarks. Without common benchmarks and shared indicators, each company - whether it is producing a CER or an LCI on a product or material - ends up in a class of its own.

"It is very difficult indeed to make sensible comparisons between different business sectors," said Martin Wright of *Tomorrow* magazine. With companies choosing their own metrics and environmental performance indicators, benchmarking is more of a hope than a reality. This represents a major problem for stakeholders wishing to com-

pare one LCA with another in order to establish and stimulate best practice.

When asked whether the benchmarkability of LCA data was a key issue, some survey respondents were adamant that comparability was not an issue or even a requirement. David Cockburn of PIRA and Anders Linde of EUROPEN agreed (in Cockburn's words) that "there is absolutely no requirement that LCAs are benchmarkable, because each study sets its own scope, objectives and boundaries. However," he noted, "that doesn't mean that *transparency* is not important." The purpose, said Linde, "is not to have major comparability, but to better understand systems and to improve their performance."

In stark contrast, a few respondents argued forcefully for benchmarking and benchmarkability. "This is a question that can make or break an ecological free market." said Professor Schmidt Bleek of Germany's Wuppertal Institute.

Most respondents noted that it all depends of whether the data and findings are being used internally or externally. A typical reply: "If the results of an LCA enter the public domain, comparability and benchmarkability become much more important." Comparability, concluded Rolf Bretz of Ciba, is "indispensable": if we fail to achieve comparability and benchmarkability in the LCA field, we cannot expect LCA to survive for long in the commercial world.

In terms of making comparisons possible, a number of necessary and desirable steps were suggested. These included:

- The development of a common LCA framework or methodology;
- Improved, explicit definitions of methods, indicators, scope and boundaries in LCA projects;
- The provision of better quality data - which should be more widely accessible;
- The construction of standard data sets;
- Greater transparency for LCI and LCA processes;
- Further work on commonly accepted approaches to impacts and how to assess them.

One idea that came up repeatedly as an aid to benchmarking was that of creating a unified LCA database. A number of respondents supported this idea strongly, particularly those associated with SPOLD. David Cockburn of PIRA felt that a good database in a common format could be "very useful". Some, among them Dennis Postlethwaite of Unilever, see the growing calls for databases as a reaction to concerns that some companies are "switching off" in the LCA field and may in future refuse to disclose potentially sensitive data.

But there were also sceptics: David Chesneau of BP Chemicals noted that databases are useful in theory, but warned that "Free data can be pretty worthless unless the way in which they are derived, and their limitations, are understood." Anders Linde of EUROPEN reported that "EUROPEN feels that databases are not very useful in practice, as they use industry averages and provide diluted information, which lowers the quality of the LCA." Clearly the usefulness of databases will depend upon the applications for which they are envisaged, the nature of the data collected and the ease with which different styles of analysis can be supported.

More specifically, the following criteria apply:

- The data should be updated regularly;
- Ranges of uncertainty should be indicated;
- The date and source of any data should be clearly identified;
- Formats should be harmonised, wherever possible;
- Particular attention should be paid to gathering essential infrastructure data relating, for example, to energy, transport and solid waste management.

2.2.4 From Management Systems to Strategy

Management systems	Ü	Life-cycles, business design, strategy

In environmental management, it is possible to point to a number of instances where management systems were set up in a vacuum. Sometimes, neither the data delivery systems which allow the system to operate effectively, nor the feedback loops indicating where change should take place, were in place. And, to a degree, the same problems can apply to LCA.

Many early LCA projects ran ahead of any commercial desire to apply life cycle thinking: a case of the cart being put ahead of the horse. But we now see a growing number of companies reporting on their LCA work and also beginning to apply life-cycle thinking to such areas as business design and strategy.

Whatever happens, however, there was general consensus amongst those who we interviewed that the LCA process needs to be speeded up if it is to be properly integrated into business design and strategy. Said Professor Schmidt Bleek of the Wuppertal Institute: “A system must be found that is sufficiently simple, safe and cost-effective so that a million products can be assessed quickly and repeatedly.” Among our student respondents, there was strong agreement from Gareth Rice of the University of Surrey: “Anything that reduces the time element in conducting an LCA has to be a good thing” he said.

To ease the burden on industry and particularly on SMEs, there was strong support for government incentives and for Multi-client studies. The availability of suitable databases, said Federica Ranghieri of Italy’s Fondazzione Mattei, would be critical in helping SMEs to weather the transition.

2.2.5 Impacts and Outcomes

Inputs and outputs	Ü	Impacts and outcomes

Data on industry’s inputs and outputs are obviously welcome, but they are only useful if they can be linked to potential real-world environmental impacts - and to programmes for reducing and making good those impacts.

The issue of impacts is one of the thorniest which face LCA practitioners, and remains a sticking point - so much so that some people, such as Peter Hindle of Procter & Gamble, consider full blown LCAs to be an all but impossible dream. He places much more faith in LCIs (life cycle inventories).

But, as in the field of corporate environmental reporting, the demand for information on impacts and outcomes will inevitably drive the future evolution of LCA. The necessary shifts here are from data to information and knowledge, and from understanding to action. In short, what do all the emissions and waste data produced for LCA projects and published in CERs actually *mean* in terms of environmental decline or progress, let alone of longer term sustainability?

To make this happen, more work is needed in the area of building state-of-the-environment databases - and of better integrating technology, project and product impact assessments with these larger sets of data on environmental trends.

2.2.6 Standards

Ad-hoc operating standards	Ü	Global operating standards

In a globalising economy, the challenges facing business are becoming increasingly complex. Companies often complain that they operate in markets where the "playing field is uneven", but the evidence suggests that they are often comfortable applying different standards in different parts of the world. Whatever the facts of the matter, one message has emerged clearly from recent controversies: companies operating internationally will find it increasingly difficult to apply different standards - whether in relation to site management, reporting or LCA - in different worlds regions and countries.

Many practitioners see the work of the International Standards Organisation (ISO), and particularly its work on ISO 14040, as pivotal. The standards setting bodies noted that ISO 14040 and ISO 14041 should be ready by 1997. That does not mean that they all support it whole-heartedly, however. But even they accepted, as Christina Senabulya of the British Standards Institution (BSI) put it, that "the acceptability of this family of standards will be decided in the marketplace."

Most practitioners and standard-setters saw significant value in the harmonisation of national standards - as long as they could be harmonised at the right level. Although ISO and national standards bodies were most often mentioned in this context, at least one NGO saw the European Environment Agency (EEA) itself as having an important potential role to play in helping to ensure appropriate levels of standardisation and the build the associated credibility for the tools and their users.

2.2.7 Corporate Governance

Public relations	Ü	Corporate governance

Most report-makers find other companies' LCAs and CERs useful, when they can get access to them, but even some report-makers now take their fellow report-makers to task for producing LCA-related documentation and CERs which are "largely PR". The shift to a more governance-focused approach to reporting is signalled by the views of the financial institutions. This trend is likely to affect the financial markets in waves, the first hitting insurers, the second hitting the banks and the third, eventually, hitting the equity markets.

The insurers have had plenty of warning, with some 20% of Lloyd's losses associated with environmental liabilities in the United States. As a result, some insurance companies are taking a much greater interest in major issues like global warming and climate change.

The fact that a growing number of banks is beginning the process of environmental reporting suggests that the environmental aspects of corporate governance will also be moving sharply up the agenda over the next decade.

For the equity and other fast-paced financial markets, environmental issues may be shadowed by the scale of the problems that have rocked institutions like Barings, Daiwa, Sumitomo and Morgan Grenfell/Deutsche Bank, but sustainable development is going to depend on the capacity of financial analysts to think longer term than they currently find possible. Working out how this transition can be driven forward is perhaps the biggest challenge now facing the sustainable development community world-wide.

Among the financial sector respondents, there was a strong feeling that some form of verification would be needed if they were to use LCA data. Sarita Bartlett of Storebrand felt that a company's commitment to LCA could become an important indicator for whether or not it is taking its environmental management responsibilities seriously. Anne-Maree O'Connor at NPI, meanwhile, felt that companies are only likely to undertake LCAs (and consequently divulge useful information about them) if encouraged to do so through incentives or, conversely, taxes. Corporate governance is, in other words, seen to need a helping hand.

2.2.8 Will LCA become Mandatory?

Voluntary reporting	Ü	Mandatory reporting

There is much to be said for the voluntary approach to reporting - not least because it encourages greater experimentation by report-makers and the same holds true for LCA. Both in the field of reporting and of life-cycle assessment, this is still the case, but there are clear signs, at least among report-makers, users and other stakeholders, that there will be growing calls for mandatory reporting. Will the same hold true for LCA?

The ecolabelling respondents generally felt that it would be a mistake to make LCA mandatory. Paul Jackson of the UK Eco-labelling Board noted that this approach would impose excessive costs on industry, most particularly on SMEs. Mariane Hounum of the Danish EPA agreed, pointing out that "LCA is a tool to achieve better understanding and knowledge, a base on which to make decisions. Therefore you have to leave the choices and decisions free - they cannot be forced."

Interestingly, the NGOs tended to agree. The Rocky Mountain Institute was typical in arguing that LCA is a "knowledge tool", and therefore should not be imposed on people. If it did become mandatory for any reason, the choices made on the basis of the information provided should still be open. "It is better to let the public choose, than mandating choices," RMI noted. "But this means that the public - and particularly consumers - have to be educated and informed."

The consensus among the practitioners was that a mandatory requirement is unlikely and would be unhelpful if it did develop. "I tried hard, but I couldn't see a situation where LCA would be mandatory," replied Nancy Russotto of APME. "Mandatory requirements usually lower the quality of tools," said Anders Linde of EUROPEN. However, a number of industry people wondered whether such a requirement might not slip "through the back door" in the form of requirements in relation to product stewardship or supplier vetting that are best satisfied by LCA.

David Cockburn of PIRA concluded that any legislation setting environmental performance standards could have the same effect. Another regulatory pressure in this direction was felt to be integrated pollution prevention and control. And Anne-Maree O'Connor of NPI suggested that, although unlikely, a mandatory requirement might be pushed forward in tandem with financial incentives or taxes on landfill, emissions and raw materials.

2.2.9 Setting LCA Boundaries

Company determines reporting boundaries	Ü	Boundaries set through stakeholder dialogue

"Critics," as one of the Rocky Mountain Institute respondents neatly put it, "undermine credibility." It therefore seems sensible, where possible, to address criticism at the start of the LCA process, rather than at the end. Marcel Bovy of IMSA was one of those who argued strongly that LCA processes and data depend for their credibility on the approval of "opinion leaders", and this point is spelled out more clearly in the IMSA / SPOLD *Synthesis Report on the Social Value of LCA*.

One of the main reasons why corporate environmental reporting has not yet transformed the credibility of reporting companies is that the process of deciding when, how and to whom to report is often controlled by the companies themselves. Again, the same holds true for LCA: a key part of the credibility issue revolves around the fact that companies choose their own boundaries, methodologies and indicators. For CERs and LCAs alike to be credible, and for stakeholders to become genuinely engaged, they must be involved in negotiating the relevant project boundaries.

To date, many stakeholders have not been sufficiently engaged, nor perhaps sufficiently knowledgeable, to articulate their needs and expectations effectively. But this is likely to change, potentially bringing enhanced usability and credibility.

2.2.10 The Triple Bottom Line

Environmental performance	Ü	'Triple bottom line' performance

Sustainable development will require business to assess progress against economic, environmental and social indicators. A number of CERs are now referring to this building transition, among them those produced by General Motors. This does not necessarily mean that we will see booming corporate demand for social life-cycle assessments (LCA_{soc}), but it does mean that the social *context* of LCA work will become more important - as will stakeholder involvement throughout the process.

The NGO respondents typically saw LCA as unable to address the wider - and particularly social - dimensions of the problems that most exercise them. WWF, for example, noted that LCA cannot address the "social and ethical issues" which are becoming an increasingly important part of the debate. But they also felt that wider stakeholder involvement might help to address at least some these gaps.

Interestingly, the media respondents agreed that this was a trend that LCA practitioners would have to cope with: "As corporate environmentalism increasingly embraces ethics," concluded Martin Wright of *Tomorrow* Magazine, "you would have to assume that these ideas will increasingly be incorporated into LCA."

2.3 The Next Five Years

Among the likely trends identified by survey respondents, the following stood out:

- LCA will be seen as an integral part of the environmental management tool-kit, but will also find new applications in areas such as corporate strategy;
- Customer industries will increasingly demand at least some form of life-cycle information from key suppliers;
- There will be more widely accepted standards and methodologies;
- Market pressures will push greater benchmarking against industry averages;
- We will see more LCIs integrated into new product development;
- There will be more commonality and greater availability of data;
- Expect more LCIs on computers - and, potentially, available via the Internet;
- There will be a rapidly an evolving debate on - and better methods for - impact assessment;
- And all respondents, whether or not they knew how to deal with these require ments, accepted that there would be a greater focus on peer review, verification and stakeholder dialogue to boost LCA credibility.

3. Applications of LCA

The target group for this chapter is the environmental manager (or the person responsible for environmental activities) in small and medium sized enterprises. The chapter outlines areas of use in LCA in both the private and the public sectors, and gives references to programmes and projects where LCA plays an integral part. The chapter also gives a brief introduction to some conceptually related programmes, e.g. concepts and tools which use similar kinds of data and which can be used to support decision making in related areas of environmental management.

LCA methodologies were originally developed to create decision support tools for distinguishing between products, product systems, or services on environmental grounds (Throughout the chapter, the term "product" is used as a synonym for both products, product systems, and services).

During the evolution of LCA, a number of related applications emerged, of which we give some examples below:

- Internal industrial use in product development and improvement
- Internal strategic planning and policy decision support in industry,
- External industrial use for marketing purposes, and
- Governmental policy making in the areas of ecolabelling, green procurement and waste management opportunities.

The list is not exhaustive, but indicates that there is a wide variation of applications. This variation is also reflected in the level of sophistication and to some extent also in the choice of methodology.

A critical remark on the use of LCA
The use of LCA for strategic decisions, e.g. in choosing between different systems delivering a common function, has often been associated with disputes about the validity of such assessments. These disputes - or "LCA-wars" - have, however, proven to be of great value in the development of a proper LCA-methodology and data as they ensure that boundary and functionality definitions are adequately covered and are transparent. Accordingly, one of the essential requirements in the Draft International Standard ISO 14040 (ISO 1997a) is the following demands for external communication of LCA:

> The results of the LCA shall be fairly and accurately reported to the intended audience. The type and format of the report shall be defined in the scope phase of the study.
>
> The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA study. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study.
> (....)
>
> In comparative studies, the equivalence of the systems being compared shall be evaluated before interpreting the results. Systems shall be compared using the same functional unit and equivalent methodological considerations such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluating inputs and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported.
>
> In the case of comparative assertions disclosed to the public, this evaluation shall be conducted in accordance with the critical review process. Another requirement for comparative assertions disclosed to the public is that an impact assessment shall be performed.
> (....)

3.1 Levels of sophistication in LCA for different applications

Most of the efforts in the development and standardisation of LCA have been directed towards a *detailed* LCA, and this type of LCA is accordingly the focus of the chapter on

LCA methodology. In practice, however, very few detailed LCAs, which are based on a coherent methodology, have been published.

The first part of the present chapter therefore includes a brief description of two other levels of LCA, i.e. the *conceptual* and the *simplified* levels. It should be noted that at present it is not possible to make a distinction between conceptual and simplified LCAs or between simplified and detailed LCAs. Rather, the three levels should be regarded as a continuum with an increasing level of detail, suitable for decision making in different applications.

In the subsequent descriptions of LCA applications, a reference is given to the level of LCA used in the different applications, although it is not possible to describe the methodologies in detail. During the development of LCA methodology, many synonyms for less detailed LCAs have been suggested. This is also reflected in the present review as the authors refer to the actual terminology used in the report (streamlined LCA, partial LCA, screening LCA, Life cycle review, simplified LCA, Life cycle thinking, LCA concept, LCA tool, etc.)

When reading the following it should be borne in mind that irrespective of the terminology used, an LCA should always be based on a holistic approach, i.e. at some point of the study it must include the *full* life cycle of the product and examine *all* inputs and outputs.

3.1.1 Conceptual LCA - Life Cycle Thinking

The conceptual LCA is the first and simplest level of LCA. At this level the life cycle approach is used to make an assessment of environmental aspects based on a limited and usually qualitative inventory. A conceptual LCA can often answer basic questions like "Is there a basis for pursuing a green marketing strategy?", "Is the product significantly different from competing products?" or "Does the product have some clear unequivocal benefits or shortcomings for selected environmental issues?". Key decisions about green marketing and new product development do not necessarily need a highly quantitative analysis, but rather an understanding of the relative advantages, disadvantages and uncertainties for an existing or new product (Hirschhorn, 1993).

The results of a conceptual LCA can for instance be presented using qualitative statements or simple scoring systems, indicating which components or materials have the largest environmental impacts - and why. Limitations in the inventory can occur in the form of omissions of one or more of the phases in the life cycle, e.g. those phases for which the decision-maker does not have any improvement options. Another possibility is to reduce the number of examined parameters, e.g. by investigating the energy consumption in the life cycle, but not the related emissions and their contribution to different environmental impacts.

It is obvious from the requirements of the ISO standard that conceptual LCAs are not suitable for marketing purposes or other public dissemination of the results. However, a conceptual LCA may help the decision maker identify which products have a competitive advantage in terms of reduced environmental impacts. Subsequent simplified or detailed LCAs fulfilling the requirements of a standard can be established and used for public information.

Instead of "Conceptual LCA", the SETAC EUROPE LCA Screening and Streamlining Working Group uses the term "Life Cycle Thinking" (Christiansen *et al.*, 1997):

> Life Cycle Thinking is a mostly qualitative discussion to identify stages of the life cycle and/or the potential environmental impacts of greatest significance e.g. for use in a design brief or in an introductory discussion of policy measures. The greatest benefit is that it helps focus consideration of the full life cycle of the product or system; data are typically qualitative (statements) or very general and available-by-heart quantitative data.

3.1.2 Simplified LCA

The SETAC EUROPE LCA Screening and Streamlining Working Group defines simplified LCA as (Christiansen *et al.*, 1997):

> **Simplified LCA** is an application of the LCA methodology for a comprehensive screening assessment i.e. covering the whole life cycle but superficial e.g. using generic data (qualitative and/or quantitative), standard modules for transportation or energy production, followed by a simplified assessment i.e. focusing on the most important environmental aspects and/or potential environmental impacts and/or stages of the life cycle and/or phases of the LCA and a thorough assessment of the reliability of the results.

The aim of simplifying LCA is to provide essentially the same results as a detailed LCA, but with a significant reduction in expenses and time used. Simplification presents a dilemma, however, since it is likely to affect the accuracy and reliability of the results of the LCA. Thus, the primary object of simplification is to identify the areas within the LCA which can be omitted or simplified without significantly compromising the overall result.

Simplification of LCA consists of three stages which are iteratively interlinked:

- Screening: Identifying those parts of the system (life cycle) or of the elementary flows that are either important or have data gaps
- Simplifying: Using the findings of the screening in order to focus further work on the important parts of the system or the elementary flows.
- Assessing reliability: Checking that simplifying does not significantly reduce the reliability of the overall result.

The terms "Screening LCA" and "Streamlined LCA" are often used as synonyms for a simplified LCA. However, a clear distinction should be made. Screening as a part of the simplification procedure can help to identify the parts (or life cycle stages) of a product system that can be left out in a simplified LCA. In principle, a screening LCA which already has certain parts missing would not be capable of identifying all key issues, as it does not cover the full life cycle or all environmentally important aspects. In other words, the screening step in simplified LCA should be comprehensive in coverage, but may be superficial in detail.

Screening LCA is for instance used in environmental labelling to identify the environmental "hot spots", i.e. the areas where labelling criteria are assumed to have the greatest effects. Another use of screening LCAs is to identify the processes where emissions of particular interest occur in the life cycle. This procedure may be followed by application of other environmental management tools, e.g. risk assessment, to assess whether unwanted effects actually will occur.

Depending on the application, the data can be quantitative (site specific/generic) or qualitative. Screening indicators such as energy demand, MIPS (material intensity per service unit) and key substances (substances

Table 3-1
Level of detail in some applications of LCA. "x" in bold indicates the most frequently used level.

	Level of detail in LCA			
Application	**Conceptual**	**Simplified**	**Detailed**	**Comments**
Design for Environment	**x**	x		No formal links to LCA
Product development	x	**x**	x	Large variation in sophistication
Product improvement		x		Often based on already existing products
Environmental claims (ISO type II-labelling)	**x**			Seldom based on LCA
Ecolabelling (ISO type I-labelling)	x			Only criteria development requires an LCA
Environmental declaration (ISO type III-labelling)			x	Inventory and/or impact assessment
Organisation marketing		**x**	x	Inclusion of LCA in environmental reporting
Strategic planning	**x**	**x**		Gradual development of LCA knowledge
Green procurement	x	**x**		LCA not as detailed as in ecolabelling
Deposit/refund schemes		x		Reduced number of parameters in the LCA is often sufficient
Environmental ("green") taxes		x		Reduced number of parameters in the LCA is often sufficient
Choice between packaging systems	x		**x**	Detailed inventory, Scope disputed LCA results not the only information

with a known contribution to one or more environmental impacts) can be used to identify the hot spots in the life cycle. Using combinations of several indicators may increase the reliability of the screening. Indicators which only relate to one phase of the life cycle, e.g. recyclability and degradability of products, should only be used in combination with other indicators.

Simplified LCAs may be used externally if reported in accordance with the requirements in the ISO standard (ISO 14040). However, most simplified LCAs are used for internal purposes without formal requirements for reporting. To avoid misinterpretation of the results, the user of the LCA should be made explicitly aware of the limitations of the study, e.g. by stating all simplifying methods applied in the LCA as recommended in the SETAC report (Christiansen (ed), 1997).

The level of detail in some of the applications is shown in Table 3-1. The contents of each of the applications is described in more detail in the following sections.

3.2 Private sector applications

The use of LCA in the private sector varies greatly. This differentiation depends to a large extent on where a given company is situated in the product chain and on the key driver for the LCA activity, e.g. legislation or market competition. For business teams, the LCA tool should be used to understand the environmental issues associated with upstream and downstream processes as well as on-site processes. This understanding can be used for continuous improvement in reducing the impacts throughout the supply chain.

Commodity producers (chemicals, plastics, metals) most often perform life cycle inventories to be used in comparative assertions or for assessing waste management and recycling options. Producers of intermediates and components provide data for their customers, and producers of final goods combine the knowledge from upstream and downstream processes to design and manufacture products with the least environmental impact. Time in this context, is an important factor in LCA. For companies producing final goods in

Important issues in Design for Environment (WICE, 1994)

- Materials selection
  - Minimise toxic chemical content
  - Incorporate recycled and recyclable materials
  - Use more durable materials
  - Reduce materials use
- Production impacts
  - Reduce process waste
  - Reduce energy consumption
  - Reduce use of toxic chemicals
- Product use
  - Energy efficiency
  - Reduce product emissions and waste
  - Minimise packaging
- Design for recycling and reuse
  - Incorporate recyclable materials
  - Ensure easy disassembly
  - Reduce materials diversity
  - Label parts
  - Simplify products (e.g. number of parts)
  - Standardise material types
- Extending the useful life of products and components
  - Design for remanufacture
  - Design for upgrades
  - Make parts accessible to facilitate maintenance and repairs
  - Incorporate reconditioned parts or subassemblies
- Design for end of life
  - Safe disposal

a competitive market, the product development cycles are short and accordingly, comprehensive LCAs are not feasible with the presently available data bases because the analysis are time consuming.

The following sections give a short introduction to some of the concepts and tools in which LCA is an integral part, and to some of the concepts with a close relation to LCA and life cycle approaches.

3.2.1 Product development

Design for the Environment (DfE)

Design for the environment is a general term for a number of methods for incorporating environmental factors into the design process. The concept of DfE has been developed without formal links to LCA, but as can be seen from the following paragraphs the two approaches are very similar and may not be distinguishable from each other in many cases.

Specific principles for DfE differ from company to company, but some common themes have been described by the World Industry Council for the Environment (WICE, 1994) (see Box page 28). DfE seeks to optimize the environmental performance of a product throughout its life cycle. and integrates concepts of pollution prevention in manufacturing and concerns about energy efficiency of products. Another major objective of DfE among manufacturers is to design products with the goal of minimizing after-life impacts and costs.

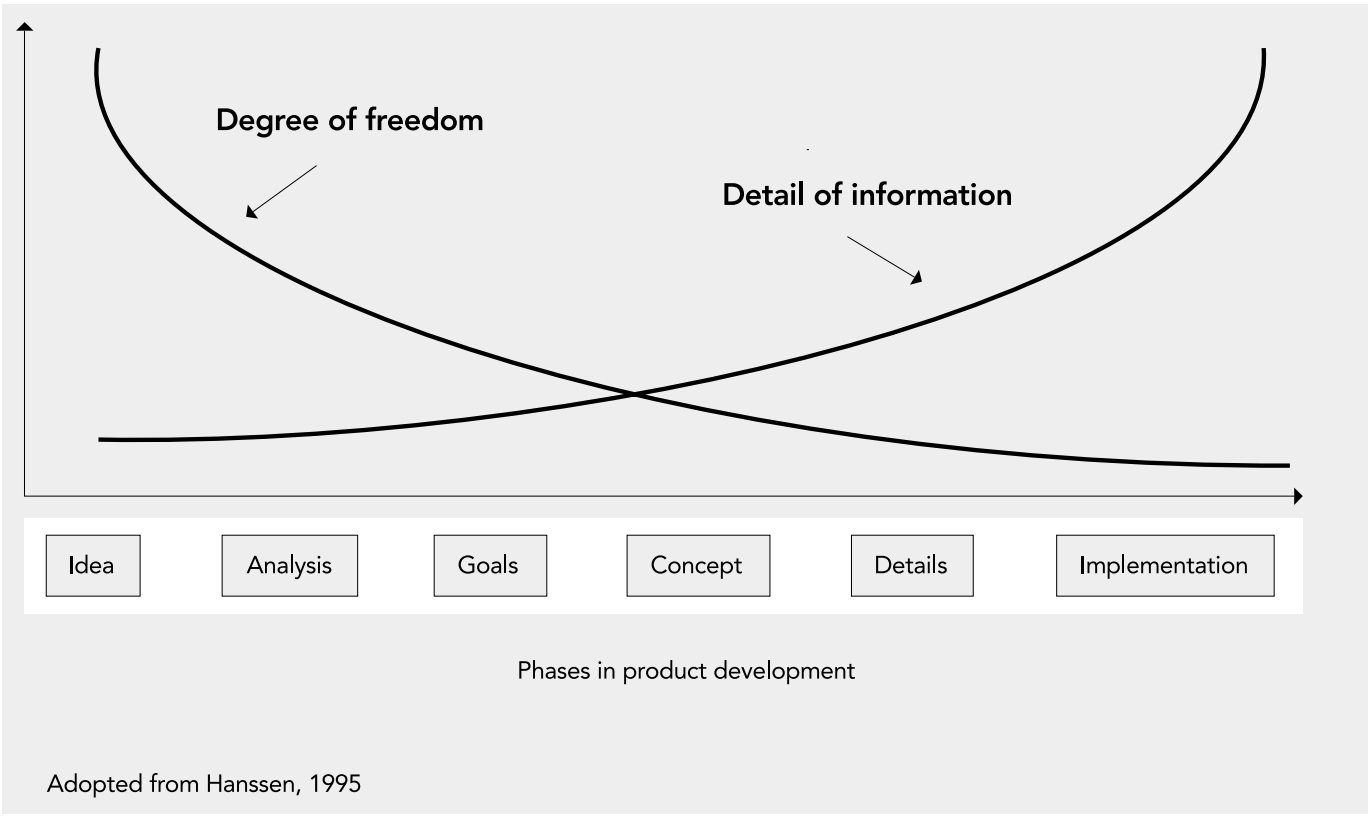
DfE thus conceptually addresses the same problem areas as LCA. Dedicated LCA tools were not an integral part of early DfE initiatives, but as is shown in the next section, the development of LCA has now to a large degree been connected to product development and - accordingly - to DfE as a concept.

LCA and Product development and improvement - introduction

Using LCA in product development is an obvious choice as a large part of the future environmental impacts of a product (system) is determined by the design and construction phase. By incorporating LCA in the design phase, companies have the possibility of avoiding or minimizing foreseeable impacts without compromising the overall quality of the product.

Figure 3-1

Relationship between the designers' degree of freedom and the level of information.



Product development may follow different concepts and routes. Some common phases of most development methodologies are given below in Figure 3-1, along with an illustration of the relationship between the designer's degree of freedom and the available information during the product development process.

In the idea-phase there is almost an unlimited number of possibilities with respect to design, choice of materials, function etc. The number of options decreases with the development process, and changes to the final product and of the necessary production tools often require a whole new development process.

It is therefore necessary that relevant environmental tools are available and used as early as possible in the development process. For simple products, e.g. packaging, it is possible to apply a detailed and quantitative LCA since information on most of the commonly used materials is now available. For more complicated products the number of possibilities is very high, and as the database on "exotic" materials is limited, the application of quantitative and detailed LCAs to such products may prove to be very resource demanding and at the same time not very precise. Conceptual or simplified LCAs may in these cases be of more help in the early stages of product development, possibly in the form of life cycle based design tools (e.g. design rules and checklists).

When improving already existing products, the use of LCA may become easier (a simplified LCA), simply because it is possible to make a LCA of the old ("reference") product with a well-known life cycle and use the results to identify where the environmental "hot spots" are. In this case data collection and interpretation are generally far less resource intensive, and the results can be communicated to the customers in terms of absolute environmental improvements.

Several research programs on how to incorporate environmental issues in product development have been conducted. The list below is not intended to give an exhaustive overview, but merely mentions some programs already completed. Information on other programs can be found in reports from industry sector conferences (e.g. the packaging, automotive and electromechanical industries) and from meetings in LCA-orientated societies (e.g. SETAC's annual meetings and symposia for case studies). A broad list of references on Life Cycle Design and related approaches can be found in Keoleian & Menerey (1994) and in Ryding (1995).

The Product Ecology Project (Sweden)
The Product Ecology Project in Sweden was launched in 1992 as an initiative by the Federation of Swedish Industries. The core idea of the project was to develop an LCA-based calculation system to help product developers, purchasers and other decision-makers in taking environmental impacts from processes and products into account. The results from the study are published in Ryding (1995). Furthermore, a PC-based software version of the Environmental Priority System (EPS) to be used as an in-company tool has been developed, and an education package on environmentally sound product development is available.

The NEP project (Scandinavia)
The Nordic project on Environmentally Sound Product development (NEP) includes most Nordic countries (S, N, SF) and consists of two parts, namely development of a common structure for a LCA database, and a number of case studies, primarily performed by Swedish and Norwegian companies. In the project, LCA was integrated with systematic product development tools like Quality Function Deployment (QFD) and Life Cycle Cost Analysis (LCCA) (Hanssen, 1994, Hanssen, 1995, Hanssen *et al.*, 1995). The industrial members of the project group were apparently satisfied with the integrated concept, but it was also a common experience that there was a lack of information concerning environmental performance, customer requirements valuation and life cycle economy.

The Eco-Design programme (The Netherlands)
The Dutch Eco-Design programme was an experimental project in which eight companies tried to incorporate environmental aspects in order arrive at improved products. One of the basic ideas in the project was to establish a team consisting of product developers from inside a company together with environmental experts. Both quantitative LCAs and a more conceptual life cycle approach were used in the project, which is only documented to a limited extent, e.g. Zweers *et al.* (1992).

The Milion and the Promise programmes (The Netherlands)
The Dutch Milion programme has been somewhat similar in set-up and has been

demonstrated for 6 products. It appears that substantial improvements have been implemented, but for reasons of confidentiality, no detailed reports have been published (Christiansen *et al.*, 1995).

The Promise programme was formulated in the Netherlands with the experiences from the Eco-design and the Milion project as a background. The main results are a manual for environmental product development (Brezet *et al.*, 1994) and a report for the parliament on how to stimulate environmental product development and improvement. The manual is described as a framework for product development rather than an operational methodology (Christiansen *et al.*, 1995).

The Eco-Indicator Programme (The Netherlands)
The Eco-Indicator programme has resulted in a screening LCA procedure for design purposes. The idea is to have a single number for each unit process and material, reflecting the cradle to grave impacts. In having single numbers for each unit process, it is not necessary to establish process trees, collect emission data and agree on allocation rules. The LCA-work is thereby simplified significantly, but the methodology gives no freedom to work with other data sets, e.g. on different technologies. The results of the programme and the methodology has been published by Goedkoep *et al.* (1996) and is continuously being updated.

The Materials Technology Programme (Denmark)
In the Danish Materials Technology Programme a methodology for screening potential life cycle impacts during the development of materials and products was developed (Schmidt *et al.* (eds.), 1994). The methodology and the accompanying paper database can be used for preliminary calculations of the contribution to global and environmental impacts as well as qualitative screening of potential health and ecological impacts and waste management options. The methodology pinpoints potential hot-spots in the life cycle and gives the basis for comparisons with existing technologies.

The EDIP project (Denmark)
The Danish EDIP-project from 1991-1996 involved five Danish companies in collaboration with the Institute for Product Development at the Technical University of Denmark and other centres of knowledge. The aim of the project was to give the design team at the companies access to methods and tools supporting the introduction of environmental criteria in product development. The tools are based on state-of-the-art LCA methodology and supposed to be used interactively between a product developer and an environmental specialist. Detailed criteria and methods for assessment of environmental impacts have been extensively reported (e.g. Wenzel *et al.*, 1996 and 1997), and a supporting database has been released by the Danish Environmental Protection Agency.

Quality Function Deployment (Denmark)
The Danish QFD-project (Olesen, Schmidt and Petersen, 1997).) demonstrates how both customer and environmental requirements can be integrated in product development using the Quality Function Deployment methodology. Important quality and functional aspects are identified via interviews with stakeholders, while the most important environmental aspects are identified using simplified LCA. All aspects are subsequently related to the technical properties of the components in the product, and options for improvements can be analysed taking both environmental and market considerations into account.

The Life Cycle Design Project (U.S.A.)
The Life Cycle Design Project in the USA resulted in a Life Cycle Design Guidance Manual (Keoleian and Menerey, 1993). The core of the project is the framework of formulating 5 conceptual requirement matrices on environmental, performance, cost, legal and cultural aspects of the design process in relation to the whole life cycle. The formulation, identification and weighting of various design requirements are highlighted as crucial points in a successful project, in conjunction with a well organized environmental management system. The second phase of the project is a number of demonstration projects, the results of which are currently being reported. Further information can be obtained from the U.S. EPA.

Strategies for Industrial Production in the 21st Century (Germany)
As a part of the German research programme “Strategies for Industrial Production in the 21st Century” an iterative screening LCA methodology has been developed and used in product development (Fleischer & Schmidt, 1997). The aim of the methodology is to produce results in time to be useful during product development and to facilitate the communication between the LCA practitioner and the product design team. The starting point is qualitative (or semi-

quantitative) information on key issues and subsequent iterations may include selected data or even all data. The system boundaries are enlarged step by step in parallel with the product development, but the level of detail is only increased if it delivers valuable information for the decision making process. The method is also described in Christiansen (1997).

3.2.2 Marketing

Marketing is the traditional way of communicating product properties and capabilities which are consistent with the consumer's expectations and demands. As the level of environmental consciousness is increasing, more attention is being paid by the consumer to the environmental properties of goods and services. This is being used (and misused) by many companies to attempt to increase their market share, and development of criteria and guidelines for environmental marketing has a high priority.

At least four different kinds of environmental marketing can be distinguished:

- Environmental labelling
- Environmental claims
- Environmental declarations
- Organization marketing

Environmental labelling (ISO Type I-labelling)
Discussed in the section Public Policy Making.

Environmental claims (ISO Type II-labelling)
An environmental claim is presently defined by ISO (ISO/DIS 14021 and ISO/CD 14022) as a

> label or declaration that indicates the environmental aspects of a product or service that may take the form of statements, symbols or graphics on product or packaging labels, product literature, technical bulletins, advertising, publicity or similar applications.

Environmental claims are often uni-dimensional and related to the "Environmental issue of the year or month", e.g. "Lead-free gasoline", "Phosphate-free detergent", "CFC-free hair spray" etc. Very few of such environmental claims are based on a LCA, and in many cases the claim focuses on irrelevant issues, while failing to address those issues which are important in a life cycle perspective.

The use of environmental claims will probably decrease along with increasing consumer environmental awareness of the consumer and the introduction of formalized methods for marketing environmentally preferable products.

Environmental declarations (ISO Type III-labelling)
The most recent ISO-proposal for a definition of environmental label or declaration is (ISO 1997e)

> communication of a product environmental claim that may take the form of statements, symbols, or graphics on product or package labels, product literature, technical bulletins, advertising, publicity, etc.

Environmental declarations may be a tool in eco-marketing to transfer the results from a life cycle investigation of a product (either as a life cycle inventory or a life cycle assessment) to the individual decision-making process of a consumer. The concept is in principle similar to that of declaration on food products, but is not yet fully developed. If a similar concept is developed, the definition of environmental declarations could be "Quantified product information labels in which the findings of an LCA are reported under a set of pre-established indices".

The general idea is to give a (graphic) presentation of a pre-set number of environmental impacts, e.g. by using a bar diagram. The main difference in relation to ecolabels is that environmental declarations are neutral, i.e. they contain no information on whether the product is worse or better than other products fulfilling the same service. Two (or more) environmental declarations can on the other hand illustrate the actual difference between products, and for environmentally conscious consumers this can be a valuable supplement to just choosing between labelled products. A graphical presentation can be very suitable for this purpose, but great care must be taken to avoid the possibility of misinterpretation, especially when the consumer is comparing different products.

The use of LCA is thus a prerequisite for environmental declarations. Standardisation efforts have been initiated by ISO (ISO T 207/SC3/WG 1) and include requirements on methodology, transparency, external review, comparative assertions, labelling components, administrative guidelines, and procedures governing the accreditation and

Table 3-2
Differences between environmental declarations and ecolabels.

Parameter	Environmental declaration	Environmental labelling
Type of LCA	Detailed inventory and impact assessment - or simplified LCA?	LCA used to pinpoint key features
Type of assessment	Neutral	Positive (evaluation by experts)
Number of products with declaration or label	All (in principle)	Only the best 10-30% of the product group
Target group	Wholesale dealers Professional buyers Environmentally conscious consumers	Consumers in general
Information level	Complex	Simple
Information content	Bar diagram and/or numbers suggested	Label
Comparative assertion possible	Yes, with two or more declarations available	No
Updating	With product changes	Variable, but the criteria are renewed every three years in many schemes

conduct of Type III labelling practitioners.

A main obstacle to the success of environmental declarations may be that huge amounts of information, e.g. a whole LCA, is to be conveyed in just one picture, understandable by the consumer. Firstly, a large amount of work is necessary to establish life cycle assessments of a wide range of consumer products from several suppliers. Secondly, it will most probably require a highly informed consumer to fully understand and use the environmental declaration, and the success of environmental declarations thus depends on educational efforts as well as the actual environmental documentation.

Table 3-2 presents some of the main differences between environmental labels and environmental declarations.

Organisation marketing
The classical marketing of environmental performance has mainly been orientated towards products as described above. However, with the increasing number of companies being certified according to ISO 14001, EMAS or BS 7750, some marketing initiatives are being directed towards the environmental capabilities of the company *per se*. It should be noted that the BS 7750 has been superseded by EMAS and that the ISO 14001 standard may supersede the EMAS in the future.

As organizations implement the necessary policies for certification they are also encouraged to formalize the implementation of LCA procedures and life cycle thinking through the environmental management system.

> The EU Environmental Management and Auditing Scheme (EMAS) (Council Regulation (EEC) No 1836/93 of 29 June 1993) states in Annex I.D. “Good management practices” that
> (....)
>
> 2. The environmental impacts of all new activities, products and processes shall be assessed in advance.
> (.....)
>
> The ISO 14001 states in section A4.2.1 “Environmental aspects” that
>
> The process is intended to identify significant environmental activities associated with activities, products and services, and is not intended to require a detailed life cycle assessment. Organisations do not have to evaluate each product, component or raw material input. They may select categories, products or services to identify those aspects most likely to have a significant impact.
> (.....)

EMAS makes no explicit links to LCA and there are some very basic differences: EMAS is a management system and site-based, while LCA is product-oriented. EMAS also focuses on continuous environmental improvement, not on actual or potential impacts. There is, however, an implicit link between EMAS and LCA in that participating sites are encouraged to think holistically about their activities - but no guidelines are given as to which time or spatial dimensions are appropriate from the point of view of product stewardship. A thorough introduction to EMAS has been developed by SustainAbility for EPE (European Partners for the Environment). This introduction can be found at EPE's homepage (http://www.epe.be/epe/emas/new/emashome.html).

How LCA will be implemented in environmental management is thus not clear. One obvious choice would be to make a LCA of a typical product in the company's product range and use this as a starting point for discussions with suppliers and for information to the customers. Both issues are readily documented in an environmental report as outlined in the EMAS.

3.2.3 Strategic planning

Integration of environmental aspects in strategic business planning is becoming a common feature in many companies. The handling of environmental concerns is often formalised in an environmental management scheme like EMAS (Environmental Management and Auditing scheme) or the ISO 14001 Standard, but many companies still handle the issues on a case-to-case basis.

A recent publication from the European Environment Agency (CCEM: Environmental Management Tools for SMEs: A Handbook (1997)) gives an overview of the following tools:

- Environmental policies
- Environmental management systems
- Environmental auditing
- Environmental performance indicators
- Ecobalances
- Life cycle assessment
- Environmental labelling
- Environmental reporting
- Environmental charters

The handbook thus addresses some of the same concepts as discussed in this chapter. However, the level of detail is significantly higher, and the handbook may be very useful for many SMEs wanting to integrate environmental issues in their work.

There are several motivating factors behind the decision to integrate environmental issues, many of which are interrelated, e.g.:

- Consumer demands
- Compliance with legislation
- Community needs for environmental improvement
- Security of supply
- Product and market opportunities

The environmental performance is thus changing from being a mandatory property of many products (all regulatory requirements shall be fulfilled) to being a strong positioning property on the market. LCA - or, perhaps, rather the Life Cycle Approach - is in this context a very important tool. It can be used both in relation to existing products (do they fulfil current and near-future environmental demands from the consumers?) and to identify market segments to be opened for environmentally benign products. Some basic product strategies in relation to environmental performance and market potentials (Hanssen, 1995) can be seen in Figure 3-2.

LCA information can provide decision-makers with an understanding of the environmental pros and cons of their products and services. The challenge for both external and internal LCA-practitioners in a company is to present the results of a LCA study in a way that can be fully understood by the top management. Many business managers are not educated in environmental issues like ecology and environmental modelling, and educational programs should therefore include the top management as well as other employees at all levels.

To achieve maximum confidence in the strategies derived from using LCA, fine detail in approach is preferable. However, many business decisions cannot wait, and simplified LCAs with an emphasis on problem identification and differences between

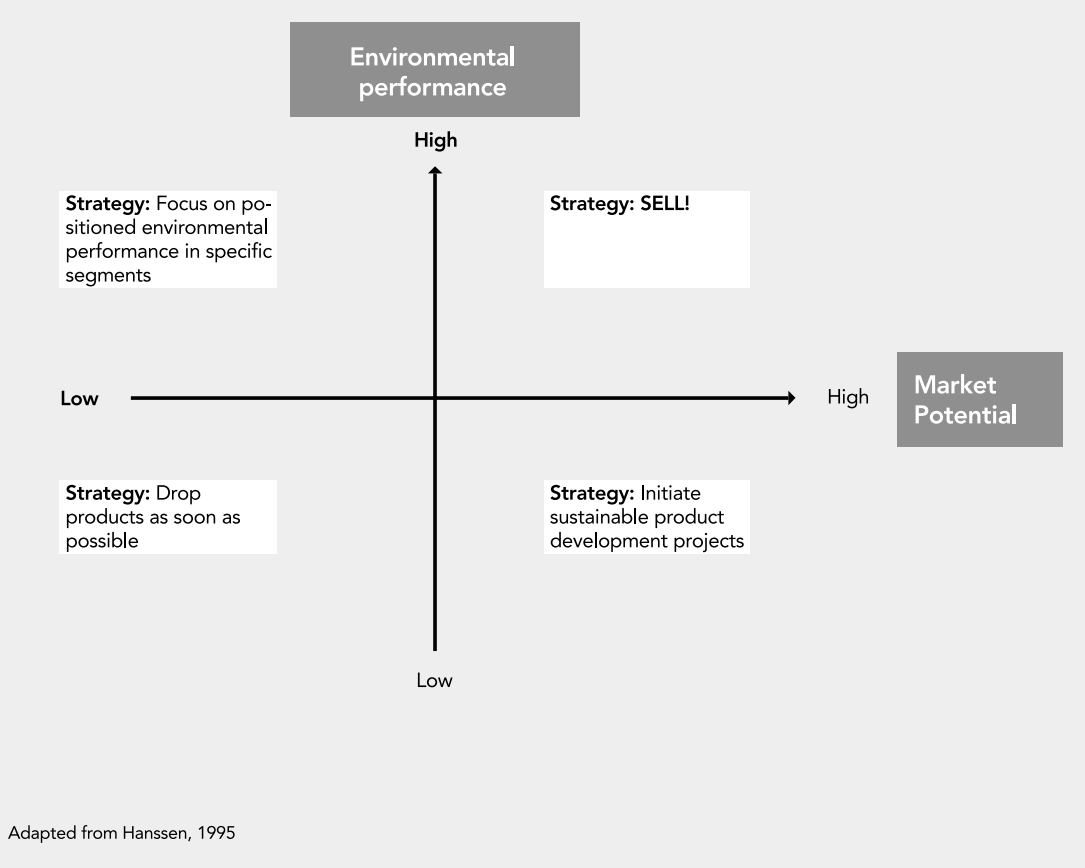


Figure 3-2
Basic product strategies in relation to environmental performance and market potentials.

products on the market will in many cases be sufficient. In the longer term, more systematic LCA-activities within a company will help in building up a database of information, suitable for decisions on all levels of activities.

3.2.4 Conceptually related programmes

LCA cannot be used as the only decision support tool in environmental management. The term Conceptually Related Programmes (CRP) has been used by SETAC to describe a wide range of approaches to environmental management used to support environmental decision making.

Most CRPs are not very accurately defined. The SETAC workgroup on Conceptually Related Programmes has divided them into two groups, i.e. Environmental Management Tools and Environmental Management Concepts (de Smet *et al.*, 1996). The Environmental Management Concepts have been defined as "ideas for achieving sustainability originating in specific professional disciplines" while the Environmental Management Tools have been defined as "measuring techniques with systematic step-by-step procedures and / or computational algorithm; often used to support a concept". Many of the programmes are thus interrelated and cannot be easily distinguished from each other. Also, many companies are combining several concepts and tools in order to meet their goals for improvement of environmental performance.

Life cycle management

The concept of Life cycle management has recently been described (Environment Canada, 1997). The basic idea in Life cycle management is to establish a thorough knowledge of the environmental burdens of the products manufactured by the company and use this for improvement actions. The process includes employees at most levels of the company and starts with an identification of all unit processes at the production site and an analysis of the related in- and outputs. In the next step up- and downstream processes are examined. The results from the process can be used to establish an LCA, but it is more important that the results are used to minimize the environmental bur-

dens. This is done by using a set of tools tailored to meet the needs of a given company, e.g. design for the environment, pollution prevention strategies, waste audits, green procurement etc.

Product Stewardship
Product Stewardship is defined as "the responsible and ethical management of a product during its progress from inception to ultimate use and beyond". The purpose of Product Stewardship is to make health, safety and environmental protection an integral part of designing, manufacturing, marketing, distributing, using, recycling and disposing of products. The concept was developed by the chemical industry in 1987 in order to reduce the risks associated with chemical products at all stages of the life cycle, but today Product Stewardship is also applied to complex products and services. The relationship to LCA is obvious, a major difference being that the environmental impacts are not aggregated over the whole life cycle (http://www.py.iup.edu/college/chemistry/chem-course/TOC1.html#CMA's).

Cleaner Production
Cleaner production is defined by UNEP (United Nations Environmental Programme) as the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment. For production processes, Cleaner Production includes conserving raw materials, and reducing the quantity and toxicity of all emissions and wastes before they leave a process. For products the strategy focuses on reducing impacts along the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product.

A Cleaner Production Programme (CPP) was established in 1989 by UNEP (United Nations Environmental Programme) (http://www.unepie.org/cp/home.html) to increase world-wide awareness of the cleaner production concept, help industry and governments develop cleaner production programs, foster the adoption of cleaner production and facilitate the transfer of cleaner production technologies. The Programme works with experts world-wide, transfers information, holds training sessions, publishes technical reports and supports demonstration projects.

LCA is not a formal demand in the UNEP programme, but an Expert Seminar was held in Amsterdam in 1993 to facilitate the integration of LCA and Cleaner Production. In relation to LCA, dissemination of the results from cleaner production programmes may prove to be a valuable source of information with regard to both specific processes and products.

Industrial ecology
Industrial ecology can be defined as the network of industrial processes as they may interact with each other and live with each other, not only in the economic sense but also in the sense of direct use of each others material and energy wastes (Ausubel (1992), quoted from de Smet *et al.*, 1996).

Industrial ecology is concerned with the evolution of technology and economic systems such that human activities mimic mature biological systems as regards being self-contained in their material and resource use (Allanby (1994), quoted from de Smet *et al.*, 1996). Its object of analysis is industrial processes rather than products and it emphasises the need for greater synergy, i.e. the potential for reduction in environmental impacts by linking different manufacturing process via their waste streams and encouraging cyclic flows of materials.

Programmes where industrial ecology has been implemented tend not to have a direct relation to LCA. However, companies entering industrial ecology programmes should expect an improved environmental profile of their products as they are reflected in an LCA. This requires that the allocation procedures used in LCA are developed further in order to handle the complex waste streams between several industries in a sensible manner.

Evaluation of Environmental Performance
The concept of environmental performance evaluation is being developed for use in an Environmental Management System to quantify, understand and track the relevant environmental aspects of a system. The basic idea is to identify indicators (environmental, operational and management) which can be measured and tracked to facilitate continuous improvements. ISO (ISO/TC 207/SC4/WGs 1-2) is currently developing a standard (ISO 14031 Evaluation of Environmental Performance) to be published mid 1998.

Technology assessment
Technology assessment (TA) can be defined as the assessment of the impacts of introduction of new technologies. The major difference between TA and LCA is that in technology assessment a wide range of economic,

social and environmental aspects is taken into account, whereas in LCA only environmental issues are addressed. LCA can thus be regarded as an integral part of technology assessment.

Overall Business Impact Assessment
A new concept, Overall Business Impact Assessment (OBIA), was introduced by Unilever at the SETAC Case Study Symposium in 1996 (Taylor & Postlethwaite, 1996). Instead of focusing on single products or product systems, the OBIA assesses the totality of the effects of all the individual products produced by a business on an annual basis, as measured by LCA, together with the effects associated with factory and office operations, as deducted from conventional environmental audits. The proposed OBIA-methodology permits the screening of several "what if" scenarios, i.e. investigating the environmental effect of changing critical parameters and variables in the system.

Environmental impact assessment (EIA)
EIA is an activity directed at the identification and quantification of the impacts of people's actions on human health and well-being and at the interpretation and communication of information about these impacts. EIA is generally used during the planning phase to investigate changes to the environment at a specific site caused, for instance, by construction projects. The level of detail in an EIA is often higher than in LCA because aspects like concentration of emitted pollutants and duration of exposure are taken into account. EIAs can thus be used to supply precise data to site-specific LCAs and as control reference in generic LCAs.

Risk Assessment (RA)
RA is not one unique tool but rather a number of tools developed to investigate the potential risk to human health or the environment from specific situations like transport of dangerous goods or the use of specific substances. In all cases, RA includes at least two steps which also are used in many LCAs, namely hazard identification and exposure assessment. The exposure assessment may yield valuable information on emissions from a given activity and the hazard identification may be of help in the impact assessment, depending on the methodology used (http://intwww.eea.eu.int/frproj.htm).

Substance flow analysis (SFA)
The objective of SFA is to make an inflow and outflow balance of one particular substance (or group of substances) through the material economy, giving the opportunity of identifying environmental improvements related to the substance. The modelling and data collection approach is in many cases quite similar to that used in LCA, except that the substance flow is not being related to a functional unit. SFA may thus be a useful data source for LCA (and *vice versa*) but its main application is to identify environmental policy options, e.g. by showing which flows might be restricted in order to reduce the emissions of a substance or a material. Most SFAs are limited to specific geographic boundaries, e.g. the national level.

Energy and material analysis (EMA)
Energy and materials analysis is to a large extent similar to the inventory phase in a LCA since it quantifies all materials and energy that enter or exit the system under study. One major difference is that EMA does not necessarily involve the whole life cycle of a product or a service, instead focusing on one specific phase or production process. Another difference is that the results from an EMA is not explicitly translated into potential environmental impacts.

Integrated substance chain management (ISCM)
Integrated substance chain management is a decision support tool in which the life cycle approach is combined with economic considerations in order to analyse and reduce the overall environmental impacts of substance chains (VNCI, 1991). The methodology focuses on (potential) actions and questions like "What is the total effect of substance A on the environment?" are not answered within the framework. Instead the 80/20 rule is applied ("what 20 percent of elements account for 80 percent of the total?") in order to answer action-orientated questions like "What would be the environmental and economic impact of installing a recycling system for substance A?". The environmental part of the methodology is thus conceptually very similar to a simplified LCA. According to VNCI, the methodology can also be used for products, services, companies, regions, etc.

MFA refers to accounts in physical units, e.g. in terms of tonnes, comprising the extraction, production, transformation, consumption, recycling and disposal of materials, broadly defined. The concept is thus similar to or combines other CRPs like substance flow analysis, integrated substance chain management and energy and materials

analysis (http://oasis.leidenuniv.nl/interfac/cml/conaccou).

Hybrid models
Many LCAs published today must be considered as hybrid models since they not only make use of the LCA framework but also take into account one or more issues from conceptually related programmes. Such hybrid models may prove to be of great value because they make it possible to address *ad hoc*-problems in the context of a life cycle approach. One such example is the Danish report "Development of environmentally friendly cookers and stoves" (see Box) (Schmidt *et al.* (1996)), where an LCA is made along with elements from material flow analysis (MFA), technology assessment (TA) and risk assessment (RA). The government sponsored study was primarily directed towards the cooker industry, but the results can also be used in green procurement.

3.3 Public policy making

Sustainable development has been included as a major item on most governmental agendas since the 1992 Rio summit. Although a precise definition of sustainable development has not been given, it is obvious that LCA or a life cycle approach must be used to ensure that actions towards a more sustainable future will have the desired effect. LCA as a specific tool can ensure this in some cases, while LCA as an approach or as a strategic tool can give directions but not the whole answer, and must therefore be applied along with other tools such as risk assessment, environmental impacts assessment, cost-benefit analysis and others.

The main governmental applications are

- Product-oriented policy
- Deposit-refund schemes, including waste management policies
- Subsidies and taxation, and
- General (process-oriented) policies

The government's role in product publicity is mainly to facilitate and support, and this can be done by increasing the available information to both individual consumers and institutional and governmental buyers. The present chapter focuses on the product-

Environmentally friendly cookers and stoves

The Danish EPA initiated in 1995 a study assessing which cooking technology (gas/electricity, glass ceramics/induction) had the least environmental impacts. The study used a cooker with glass ceramic top plate as the reference product and investigated the outcome of possible changes in technology.

Some of the results are of a general character for an energy consuming device operating in Denmark:

- The energy consumption in the use phase constituted more than 95% of the total energy consumption during the usable life,
- Almost all global and regional impacts were related to the energy consumption, while the local impacts were related to the production of raw materials,
- Gas technology was less demanding than electricity in terms of consumption of primary energy, but gas had a greater impact on indoor climate and human health. Gas burning will generate concentrations of nitrogen dioxide in kitchens of a magnitude similar to that causing an increased incidence of respiratory diseases in children and asthmatics. Therefore, gas technology with less emissions of NO_2 and no increase in CO-emissions should be developed,
- Better measurement standards for cooking efficiency were necessary in order to compare different technologies,
- Most materials in a conventional cooker are recycled in Denmark today. Glass ceramics are not recycled, and future development should focus on recycling technologies or development of new materials for cook tops.

The finding, that gas technology may have a greater impact on human health, would not have appeared, if the assessment has been based on "conventional" LCA-methodology, e.g. by using equivalence factors for impacts on human health in stead of a specific toxicological assessment. This stresses the need for more flexible approaches, in which expert judgement may play an important role in LCA.

oriented policy as this is the most promising area in relation to LCA and the life cycle approach. A broader survey of life cycle based government policies can be found in Curran (1997).

3.3.1 Environmental labelling

An environmental label ("ecolabel") can be seen as a "seal of approval" for environmentally benign products and can therefore be attractive for marketing purposes. Ecolabels at the same time convey information to the consumer in a simple but yet objective way, enabling individuals to include environmental concerns in their own decisions along with considerations on e.g. economy and quality.

The general objective of national and supranational ecolabelling schemes is to make products with less environmental impacts visible to the consumer. The success of an ecolabelling scheme is thus to some extent dependent on the number of product groups with an ecolabel (see appendix 3.1 for details).

The EU Ecolabel ("The Flower")

The EU Regulation (Commission Regulation No 882/92) seeks to:

- Promote the design, production, marketing and use of products which have a reduced environmental impact during their entire life cycle
- Provide consumers with better information on the environmental impacts of products, without, however, compromising product or workers safety and significantly affecting the properties which make a product fit for use

The EU labelling scheme has undertaken a large amount of work in establishing a common framework for criteria development as well as in the development itself.

The EU ecolabelling scheme has so far resulted in criteria for 12 product groups:

EU-ecolabelling criteria have been developed for

- Washing machines
- Soil improvers
- Kitchen towels
- Laundry detergents
- T-shirts and bed linen
- Paints and varnishes
- Dishwashers
- Toilet paper
- Double-ended light bulbs
- Single ended light bulbs
- Copying paper
- Refrigerators

Examples of ecolabels in individual countries and in supranational institutions
http://www.interchg.ubc.ca/ecolabel/gen.html

Germany: The Blue Angel	The Netherlands: Stichting Milieukehr
Spain: AENOR	Greece: ASAOS
France: AFNOR	Luxembourg: Ministere de l'Environment
Israel: Green Label Program	Brasil: Departemento de Certificacao Gerente
U.S.A.: Green Seal	Canada: Environmental Choice Program
Japan: Ecomark	Taiwan (ROC): Green Mark Program

Sweden, Norway, Finland, Denmark and Iceland: Nordic ecolabelling scheme ("The Swan")
http://www.sis.se/Miljo/Ecolabel.htm

All EU-countries: European Union Ecolabel Award Scheme ("The Flower")

Other ecolabelling schemes
A number of official and private ecolabelling schemes are in evidence all over the world today (see box). The nature of and criteria for private labelling schemes is often obscure, while official schemes like the Nordic "Swan", the EU "Flower" and the German "Blue angel" explicitly demand that the award of the label is based on the life cycle approach (Type I labelling).

The German ecolabelling scheme "The Blue Angel" released the first set of criteria in 1978 and in 1997, criteria had been developed for about 88 product groups. The Nordic ecolabel scheme ("The Swan") has so far developed criteria for about 43 product groups, the Canadian scheme covers 47 product groups, the Japanese 68 product groups and the Taiwanese 26 product groups (http://www.interchg.ubc.ca/ecolabel).

The relationship between LCA and ecolabelling
Some industries have pointed out that LCA cannot be used as a scientific methodology to integrate the inherently diverse and complex trade-offs of environmental product issues; or the often conflicting judgements of criteria-setting stakeholders. However, in many labelling schemes, all important stakeholders are members of the working group for each product, ensuring that all relevant issues are raised and discussed in detail. Furthermore, the criteria for a given product group are revised on a regular basis, giving the possibility of using updated LCA-information in the new criteria. The iterative procedure also gives the possibility of changing scoring systems or qualitative criteria into hurdles as the level of information increases.

As far as industry is concerned, the procedure of achieving an ecolabel does not include actually performing an LCA of a product. Instead, the overall environmental performance of the company and its suppliers should be of such quality that the criteria for achieving the ecolabel can be met.

ISO is developing a standard for Type I labelling (ISO 14020 Environmental Labels and declarations - General Principles). The work is expected to result in a committee draft in mid 1998, but it is already clear that a description of the LCA methodology to be used will be an important part of the standard.

3.3.2 Green procurement

Taking environmental aspects into consideration in public and institutional procurement is becoming common practice in many countries. Public procurement accounts for a large share of the overall market and can thus be an important factor in the development and marketing of environmentally friendly products.

Both national and supranational organisations have formulated policies on green procurement. OECD have issued "Council Recommendations on Improving the Environmental Performance of Government" (C(96)39/FINAL), which advocates that Member Countries should

> ... "identify goals and set targets and time frames for optimising the use of energy, water and materials in day-to-day operations, in particular through reduction, re-use, recycling and recovery measures" and
>
> ... "establish and implement policies for the procurement of environmentally sound products and services within governments"...

The Danish Environmental Protection Agency has formulated the following objectives for the public "green" procurement in Denmark (Miljøstyrelsen, 1996):

> To decrease the environmental impacts, including energy related impacts, from public production and consumption, and
>
> To urge all other parts of the society also to use resource and environmentally friendly products and production methods.

Other nations have published objectives of a similar nature.

In those cases where an official ecolabel exists for the product in question the obvious choice is to demand products fulfilling the criteria for the ecolabel. Public procurement organizations can then make their choice without time-consuming evaluations and comparisons of all incoming offers.

However, as criteria for ecolabels have only been developed for relatively few product groups, it is often necessary to choose another methodology if new product groups shall be included in programs for green procurement. The major problem in this context is to develop criteria which ensure that the products have a good environmental performance, and at the same time give the responsible persons a tool which enables them to choose between a number of products with different environmental features.

In Denmark, this is done through a steering committee of some of the major stakeholders, i.e. industry, relevant governmental agencies, and the big institutional consumers. A simplified LCA is performed on the product group and the key features are pinpointed and ranked according to their estimated importance. The result is an environmental guide containing brief background information on the environmental impacts of the products in questions and a page with the 5-10 most important questions to be answered by the supplier. For some product groups the guide only considers qualitative aspects, e.g. product/technology characteristics or aspects relating to the environmental policy of the possible suppliers, while for other product groups quantitative information on e.g. energy consumption is also requested from suppliers. The project organization ensures that quick updates are possible whenever new and relevant information is available.

In other procurement organizations the number of environmental questions is considerably higher. The Swedish NUTEK-agency (http://www.nutek.se/home_page_-eng.html) have for example developed detailed questions on the environmental performance of office supplies. The criteria are based on national and international eco- and energy labels as far as possible, but the final interpretation and ranking of more than 100 questions about environmental performance lies with one or a few persons in a procurement department who do not necessarily have an adequate environmental education.

3.3.3 Other governmental applications

LCA can give valuable information in the development of general (product) policy strategies. Examples are choice of fuels for electricity generation, assessment of bulk transport by train, ship or road, and assessment of waste management options, e.g. best environmental treatment of specific types of waste, environmental impacts of new recycling techniques for plastics.

Waste management

Using LCA-methodology in waste management is an obvious choice for both governments and industries. It can be argued that examination of one phase of the life cycle may lead to wrong conclusions, but waste handling can actually be seen as a production process in which discarded products are used as raw material for production of new materials or energy. LCA can in this connection be used to prioritise actions (which areas constitute the largest problem) and also to choose the best option(s) from an environmental point of view. The latter has been the focus of many published LCAs especially on paper and plastics. Detailed assessments can be found in Dalager *et al.* (1995) and Finnveden *et a.l* (1994), and a number of case studies have been published in Finnveden & Huppes (eds.), 1995.

The treatment of waste management in LCA poses some of the same problems as for other phases of the life cycle, e.g. with respect to allocation principles and time frame. The main reason for this is that several kinds of waste will be mixed before the waste handling process starts. Characterisation of waste thus becomes an important issue when establishing an inventory. A more serious problem is that the fate of different waste fractions in a landfill is unknown at the moment, and therefore this management option cannot be analysed in detail. A number of theoretical problems and their possible solution is addressed in Finnveden & Huppes (eds.), 1995.

Packaging policies

The most prominent governmental use of LCA has been in the field of packaging. LCAs on milk packaging (cartons, glass or plastic bottles), beer bottles and beer cans, impact of PVC from packaging etc. have in many countries been used as a decision support in the political arena, although the LCAs have seldom given an unequivocal answer as to which system is environmentally preferable. The situation becomes even more complicated when comparing LCAs of similar product systems functioning in different countries (see for example Christensen, 1992). Differences in the outcome can be caused by differences in geographic boundaries and conditions, data quality and assessment methodology. Opposing claims in earlier LCA studies have, however, been healthy for the development of LCA in helping to ensure that LCAs are properly undertaken through the use of recognised/accepted methodologies and data, and that they are properly interpreted and reported.

LCAs of packaging options almost always initiates a debate on the objectivity of LCA when published. The main reason is that the packaging industry has strong vested economic interests, and a change in a packaging concept, e.g. from glass bottles to aluminium cans may cause several companies to signifi-

Environmental evaluation of packaging options for beer and soft drinks

The Danish system for beer and soft drink packaging is traditionally based on reusable glass bottles with a return rate of about 95%. Earlier investigations have shown that this kind of system may be environmentally superior to other systems - e.g. aluminium cans. In 1992 the Danish EPA initiated a new LCA study on beer packaging, because the EU packaging directive required that LCA was used to assess which packaging options is environmentally most sound in order to promote or restrict.

The new study was barely a Life Cycle Inventory of glass bottles aluminium cans and steel cans. The results were accordingly not appropriate to pinpoint the best alternative from an environmental point of view. It was, however, possible to use the survey to determine where in the life cycle of the different systems the largest contributions to essential environmental parameters were expected, and then use this information as a decision support. The uncertainty of the data is considerable, e.g. for energy consumption the uncertainty has been estimated to 30% plus differences in the outcome of possible allocation principles.

The results show that the different options (e.g. glass bottles (reusable, one-way), aluminium cans and steel cans with aluminium lid) behave very differently with respect to environmental aspects. Thus, the discussion about which system to prefer must take at least three weak points of the study into account:

1. No assessment methodology has been used - only an inventory has been established
2. The inventory is associated with large uncertainties for essential environmental parameters
3. Each packaging option has its good and bad sides in comparison with the others.

There is no doubt that better data and a sound assessment methodology would enhance the use of the results. However, due to the inherent differences of the system options, subjective weighting of the environmental aspects in the evaluation phase will always have a large impact on the final decision.

cantly slow down their activities whereas other companies will expand. Other participants in the debate can be supranational bodies (e.g. the EU Commission and the World Trading Organisation) and NGO's pursuing environmental goals without economic considerations. Two examples on this kind of application is the Danish study on beer and soft drink packaging (see Box) (Pommer & Wesnæs, 1995) and the German study "Eco-balance for drink packaging" (Schmitz *et al.*, 1996).

Given the weaknesses of LCA, e.g. that the valuation phase can never be 100% objective, it is not surprising that such debates often occur. The recommendation from the Nordic LCA-project (Lindfors *et al.*, 1995) is that several assessment methodologies should be used in the LCA, thereby improving the necessary decision support. Future refinement of the database and standardisation of LCA-methodology will decrease the uncertainty and thereby improve the validity of the results. However, it should be remembered that LCA is only one of several decision support tools and that aspects which are not included in a LCA may be of equally great importance.

Other areas for decision support
Other areas where LCA has been used as a decision support tool are environmental taxes, integrated life cycle management and deposit / refund schemes. An LCA can in these cases be used to analyse the environmental consequences of a change in human behaviour, and the efforts can be directed towards the most favourable solutions.

3.4 Future applications

It is anticipated that LCA or the life cycle approach can and will be integrated with other decision support tools in almost all areas where environmental issues are important. The amount of LCA-relevant information is increasing, giving the possibility of extending LCA into new production areas as well as all the application areas mentioned in this chapter. With the increasing amount of information, the applications of LCA will become more varied and the results will be more precise. But it is worth remembering that there are only few situations where LCA can be used as the only decision support tool.

LCA should also be an integral part in the development of extended producer responsibility (EPR) as suggested by OECD. EPR can for instance be employed by governments as a strategy to transfer the costs of municipal

waste management from local authorities to those actors most able to influence the characteristics of products which can become problematic at the post-consumer stage. Design for Environment, Risk Assessment and LCA can give input from different angles to the decision makers, ensuring that sub-optimal solutions are not implemented.

Finally, the integration of life cycle approaches and environmental management systems is seen as a potentially key area for further development: Environmental management schemes require that indirect environmental aspects are considered and that requirements are communicated in the product chain i.e. to suppliers and customers. Life Cycle Assessment and other life cycle approaches and tools will require more systematic data collection and maintenance if they are to survive as a quantification tool for assessing the direct and indirect environmental aspects and potential impacts throughout the life cycle of a product.

The ability to apply and use LCA in the future is critically dependent upon the ability to actually do authentic LCAs. This requires that the necessary facilities, i.e. agreed methodologies and, especially, data, are available. As is shown in the following chapters, both methodologies and data are becoming more precise and better documented. This, together with the development of the ISO LCA-standards, warrants that the future use of LCA will be even more beneficial than the current experience shows.

Appendix 3.1:

Environmental labelling

Concepts for the development of cleaner products are described elsewhere (LCA and product development) along with an introduction to governmental strategies (primarily ecolabelling) used to promote the most environmental benign products (Public sector applications). Ecolabels can be seen as a means of conveying information to the consumer in a simple yet objective way, enabling individuals to include environmental concerns in their own decisions along with considerations on e.g. economy and quality.

Environmental labelling schemes have been initiated in many individual countries and as international activities in the Nordic countries and in the EU. The framework and procedure for criteria development differ from scheme to scheme, and the criteria for the product groups are accordingly widely differentiated.

The two ecolabelling schemes described in the following section are rather similar in organization and procedures. However, it is remarkable that the EU ecolabelling scheme has only produced criteria for eight product groups while the Nordic ecolabelling scheme has produced criteria for 43 product groups during the same period.

Like all other “serious” ecolabels both schemes feature LCA as a very important element in the setting of environmental criteria. The difference in the number of developed criteria can perhaps be attributed to differences in the complexity of the LCA methodology applied. Another possible explanation is that the perception of the Nordic ecolabelling scheme by the Nordic industry and consumers has been more favourable than the EU ecolabelling scheme. A market success for a labelled product will be quickly reflected in the wish for ecolabelling of more product groups.

The EU ecolabelling scheme was initiated in 1992 by Council Regulation EEC N° 880/92. The procedural guidelines for the establishment of product groups and ecological criteria are set out in the Commission information on ecolabelling (No 6, 1994). The formal framework is described in 11 points, identifying the role of national and EU bodies participating in the procedure.

This framework will not be described in detail, while the six phases in criteria development is described below:

Phase One (preliminary study) has the objective of allowing the Commission, the Competent Bodies and the Consultation Forum to consider the feasibility of establishing the product group and ecological criteria, including an indication of what is available, the nature of the market, including industrial and economic interests and structures, the perceived environmental issues, what needs to be done, the advantages of the product group being labelled and some of the problem areas.

Phase Two (market study) has the purpose of assembling information on the nature of the market in more detail, including the distribution of different types and sub-types of product, the market shares held by manufacturers and by main brands on an European Union and Member State basis, and imports to the Community.

Phases Three and Four (inventory; impact assessment) have the aim of carrying out an inventory and then an assessment of the impacts on the environment, using internationally recognized methods, in an objective, qualified and representative manner, on a “cradle-to-grave” basis.

Phase Five (setting of criteria). The main elements of this phase are to determine the:

- most important environmental impacts, based on results of phases three and four, and identify the accessible areas of economic and technical development which are the most relevant to the environmental impacts;
- applicable criteria and define the level required for each criterion with refer ence to the Policy Principles document;
- necessary test methods and certification procedures and consider solutions for qualitative and other related issues.

Consideration should also be given to how the visibility and effectiveness of the criteria can be evaluated.

Phase Six (presentation of a draft proposal for a Commission decision). The Lead Competent Body will present the final report to the Commission which will then put into operation the formal procedures required by the Regulation:

- Internal Commission procedures
- Presentation of the draft decision on the establishment of a product group and ecological criteria to the Consultation Forum and Regulatory Committee
- Formal procedure for a Commission decision.

Guidelines for the application of life cycle assessment in the EU ecolabelling Programme were issued by the Groupe des Sages in 1994 (de Haes *et al.*, 1994). The objectives of the guidelines are to support the Member States in establishing ecolabelling criteria which are based on a methodology that is both scientifically sound and workable in practice, and to improve uniformity in the methods applied in different Member States. The key conclusions and recommendations from the Groupe des Sages are:

- Life cycle assessment can make a significant contribution in providing a scientific, unifying and transparent basis for the EU Ecolabelling Programme.
- It is central to this Programme because it compares different products on the basis of their common function.
- It relates environmental impacts, at all stages from cradle to grave, to both market changes and technological improvements.
- It is a methodology still in the process of development, requiring additional research and systematic data collection.
- Therefore policy makers, competent bodies and practitioners must remain aware of the current capabilities and limitations of LCA and should support its continuous development.
- It should be clear, however, that LCA is only a decision support tool; it cannot replace actual decision making.

In the report from the second phase of the work in the Groupe des Sages (de Haes *et al.*, 1995), the following recommendations on the setting of criteria are given:

Ecolabelling criteria can be derived from different parts of the LCA-process:

- Product or technology characteristics
- Hurdle criteria: results of inventory analysis and results of classification / characterisation
- Scoring systems: results of a structured valuation step

Hurdle criteria are in general to be preferred because they are transparent and give a clear guide for product improvement. **Product or technology characteristics** can only be used as criteria if they are validated carefully in order to confirm whether they correspond to substantiated environmental impacts without impacts elsewhere or inhibiting development towards future cleaner technology. **Scoring systems** can only be used if other types of criteria appear to be technically impossible or undesirable, and weighting factors in a scoring system should be determined by an authorized body, not by the LCA-practitioners themselves. The criteria should be validated on their comprehensibility for all parties involved.

The Nordic ecolabelling scheme ("The Nordic Swan") was initiated by the Nordic Council of Ministers and is common to Sweden, Norway, Finland and Iceland (and in the near future also Denmark). The work in the various countries is co-ordinated through the Nordic co-ordination body which decides on a set of common rules for Nordic Environmental Labelling (http://www.sis.se/Miljo/Ecolabel.htm).

The objective of the Nordic Ecolabelling scheme is to promote development, production and marketing of products with a reduced environmental impact in its entire life cycle. The objective is also to improve the flow of information to the customers on the environmental impacts of products.

The co-ordinating body determines matters such as the product groups and the criteria that shall apply to environmental labelling. The decisions taken in the co-ordinating body must be unanimous. Draft criteria are drawn up by inter-Nordic expert groups with a balanced composition of experts from environmental authorities and organisations, commerce and industry etc. The criteria

work can also be carried out nationally. The secretariat which is responsible for the work then decides how the work should be carried out. The other countries shall be kept informed of the work, e.g. by receiving preliminary criteria drafts. The other countries also have the right to appoint their own experts as observers.

The General Agreement for Nordic Eco-labelling states the following conditions for criteria development:

1. Relativity. The label shall be awarded after a comparative evaluation. On the basis of the comparison, a level is defined for criteria, and the products that exceed this level will be awarded the label.

2. Standards shall be set high, in any case higher than the strictest official rules in one of the Nordic countries. Criteria should also be made so strict that no product is awarded the label at the moment if it is known that product development could make products satisfy the criteria within a short time.

3. Life cycle. The whole product's life cycle (procurement of raw materials, manufacturing process, use, refuse) shall serve as the basis for comparison.

4. Environmental aspects. Attention shall be paid to environmental problems throughout the product's life cycle that shall form the basis of the choice of a limited number of aspects on which environmental labelling is based. These important aspects include the use of energy and resources, discharges into the air, water and soil, noise and odor pollution; and refuse/recycling. In order to correctly formulate criteria, attention must also be paid to the total market share of the products expected to fulfill the criteria.

5. Criteria are laid down within "a product group". This is defined, as appropriate, in relation to the system's objectives. In general, products with the same range of use form a group, regardless of type. This is the case when it is considered desirable to reduce the use of one type of product in favour of another of identical/similar utility for the consumer. An example is the choice between plastic and paper as a raw material for a product.

In some cases it would be more practical to label products within the same product type. This could be done when a majority of products of a certain type need to be im proved with a view to the environment.

6. Criteria are laid down so that the greatest benefit is achieved in relation to the objec tives. Priority is thus given to:

a. The product's effects on the environment, qualitatively and quantitatively.

b. The consumer's need for information.

c. The potential for bringing about changes in the market.

The criteria proposal is circulated for comment before being finalized by the Nordic co-operating body. The consultation time is usually 4-6 weeks. When the criteria have been authorized, companies may apply for licences within the group. Licence applications and licence issuing is handled by the secretariats of the various countries.

4. Methodological framework

This chapter describes the methodological framework for life cycle assessment. The target audience includes LCA practitioners, and other environmental professionals with a strong interest in environmental assessment. Figure 4-1 show the different phases of an LCA. The whole life cycle assessment also interacts with the direct applications.

As shown in Figure 4-1 the life cycle assessment framework is described by four phases:

- goal and scope definitions
- inventory analysis
- impact assessment
- interpretation

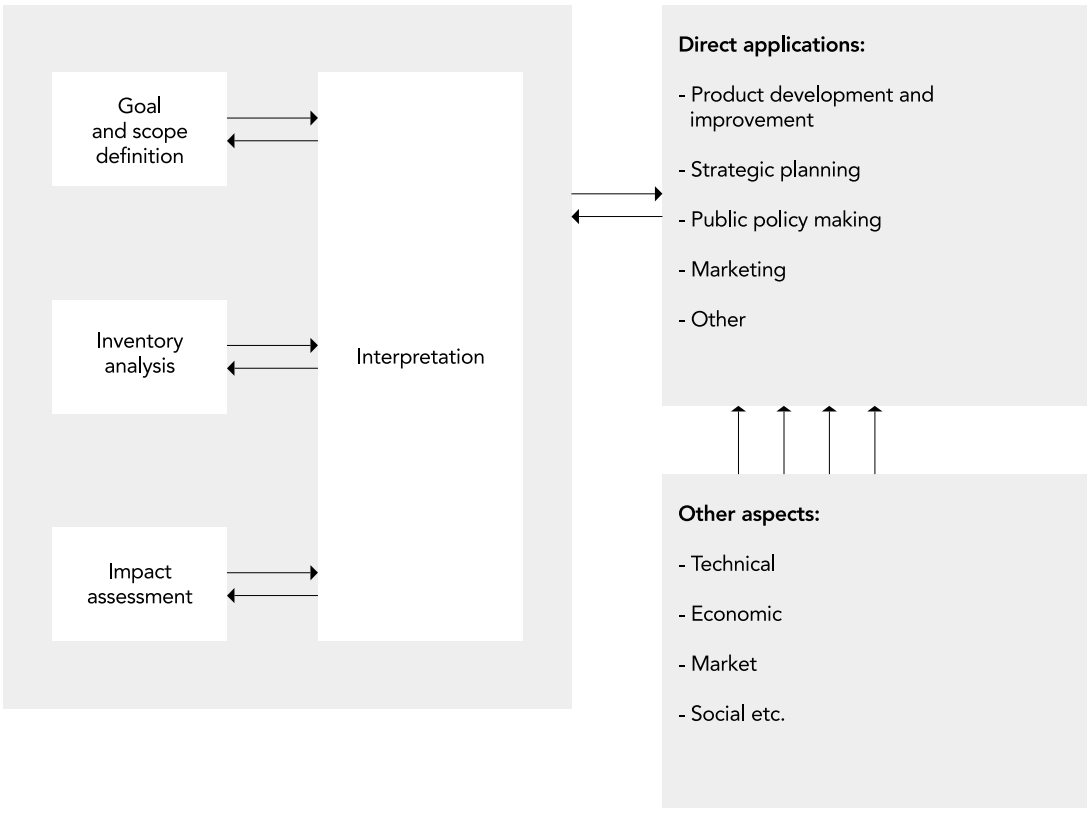
The double arrows between the phases indicate the interactive nature of LCA as illustrated by the following examples: when doing the impact assessment it can become clear that certain information is missing which means that the inventory analysis must be improved, or the interpretation of the results might be insufficient to fulfil the needs required by the actual application which means that the goal and scope definition must be revised.

4.1 Introduction

The principles, procedures and methods of LCA are presented based on the terminology and structure of the ISO Environmental Management Systems, tools and standards on LCA:

- FDIS / ISO 14 040: Environmental management - Life cycle assessment - Principles and framework ISO (1997a).

Figure 4-1
Life cycle assessment framework - phases of an LCA (ISO, 1997a).



- DIS / ISO 14 041.2: Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis. ISO (1997b).

- CD / ISO 14 042.1: Environmental management - Life cycle assessment - Life cycle impact assessment. ISO (1997c).

- CD / ISO 14 043.1B: Environmental management - Life cycle assessment - Life cycle interpretation. ISO (1997d).

Selected parts of the standard have been included where appropriate. Please note that the standards on impact assessment and interpretation are still under development and discussion i.e. the quotations shall be regarded as preliminary statements as consensus in ISO has not been reached yet. The quotations from the standards are supplemented by other literature references on LCA, such as:

- Nordic Guidelines on Life-cycle Assessment and Technical Reports (Lindfors *et al.*, 1995a;b;c);

- Report from Hankø, Norway on LCA in: Strategic management, Product development and improvement, Marketing and Ecolabelling, and Government Policies (Christiansen *et al.*, 1995);

- SETAC Working Group Reports 1996-97: Simplifying LCA, Enhancing inventory methodology, Impact assessment, Case studies, and Conceptually related programmes;

- LCANET workshop background and summary papers 1996 on: Positioning and application of LCA, Goal and scope definition and inventory analysis, Impact assessment and interpretation, and Databases and software.

Below we present a methodological framework for a detailed life cycle assessment. This can be considered as a tool box from which individual components can be selected, depending on the particular application.

In summary, there is no one way to life cycle assessment. The technique can be applied with different levels of sophistication, as long as the life cycle approach to assessing choices is retained. Life cycle thinking is the key issue. Irrespective the chosen level of sophistication there is some basic requirements to the LCA i.e. clear and explicit statement of study purpose and goal, reference to the methodology used (e.g. definition of the functional unit, the system boundaries, and the allocation criteria etc.). These requirements can be summarised as a need for transparency in the study i.e. the above-mentioned conditions shall be clear to the readers of the LCA report.

4.2 Technical introduction

Over the past 20-30 years, life cycle assessment has been used by many organisations and companies throughout the last 20 - 30 years either for internal or external use. For the most part, however, the lack of international consensus or standards on environmental assessment or life cycle assessment, has rendered the results non-comparable and variable. Beginning in 1990, several organisations - including SETAC (Society of Environmental Toxicology and Chemistry) and from 1993 ISO (International Standards Organisation) - began striving to develop consistency in approach to the emerging field. These efforts produced a number of guidelines and draft standards on different aspects of life cycle assessment, with varying degrees of success. The development of LCA methodology in Europe has been further promoted and supported by, among others, SPOLD (Society for the Promotion of LCA Development).

Figure 4-2 illustrates the technical framework for life cycle assessment developed by SETAC in 1993 (Consoli *et al.*, 1993). This terminology presented has been developed further since then, as reflected in the list of definitions given below and throughout the following text.

4.2.1 Definitions

During the work funded by the Nordic Council of Ministers to prepare a Nordic guideline for life cycle assessment, the SETAC definition of LCA (Consoli *et al.*, 1993) was modified (Lindfors *et al.*, 1995c):

> "A process to evaluate the environmental burdens associated with a product system, or activity by identifying and quantitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment. The assessment includes the entire life cycle of the product or activity, encompassing extracting and processing raw materials;

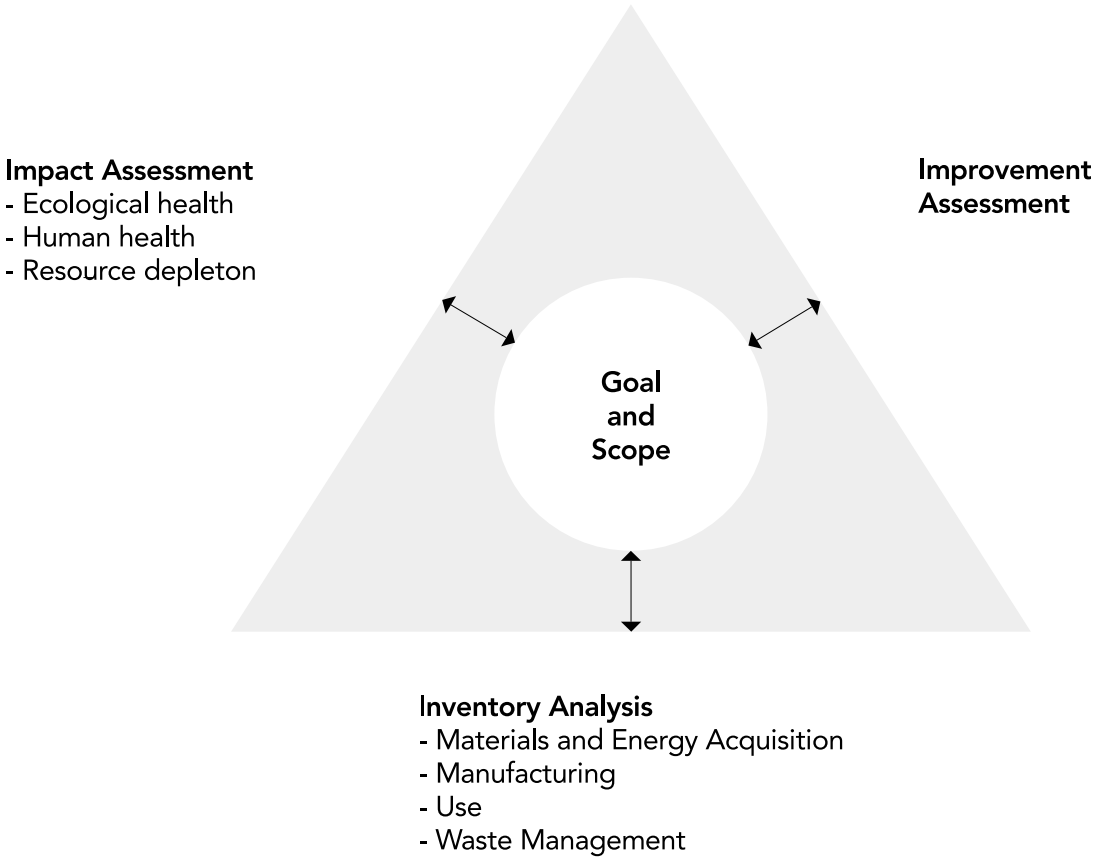


Figure 4-2
Technical framework for life cycle assessment (Consoli et al., 1993).

manufacturing; distribution; use; re-use; maintenance; recycling and final disposal; and all transportation involved. LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects".

The ISO/FDIS standard in Life Cycle Assessment (1997a) gives the following definition:

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory and impact phases in relation to the objectives of the study

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences.

The ISO terminology will, whenever possible, be used in this guide. The terminology is presented in appendix 4.1.

4.3 Goal and scope definition

Goal and scope definition is the first phase in a life cycle assessment containing the following main issues:

- goal
- scope
- functional unit
- system boundaries
- data quality

- critical review process

The definition of the goal and scope is the critical parts of an LCA due to the strong influence on the result of the LCA. In the Nordic guidelines on life cycle assessment the following minimum decisions and definitions that need to be made are listed (Lindfors *et al.*, 1995c):

- the purpose and intended application
- the function of the studied systems(s) and a defined functional unit
- the studied product group and chosen alternatives, if relevant
- the system boundaries applied
- the data quality needed
- the validation or critical review process needed

The different needs are described in detail below.

4.3.1 Goal

The definition of the purpose of the life cycle assessment is an important part of the goal definition.

> The goal of an LCA study shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated.

The goal definition also has to define the intended use of the results and users of the result. The practitioner, who has to reach the goal, needs to understand the detailed purpose of the study in order to make proper decisions throughout the study. Examples of goals of a life cycle assessment are:

- to compare two or more different pro ducts fulfilling the same function with the purpose of using the information in marketing of the products or regulating the use of the products
- to identify improvement possibilities in further development of existing products or in innovation and design of new products
- to identify areas, steps etc. in the life cycle of a product where criteria can be set up as part of the ecolabelling criteria to be used by e.g. the ecolabelling board

The goal definition determine the level of sophistication of the study and the requirements to reporting. Transparency is essential for all kind of LCA studies. The target group of the LCA study is also important to have in mind in the choice of reporting method.

The goal can be redefined as a result of the findings throughout the study e.g. as a part of the interpretation.

4.3.2 Scope

The definition of the scope of the life cycle assessment sets the borders of the assessment - what is included in the system and what detailed assessment methods are to be used.

> In defining the scope of an LCA study, the following items shall be considered and clearly described:
>
> - the functions of the system, or in the case of comparative studies, systems;
> - the functional unit;
> - the system to be studied;
> - the system boundaries;
> - allocation procedures;
> - the types of impact and the methodology of impact assessment and subsequent interpretation to be used;
> - data requirement;
> - assumptions;
> - limitations;
> - the initial data quality requirements;
> - the type of critical review, if any;
> - the type and format of the report required for the study
>
> The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal.
>
> LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

Lindfors et al. (1995c) summarises the single points mentioned in the ISO standard in the following issues to be used in the scoping procedure:

- product group
- studied alternatives
- system boundaries
- impact assessment boundaries
- data quality goals

The product or product group in focus has to be described in detail in order to identify alternatives to be included in the study. The alternative products or product groups have to be described in detail too, in order to be able to define the system(s) boundaries. The definition of the system(s) boundaries are important in the data collection phase because the system(s) boundaries determine the amount of the work to be done. Impact assessment include a number of different impact categories and impact assessment methods. The impact categories have to be chosen from a default list of categories described in the chapter on Category definition. The impact assessment boundaries limit the number of impact categories to be considered. If necessary, the scope can be revised during the study to include new or exclude some of the already chosen impact categories. The data quality goals depend on the overall goal of the study, and include assessment of the level of:

- accuracy, precision and representative ness of individual data sets (e.g. site-specific or average, measured or estimated data, acceptable age of data etc.)
- specific data dependent on the included impact categories

The data quality goals can be changed during the study e.g. in the interpretation phase.

4.3.3 Functional unit

Definition of the functional unit or performance characteristics is the foundation of an LCA because the functional unit sets the scale for comparison of two or more products including improvement to one product (system). All data collected in the inventory phase will be related to the functional unit. When comparing different products fulfilling the same function, definition of the functional unit is of particular importance.

> One of the main purposes for a functional unit is to provide a reference to which the input and output data are normalised. A functional unit of the system shall be clearly defined and measurable. The result of the measurement of the performance is the reference flow.
>
> Comparisons between systems shall be done on the basis of the same function, measured by the same functional unit in the form of equivalent reference flows.

Three aspects have to be taken into account when defining the functional unit (Lindfors et al., 1995c):

- the efficiency of the product

Table 4-1

Definition of the functional unit and expanding system boundaries.

Waste treatment Treatment of municipal household waste with or without biological treatment of the organic fraction can be considered as a service system. The system treats waste and produces biological fertilizer (compost from aerobic or anaerobic degradation of organic material) and energy (biogas from anaerobic degradation). Different systems can be compared by including “avoided” emissions from producing energy and fertilizers in the scenarios including biological waste treatment. As an alternative the system boundaries for the basic scenario as well as the alternative scenarios including biological waste treatment can be expanded so that they all produce the same amount of energy and fertilizer. In this case calculation with “avoided” emissions is of no current interest.

- the durability of the product
- the performance quality standard

When performing an assessment of more complicated systems e.g. multi-functional systems special attention has to be paid to by-products.

> If additional functions of one or other of the systems are not taken into account in the comparison of functional units then these omissions shall be documented. For example, systems A and B perform functions x and y which are represented by the selected functional unit, but system A also performs function z which is not represented in the functional unit. As an alternative, systems associated with the delivery of function z may be added to the boundary of system B to make the systems more comparable. In these cases, the selected processes shall be documented and justified.

Waste treatment systems are an example of processes with different outputs (e.g. energy and fertilizer). When comparing different systems, inclusion of the produced amount of energy and fertilizer is an example of handling of different by-products in the definition of the functional unit. This is also an example of changing the system boundaries to get a more logical system to investigate, see Table 4-1. In the actual case the system has been expanded to avoid calculations with avoided emissions that could lead to negative emissions in the calculations.

4.3.4 System boundaries

The system boundaries define the processes / operations (e.g. manufacturing, transport, and waste management processes), and the inputs and outputs to be taken into account in the LCA. The input can be the overall input to a production as well as input to a single process - and the same is true for the output. The definition of system boundaries is a quite subjective operation and includes the following boundaries (Lindfors et al., 1995c): geographical boundaries, life cycle boundaries (i.e. limitations in the life cycle) and boundaries between the technosphere and biosphere. Due to the subjectivity of definition of system boundaries, transparency of the defining process and the assumptions are extremely important

> The initial system boundary defines the unit processes which will be included in the system to be modelled. Ideally, the product system should be modelled in such a manner that the inputs and outputs at its boundary are elementary flows. However, as a practical matter, there typically will not be sufficient time, data, or resources to conduct such a comprehensive study. Decisions must be made regarding which unit processes will be modelled by the study and the level of detail to which these unit processes will be studied. Resources need not be expended on the quantification of minor or negligible inputs and outputs that will not significantly change the overall conclusions of the study. Decisions must also be made regarding which releases to the environment will be evaluated and the level of detail of this evaluation. The decision rules used to assist in the choice of inputs and outputs should be clearly under stood and described.
>
> Any omission of life cycle stages, processes or data needs should be clearly stated and justified. Ultimately, the sole criterion used in setting the system boundaries is the degree of confidence that the results of the study have not been compromised and that the goal of a given study has been met.

Wastewater treatment is an example of a process that often is omitted when defining the system boundaries

4.3.5 Data quality

The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA. The data quality can be described and assessed in different ways. It is important that the data quality is described and assessed in a systematic way that allows others to understand and control for the actual data quality.

Initial data quality requirements shall be established which define the following parameters:

- Time-related coverage: the desired age (e.g. within last 5 years) and the minimum length of time (e.g. annual).
- Geographical coverage: geographic area from which data for unit processes should be collected to satisfy the goal of the study (e.g. local, regional, national, continental, global).
- Technology coverage: nature of the technology mix (e.g. weighted average of the actual process mix, best available technology or worst operating unit).

Further descriptions which define the nature of the data collected from specific sites

versus data from published sources, and whether the data should be measured, calculated or estimated shall also be considered.

Data from specific sites should be used for those unit processes that contribute the majority of the mass and energy flows in the systems being studied as determined in the sensitivity analysis ... . Data from specific sites should also be used for unit processes that are considered to have environmentally relevant emissions.

In all studies, the following additional data quality indicators shall be taken into consideration in a level of detail depending on goal and scope definition:

- Precision: measure of the variability of the data values for each data category expressed (e.g. variance).
- Completeness: percentage of locations reporting primary data from the potential number in existence for each data category in a unit process.
- Representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geo graphic and time period and technology coverage).
- Consistency: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis.
- Reproducibility: qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study.

Where a study is used to support a comparative assertion that is disclosed to the public, the above mentioned data quality indicators shall be included.

The data quality can be described systematically by using data quality indicators. Each data quality indicator can be assessed by using a scale from e.g. 1 - 5, where 1 denotes the best quality (Weidema, 1994b). An example of a data quality index for a data-set can be (1,3,2,1,1) indicating that precision is high, the completeness is medium etc.

The methodology to describe data quality systematically is still quite new. The methodology is still being developed in order to make it more applicable to describe the different environmental data used in a life cycle assessment.

4.3.6 Critical review process

In other uses of environmental standards, certification of a system or product or accreditation of the measuring laboratory is applied. In LCA it is not yet clear what to certify: The study, the individual practitioner or the company of the practitioner. Therefore, a variation of the peer review set-up used in scientific journals is used as described below.

The purpose of the critical review process is to ensure the quality of the life cycle assessment. The review can be either internal, external or involve interested parties as defined within the goal and scoping definition.

The critical review process shall ensure that:

- the methods used to carry out the LCA are consistent with this international standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reason able in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study;
- the study report is transparent and consistent.

(...)

If an LCA study is to be critically reviewed, the scope of the critical review should be defined during the goal and scope definition phase of the study. The scope should identify why the critical review is being undertaken, what will be covered and to what level of detail, and who needs to be involved in the process.

(...)

Internal review

A critical review may be carried out internally. In such case, it shall be performed by an internal expert independent of the LCA study.

(...)

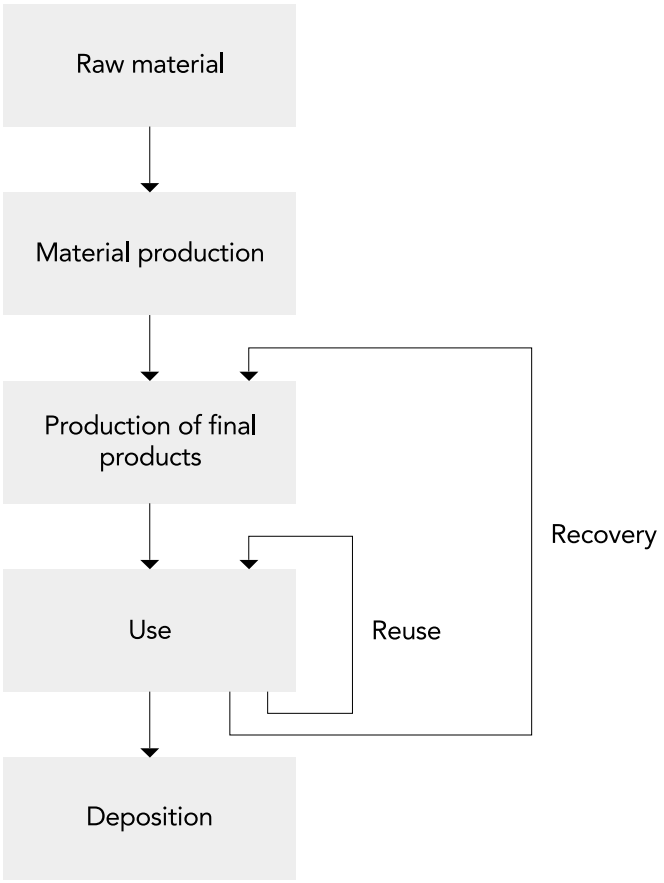


Figure 4-3
Example of a simple flow sheet to be used as support in the data collection.

Expert review
A critical review may be carried out externally. In such a case, it shall be performed by an external expert, independent of the LCA study.

(...)

Review by interested parties
An external, independent expert is selected by the original study commissioner to act as chairperson of a review panel. Based on the goal, scope and budget available for the review, the chairperson selects other independent qualified reviewers.

"Interested parties" also include stakeholders. The review process can be undertaken in parallel to the LCA study and corrections can be made continuously (in-process critical review). Otherwise the critical review can be made on the final draft with the possibility to make corrections before finishing the report (end-of-process critical review). In some cases it may be relevant to publish the critical review report along with the LCA study.

4.4 Inventory analysis

Inventory analysis is the second phase in a life cycle containing the following main issues:

- data collection
- refining system boundaries
- calculation
- validation of data
- relating data to the specific system
- allocation

The different issues will be described in detail below. The description will be based on the terminology defined by ISO; see appendix 4.1. This section includes a short presentation of software tools that can be a useful help in structuring and calculating the inventory data. The inventory analysis and the tasks to be fulfilled can obviously be supported by a flow sheet for the considered

product; an example of a flow sheet can be seen in Figure 4-3. Each of the different phases can be made up from different single processes e.g. production of different kinds of raw material to be combined in the material production phase. The different phases are often connected by transport-processes. Reuse do often involve a cleaning process.

Compilation of a proper process diagram is crucial to succeed the LCA study i.e. to be sure to include all relevant processes etc. The process diagram do also have a function in the reporting of the LCA while it improve the transparency of the study.

4.4.1 Data collection

The inventory analysis includes collection and treatment of data to be used in preparation of a material consumption, waste and emission profile for all the phases in the life cycle, but also for the whole life cycle. The data can be site specific e.g. from specific companies, specific areas and from specific countries but also more general e.g. data from more general sources e.g. trade organisations, public surveys etc. The data have to be collected from all single processes in the life cycle. These data can be quantitative or qualitative. The quantitative data are important in comparisons of processes or materials, but often the quantitative data are missing or the quality is poor (too old or not technologically representative etc.). The more descriptive qualitative data can be used for environmental aspects or single steps in the life cycle that cannot be quantified, or if the goal and scope definition allow a non-quantitative description of the conditions.

> "Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system. Interpretation may be drawn from these data, depending on the goals and scope of the LCA. These data also constitute the input to the life cycle impact assessment.
>
> The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data-collection procedures so that the goals of the study will still be met. Sometimes, issues may be identified that require revisions to the goal or scope of the study.
>
> The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundaries. The procedures used for data collection may vary depending on the scope, unit process or intended application of the study. Data collection can be a resource intensive process. Practical constraints on data collection should be considered in the scope and documented in the report.
>
> Some significant calculation considerations are outlined in the following:
>
> - allocation procedures are needed when dealing with systems involving multiple products (e.g. multiple products from petroleum refining). The materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified;
>
> - the calculation of energy flow should take into account the different fuels and electricity sources used, the efficiency of conversion and distribution of energy flow as well as the inputs and outputs associated with the generation and use of that energy flow.

Data collection is often the most work intensive part of a life cycle assessment, especially if site specific data are required for all the single processes in the life cycle. In many cases average data from the literature (often previous investigations of the same or similar products or materials) or data from trade organisations are used. A number of European trade organisations have published or plan to publish "cradle-to-gate" data that include information on inputs and outputs for materials through production of semi-manufactured product to final products.

The average data can be used in the conceptual or simplified LCA to get a first impression of the potential inputs and outputs from producing specific materials. When doing a detailed LCA site specific data must be preferred. Average data are often some years old and therefore do not represent the latest in technological development.

The result of the data collection can be presented in an inventory table as shown in Table 4-2 with an example from the material data published by the Association of Plastic Manufacturers of Europe (APME).

Table 4-2

Inventory table presenting "Gross inputs and outputs associated with the production of 1 kg of PVC averaged over all the polymerisation processes" (Boustead, 1994).

		Unit	Average[1]
Fuels	Coal	MJ	6.96
	Oil	MJ	6.04
	Gas	MJ	15.41
	Hydro	MJ	0.84
	Nuclear	MJ	7.87
	Other	MJ	0.13
	Total fuels	MJ	37.24
Feedstock	Oil	MJ	16.85
	Gas	MJ	12.71
	Total feedstock	MJ	29.56
Total fuel plus feedstock		MJ	66.80 (48 - 89)
Raw materials	Iron ore	mg	400
	Limestone	mg	1600
	Water	mg	1900000
	Bauxite	mg	220
	Sodium chloride	mg	690000
	Sand	mg	1200
Air emissions	Dust	mg	3900
	Carbon monoxide	mg	2700
	Carbon dioxide	mg	1944000
	Sulfur oxides	mg	13000
	Nitrogen oxides	mg	16000
	Chlorine	mg	2
	Hydrogen chloride	mg	230
	Hydrocarbons	mg	20000
	Metals	mg	3
	Chlorinated organics	mg	720
Water emissions	COD	mg	1100
	BOD	mg	80
	Acid as H^+	mg	110
	Metals	mg	200
	Chloride ions	mg	40000
	Dissolved organics	mg	1000
	Suspended solids	mg	2400
	Oil	mg	50
	Dissolved solids	mg	500
	Other nitrogen	mg	3
	Chlorinated organics	mg	10
	Sulfate ions	mg	4300
	Sodium ions	mg	2300
Solid waste	Industrial waste	mg	1800
	Mineral waste	mg	66000
	Slags and ash	mg	47000
	Inert chemicals	mg	14000
	Regulated chemicals	mg	1200

1. The average values cover a broad spectrum different values representing different technologies. In many cases the actual range of e.g. emissions is more applicable when comparing site specific data with "average" data.

When making a detailed LCA the inventory tables are invariably detailed, intricate and complex whereas the inventory tables required in a streamlined LCA may be more simple if stated in the goal and scope definition i.e. focus on selected emissions as e.g. carbon dioxide, sulfur dioxides and nitrogen oxides.

The applicability of data-sets for specific products i.e. site specific data in life cycle assessment depend on the format of the data. In order to ensure the applicability of industrial data SPOLD has initiated a project with the aim to develop a standard format for data sets to be used in LCA and with the second aim to ensure consistency in registration of data in a database. The structure of the extensive SPOLD data format consists of five parts (SPOLD, 1996):

A Data identification; Data sources and treatment.

B System model (Sub systems; Cut-off rules; Co-products and allocation rules; Energy models; Transport models; Waste models; Other assumptions; Other information).

C System structure

D1 Data 1: Inputs (Known inputs from technosphere; Known inputs from nature)

D2 Data 2: Outputs (Known outputs to technosphere; Known outputs to nature).

D3 Data 3: Other

D4 Data 4: Balances

E List of references

The SPOLD data format will be available by downloading from WWW (http://ipt.dtu.dk/~ap/icc/).

4.4.2 Refining system boundaries

The system boundaries are defined as a part of the scope definition procedure. After the initial data collection, the system boundaries can be refined e.g. as a result of decisions of exclusion life stages or sub-systems, exclusion of material flows or inclusion of new unit processes shown to be significant according to the sensitivity analysis.

> Reflecting the iterative nature of LCA, decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance, thereby verifying the initial analysis (...). The initial product system boundary shall be revised in accordance with the cut-off criteria established in the scope definition. The sensitivity analysis may result in:
>
> - the exclusion of life cycle stages or subsystems when lack of significance can be shown by the sensitivity analysis
> - the exclusion of material flows which lack significance to the outcome of the results of the study
> - the inclusion of new unit processes that are shown to be significant in the sensitivity analysis
>
> The results of this refining process and the sensitivity analysis shall be documented. This analysis serves to limit the subsequent data handling to those input and output data which are determined to be significant to the goal of the LCA study.

4.4.3 Calculation procedures

No formal demands exist for calculation in life cycle assessment except the described demands for allocation procedures. Due to the amount of data it is recommended as a minimum to develop a spreadsheet for the specific purpose. A number of general PC-programs/software for calculation are available e.g. spreadsheets/spreadsheet applications (EXCEL/Lotus etc.), together with many software programs developed specially for life cycle assessment. The appropriate program can be chosen depending on the kind and amount of data to be handled.

4.4.4 Validation of data

The validation of data has to be conducted during the data collection process in order to improve the overall data quality. Systematic data validation may point out areas where data quality must be improved or data must be found in similar processes or unit processes.

> During the process of data collection, a permanent and iterative check on data validity should be conducted. Validation may involve establishing, for example, mass balances, energy balances and/or comparative analysis of emission factors. Obvious anomalies in the data appearing from such validation procedures shall result in (alterna-

tive) data values complying with the data quality requirements as established (...).

For each data category and for each reporting location where missing data are identified, the treatment of the missing data should result in:

- an acceptable reported data value;
- a "zero" data value if justified; or
- a calculated value based on the reported values from unit processes employing similar technology

Data from similar processes or unit processes do often have a lower overall data quality. This can be reflected in the data quality index for the specific data-set.

4.4.5 Relating data

The fundamental input and output data are often delivered from industry in arbitrary units e.g. energy consumption as MJ/machine/week or emissions to the sewage system as mg metals/litre wastewater. The specific machine or wastewater stream is rarely connected to the production of the considered product alone but often to a number of similar products or perhaps to the whole production activity.

For each unit process, an appropriate reference flow shall be determined (e.g. one kilogram of material or one megajoule for energy). The quantitative input and output data of the unit process shall be calculated in relation to this reference flow.

Based on the refined flow chart and systems boundary, unit processes are interconnected to allow calculations of the complete system. This is accomplished by normalising the inputs and outputs of a unit process in the system to the functional unit and then normalising all upstream and downstream unit processes accordingly. The calculation should result in all system input and output data being referenced to the functional unit. Care should be taken when aggregating the inputs and outputs in the product system. The level of aggregation should be sufficient to satisfy the goal of the study.

Data categories should only be aggregated if they are related to equivalent substances and to similar environmental impacts. If more detailed aggregation rules are required, they should be justified in the goal and scope definition phase of the study or this should be left to a subsequent impact assessment phase.

The reference flow or functional unit shall be defined in order to describe and cover the actual production/function of the considered product e.g. by number of hours the actual machinery is in action per week or the actual emission of wastewater from the process. If this is not the case it will not be possible to relate data to the actual product.

4.4.6 Allocation and recycling

When performing a life cycle assessment of a complex system, it may not be possible to handle all the impacts and outputs inside the system boundaries. This problem can be solved either by:

1. expanding the system boundaries to include all the inputs and outputs, or by
2. allocating the relevant environmental impacts to the studied system

When avoiding allocation by e.g. expanding the system boundaries there is a risk of making the system too complex. The data collection, impact assessment and interpretation can then become too expensive and unrealistic in time and money. Allocation may be a better alternative, if an appropriate method can be found for solving the actual problem.

Since the inventory is intrinsically based on material balances between inputs and outputs, allocation procedures should approximate as much as possible such fundamental input-output relationships and characteristics. Some principles should be kept in mind when allocating loadings. They are general and thorough enough to be applicable to co-products, internal energy allocation, services (e.g. transport, waste treatment), and to recycling, either open or closed-loop:

- The product system under consideration seldom exists in isolation; it generally includes unit processes which may be shared with other product systems. The study should identify these unit processes and deal with them according to the procedures presented below.
- The inputs and outputs of the unallocated system shall equal the sum of the corresponding inputs and outputs of the allocated system. Any deviation from mass and energy balance shall be reported and explained.
- Whenever several alternative allocation

procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

Allocation can be necessary when dealing with:

- Multi-output "black box" processes, i.e. when more than one product is produced and some of those product flows are crossing the system boundaries.
- Multi-input processes, such as waste treatment, where a strict quantitative causality between inputs and emissions etc. seldom exists.
- Open-loop recycling, where a waste material leaving the system boundaries is used as a raw material by another system, outside the boundaries of the studied system.

On the basis of the principles presented above, the following descending order of allocation procedures is recommended:

1. Wherever possible, allocation should be avoided or minimised. This may be achieved by subdividing the unit process into two or more sub-processes, some of which can be excluded from the system under study. Transport and materials handling are examples of processes which can sometimes be partitioned in this way. For systems which deliver more than one product or function, or involve recycle streams, allocation may be avoided or reduced by including further unit processes thereby expanding the system boundaries so that inputs, outputs or recycles remain within the system.

2. Where allocation cannot be avoided, the system inputs and outputs should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they must reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. These "causal relationships" between flows into and out of the system may be represented by a process model, which can also represent the economic relationship of the system. The resulting allocation will not necessarily be in proportion to any simple measure such as mass or molar flows of co-products.

3. Where physical relationship cannot be established or used as the basis for allocation the inputs should be allocated between the products and functions in a way which reflects economic relationships between them. For example, burdens might be allocated between co-products in proportion to the economic value of the products.

Any deviation from these procedures shall be documented and justified.

Some inputs may be partly co-products and partly waste. In such case, it is necessary to identify the ratio between co-products and waste since burdens shall / are to be allocated to the co-product only.

There shall be uniform application of allocation procedures to similar inputs and outputs of the systems under consideration. For example if allocation is made to useable products (e.g. intermediate or discarded products) leaving the systems, then the allocation procedure shall be similar to the allocation method used for such products entering the systems. The allocation procedure may vary the allocation factor from 0 % to 100 %.

Lindfors et al. (1995c) suggest allocations should be based on the following guiding principle mentioned in descending order:

- natural causality or an adequate approximation
- economic / social causality e.g. expected gain or gross sales value
- physical parameters as allocation parameter e.g. mass of outputs, energy content of the output, exergy content of output, area of output, volume of output, molar content of output or arbitrary numbers (100 / 0 % or 50 / 50 %)

The 50 / 50 % allocation method is recommended for simplified LCA because the method ensure that information on "key issues" is not lost. This method can be used in allocation of environmental loadings caused by primary production, waste management and recycling processes.

Recycling of products implies that the environmental inputs and outputs associated with the manufacturing of a product and its recycling are to be shared by more than one product system.

> Any system in which recycling occurs, can usually be described as one of three different models:
>
> A. If sufficient information is available as to the proportion of recycled product that is used in another product system (the export ratio), an open-loop recycling approach can be chosen. Open-loop recycling is actually a special case of allocation (...).
>
> B. If sufficient information is available on the proportion of recycled product that is used in the same product system, a closed-loop recycling approach can be chosen. The recycled product replaces an amount of the virgin product.
>
> C. If sufficient information is available about how many times the same material is recycled (whether or not within the same product system), the "virgin" environmental inputs and outputs of each product cycle may be divided by the number of cycles which these material will undergo. The result will be added to the other environmental inputs and outputs of each single product cycle ("cascade recycling"). This model would comprise a sequence of models A and / or B.
>
> Claims regarding recycling shall be documented and justified and be based on actual practice rather than theoretical possibilities.

The detail and complexity of the allocation procedures to be used depend on the level of sophistication of the actual life cycle assessment.

4.5 Impact assessment

Impact assessment is the third phase in a life cycle assessment containing the following main issues:

- category definition
- classification
- characterization
- valuation / weighting

The elements are explained in relation to the Draft ISO standard CD 14042.1 (ISO, 1997c). The different impact categories are described briefly with reference to detailed descriptions of the methodologies. Weighting or equivalence factors are also presented where found appropriate.

The impact assessment can be expressed as a "quantitative and / or qualitative process to characterise and assess the effects of the environmental interventions identified in the inventory table" (Heijungs & Hofstetter, 1996). According to these authors, "the impact assessment component consists in principle of the following three or four elements: classification, characterization, (normalisation,) and valuation"; normalisation and valuation are sometimes merged. Valuation is proposed changed to weighting by ISO (ISO, 1997c) and this terminology has been adapted by the SETAC-Europe working group (Udo de Haes, 1996a). The terminology is presented in appendix 4.1.

The framework for life cycle impact assessment is defined as follows (ISO, 1997c):

> The life cycle impact assessment framework and its procedure should be transparent and provide the flexibility and practicality for this wide range of application. A large range in the levels of effort and intensity of the analysis are possible with life cycle assessment for different applications. In addition, impact assessment should be effective in terms of cost and resources used.
>
> Life cycle impact assessment is composed of several individual elements. These are category definition, classification, characterization, and weighting.
>
> The distinction into different elements is necessary for several reasons:
>
> - Each element represents a different specific procedure;
> - All elements are not required for all applications;
> - Methods, assumptions and value-choices can be made more transparent and can be documented and reviewed;
> - The effects of methods, assumptions, and value-choices on the results can be demonstrated.

Depending on the goal and scope of the study and on the application of the study all or parts of the elements can be used.

4.5.1 Category definition

The life cycle impact assessment involves as a first element the definition of the impact categories to be considered (ISO, 1997c). This is a follow-up of the decisions made in the goal and scoping phase. Based on the type of information collected in the inventory phase the boundaries defined in the goal and scoping may be redefined.

> The aim of this section is to provide guidance for selecting and defining the environmental categories.
>
> Numerous environmental categories have been proposed for life cycle impact assessment. Most studies will select from these previous efforts and will not define their own categories. The selection of categories should be consistent with the goal and scope of the study. This selection should not be used to avoid or disguise environmental issues or concerns. The completeness and extent of the survey of categories is goal and scope dependent.

The impact categories are selected in order to describe the impacts caused by the considered products or product systems. A number of questions have to be considered when selecting impact categories (Lindfors et al., 1995):

- Completeness - all environmental problems of relevance should be covered by the list
- Practicality - the list should not contain too many categories
- Independence - double counting should be avoided by choosing mutually independent impact categories
- Relation to the characterization step - the chosen impact categories should be related to available characterization methods

The impact categories considered are:

- Abiotic resources
- Biotic resources
- Land use
- Global warming
- Stratospheric ozone depletion
- Ecotoxicological impacts
- Human toxicological impacts
- Photochemical oxidant formation
- Acidification
- Eutrophication
- Work environment

The impact categories are described in details in appendix 4.2.

4.5.2 Classification

The life cycle impact assessment includes as a second element classification of the inventory input and output data (ISO, 1997c).

> The classification element aims to assign inventory input and output data to categories.
>
> The assignment of inventory data is the simplest or minimum level of life cycle impact assessment. This can be used to identify and flag issues associated with inventory input and output data. At this stage, there is an implicit assumption of 'less is better' and excludes several important considerations such as differences in potency or environmental persistence.

Classification is a qualitative step based on scientific analysis of relevant environmental processes. The classification has to assign the inventory input and output data to potential environmental impacts i.e. impact categories. Some outputs contribute to different impact categories and therefore, they have to be mentioned twice. The resulting double counting is acceptable if the effects are independent of each other whereas double counting of different effects in the same effect chain (e.g. stratospheric ozone depletion and human toxicological effects as e.g. skin cancer) is not allowed.

The impact categories can be placed on a scale dividing the categories into three (four) different space groups: global impacts, (continental impacts,) regional impacts and local impacts. The grouping is not unequivocal for all the impact categories exemplified by e.g. environmental toxicity which can be global, continental, regional as well as local. The impact categories is often related directly to exposure i.e. global exposure is leading to global impacts, continental exposure is leading to continental impacts. Some of the impact categories are strongly correlated with continental,

The "Leiden list" SETAC-Europe (1992)	SETAC "default list"[1] Udo de Haes (1996b)	"Nordic list" Lindfors et al. (1995c)	ISO preliminary list ISO (1997c)	Scale/comments
non-renewable	abiotic resources	energy and materials	abiotic resources	global
scarce, renewable	biotic resources		biotic resources	global
		water		
	land	land	land use	local
global warming	global warming	global warming	global warming / climate change	global
	depletion of stratospheric ozone	depletion of stratospheric ozone	stratospheric ozone depletion	global
human toxicity	human toxicological impact	human health, toxicological excl. work environment	human toxicity	global, continental, regional, local
		human health, non-toxicological excl. work environment		
occupational safety		human health impacts in work environment		local
environmental toxicity	ecotoxicological impacts	ecotoxicological impacts	ecotoxicity	global, continental, regional, local
photo-oxidant formation	photo-oxidant formation	photo-oxidant formation	photochemical oxidant formation (smog)	continental, regional, local
acidification	acidification	acidification	acidification	continental, regional, local
eutrophication	eutrophication (incl. BOD and heat)	eutrophication	eutrophication	continental, regional, local
COD (chemical oxygen demand) discharge				local
effects of waste heat on water				local
nuisance (smell, noise)	odour			local
	noise			local
	radiation			local, regional
space requirement				local
final solid waste (hazardous)				regional, local
final solid waste (non-hazardous)				regional, local
	casualties			local
		habitat alterations and impacts on biological diversity		local

1. The SETAC "default list" also mention some "flows not followed up to system boundary: input related (energy, materials, plantation woods etc.) and output related (solid wastes etc.)".

Table 4-3
Selected lists of impact categories; references are given in the list.

regional or local conditions i.e. some localities are more predisposed to certain impacts than other localities. Certain lakes in Scandinavia can be mentioned as examples of localities that are more predisposed to acidification than lakes in other parts of Europe. The time aspect is also important when considering certain impact categories e.g. global warming and stratospheric ozone depletion with time horizons on 20 to 500 years.

To date, consensus has not been reached for one single default list of impact categories. Therefore, the relevant impact categories may be selected from a preliminary list of examples. A number of suggestions for lists of impact categories with reference to the scale in which they are valid are shown in Table 4-3. Consensus about handling the impact categories has mainly been obtained for the global impacts. Development of methodologies for the other categories is still being discussed in different expert groups e.g. within the framework of SETAC.

4.5.3 Characterization

The life cycle impact assessment includes, as a third element, characterization of the inventory data (ISO, 1997c).

> The characterization of characterization is to model categories in terms of indicators, and, if possible, to provide a basis for the aggregation of the inventory input and output within the category. This is also done in terms of the indicator to represent an overall change or loading to that category. The result of characterization is that the combination of category indicators represents initial loading and resource depletion profile.
>
> Each category should have a specific model for the relationship between the input and output data and the indicator. The model should be based on scientific knowledge, where possible, but may have simplifying assumptions and value-choices. The representativeness and accuracy of each model depends on several factors, such as spatial and temporal compatibility of the category, with the inventory. The relationship between the inventory input and output data and the category indicator is normally strong (or within reach). The relationship between the indicator and the endpoint(s) is usually weaker and may be mainly qualitative.

The impact categories are described in detail in appendix 4.2 and the equivalence factors are described in the sub-chapter on the different impact categories and also presented in tables when found appropriate. Characterization is mainly a quantitative step based on scientific analysis of the relevant environmental processes. The characterization has to assign the relative contribution of each input and output to the selected impact categories. The potential contribution of each input and output to the environmental impacts has to be estimated. For some of the environmental impact categories there is consensus about equivalency factors to be used in the estimation of the total impact (e.g. global warming potentials, ozone depletion potentials etc.) whereas equivalence factors for other environmental impacts are not available at consensus level (e.g. biotic resources, land use etc.).

4.5.4 Valuation/Weighting

The previous element, characterization, results in a quantitative statement on different impact categories e.g. global warming, stratospheric ozone depletion and ecotoxicological effects. Comparison of these categories is not immediately possible. Therefore, the life cycle impact assessment includes as a fourth element a valuation / weighting of the impact categories against each other (ISO, 1997c).

> Weighting aims to rank, weight, or, possible, aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results. The weighting process is not technical, scientific, or objective as these various life cycle impact assessment results e.g., indicators for greenhouse gases or resource depletion, are not directly comparable. However, weighting may be assisted by applying scientifically-based analytical techniques. Weighting may be considered to address three basic aspects:
>
> - to express the relative preference of an organisation or group of stakeholders based on policies, goals or aims, and personal or group opinions or beliefs common to the group;
> - to ensure that process is visible, documentable, and reportable, and
> - to establish the relative importance of the results is based on the state of knowledge about these issues.

Weighting is a qualitative or quantitative step not necessarily based on natural science but often on political or ethical values. Weight-

ing has previously been referred to as valuation. Weighting methods have been developed by different institutions based on different principles (Lindeijer, 1996):

- "Proxy approach"
- "Technology abatement approach"
- "Monetarisation"
- "Authorized goals or standards" ("Distance to target")
- "Authoritative panels" ("Societal approach")

Proxy approach
In this approach one or several quantitative measures are stated to be indicative for the total environmental impact. Energy consumption, material displacement and space consumption are examples on using this approach.

Technology abatement approach
The possibility of reducing environmental burdens by using different technological abatement methods can be used to set a value on the specific environmental burden. This approach can be applied to inventory data as well as impact scores.

Monetarisation
This approach can be described with the following premises:

- "utilitarianism (values are measured by the aggregation of human preferences)
- willingness to pay / accept is an adequate measure of preferences
- values of environmental quality can be substituted by other commodities"

This approach can be applied to inventory data as well as impact scores.

Authorized goals or standards
Environmental standards and quality targets as well as political reduction targets can be used to calculate critical volumes for emissions to air, water, soil or work environment. The targets or standards can be formulated by national or local authorities, within a company etc.

Authoritative panels
The authoritative panel can be made up of lay people, of societal group panels, of scientific experts, of governments or international bodies. The credibility of a panel, according to Volkvein et al. (1996), can be improved by using:

1. "LCA-experts from different societal groups as panellists.
2. Peer reviewed sets of valuation criteria, rules for their application, a transparent ranking technique.
3. Documentation of the arguments leading to the final valuation."

The present methods - with some still under development "as a method" - are described briefly in Table 4-4.

The different methods focus on different impacts as can be illustrated by case studies in which the different methods have been tested.

4.6 Interpretation

Interpretation is the fourth phase in life cycle assessment containing the following main issues (ISO, 1997d):

- identification of significant environmental issues
- evaluation
- conclusions and recommendations

The different elements are explained in relation to the ISO standard. The ISO standard on interpretation is the least developed part of the standard and therefore the description below is expected to be revised when the standard is finally approved.

> Life cycle assessment interpretation is a systematic procedure to identify, qualify, check, and evaluate information from the conclusions of the inventory analysis and / or impact assessment of a 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 is also a process of communication designed to give credibility to the results of the more technical phases of LCA, namely the inventory analysis and the impact assessment, in a form which is both comprehensible and useful to the decision maker.

Interpretation is performed in interaction

Table 4-4
Different methods for weighting different impact categories (adapted from Lindeijer, 1996).

Method	Methodology	Characteristics/comments	Reference
Energy requirement	Equal energy requirement	Proxy	Franklin
MIPS	Equal material displacement	Proxy	Schmidt-Bleek (1994)
SPI	Equal space consumption	Proxy, Technology	
Abatement energy	Equal space consumption including energy for abatement of environmental burden	Technology	Cramer *et al.* (1993)
Abatement costs	Equal modelled costs for abating emissions according to national goals	Technology, monetarisation, authorized targets	Kroon *et al.* (1994)
Abatement costs/ The Tellus system	Equal costs for abating emissions, most human toxic emissions abatement costs extrapolated from characterization factors via lead (combining carcinogenic and non-carcinogenic substances via PEL values)	Monetarisation, authorized standards	Tellus Institute (1992)
DESC	Equal projected generic costs for abatement of Technology, monetarisation, burden according to national goals derived per impact category	Technology, monetarisation, authorized targets	Krozer (1992)
The EPS system	The EPS system is based on "willingness to pay" to restore the concerned effect to their normal status. The concerned effects are biodiversity, production, human health, resources and aesthetic values.	Monetarisation, technology. The willingness to pay/the weighing will be different from country to country.	Steen & Ryding (1992); Boström & Steen (1994)
The "Molar" method	Equal critical volume scores, the volume of each medium weighted according to their mole density	Authorized standards	Schaltegger & Sturm (1991)
The Critical volume" method	Equal critical volume scores weighted subjectively	Authorized standards	Kohlert & Thalmann (1992)
The "Critical surface time" method	Equal critical immission volumes weighted subjectively	Authorized standards	Jolliet (1994a)
The "Ecoscarcity" approach	Equal scores over proportional distances to political targets	Authorized standards	Ahbe et al. (1990)
The "Effect category" method			Baumann et al. (1993)
Distance to target	Equal scores of distances to political targets optionally additionally weighted subjectively	Authorized targets	Corten et al. (1994)
NSAEL	Equal scores of overshoots of sustainable targets optionally weighted subjectively	Authorized targets	Kortman et al. (1994)
The "Eco-indicator 95" method	Equal scores of distances to science-political targets contributing to the equally weighted safeguard subjects 1 on a million human lives, 95 % of ecosystems and human health complaints due to smog	Authorized targets	Goedkoop (1995)
Iso-utility functions	Equal panel scores on relative (negative) utilities of actual impact scores	Panel	Tukker (1994)
Iso-preference approach	Equal panel preferences for elasticities in relative impact scenarios	Panel	Heijungs (1994)
Delphi technique	Equal expert panel scores on actual impacts	Panel	Wilson & Jones (1994)
Questionnaire	Equal industry/science panel scores on impact categories	Panel	Nagata et al. (1995)
Panel questionnaire	Equal societal group panel scores on impact categories	Panel	Kortman et al. (1994)
Structured dialogue	Panel agreement on weights based on argumentation	Panel	Weidema (1994a)
Argumentative evaluation	Societal group consensus on the interpretation of product systems comparison with inputs from normalisation, environmental problem weights by a political panel and a sensitivity analysis	Panel	Schmitz et al. (1994)
Export panel prioritisation	Equal interpretation of product systems comparison using a qualitative valuation of normalisation data and expert panel scores on the criteria time, space and hazard	Panel	Volkwein et al. (1996)

with the three other phases of the life cycle assessment. If the results of the inventory analysis or the impact assessment is found not to fulfil the requirements defined in the goal and scoping phase, the inventory analysis must be improved by e.g. revising the system boundaries, further data collection etc. followed by an improved impact assessment. This iterative process must be repeated until the requirements in the goal and scoping phase are fulfilled as can be described by the following steps:

1. Identify the significant environmental issues.

2. Evaluate the methodology and results for completeness, sensitivity and consistency.

3. Check that conclusions are consistent with the requirements of the goal and scope of the study, including, in particular, data quality requirements, predefined assumptions and values, and application oriented requirements.

4. If so, report as final conclusions. If not, return to step 1 or 2.

This procedure has to be repeated until 3 is fulfilled.

The aim of interpretation is to reduce the number of quantified data and / or statements of the inventory analysis and / or impact assessment to the key results to facilitate a decision making process based on, among other inputs, the LCA study. This reduction should be robust to uncertainties in data and methodologies applied and give an acceptable coverage and representation of the preceding phases.

4.6.1 Identification of significant environmental issues

The first step in the identification is the selection of key results in a prudent and justifiable manner.

> The objective of this step is to structure the information from the inventory analysis and - if additionally conducted - from the life cycle impact assessment phase in order to determine the significant environmental issues in accordance with the goal and scope definition.
>
> Environmental issues are inputs and outputs i.e. results of the inventory phase and environmental indicators i.e. the results of the life cycle impact assessment phase if LCIA is conducted.
>
> Significant environmental issues are found to represent the most important results of the study in accordance with the goal and scope definition.

The identification step include structuring and presentation of relevant information:

- results from the different phases i.e. presentation of e.g. data from inventory analysis in tables, figures or diagrams etc. or presentation of results of the impact assessment
- methodological choices
- valuation methods used
- role and responsibility of different interested parties

Depending on the complexity of the LCA study the significant environmental issues of the considered system can be e.g. CO_2, NO_x, and SO_2 or they can be e.g. global warming, stratospheric ozone depletion, ecotoxicological and human toxicological impacts etc.

4.6.2 Evaluation

The second step, involving three elements, is firstly to conduct a qualitative check of the selection of data, processes etc. e.g. to discuss the possible consequences of leaving out information, secondly to apply a systematic qualitative or quantitative analysis of any implications of changes in the input data (directly as data uncertainty and indirectly caused by methodological or epistemological uncertainties), and thirdly to discuss the variations identified in the frame of the goal and scope, e.g. the data quality goals of the study.

> The objective of this step is to establish confidence in the result of the study, based on the preceding LCA phases, and on the significant environmental issues identified in the first step of the interpretation. The results should be presented in such a form as to give the commissioner or any interested party a clear and understandable view of the outcome of the study.
>
> The evaluation shall be undertaken in accordance with the goal and scope, and should take into account the final use of the study.
>
> The interpretation made at this stage shall be

reinforced by the facts and calculations brought forward in at least the three following elements:

1. completeness check;
2. sensitivity check;
3. consistency check.

and supplemented by results of:

- uncertainty analysis and
- data quality assessment

The methodology for the above mentioned elements in the evaluation step is only developed to a limited degree. Below completeness, sensitivity and consistency check are described briefly.

Completeness check
Completeness check is a qualitative procedure.

The objective of this first element in the evaluation step is to ensure that the significant environmental issues previously identified adequately represent the information from the different LCA phases (inventory analysis, impact assessment) in accordance with the goal and scope defined.

The procedure focus on the information collected in the inventory phase. In many LCA studies there will be some data sets that are unavailable or incomplete i.e. there will be a data gab unless necessary resources are used to improve the data set. The completeness check has to decide whether it is necessary to complete the data set. If the data set is important according to the defined environmental issues, the data collection can be improved or the goal and scope definition can be revised.

Sensitivity check
Sensitivity check involves a systematic procedure for estimating the effects of variations in parameters to the outcome of the study with the aim to establish a required degree of confidence in the results of the study relative to its overall goal.

The objective of this step is:
- to review the results of the sensitivity analyses and uncertainty analyses that were performed in the different phases (inventory analysis, impact assessment), and
- to assess if the significant environmental issues, previously identified as the most important ones, are found to exceed the acceptable variations stated in the goal and the scope of the study.

By conducting a sensitivity analysis, the stability of those parameters are checked.

The sensitivity analysis can be done by making a kind of “what if” scenario, where the value of different input parameters are changes systematically. A more proper way to do sensitivity analysis is to change the input parameters systematically by using simulations (e.g. Monte Carlo simulations).

Consistency check
Consistency check is also a qualitative procedure.

The objective of this element of the evaluation step is to conduct a thorough check on the consistency of methods, procedures and treatment of data used throughout the study.

The procedure has to test whether methods etc. have been used consistently and especially within comparative studies. The following items are subjects for consistence check:

- regional and / or temporal differentiations
- system boundaries
- allocation methods
- differentiation between foreground and background processes
- valuation / weighting methods

The completeness, sensitivity and consistency check can be supplemented by the results of uncertainty analysis and data quality assessment. Both are performed throughout the study as they are closely related to the individual data and calculations. The conclusions of the uncertainty analysis and data quality assessment are important in the process of interpretation of the data and the results of the calculations.

4.6.3 Conclusions and recommendations
The final step of the interpretation is more or less similar to the traditional concluding and recommending part of a scientific and technical assessment, investigation or alike.

The aim of this third step of the interpreta-

tion is to reach conclusions and recommendations for the report of the LCA study or life cycle inventory study.

This step is important to improve the reporting and the transparency of the study. Both are essential for the readers of the LCA report.

The results of the critical review of the study shall also be included when presenting the conclusions and recommendations.

4.7 References (chapter 3 and 4)

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Appendix 4.1:

Terminology

Terminology used in life cycle assessment as defined by ISO (ISO, 1997a; 1997b; 1997d) and SETAC Europe (modified from Heijungs & Hofstetter, 1996). The list is preliminary, as ISO work is still in progress.

Abiotic resource Object that can be extracted from the environment to serve as an input for the product system, and is distinguished from a biotic resource by its non-living nature.

Allocation Partitioning the input or output flows of a process to the product system under study.

Ancillary input Material input that is used by the unit process producing the product, but is not used directly as a part of the product.

Areas for protection Broad social values with respect to the environmental policy (e.g. human health, ecological health, biodiversity, intergenerational material welfare, aesthetic values).

Biotic resource Object that can be extracted from the environment to serve as an input for the product system, and that is distinguished from an abiotic resource by its living nature.

Characterization Second element within impact assessment succeeding the classification element and preceding valuation, in which analysis / quantification, and aggregation of the impacts within the chosen impact categories takes place.

Characterization factor (exposure factor, effect factor, exposure-effect actor, equivalence factor) A factor which expresses the contribution of a unit environmental intervention (such as the atmospheric emission of 1 kg CFC-11) to the chosen impact categories (such as global warming and ozone depletion).

Classification First element within impact assessment, which attributes the environmental interventions listed in the inventory table to a number of selected impact categories.

Comparative assertion Environmental claim regarding the superiority or equivalence of one product versus a competing product which performs the same function.

Completeness check Process of verifying that information from the different phases (inventory analysis, life cycle impact assessment) are sufficient for interpretation to reach conclusions

Conclusions and recommendations Conclusions summarise the identification and evaluation of significant environmental issues. Recommendations are those features that arise directly from conclusions, given the goal of the study.

Consistency check Process of verifying that the interpretation is done in accordance with the goal and scope definition, before conclusions are reached.

Co-product Any of two or more products coming from the same unit process.

Data category Classificatory division of the input and output flows from a unit process or product system.

Data quality Nature or characteristics of collected or integrated data.

Effect A specific change in human health, in eco-system or the global resource situation as a consequence of a specific impact.

Elementary flow 1) Material or energy entering the system being studied, which has been drawn from the environment without previous human transformation 2) Material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation.

Energy flow Input flow to or output flow from a unit process or product system measured in units of energy.

Environment Entire surroundings and conditions in which individuals, populations and organisations operate and interrelate. The surroundings include air, water, land, natural resources, flora, fauna and humans and extends from within an organisation's location to the global system.

Environmental aspect Element of an organisation's activities, products or services which can interact with the environment.

Environmental index Resulting score representing the perceived harmfulness to the environment, obtained by quantitative weighting as a result of the valuation element.

Environmental intervention (environmental flow, environmental burden, stressor, elementary flow) Exchange between the atmosphere (the "economy") and the environment including resource use, emissions to air, water, or soil.

Environmental issue Inputs and outputs (results from the LCI) and - if additionally conducted-environmental indicators (results from the LCIA), which are defined in general terms as being important in the goal and scope definition.

Evaluation It is the second step within the life cycle interpretation including completeness check, sensitivity check, consistency check, other checks.

Feedstock energy Gross combustion heat of raw material inputs, which are not used as an energy source, to a product system.

Final product Product which requires no additional transformation prior to its use.

Fugitive releases Uncontrolled emission to air, water or land.

Functional unit Quantified performance of a product system for use as a reference unit in a life cycle assessment study.

Goal and scope definition Activity that initiates an LCA, defining its purpose, boundaries, limitations, main lines and procedures (see above).

Impact The consequences for health, for the well-being of flora and fauna or for the future availability of natural resources, attributable to the input and output streams of a system.

Impact vs. effect Most of the environmental problems treated in present characterization methods are quantified at the level of environmental impacts (e.g., ozone formation, H^+ deposition, ozone depletion, rise of radiate forcing). Environmental effects are the chosen endpoints within these impact chains (e.g., reduced human health, reduced growth of crop, dying of plants, reduced biodiversity etc.). This means that all steps in the cause-effect chain are impacts while effects are the chosen endpoints.

Impact assessment (life cycle impact assessment) Quantitative and / or qualitative process to characterise and assess the effects of the environmental interventions identified in the inventory table. The impact assessment component consists in principle of the following three or four elements: classification, characterization, (normalisation,) and valuation.

Impact category (problem type, environmental problem, environmental theme) Chosen level in the cause-effect chain of the considered environmental effect type, relating somehow to the areas for protection. The impact score profile gives the scores for the impact categories.

Impact score Contribution of a product system to one impact category.

Impact score profile (environmental profile) List of impact scores for all impact categories.

Indicator A simplification and distillation of complex information intended as a summary description of conditions or trends to assist decisions.

Input Material or energy which enters a unit process - material may include raw materials and products.

Interested party Individual or group concerned with or affected by the environmental performance of a product system, or by the results of the life cycle assessment.

Intermediate product Input or output from a unit process which requires further transformation.

Inventory table List of environmental entities added to and taken from the environment (environmental interventions) through economic actions which are directly caused by processes within a product system. It is the main result of the inventory analysis.

Life cycle Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal.

Life cycle assessment Compilation and evaluation of the inputs, outputs and the

potential environmental impacts of a product system throughout its life cycle.

Life cycle impact assessment Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

Life cycle interpretation Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined in line with the defined goal and scope in order to reach conclusions and recommendations.

Life cycle inventory analysis Phase of life cycle assessment involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle.

Normalisation An optional element within impact assessment which involves relating all impact scores of a functional unit in the impact score profile to a reference situation. The reference situation may differ per impact category, and is the contribution of a certain period of time to the problem type at hand. Normalisation results in a normalised impact score profile which consists of normalised impact scores.

Output Material or energy which leaves a unit process - material may include raw materials, products, emissions and waste.

Practitioner Individual or group of people that conducts a life cycle assessment.

Process energy Energy input required to a unit process to operate the process or equipment within the process excluding production and delivery energy.

Process flow diagram Chart containing label led boxes connected by lines with directional arrows to illustrate the unit process or subsystem included in the product system and the interrelationships between those unit processes.

Product system Collection of materially and energetically connected unit processes which performs one or more defined functions - in the ISO standard, the term “product” used alone not only includes product systems but also can include service systems.

Production and delivery of energy The energy input into processes which extract, generate, process, refine and deliver process energy.

Raw material Primary or secondary material that is used to produce a product.

Recycling, closed loop Recovery of material on the same factory that produced the material. This kind of recovery require a “take back” arrangement.

Recycling, open loop Recovery of material - but not on the same factory as produced the material. This kind of recovery require a central collection of used material.

Sensitivity analysis Systematic procedure for estimating the effects on the outcome of a study of the chosen methods and data and uncertainty therein.

System boundary Interface between a product system and the environment or other product systems.

Transparency Open, comprehensive and understandable presentation of information.

Uncertainty analysis A systematic procedure to ascertain and quantify the uncertainty introduced in the results of a LCI due to the cumulative effects of input uncertainty and data variability. It uses either ranges or probability distributions to determine uncertainty in the results.

Unit-process Smallest portion of a product system for which data are collected when performing a life cycle assessment.

Valuation / weighting Last element within impact assessment following the characterization / normalisation element, in which the results of the characterization / normalisation, in particular the (normalised) impact scores, are weighted against each other in a quantitative and / or qualitative way in order to be able to make the impact information more decision-friendly. This is an element which necessarily involves qualitative or quantitative valuations which are not only based on natural sciences. For instance, political and / or ethical values can be used in this element. The valuation can result in an environmental index.

Valuation factor Factor in the evaluation element transforming the impact score profile in an environmental index.

Waste Any output from the product system which is disposed of.

Appendix 4.2:

Impact categories

Description of impact categories
The different impact categories mentioned in the preliminary ISO list supplemented with relevant other categories e.g. "work environment" will be described briefly below with examples on potential effects:

- abiotic resources
- biotic resources
- land use
- global warming
- stratospheric ozone depletion
- ecotoxicological impacts
- human toxicological impacts
- photochemical oxidant formation
- acidification
- eutrophication
- work environment

It shall be stressed that international consensus not has been reached for treatment of all the impact categories, and that the description of different approaches can not be considered as complete but as selected examples.

Equivalence factors for relating relevant inputs and outputs to the impact categories will be presented in tables. References to more detailed descriptions of the impact categories and practical uses of the different categories will be given, where possible.

Abiotic resources
Abiotic resources cover three subcategories (Finnveden, 1996):

- deposits e.g. fossil fuels, mineral ores, aquifers, sediments, clay, peat, gravel etc.
- funds e.g. ground water, lake water, soil
- natural flow resources e.g. air, water, solar radiation and ocean currents

Deposits such as mineral ores are considered to be limited resources because they are not renewable within a relevant time horizon. According to US Bureau of Mines the mineral deposits can be divided into known deposits and not yet found deposits. The known deposits can be divided into approved deposits and supposed deposits and the not yet found deposits can be divided into hypothetical and speculative deposits. The known deposits constitute a reserve that is profitable to extract and a reserve base that is marginal, profitable or sub-economic to extract (Møller & Schmidt, 1994). For a number of minerals, metals and fossil fuels the "reserve to use" ratio can be used in the assessment of the actual impact category (Lindfors et al., 1995). The weighting factor W_{ij} can be expressed as:

$$W_{ij} = \frac{1}{U_j} = \frac{G_j}{R_j}$$

where R_j is the reserve of mineral j and G_j is the current global consumption and U_j is the reserve to use ratio.

Biotic resources
Abiotic resources cover one subcategory (Finnveden, 1996):

- funds e.g. fauna (fish etc.) and flora

The biotic funds can be harvested in a non-sustainable and a sustainable way. As an example, harvesting of forests can be mentioned. In many areas (e.g. rain forests in the tropics) the harvest of the wood is faster than the growth, leading to resource depletion or increased competition between species. In other areas (e.g. softwood forests in Scandinavia) the harvest of wood is slower than the planting and growth of trees. Overuse of environmental resources may also influence ecosystem e.g. the species or genetic diversity, leading to irreversible loss of genetic material.

Land use
Land use and transformation can be seen from two perspectives (Finnveden, 1996):

- land as a resource for humans, i.e. area for e.g. food production
- land use related to ecosystem and land-

scape degradation, landscape fragmentation, desiccation, habitat alterations and impacts on e.g. biodiversity

Land use and transformation can be a reversible effect, but within small to large time frames.

Global warming

Global warming - or the "greenhouse effect" - is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected by the soil surface but the content of carbon dioxide (CO_2), and other "greenhouse" gasses (e.g. methane (CH_4), nitrogen dioxide (NO_2), chlorofluorocarbons etc.) in the atmosphere reflects the IR-radiation resulting in the greenhouse effect i.e. an increase of temperature in the lower atmosphere to a level above normal. The possible consequences of the greenhouse effect include an increase of the temperature level leading to melting of the polar ice caps, resulting in elevated sea levels. The increasing temperature level may also result in regional climate changes.

The potential global warming or greenhouse effect is normally quantified by using *global warming potentials* (GWP) for substances having the same effect as CO_2 in reflection of heat radiation. GWP for greenhouse gases are expressed as CO_2-equivalents i.e. their effect are expressed relatively to the effect of CO_2. Global warming potentials are developed by the "Intergovernmental Panel on Climatic Change" (IPCC) for a number of substances (Albritton et al., 1996). GWPs are normally based on modelling and are quantified for time horizons of 20, 100 or 500 years for a number of known greenhouse gasses (e.g. CO_2, CH_4, N_2O, CFCs, HCFCs, HFCs and several halogenated hydrocarbons etc.).

Hauschild & Wenzel (1997a) suggest modelling and quantification of GWP for indirect effects of e.g. VOCs of petrochemical origin by using their photochemical ozone creation potential (POCP) as shown in the following formula:

$$GWP(O_3)_{gas(i)} = GWP(O_3)_{CO} \frac{POCP_{gas(i)}}{POCP_{CO}}$$

where $GWP(O_3)_{gas(i)}$ express the GWP of tropospheric oxidation of gas i, $GWP(O_3)_{CO}$ express GWP of CO, $POCP_{gas(i)}$ express the total photochemical formation of ozone by oxidation of gas i, and $POCP_{CO}$ express the formation of ozone by oxidation of CO.

GWP for known greenhouse gases are shown in Table 4-5.

The potential greenhouse effect of a process can be estimated by calculating the product of the amount of emitted greenhouse gas per kg produced material and the potential for greenhouse effect given in kg CO_2-equivalents per kg for each gas. Finally, the contribution to the potential greenhouse effect from each gas has to be summarised. This calculation procedure can be expressed mathematically as:

Potential greenhouse effect (kg CO_2-eq.) = $\Sigma_i GWP_i \times m_i$

If a specific time horizon cannot be chosen and justified in the goal definition it is suggested to estimate the greenhouse effect based on GWPs for 20, 100 as well as 500 years (Lindfors et al., 1995c).

Stratospheric ozone depletion

Decomposition of the stratospheric ozone layer will cause increased incoming UV-radiation leading to impacts on humans such as increased levels of e.g. skin cancer, cataracts and decreased immune defence, but also impacts on natural organisms and ecosystems e.g. plankton in the South Pole region, where the decomposition of the ozone layer is already significant.

The stratospheric ozone layer occurs at an altitude from 10 - 40 km, with maximum concentration from 15 - 25 km. The maximal generation of stratospheric ozone (O_3) occur in the top of the stratosphere at the altitude of 40 km as a result of a reaction of molecular oxygen (O_2) and atomic oxygen (O). The reaction depends on the UV-radiation used in the decomposition of oxygen and the availability of other molecules used in the absorption of excess energy from the decomposition process.

The decomposition of ozone is enhanced by the stratospheric input of anthropogenic halogenated compounds (e.g. CFCs, HCFCs, halons etc.). Ozone depletion potentials (ODP) have been presented by the World Meteorological Organisation (WMO) for a number of halogenated compounds (Solomon & Wuebbles, 1995; Pyle et al., 1991). The ODPs are given as CFC-11 equivalents i.e.:

Table 4-5

Global warming potentials (GWP) given in kg CO_2-eq./kg gas (Albritton et al., 1996).

Substance	Formula	GWP, 20 years	GWP, 100 years	GWP, 500 years	Life time, years
Carbon dioxide	CO_2	1	1	1	150
Methane	CH_4	62	25	7.5	10
Nitrogen dioxide	NO_2	290	320	180	120
Tetrachloromethane	CCl_4	2,000	1,400	500	42
Trichloromethane	$CHCl_3$	15	5	1	0.55
Dichloromethane	CH_2Cl_2	28	9	3	0.41
Chloromethane	CH_3Cl	92	25	9	0.7
1,1,1-Trichloroethane	CH_3CCl_3	360	110	35	5.4
Tetrafluoromethane	CF_4	4,100	6,300	9,800	50,000
Hexafluoroethane	C_2F_6	8,200	12,500	19,100	10,000
CFC-11	$CFCl_3$	5,000	4,000	1,400	50
CFC-12	CF_2Cl_2	7,900	8,500	4,200	102
CFC-13	CF_3Cl	8,100	11,700	13,600	640
CFC-113	$CF_2ClCFCl_2$	5,000	5,000	2,300	85
CFC-114	CF_2ClCF_2Cl	6,900	9,300	8,300	300
CFC-115	CF_2ClCF_3	6,200	9,300	13,000	1,700
HCFC-22	CHF_2Cl	4,300	1,700	520	13
HCFC-123	CF_3CHCl_2	300	93	29	1.4
HCFC-124	CF_3CHFCl	1,500	480	150	5.9
HCFC-141b	$CFCl_2CH_3$	1,800	630	200	9.4
HCFC-142b	CF_2ClCH_3	4,200	2,000	630	19.5
HCFC-225ca	$C_3F_5HCl_2$	550	170	52	2.5
HCFC-225cb	$C_3F_5HCl_2$	1,700	530	170	6.6
HFC-23	CHF_3	9,200	12,100	9,900	250
HFC-32	CH_2F_2	1,800	580	180	6
HFC-43-10me	$C_5H_2F_{10}$	3,300	1,600	520	21
HFC-125	CF_3CHF_2	4,800	3,200	1,100	36
HFC-134	CHF_2CHF_2	3,100	1,200	370	12
HFC-134a	CH_2FCF_3	3,300	1,300	420	14
HFC-143	CHF_2CH_2F	950	290	90	3.5
HFC-143	CF_3CH_3	5,200	4,400	1,600	55
HFC-152a	CHF_2CH_3	460	140	44	1.5
HFC-227ea	C_3HF_7	4,500	3,300	1,100	41
HFC-236fa	$C_3H_2F_6$	6,100	8,000	6,600	250
HFC-245ca	$C_3H_3F_5$	1,900	610	190	7
Halon 1301	CF_3Br	6,200	5,600	2,200	65
Sulfur hexafluoride	SF_6	16,500	24,900	36,500	3,200
Carbon monoxide	CO	-	-	-	months
non-Methane VOC	-	-	-	-	days-months
Nitrogen oxides	NO_x	-	-	-	days

$$ODP_i = \frac{\textit{modelled stratospehic ozone depletion due to compound } i}{\textit{modelled stratospehic ozone depletion due to same quantity of CFC-11}}$$

ODPs are presented in Table 4-6 for CFCs, HCFCs and halons.

The potential depletion of stratospheric ozone as an effect of certain process can be estimated by summarising the ODPs:

Stratospheric ozone depletion potential (kg CFC-11 equivalents) = $S_i\ ODP_i \acute{}\ m_i$

Ecotoxicological impacts

Ecotoxicological impacts depend on exposures to and effects of chemical and biological substances. The potential effects on ecosystems depend on the actual emission and fate of the specific substances emitted to the environment. An effect factor is proposed in the following formula for effect scores (S).

$$S_i^{nm} = E_i^m F_i^{nm} M_i^n$$

M is the emission of a substance i to an initial medium n (air, water or soil), E is effect factor for a substance i in the medium m (air, water, soil or food chain), and F is fate and exposure factor for a substance i emitted to an initial medium n and transferred to compartment m.

The fate of chemical substances depend on:

- degradation rate (aerobic / anaerobic, hydrolytic / photolytic)
- bioaccumulation
- evaporation
- deposition

The degradation rate will affect both the possibility of the substance to reacting the target organism and the kind of toxic effect. Readily degradable substances can show acute toxic effects depending on the degradation type and rate in the actual medium, whereas substances which are not readily degradable can bioaccumulate in the environment and / or show chronic toxic effects. The rates of evaporation / deposition will affect the transfer of substances between the different mediums e.g. air, water, soil or food chains), e.g. in aeration of leads to evaporation of volatile substances from the water, and thereby protecting the biological processes in the wastewater treatment plant against potential toxic or inhibitory effects but also burdening the surroundings.

One way of assessing the potential ecotoxicological effects of chemical substances is to use the criteria for classification of substances as "Dangerous for the Environment" (indicated by the symbol N) (EEC, 1993):

- biodegradation
- bioaccumulation
- aquatic toxicity (acute / chronic)
- terrestrial toxicity

Criteria already exist for assessing biodegradation, bioaccumulation and aquatic effects whereas no formalised criteria have been developed for terrestrial toxicity. Guidance to the actual assessment procedure can be found in Pedersen et al. (1995).

A number of different methods addressing chemical fate, route of exposure and toxicological effect into account have been developed:

- Quantitative approach with partial fate analysis (Lindfors et al., 1995; Finnveden et al., 1992)
- MUP-method (Jensen et al., 1994)
- EDIP-method (Hauschild et al., 1997a)
- The "ecotoxicity potential approach" (Guinée & Heijungs, 1993; Guinée et al., 1996)
- The "provisional method" (Heijungs et al., 1992)

The present methods are described briefly in Table 4-7.

International consensus on specific methods for assessing ecotoxicological impacts has not yet been reached and development of some of the methods is still in progress. It is therefore recommended to use different methods when assessing potential ecotoxicological impacts for a specific data-set.

Human toxicological impacts

The impact category "human toxicological impacts" is another of the most difficult categories to handle. Human toxicological impacts depend on exposure to and effects

Table 4-6

Ozone depletion potentials (OPD) given in kg CFC-11 equivalents/kg gas (Solomon & Wuebbles, 1995; Pyle et al., 1991; Solomon & Albritton, 1992).

Substance	Formula	Life time, years	Total ODP	5 years	10 years	15 years	20 years	30 years	40 years	100 years	500 years
CFC-11	$CFCl_3$	50±5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CFC-12	CF_2Cl_2	102	0.82	-	-	-	-	-	-	-	-
CFC-113 C	$CF_2ClCFCl_2$	85	0.90	0.55	0.56	0.58	0.59	0.62	0.64	0.78	1.09
FC-114	CF_2ClCF_2Cl	300	0.85	-	-	-	-	-	-	-	-
CFC-115	CF_2ClCF_3	1,700	0.40	-	-	-	-	-	-	-	-
Tetrachloromethane	CCl_4	42	1.20	1.26	1.25	1.24	1.23	1.22	1.20	1.14	1.08
HCFC-22	CHF_2Cl	13.3	0.04	0.19	0.17	0.15	0.14	0.12	0.10	0.07	0.05
HCFC-123	CF_3CHCl_2	1.4	0.014	0.51	0.19	0.11	0.08	0.06	0.04	0.03	0.02
HCFC-124	CF_3CHFCl	5.9	0.03	0.17	0.12	0.10	0.08	0.06	0.05	0.03	0.02
HCFC-141b	$CFCl_2CH_3$	9.4	0.10	0.54	0.45	0.38	0.33	0.26	0.22	0.13	0.11
HCFC-142b	CF_2ClCH_3	19.5	0.05	0.17	0.16	0.15	0.14	0.13	0.12	0.08	0.07
HCFC-225ca	$C_3F_5HCl_2$	2.5	0.02	0.42	0.21	0.14	0.10	0.07	0.05	0.03	0.02
HCFC-225cb	$C_3F_5HCl_2$	6.6	0.02	0.21	0.17	0.14	0.11	0.09	0.07	0.04	0.03
1,1,1-Trichlorethan	CH_3CCl_3	5.4±0.4	0.12	1.03	0.75	0.57	0.45	0.32	0.26	0.15	0.12
Halon 1301	CF_3Br	65	12	10.3	10.4	10.5	10.5	10.7	10.8	11.5	12.5
Halon 1211	CF_2ClBr	20	5.1	11.3	10.5	9.7	9.0	8.0	7.1	4.9	4.1
Halon 1202	CF_2Br_2		~1.25	12.8	12.2	11.6	11.0	10.1	9.4	7.0	5.9
Halon 2402	CF_2BrCF_2Br	25	~7	-	-	-	-	-	-	-	-
HBFC 1201	CF_2HBr		~1.4	-	-	-	-	-	-	-	-
HBFC 2401	CF_3CHFBr		~0.25	-	-	-	-	-	-	-	-
HBFC 2311	$CF_3CHClBr$		~0.14	-	-	-	-	-	-	-	-
Methylbromid	CH_3Br	1.3	0.64	15.3	5.4	3.1	2.3	1.5	1.2	0.69	0.57

Table 4-7

Different methods for the assessment of ecotoxicological impacts.

Method	Effects concerned	Criteria/comments	Reference
Quantitative approach with partial fate analysis based on EEC directives	1) Acute toxicity 2) Acute toxicity for not readily degradable compounds 3) Potential bioconcentration 4) Potential bioconcentration for not readily degradable compounds	EEC criteria for degradability.	Lindfors et al. (1995)/ Finnveden et al. (1992)
MUP-method	1) Acute toxicity 2) Potential bioconcentration 3) Biodegradability	EEC criteria for classification of substances as dangerous for the environment (EEC, 1993).	Jensen et al. (1994)
Quantitative approach with partial fate analysis	1) Acute, aquatic toxicity 2) Chronic, aquatic toxicity 3) Chronic, terrestrial toxicity 4) Acute toxicity to wastewater treatment plants	Critical volume. The fate analysis includes evaporation, deposition, and degradation. The ecotoxicity factors are based on PNEC for acute aquatic, chronic aquatic and terrestrial toxicity, and LOEC for micro-organisms in wastewater treatment plants.	Hauschild et al. (1997a)
The "ecotoxicity potential approach"	1) Terrestrial ecotoxicity 2) Aquatic ecotoxicity		Guinée & Heijungs (1993)/ Guinée et al. (1996)
The "provisional method"	1) Terrestrial ecotoxicity 2) Aquatic ecotoxicity	The provisional classification factors for ecotoxicity are derived from NOEC or LC_{50} multiplied by a safety factor. The classification factors are expressed by m^3 water/mg substance and kg soil/mg substance leading to results as m^3 polluted water and kg polluted soil .	Heijungs et al. (1992)

of chemical and biological substances. The potential effect on humans depends as for ecotoxicological impacts on the actual emission and fate of the specific substances emitted to the environment.

The human toxicological effects can be:

- acute toxicological effects
- irritation
- allergenic reactions
- genotoxicity
- carcinogenicity
- neurotoxicity
- teratogenicity

A number of different methods trying more or less to take chemical fate, route of exposure and toxicological effect into account has been developed. A screening procedure can be used to focus on the most dangerous substances which can be assessed by using a more detailed procedure (e.g. Hauschild et al., 1997b).

- Critical volumes (BUS, 1984; Habersatter, 1991)
- The "provisional method" (Heijungs et al., 1992)
- The Tellus method (Tellus Institute, 1992)
- The MUP-method (Jelnes et al., 1994; Schmidt et al., 1994b))
- The "toxicity potential approach" (Guinée & Heijungs, 1993; Guinée et al., 1996)
- The "critical surface-time (Jolliet 1994a;b; Jolliet & Crettaz, 1996)
- The EDIP method (Hauschild et al., 1997b)

The present methods are described briefly in Table 4-8.

International consensus on specific methods for assessing toxicological impacts has not yet been reached and development of some of the methods is still in progress. It is therefore recommended to use different methods when assessing potential toxicological impacts for a specific data-set.

Photochemical oxidant formation (smog)

Photochemical ozone formation is caused by degradation of organic compounds (VOC) in the presence of light and nitrogen oxide (NO_x) ("smog" as a local impact and "tropospheric ozone" as a regional impact). The biological effects of photochemical ozone can be attributed to biochemical effects of reactive ozone compounds. Exposure of plants to ozone may result in damage of the leaf surface, leading to damage of the photosynthetic function, discolouring of the leaves, dieback of leaves and finally the whole plant. Exposure of humans to ozone may result in eye irritation, respiratory problems, and chronic damage of the respiratory system.

The reaction can be described in a simplified way in terms of four steps (Nichols et al., 1996; Hauschild & Wenzel, 1997c):

1. Reaction between organic compounds (VOC) and hydroxyl radicals (OH) to form organic peroxy radicals
2. The peroxy radicals react with nitrogen oxide (NO) to form nitrogen dioxide (NO_2)
3. Nitrogen dioxide (NO_2) react in the presence of sunlight to form nitrogen oxide (NO) and oxygen atoms
4. Atomic oxygen reacts with oxygen (O_2) to form ozone (O_3)

The photochemical ozone formation can be quantified by using photochemical ozone creation potentials (POCP) for organic compounds. POCPs for organic compounds are expressed as ethylene (C_2H_4) equivalents i.e. their impacts are expressed relative to the effect of C_2H_4. POCP-values can be calculated in different ways as proposed by Andersson-Sköld et al. (1992) and by Heijungs et al. (1992). Andersson-Sköld et al. (1992) give the POCPs for three different scenarios:

1. Maximum differences in concentration
2. Ordinary Swedish background (NO_x) during 0 - 4 days
3. High NO_x background during 0 - 4 days

Heijungs et al. (1992) provide POCPs

Table 4-8
Different methods for the assessment of human toxicological impacts.

Method	Effects concerned	Criteria/comments	Reference
Critical volumes	Water and air pollution	The critical air volume are based on MIK-values ("Maximale Immissions-Konzentration") or MAK-values ("Maximale Arbeitsplatzkonzentration"). The critical water volume are based on (Swiss) directives for emissions into surface water.	BUS (1984)/ Habersatter (1991)
The "provisional method"	Human toxicity (not specified) - exposure by air, water and soil	The provisional classification factors for human toxicity are derived from TCL (acceptable concentration in air), AQG (air quality guideline), TDI (tolerable daily intake) or ADI (acceptable daily intake). The classification factors are expressed by kg body weight/kg substance.	Heijungs et al. (1992)
The Tellus method	Carcinogenic potency Non-carcinogenic effects Combined	Classification factors for carcinogenic potency is expressed as "isophorone equivalents" and for non-carcinogenic effects as "xylene equivalents". Classification factors for the combined effects are derived from permissible exposure levels for the two effects.	Tellus Institute (1992)
The MUP-method	Irritation Allergenic reactions Organotoxicity Genotoxicity Carcinogenicity Neurotoxicity Teratogenicity	The method is based on exposure estimated. The method cover a screening LCA with qualitative results.	Jelnes et al. (1994)/ Schmidt et al. (1994b)
The "toxicity potential approach"			Guinée & Heijungs (1993)/Guinée et al. (1996)
The "critical surface-time"			Jolliet (1994a;b) Jolliet & Crettaz, 1996)
Quantitative approach	Acute toxicity (inhalation) Acute toxicity (oral intake)	Critical volume. The fate analysis include evaporation, deposition, and degradation. The human toxicology factors are based on LC_{50}/LD_{50}, LC_{Lo}/LD_{Lo} (Lethal Concentration/ Dose Low) or LOAEL (Lowest Observed Adverse Effect Level) for test animals, or LC_{Lo}/LD_{Lo},, NOAEL (No Observed Adverse Effect Level) or LOAEL for humans with partial fate analysis	Hauschild et al. (1997b)

calculated as the contribution to ozone formation at peak ozone formation based on average of data from three different locations in Europe. POCPs according to different models are given in Table 4-9.

The photochemical ozone creation potential of certain processes can be estimated by summarising the POCPs for the VOCs:

$$\text{POCP (kg ethylene equivalents)} = S_i \, POCP_i \acute{} \, m_i$$

A method considering only POCPs for VOCs is not sufficient to describe the impact category. A possible approach can be to divide the category in two subcategories: one category for nitrogen oxides (aggregated as NO_x) and one category for VOC (aggregated with POCP as weighting factor using an appropriate scenario or all the four above mentioned scenarios) as proposed by Lindfors et al. (1995a; 1995c) in the Nordic guideline for life cycle assessment. If the inventory data do not make it possible calculating total POCP based on weighting factors due to lack of information on the composition of the VOCs, it is suggested that the data be aggregated in the following subcategories:

1. Nitrogen oxides NO_x
2. Hydrocarbons (HC) or volatile organic compounds (VOCs)
3. Carbon monoxide (CO)
4. Methane (CH_4).

Acidification

Acidification is caused by releases of protons in the terrestrial or aquatic ecosystems. In the terrestrial ecosystem the effects are seen

Compound	Andersson-Sköld et al. (1992)			Heijungs et al. (1992)	
	Maximum difference in concentration	Ordinary Swedish background during 0-4 days	High NO_x concentration during 0-4days	Average for three European locations	Range
Alkanes					
Methane	-	-	-	0.007	0.000-0.030
Ethane	0.173	0.126	0.121	0.082	0.020-0.300
Propane	0.604	0.503	0.518	0.420	0.160-1.240
n-Butane	0.554	0.467	0.485	0.410	0.150-1.150
i-Butane	0.331	0.411	0.389	0.315	0.190-0.590
n-Pentane	0.612	0.298	0.387	0.408	0.090-1.050
i-Pentane	0.360	0.314	0.345	0.296	0.120-0.680
n-Hexane	0.784	0.452	0.495	0.421	0.100-1.510
2-Methylpentane	0.712	0.529	0.565	0.524	0.190-1.400
3-Methylpentane	0.647	0.409	0.457	0.431	0.110-1.250
2,2-Dimethylbutane	-	-	-	0.251	0.120-0.490
2,3-Dimethylbutane	-	-	-	0.384	0.250-0.650
n-Heptane	0.791	0.518	0.592	0.529	0.130-1.650
2-Methylhexane	-	-	-	0.492	0.110-1.590
3-Methylhexane	-	-	-	0.492	0.110-1.570
n-Octane	0.698	0.461	0.544	0.493	0.120-1.510
2-Methylheptane	0.691	0.457	0.524	0.469	0.120-1.460
n-Nonane	0.633	0.351	0.463	0.469	0.100-1.480
2-Methyloctane	0.669	0.454	0.523	0.505	0.120-1.470
n-Decane	0.719	0.422	0.509	0.464	0.080-1.560
2-Methylnonane	0.719	0.423	0.498	0.448	0.080-1.530
n-Undecane	0.662	0.386	0.476	0.436	0.080-1.440
n-Duodecane	0.576	0.311	0.452	0.412	0.070-1.380
Average	-	-	-	*0.398*	*0.114-1.173*
Halogenated hydrocarbons					
Methylene chloride	0.000	0.000	0.000	0.010	0.000-0.030
Chloroform ($CHCl_3$)	0.007	0.004	0.003	-	-
Methylchloroform	0.007	0.002	0.001	0.001	0.000-0.010
Trichloroethylene	0.086	0.111	0.091	0.066	0.010-0.130
Tetrachloroethylene	0.014	0.014	0.010	0.005	0.000-0.020
Allyl chloride (CH_2CHCH_2Cl)	0.561	0.483	0.667	-	-
Average	-	-	-	*0.021*	*0.003-0.048*
Alcohols					
Methanol	0.165	0.213	0.178	0.123	0.090-0.210
Ethanol	0.446	0.225	0.317	0.268	0.040-0.890
i-Propanol	0.173	0.203	0.188	-	-
Butanol	0.655	0.214	0.404	-	-
i-Butanol	0.388	0.255	0.290	-	-
Butane-2-diol	0.288	0.066	0.216	-	-
Average	-	-	-	*0.196*	*0.065-0.550*
Aldehydes					
Formaldehyde	0.424	0.261	0.379	0.421	0.220-0.580
Acetaldehyde	0.532	0.186	0.615	0.527	0.330-1.220
Propionaldehyde	0.655	0.170	0.652	0.603	0.280-1.600
Butyraldehyde	0.640	0.171	0.597	0.568	0.160-1.600
i-Butyraldehyde	0.583	0.300	0.677	0.631	0.380-1.280
Valeraldehyde	0.612	0.321	0.686	0.686	0.000-2.680
Acroleine	1.201	0.832	0.827	-	-
Benzaldehyde	-	-	-	0.334	(-0.82)-(-0.12)
Average		-	-	*0.443*	*0.079-1.263*
Ketones					
Acetone	0.173	0.124	0.160	0.178	0.100-0.270
Methyl ethyl ketone	0.388	0.178	0.346	0.473	0.170-0.800
Methyl i-butyl ketone	0.676	0.318	0.666	-	-
Average	-	-	-	*0.326*	*0.135-0.535*

Compound	Andersson-Sköld et al. (1992)			Heijungs et al. (1992)	
	Maximum difference in concentration	Ordinary Swedish background during 0-4 days	High NO_x concentration during 0-4days	Average for three European locations	Range
Esters					
Dimethylester	0.058	0.067	0.046	-	-
Methyl acrylate	-	-	-	0.025	0.000-0.070
Ethyl acetate	0.295	0.294	0.286	0.218	0.110-0.560
i-Propyl acetate	-	-	-	0.215	0.140-0.360
n-Butyl acetate	0.439	0.320	0.367	0.323	0.140-0.910
i-Butyl acetate	0.288	0.353	0.345	0.332	0.210-0.590
Average	-	-	-	*0.223*	*0.120-0.498*
Olefins					
Ethene	1.000	1.000	1.000	1.000	1.000
Propene	0.734	0.599	1.060	1.030	0.750-1.630
1-Butene	0.799	0.495	0.983	0.959	0.570-1.850
2-Butene	0.784	0.436	1.021	0.992	0.820-1.570
1-Pentene	0.727	0.424	0.833	1.059	0.400-2.880
2-Pentene	0.770	0.381	0.965	0.930	0.650-1.600
2-Methyl-1-butene	0.691	0.181	0.717	0.777	0.520-1.130
2-Methyl-2-butene	0.935	0.453	0.784	0.779	0.610-1.020
3-Methyl-1-butene	-	-	-	0.895	0.600-1.540
Isobutene	0.791	0.580	0.648	0.634	0.580-0.760
Average	-	-	-	*0.906*	*0.650-1.498*
Acetylenes					
Acetylene	0.273	0.368	0.291	0.168	0.100-0.420
Aromatics					
Benzene	0.317	0.402	0.318	0.189	0.110-0.450
Toluene	0.446	0.470	0.565	0.563	0.410-0.830
o-Xylene	0.424	0.167	0.598	0.666	0.410-0.970
m-Xylene	0.583	0.474	0.884	0.993	0.780-1.350
p-Xylene	0.612	0.472	0.796	0.888	0.630-1.800
Ethylbenzene	0.532	0.504	0.621	0.593	0.350-1.140
1,2,3-Trimethylbenzene	0.698	0.292	0.868	1.170	0.760-1.750
1,2,4-Trimethylbenzene	0.683	0.330	0.938	1.200	0.860-1.760
1,3,5-Trimethylbenzene	0.691	0.330	0.989	1.150	0.740-1.740
o-Ethyltoluene	0.597	0.408	0.637	0.668	0.310-1.300
m-Ethyltoluene	0.626	0.401	0.729	0.794	0.410-1.400
p-Ethyltoluene	0.626	0.443	0.682	0.725	0.360-1.350
n-Propylbenzene	0.511	0.454	0.531	0.492	0.250-1.100
i-Propylbenzene	0.511	0.523	0.594	0.565	0.350-1.050
Average	-	-	-	*0.761*	*0.481-1.258*
Other					
Methylcyclohexane	0.403	0.386	0.392	-	-
Isoprene	0.532	0.583	0.768	-	-
Dimethylether	0.288	0.343	0.286	-	-
Propylene glycole methyl ether	0.770	0.491	0.497	-	-
Propylene glycole methyl ether acetate	0.309	0.157	0.143	-	-
Carbonmonoxide	0.036	0.040	0.032	-	-

Table 4-9
Photochemical ozone creation potentials different organic compounds

in softwood forests (e.g. spruce) as inefficient growth and as a final consequence dieback of the forest. These effects are mainly seen in Scandinavia and in the middle / eastern part of Europe. In the aquatic ecosystem the effects are seen as (clear), acid lakes without any wildlife. These effects are mainly seen in Scandinavia. Buildings, constructions, sculptures and other objects worthy of preservation are also damaged by e.g. acid rain.

Substances are considered to have an acidification effect if they result in (Hauschild & Wenzel, 1997d):

- Supply or release of hydrogen ions (H^+) in the environment
- Leaching of the corresponding anions from the concerned system

The potential effects are strongly dependent on the nature of the receiving ecosystem e.g. nitrogen oxides (NO_x) can be fixed in the ecosystem due to uptake in plants. This problem can be managed by using two scenarios as suggested by Lindfors et al. (1995a). In the two scenarios the acidification potential from NO_x and NH_3 are calculated as zero and as the theoretical maximum value respectively. Lindfors et al. (1995c) recommend that the following substances should be considered: SO_2, NO_x, NH_3 and HCl but also other substances having a proton releasing effect have to be considered (i.e. other sulfur compounds and other acids). The acidification potential (AP) can be estimated as SO_2 equivalents or as mole hydrogen (H^+). The acidification potentials for acidifying substances are given in Table 4-10.

The potential acidification effect of a given process can be estimated by summarising the acidification potentials for the actual substances:

Acidification potential (SO_2-equivalents) = Σ_i $AP_i \times m_i$

Eutrophication

Eutrophication (or nutrient enrichment) of aquatic and terrestrial ecosystems can be caused by surplus nitrogen, phosphorus and degradable organic substances. Eutrophication can be defined as: enrichment of aquatic ecosystems with nutrients leading to increased production of plankton algae and higher aquatic plants leading to a deterioration of the water quality and a reduction in the value of the utilisation of the aquatic ecosystem.

The primary effect of surplus nitrogen and phosphorus in aquatic ecosystems is growth of algae. The secondary effect is decomposition of dead organic material (e.g. algae) and anthropogenic organic substances. The decomposition of organic material is an oxygen consuming process leading to decreasing oxygen saturation and sometimes anaerobic conditions. The anaerobic conditions in the sediment at the bottom of lakes or other inland waters may furthermore result in production of hydrogen sulfide (H_2S) which may lead to "bottom up" incidents and liberation of toxic hydrogen sulfide to the surrounding water. The possible effects of the emissions leading to eutrophication depend on the receiving waters i.e. some recipients are sensitive to nutrient supply while others are not.

The effects of eutrophication of terrestrial ecosystem are seen on changes in function and diversity of species in nutrient poor ecosystems as heaths, dune heaths, raised bogs etc. and they are caused by atmospheric deposition of nitrogen compounds.

Lindfors et al. (1995c) present two methods to calculate the eutrophication potential: 1) a separate aggregation method and 2) a scenario-based approach. The separate aggregation method divides the loadings in four subcategories to be calculated separately:

1. Organic material to water measured as BOD_5
2. Total-N to water as kg N
3. Total-P to water as kg P
4. Total-N to air as kg N

In the scenario-based approach the eutrophication category is suggested to be divided into two subcategories considering aquatic ecosystems and terrestrial ecosystems, respectively. The reason for using the scenario-based approach is to take the conditions of the receiving ecosystems into account, because P is the limiting factor in some circumstances and N is the limiting factor in other. It is assumed that only the limiting factor contributes to the eutrophication and therefore, the aggregation can be done in the following subcategories:

Table 4-10

Acidification potentials for acidifying substances (Hauschild & Wenzel, 1997d).

Substance	Formula	Reaction	Molar weight g/mole	AP kg SO_2/kg
Sulfur dioxide	SO_2	$SO_2+H_2O \rightarrow H_2SO_3 \rightarrow 2H^+ + SO_3^{2-}$	64.06	1
Sulfur trioxide	SO_3	$SO_3+H_2O \rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$	80.06	0.80
Nitrogen dioxide	NO_2	$NO_2+½H_2O+1/4O_2 \rightarrow H^+ + NO_3H^-$	46.01	0.70
Nitrogen oxide	NO	$NO+O_3+½H_2O \rightarrow H^+ + NO_3^- + 3/4O_2$	30.01	1.07
Hydrogen chloride	HCl	$HCl \rightarrow H^+ + Cl^-$	36.46	0.88
Hydrogen nitrate	HNO_3	$HNO_3 \rightarrow H^+ + NO_3^-$	63.01	0.51
Hydrogen sulfate	H_2SO_4	$H_2SO_4 \rightarrow 2H^+ + SO_4^{2+}$	98.07	0.65
Hydrogen phosphate	H_3PO_4	$H_3PO_4 \rightarrow 3H^+ + PO_4^{3-}$	98.00	0.98
Hydrogen fluoride	HF	$HF \rightarrow H^+ + F^-$	20.01	1.60
Hydrogen sulfide	H_2S	$H_2S+3/2O_2+H_2O \rightarrow 2H^+ + SO_3^{2-}$	34.03	1.88
Ammonium	NH_3	$NH_3+2O_2 \rightarrow H^+ + NO_3^- + H_2O$	17.03	1.88

Table 4-11

Eutrophication potentials (EP) for different scenarios as O_2- or PO_4-equivalents (Lindfors et al., 1995c).

Substance	N to air kg O_2/kg	P-limited kg O_2/kg	N-limited kg O_2/kg	N-limited + N to air kg O_2/kg	Maximum kg O_2/kg	Maximum kg PO_4-eq./kg
N to air	20	0	0	20	20	0.42
NO_x to air	6	0	0	6	6	0.13
NH_3 to air	16	0	0	16	16	0.35
N to water	0	0	20	20	20	0.42
NO_3^- to water	0	0	4.4	4.4	4.4	0.1
NH_4^+ to water	0	0	15	15	15	0.33
P to water	0	140	0	0	140	3.06
PO_4^{3-}	0	46	0	0	46	1
COD	0	1	1	1	1	0.022

Table 4-12

Eutrophication potentials (EP) as total-N, total-P or NO_3-equivalents (Hauschild & Wenzel, 1997e).

Substance	M_w g/mole	EP(N) kg N/kg	EP(P) kg P/kg	EP kg NO_3/kg
NO_3^-	62	0.23	0	1
NO_2	46	0.30	0	1.35
NO_2^-	46	0.30	0	1.35
NO	30	0.47	0	2.07
NH_3	17	0.82	0	3.64
CN^-	26	0.54	0	2.38
Total-N	14	1	0	4.43
PO_4^{3-}	95	0	0.33	10.45
$P_2O_7^{2-}$	174	0	0.35	11.41
Total-P	31	0	1	32.03

1. Total-N to air (terrestrial effects)
2. Total-P emissions and emission of organic material to water
3. Total-N emissions and emission of organic material into water
4. Total-N emissions and emission of organic material into water and N emissions to air
5. Total-P and -N emissions to air and water and also emission of organic material to water (assuming that both N, P and organic material contribute)

The eutrophication potential (EP) can be expressed as O_2- or PO_4-equivalents and is presented in Table 4-11 for a number of substances. Hauschild & Wenzel (1997e) have calculated EP as total-N, total-P and NO_3-equivalents; Table 4-12.

The eutrophication potential of a certain process can be estimated by summarising the eutrophication factors for the organic material, P- and N-containing substances:

Eutrophication potential (O_2-equivalents) = Σ_i eutrophication potential$_i$ x m_i

The eutrophication can also be expressed as PO_4^{3-}-equivalents. In this approach, no differentiation is made between ecosystems limited by different nutrients (Lindfors et al., 1995c).

Work environment

The impact category "work environment" covers the same effects as mentioned in the subchapter on human toxicological impacts supplemented by non-chemical effects. The human toxicological effects caused by exposure to biological or chemical substances can be:

- Acute toxicological effects
- Irritation
- Allergenic reactions
- Genotoxicity
- Carcinogenicity
- Neurotoxicity
- Teratogenicity

In contrast to the assessment of human toxicological effects caused by environmental emissions, assessment of the effects in the work environment requires information on actual concentration levels. Information on concentration levels in the work environment is normally not included in the inventory.

The non-chemical effects caused by heat, noise, monotonous working conditions e.g. repetitive work can be:

- Hearing impairments
- Psychological damage
- Pain in muscles
- Pain in joints

Accidents may result in bodily harm or acute toxicological effects caused by accidental leakages etc. The human toxicological effects in the work environment differ from the effects caused by emissions of the same substances from the production to the external environment, resulting in substantial effects on a few persons, whereas human toxicological effects in the external environment are characterised by small effects on many persons (Bengtsson & Berglund, 1996).

A number of different methods to assess work environment in relation to life cycle assessment have been developed and they have been presented and compared at a workshop arranged by LCANET (Potting et al., 1997):

- Chem-methodology (Terwoert, 1994a; b; c)
- EDIP-methodology (Rasmussen, 1997)
- IVF-methodology (Bengtson & Berglund, 1996)
- IVL-methodology (Antonsson & Carlson, 1995)
- MUP-methodology (Jelnes et al., 1994; Schmidt et al., 1994b)
- PVC-methodology (Christiansen et al., 1993)
- STØ-methodology (Bjørnsen et al., 1995; Møller et al., 1995; Rønning et al., 1995; Økstad et al., 1995)

Table 4-13
Different methods for assessment of work environment.

Method	Effects concerned	Criteria/comments	Reference
Chem-methodology	Physical Physiological Chemical Biological Risk of accidents	The method is based on exposure estimates and effect registration. The method covers a screening LCA with qualitative results.	Terwoert (1994a; b; c)
EDIP-methodology	Physical Chemical Risk of accidents	The method is based on exposure estimates and effect registration. The method covers a detailed LCA with quantitative results.	Rasmussen (1997)
IVF-methodology	Physical Physiological Psychological Chemical Risk of accidents	The method is based on exposure measurements and estimates and effect registration.	Bengtson & Berglund (1996)
IVL-methodology	Physical Physiological Psychological Chemical Biological Risk of accidents	The method is based on exposure measurements and estimates and effect registration. The method covers a screening LCA with qualitative and quantitative results.	Antonsson & Carlson (1995)
MUP-methodology	Physical Chemical Risk of accidents	The method is based on exposure estimates. The method covers a screening LCA with qualitative results, combined with a scoring methodology.	Jelnes et al. (1994); Schmidt et al. (1994b)
PVC-methodology	Physical Chemical Risk of accidents	The method is based on exposure estimates. The method covers a screening LCA with qualitative results.	Christiansen et al. (1993)
STØ-methodology	Chemical	The method is based on exposure estimates. The method covers a detailed LCA with quantitative results.	Bjørnsen et al. (1995); Møller et al. (1995); Rønning et al. (1995); Økstad et al. (1995)

The present methods are described briefly in Table 4-13.

International consensus on specific methods for assessing work environment has not yet been reached and development of some of the methods is still in progress.

5. LCA Information Sources

The following sections gives an overview of some of the most important sources of information about LCA. The overview is not complete, but is meant as a starting point for companies, institutions and individuals wanting to enter the area of life cycle assessment, or to maintain and extend already existing knowledge.

The following information sources are described:

- Newsletters and Journals
- Books, Reports, Proceedings, etc.
- LCA Software
- Internet Facilities

When contemplating ordering information sources from the overview it should be borne in mind, that recent publications generally are of a much higher quality than books and reports from the beginning of the nineties as they supposedly reflect the international development in the area. However, no further assessment of the quality of the information sources is given in the overview.

5.1 Newsletters and Journals with LCA Content

A number of journals and newsletters with LCA content have appeared during the last few years. Most publications have other issues as the main content, e.g. ecolabelling, waste management and cleaner technology, but they also feature LCA-news and/or articles on LCA on a regular basis. Newsletters and journals must be considered as key information sources to recent developments due to their short production time. A list of journals addressing environmental issues (not only LCA) can be found at the Internet at http://www.lib.kth.se/~lg/ejourn.htm.

5.1.1 Newsletters

SETAC-Europe LCA News
The newsletter is published bi-monthly and is send to all SETAC-Europe members. The newsletter is free of charge and its possible to be added to the mailing list by contacting SETAC-Europe, Av.E.Mounier 83, box 1, 1200 Brussels, Belgium Tel. +32-2-772.72.81, Fax +32-2-770.53.86 or E-mail 100725.3525@compuserve.com. Editor is Roland Clift, Centre for Environmental Strategy, University of Surrey, Tel. +44 1483 259 047, Fax +44 1483 259 394, E-mail J.Libaert@surrey.ac.uk.

SETAC-US LCA News
The SETAC-US newsletter highlights environmental topics, SETAC activities, employment opportunities, and meetings of interest. A special section is devoted to LCA. The bimonthly newsletter is mailed to SETAC members, but can also be ordered from SETAC, 1010 North 12th Avenue, Pensacola, FL 32501-3370, U.S.A. Tel: +1 904-469-1500, Fax +1 904-469-9778, E-mail: setac@setac.org. The newsletter (Jan 1997 and forward) is also available on the Internet: http://www.setac.org/news.html.

APME Communique
The newsletter Communique primarily contains information on packaging news from the plastics industry. It is published by the Association of Plastics Manufacturers in Europe (APME) and can be ordered from APME, Av. E. Van Nieuwenhuyse 4, Box 3, B-1160 Brussels, Belgium Tel. (32-2) 672 82 59 Fax (32-2) 675 39 35

CSA Environmental Update
The Canadian Standards Association (CSA) publishes the Environmental Update newsletter three times a year. The newsletter primarily addresses environmental management and can be ordered from CSA Corporate Communications Fax (416) 747-4292.

Ecocycle
The newsletter Ecocycle is published bi-annually by Environment Canada and contains information on development of life-cycle management tools and product policy. The newsletter is free of charge and can be ordered at Tel. 1-819-997-3060 or Fax 1-819-953-6881 or E-mail kbrady@synapse.net. The newsletter is also available through the Internet at http://www.doe.ca/ecocycle.

EPA LCA Project Update
The EPA LCA Project Update Newsletter is designed to provide information about ongoing EPA LCA-related projects and upcoming activities. The publisher is the US

Environmental Protection Agency (EPA), Office of Research and Development, LCA Research Program. The newsletter is available through the Internet and can also be received in a paper version by sending a request to Keith Weitz at Research Triangle Institute (E-mail: kaw@rti.org or Fax +1-919-541-7155).

ESU-INFO
The newsletter is published by The Energy-Materials-Environment Group (ESU - in German Gruppe Energie-Stoffe-Umwelt) at ETH in Switzerland. The newsletter is primarily for costumers of the "Ökoinventare von Energie-systemen", but also contains information on new publications and projects. Information: Rolf Frischknecht at Institut für Energietechnik at ETH in Zürich at Tel. +01 632 12 83 or E-mail: frischknecht@iet.mavt.ethz.ch

Integrated Environmental Management
The newsletter primarily gives information and advice on environmental issues for management. Published by Blackwell Scientific Publications, Osney Mead, Oxford OX2 0EL, UK. Tel: +44 865 206 206.

ISWA Times
ISWA TIMES is a quarterly newsletter of the International Solid Waste Association. The newsletter is designed to keep members and other professionals informed of relevant issues, e.g. legislation, environmental auditing, and risk analysis. Publisher: ISWA General Secretariat, Bremerholm 1, DK-1609 Copenhagen K, Denmark. Tel: +45 3391 4491.

Warmer Bulletin
Warmer Bulletin is published six times a year, the main content being information on sustainable waste management and resource recovery. The bulletin is published by the World Resource Foundation, Bridge House, High Street, Tonbridge, Kent TN9 1DP, UK. Tel: +44 1732 368 333. E-mail: wrf@gn.apc.org, Internet:http://www.wrfound.org.uk.

5.1.2 Journals

International Journal of Life Cycle Assessment
The journal is a forum for scientists developing LCA-methodology, LCA practitioners, environmental managers, governmental agencies and other ecological institutions and bodies. The journal has ISSN 0948-3349. The editor-in-chief is Walter Klöpffer, C.A.U. The journal can be ordered from Ecomed Publishers. Tel. +49-81 91-125-469, Fax +49-81 91-125-492.

Air and Waste
The journal is published monthly by the Air and Waste Management Association, One Gateway Center, Third Floor, Pittsburg, PA 15222, USA.

Environmental Impact Assessment Review
Environmental Impact Assessment Review is a quarterly publication for planners, engineers, scientists, policy makers and administrators committed to improving the theory and practice of environmental decision making. Lawrence Susskind is senior editor and the journal is published by Elsevier Science Publishing Co., Inc., 655 Avenue of the Americas, New York, NY 10010.

Environmental Toxicology and Chemistry (ET&C)
ET&C is a monthly publication of SETAC and is distributed for free to members of SETAC. The journal is dedicated to furthering scientific knowledge and disseminating information environmental toxicology and chemistry, including the application of these sciences to hazard/risk assessment. With SETAC being a main forum for the development of LCA methodology, the ET&C journal frequently features articles on LCA. The journal can be ordered from SETAC PRESS, 1010 North 12 Avenue, Pensacola, FL 32501-3370, USA. Tel: +1 904 469 1500, Fax: +1 904 469 9778, E-mail: setac@setac.org, Internet: http://www.setac.org.

International Journal of Environmentally Conscious Design & Manufacturing
The International Journal of Environmentally Conscious Design and Manufacturing aims at providing a medium for the dissemination of accurate information about the impact and the short-term as well as the long-term effects of design and manufacturing on the environment. The journal is published four times a year by ECM Press: PO Box 20959, Albuquerque, NM 87154-0959, USA. At the homepage http://ie.uwindsor.ca/ecdm/journal it is possible to read abstracts of articles from the Journal.

Journal of Cleaner Production
The quarterly journal aims to encourage industrial innovation, new and improved products, and the implementation of new, cleaner process technologies as well as governmental policies and educational programs essential for ensuring continuous progress towards sustainability. The ISSN No. is 0959-6526. It can be ordered from Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK. Fax: +44

(0) 1865 843952. Homepage: http://www.elsevier.nl/locate/jclepro.

Waste Management & Research
The journal is a bi-monthly publication issued under the auspices of ISWA, the International Solid Waste and Public Cleansing Association. The journal publish papers on all aspects of solid waste management, but the main focus on the discussion of solutions to problems that arise primarily with municipal and industrial solid wastes. Publisher: Academic Press, 24-28 Oval Road, London NW1 7DX, UK. Homepage: http://www.hbuk.co.uk/ap/journals/wm.htm.

5.2 Books, Reports, Conference Proceedings, etc.

The development and use of LCA has been documented in a large number of reports, books and proceedings from workshops and conferences. Many publications must be considered as "grey" or "yellow" literature, i.e. they have been published without a scientific peer review and without proper identification possibilities, e.g. a ISSN- or ISBN-number. Despite these shortcomings the publications still hold important information and are included in the overview.

The section on books, reports and conference proceedings is divided into the subsections "Methodology issues", "Data sources (paper)", "Standards", and "Miscellaneous references". Please notice that books in either subsection also may contain information which is relevant in another subsection. The lists of references are in reverse chronological order and with the title of the reference given first. In doing so, we believe that it will be easier to find the documents that are of special relevance to the reader.

5.2.1 Methodology issues

The reports listed in this section reflect to a certain extent the historic development of LCA-methodology, starting with the early SETAC report "A technical framework for Life Cycle Assessment" and ending with the most recent methodology suggestions.

As outlined in the chapter on the methodological framework no consensus exist on how to treat a number of environmental effects in LCA, but the reports may give a valuable overview of the ideas generated during the development of LCA methodology. It should be noted that a number of other publications addressing methodology issues can be found under the heading "Miscellaneous references".

Environmental Assessment of Industrial Products. Edited by Wenzel H, Hauschild M and Alting L (1997). Volume 1: Tools and Case studies and Volume 2: Scientific Background. Chapman & Hall, London.

Towards a methodology for life cycle impact assessment. Udo de Haes HA (ed.) (1996). Society of environmental Toxicology and Chemistry (SETAC) - Europe. Brussels.

Miljøvurdering af produkter (Environmental assessment of Products). Wenzel H, Hauschild M, Rasmussen E (1996). Dansk Industri. (In Danish). ISBN 87-7810-542-0.

Life cycle assessment and conceptually related programmes. Draft. de Smet B, Hemming C, Baumann H, Cowell S, Pesso C, Sund L, Markovic V, Moilanen T, Postlethwaithe D (1996).

Life Cycle Assessment (LCA) - Quo vadis? Schaltegger S (ed.), Braunschweig A, Büchel K, Dinkel F, Frischknecht R, Maillefer C, Ménard M, Peter D, Pohl C, Ros M, Sturm A, Waldeck and Zimmermann P (1996). Swiss Priority Programme Environment of the Swiss National Science Foundation Synthesis. Birkhäuser Verlag AG.

Life Cycle Assessment as an Environmental systems analysis tool - with a focus on system boundaries. Finnveden G (1996). Licentiate thesis at Applied Electrochemistry, Department of Chemical Engineering and Technology at Royal Institute of Technology, KTH, Stockholm. AFR, Swedish Environmental Protection Agency, Sweden.

SETAC EUROPE LCA Screening and Streamlining Working Group. Final report, Draft 3. Christiansen K (ed.) (1996).

Research needs in life cycle assessment for the EU ecolabelling programme. Udo de Haes HA, Bensahel J-F, Clift R, Griesshammer R and Jensen AA (1995). Groupe des Sages. Final report of second phase. Leiden

LCA-Nordic Technical Reports No. 1 - 9. Lindfors L-G, Christiansen K, Hoffmann L, Virtanen Ÿ, Juntilla V, Hanssen OJ, Rønning A, Ekvall T and Finnveden G (1995). TemaNord 1995:502. Copenhagen: Nordic Council of Ministers. ISBN 92 9120 608 3, ISSN 0908-6692.

LCA-Nordic Technical Report No. 10 and Special Reports No. 1 - 2. Lindfors L-G, Christiansen K, Hoffmann L, Virtanen Y, Juntilla V, Hanssen OJ, Rønning A, Ekvall T and Finnveden G (1995). TemaNord 1995:503. Copenhagen: Nordic Council of Ministers. ISBN 92 9120 609 1, ISSN 0908-6692.

Nordic Guidelines on Life-Cycle Assessment. Lindfors L-G, Christiansen K, Hoffmann L, Virtanen Y, Juntilla V, Hanssen OJ., Rønning A, Ekvall T and Finnveden G (1995). Nord 1995:20. Copenhagen: Nordic Council of Ministers.

Miljöanpassad produktudveckling (Environmentally Sound Product Development). Ryding S-O (1995). Industriförbundet. (In Swedish)

Overview of the scientific peer review of the European life cycle inventory for surfactant production. Klöpffer W, Griesshammer R, and Sundström G (1995). Tenside Surf.Det. 32(5):378-83.

Life cycle assessment and treatment of solid waste. Proceedings of the international workshop September 28-29, Stockholm. Finnveden G, Huppes G (editors) (1995). AFR-report 98, Stockholm.

Life cycle assessment. A comparison of three methods for impact analysis and evaluation. Baumann H and Rydberg T. J.Cleaner Prod. 2(1):13-20, 1994.

Metoder, vurderingsgrundlag og fremgangsmåde. Livscyklusvurdering af nye materialer (Methods, Assessment and Procedures. Life cycle assessment of new materials). Schmidt A, Christiansen K and Pommer K. (eds.) (1994). dk-TEKNIK, Søborg (In Danish with English summary).

Allocation in LCA. Proceedings of the European Workshop on allocation in LCA at CML, Leiden 24-25 February, 1994. Huppes G and Schneider F (editors) (1994). CML, Leiden. ISBN 90-5191-078-9 (CML).

Integrating impact assessment into LCA. Proceedings of the LCA symposium held at the fourth SETAC-Europe Congress 11-14 April 1994. Udo de Haes HA, Jensen AA, Klöpffer W and Lindfors L-G (editors) (1994). SETAC, Brussels.

Impact assessment within LCA. Grisel L, Jensen AA, Klöpffer W (1994). Society for the Promotion of LCA Development (SPOLD), Brussels.

Guidelines for the application of life cycle assessment in the EU ecolabelling programme. Udo de Haes HAU, Bensahel J-F, Clift R, Fussler CR, Griesshammer R and Jensen AA (1994). Groupe des Sages. Final report of the first phase. Leiden

A Conceptual Framework For Life-Cycle Impact Assessment. Fava J, Consoli F, Denison R, Dickson K, Mohin T and Vigon B (1993). Workshop Report. SETAC and SETAC Foundation for Environmental Education, Inc., Sandestin, Florida USA, March 1993

Guidelines for Life-Cycle Assessment: a "Code of Practice". Consoli F, Allen D, Boustead I, de Oude N, Fava J, Franklin R, Jensen AA, Parrish R, Perriman R, Postlethwaite D, Quay B, Séguin J and Vigon B (eds.) (1993). Report of the workshop organised by SETAC in Portugal.

Life cycle design guidance manual. Environmental requirements and the product system. Keoleian GA and Menerey D (1993). EPA600/R-92/226. USEPA, Cincinnati, Ohio.

Weighing up the environmental balance. Anon (1993). APME/PWMI, Brussels,

Ecoprofiles of the European polymer industry. Report 7 Principles of plastics recycling. Boustead I (1993). APME/PWMI, Brussels)

Life cycle assessment: Inventory, classification, valuation, data bases. Workshop report from the workshop in Leiden 2-3 December 1991. (1992). SETAC-Europe, Brussels.

Life-Cycle Assessment Data Quality. Fava J, Jensen AA, Lindfors L, Pomper S, de Smet B, Warren J and Vigon B. Workshop Report. SETAC and SETAC Foundation for Environmental Education, Inc., Wintergreen, Virginia, October 1992

Eco-balance methodology for commodity thermoplastics. Boustead I (1992). Brussels: APME/PWMI.

Product life-cycle assessment: Inventory guidelines and principles. Batelle and Franklin Associates (1992). RREL, EPA/600/R-92/036.

Product life cycle assessment - principles and methodology. Lindfors, L.G. (editor). Nord 1992:9. Nordic Council of Ministers, Copenhagen, 1992.

Environmental life cycle assessment of products. Heijungs R, Guinée JB, Huppes G, Lankreijer RM, Udo de Haes HA, Sleeswijk

AW, Ansems AMM, Eggels PG, van Duin R, de Goede HP (1992). I Guide; II Backgrounds. CML, Leiden.

Resource and environmental profile analysis: A life cycle environmental assessment for products and procedures. Hunt RG, Sellers JD and Franklin WE (1992). Environ Impact Assess Rev 12:245-269.

Eco-balance methodology for commodity thermoplastics. Boustead I (1992). APME / PWMI, Brussels.

A Technical Framework for Life-Cycle Assessment. Fava J, Denison R, Jones B, Curran MA, Vigon B, Selke S and Barnum J. SETAC and SETAC Foundation for Environmental Education, Inc., Washington, January 1991

Oekobilanz von Packstoffen Stand 1990. Habersatter, K. Schriftenreihe Umwelt. Nr. 132. BUWAL, Bern, 1991.

Methodik für Öekobilanzen auf der basis ökologischer Optimierung. Ahbe S, Braunschweig A and Müller-Wenk (1990). Schriftenreihe Umwelt Nr. 133, BUWAL, Bern.

5.2.2 Databases (paper)

One of the most prominent problems in LCA is the lack of available data for many raw materials, intermediates, energy technologies and transportation modes. The following section identifies some of the most commonly used data sources, but it should be remembered that many of these are rather old and that they therefore may be of limited value.

The limited value is caused by two factors, i.e. the information does not necessarily reflect today's technological level (some data are collected in the early 80'es), and the procedure for data collection and presentation is most probably not in accordance with the requirements outlined in the SETAC Code of Practice or in the ISO standard.

An overview of available life cycle data sources can be found in "*Directory of life cycle inventory data sources.* Hemming C (1995). SPOLD, Brussels". This book gives information on databases in both electronic and book format. For each data source there is a description of the accessibility (price, hardware requirements) and the content in terms of both included commodities, fuels and services and data quality (geographical scope, timeframe, original data source, data checking, etc.)

For databases in electronic format, please refer to the reference above and to the section on LCA software.

European database for corrugated board life cycle studies. FEFCO, Groupement Ondulé, and Kraft Institute (1996). Paris.

Ecobalance of Packaging Materials (1996). Schriftenreihe Umwelt 250, BUWAL, Bern.

Ecological profile report for the European Aluminium Industry. Boustead I (1996). Brussels: European Aluminium Association.

Eco-profiles of the European plastics industry. Report 9 Polyurethane precursors (TDI, MDI, Polyols) (1996). Boustead I. PWMI, Brussels.

Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. von Däniken A and Chudacoff M (1995). Schriftenreihe Umwelt Nr. 232, Band 2: Daten. BUWAL, Bern.

Eco-profiles of the European plastics industry. Report 8: Polyethylene terephthalate (PET). Boustead I (1995). PWMI, Brussels.

Transporters miljöpåverkan i et livscykelperspektiv. Eriksson E, Svensson G, Lövgren G et al. (1995). FoU 126. Stiftelsen Reforsk, Malmö.

A life-cycle inventory for the production of petrochemical intermediates in Europe. Franke M, Berna JL, Cavalli L et al. (1995). Tenside Surf.Det. 32(5):384-96.

A life-cycle inventory for the production of oleochemical raw materials. Hirsinger F, Schick K, and Stalmans M (1995). Tenside Surf.Det. 32(5):420-32.

A life-cycle inventory for the production of detergent-grade alcohols. Hirsinger F, Schick K, and Stalmans M (1995). Tenside Surf.Det. 32(5):398-410.

A life-cycle inventory for the production of sulphur and caustic soda in Europe. Postletwaite D, Schul W and Stalmans M (1995).Tenside Surf. Det. 32(5):412-8.

European Life Cycle Inventory for Detergent Surfactants Production. Stalmans M, Berenbold H, Berna JL et al (1995). Tenside Surf.Det. 32(2):84-109.

Eco-profiles of the European Plastics industry. Report 5: Co-product allocation in chlorine plants. Boustead I (1994). PWMI, Brussels.

Eco-profiles of the European Plastics industry. Report 6: Polyvinyl chloride. Boustead I (1994). PWMI, Brussels.

Öekoinventare für Energiesysteme. Frischknecht, R., Hofstetter, P., Knoepfel, I., Ménard, M., Dones, R., and Zollinger, E. (editors) (1994). Bundesamt für Energiewirtschaft, Zürich.

Mineral commodities summaries 1993. U.S.Bureau of Mines (1993). U.S. Bureau of Mines, Washington. US Government printing office 337_168, 70638.

Eco-profiles of the European Plastics industry. Report 2: Olefin feedstock sources. Boustead I (1993). PWMI, Brussels.

Eco-profiles of the European plastics industry. Report 3: Polyethylene and polypropylene. Boustead I (1993). PWMI, Brussels.

Eco-profiles of the European plastics industry. Report 4: Polystyrene. Boustead I (1993). PWMI, Brussels.

World resources 1992-93. World Resources Institute (1992). Oxford University Press, New York Oxford. ISBN 0-19-506231-0.

Livscykelanalyser för förpackningsmaterial/ Packaging and the Environment. Tillmann A, Baumann H, Eriksson E. et al. (1991). SOU 1991:77. Miljödepartementet, Stockholm.

Oekobilanz von Packstoffen Stand 1990. Habersatter K (1991). Schriftenreihe Umwelt. Nr. 132. BUWAL, Bern.

5.2.3 Standards

Standards for Life Cycle Assessment and its applications are still under development. The references given below are to standards on different levels of completion (FDIS = Final Draft International Standard, DIS = Draft International Standard, CD = Committee Draft, WD = Working Draft) and to the name of the Subcommittee (SC) and Workgroup (WG) developing the standard. Please refer to your national standard organisation for further information.

ISO standards (drafts)

Environmental Labels and Declarations - General Principles (ISO CD 14020). ISO / TC 207 / SC3 / WG3.

Environmental Labels and Declarations - Environmental Labelling-Self Declared Environmental Claims-Terms and Definitions (ISO DIS 14021). ISO / TC 207 / SC3 / WG2.

Environmental Labels and Declarations - Environmental Labelling-Self Declared Environmental Claims-Symbols (ISO CD 14022). ISO / TC 207 / SC3 / WG2.

Environmental Labelling-Self Declared Environmental Claims-Testing and verification Methodologies (ISO WD 14023). ISO / TC 207 / SC3 / WG2.

Environmental Labels and Declarations - Environmental Labelling Type I - Guiding Principles, and procedures (ISO CD-2 14024). ISO / TC 207 / SC3 / WG1.

Environmental Labels and Declarations - Environmental Labelling Type III - Guiding Principles, and procedures (ISO pre-WD 14024). ISO / TC 207 / SC3 / WG1.

Evaluation of Environmental Performance (ISO CD 14031). ISO TC 207 / SC4 / WGs 1-2.
Life Cycle Assessment - Principles and Guidelines (ISO FDIS 14040). ISO TC 207 / SC5 / WG1.

Life Cycle Assessment - Life Cycle Inventory Analysis (ISO DIS 14041). ISO TC 207 / SC5 / WGs 2-3.

Life Cycle Assessment - Impact Assessment (ISO CD 14042). ISO TC 207 / SC5 / WG4.

Life Cycle Assessment - Interpretation (ISO CD 14043). ISO TC 207 / SC5 / WG5.

CEN-standards (drafts)

Terminology, symbols and criteria for life cycle analysis of packaging. CEN / TC261 / SC4 / W1

Canadian LCA-standards (final)

Life Cycle Assessment, Standard CAN / CSA-Z760, 1994.

Life Cycle Review (supporting CAN/CSA-Z760), 1994.

Design for Environment, Standard CAN/CSA-Z762, 1995.

The Canadian standards can be ordered from:
Standards Sales
Canadian Standards Association
178 Rexdale Blvd
Rexdale (Toronto), Ontario
Canada M9W 1R3
tel 416-747-4044, fax 416-747-2475

5.2.4 Applications of LCA

This section contain a number of other

papers and reports which are of interest with respect to different applications of LCA. Some of the reports also include a description of the methodology used. Many reports of similar content and quality are missing in the reference list. The main reason for this is that they are not publicly available. Please refer to the database of LCA actors for more information on LCA projects etc.

Projekte mit Bezug zu Ökobilanzen und Lebensweganalysen. Scheibe U, Neitzel H (1997). Fachgebiet III 1.3, Umweltsbundesamt, Berlin.

Iterative screening LCA in an Eco-design tool. Fleischer G and Schmidt W-P (1997). Int. J. LCA 2(1): 20-24.

Miljøvenlige komfurer og ovne. Schmidt A, Christensen BH, Jensen AA (1996). Miljøprojekt Nr. 338. Miljøstyrelsen, København. (In Danish).

Overall Business Impact Assessment (OBIA). Taylor AP, Postlethwaite D (1996). Presentation Summaries, SETAC EUROPE 4th Symposium for Case Studies, Brussels, 3 December 1996.

Sustainable product development. Hansen OJ, Rønning A and Rydberg T (1995). Final report from the NEP project. Østfold Research Foundation, Fredrikstad.

Application of life cycle assessments (LCA). Christiansen K, Heijungs R, Rydberg T et al. (eds.) (1995). Report from expert workshop at Hankø, Norway on LCA in Strategic management, product development and improvement, marketing and ecolabelling, governmental policies. Østfold Research Foundation report 07/95.

Life cycle screening of food products. Weidema BP, Pedersen RL and Drivsholm T (1995). ATV, Copenhagen.

Miljømæssig kortlægning af emballager til øl og læskedrikke. Pommer K, Wesnæs MS (1995). Arbejdsrapport fra Miljøstyrelsen Nr. 62, Copenhagen. (In Danish).

Decision support system for environmental sounder purchase of catering materials and products for inflight services. Christiansen K, Hoffmann L (1995). Prepared by Krüger Consult A/S for SAS and Danish Agency of Environmental Protection.

Sustainable development by design: Review of life cycle design and related approaches. Keoleian GA, Menerey D (1994). Air and Waste 1994;44: 645-668.

Proceedings from the workshop on methods for environmental management and sustainable product development, Hankø, Fredrikstad, 23-24 march 1994. Hanssen OJ (editor) (1994). Østfold Research Foundation, Fredrikstad.

Resource and environmental profile analysis of children's diaper systems. Sauer BJ, Hildebrandt CC, Franklin WE et al. (1994). Environ Toxicol Chemistry 13(6):1003-9.

Eco-balance for drink packaging. Schmitz S, Oels H-J, and Tiedemann A (1994). Umweltsbundesamt, Germany.

The Phosphate Report. Wilson B and Jones B (1994). Landbank Environmental Research and Consulting, London.

Design for Environment. WICE (World Industry Council for the Environment) (1994). Paris.

Development of a pollution prevention factors methodology based on a life-cycle assessment: Litographic printing study. Tolle DA, Vigon BW, Becker JR et al. (1994). EPA/600/R-94/157. USEPA, Cincinnati, Ohio.

Improved environmental performance of products. Halocarbon substitution, packaging development and life cycle assessment. Rydberg T (1994). Chalmers Tekniska Högskola, Gothenburg.

Resource and environmental profile analysis of children's diaper systems. Sauer BJ, Hildebrandt CC, Franklin WE and Hunt RG (1994). Environ Toxicol Chemistry 13(6):1003-1009.

Sustainable development by design. Keoleian GA and Menerey D (1994). Review of life cycle design and related approaches. Air and Waste Vol. 44: 645-668.

Life cycle assessment of rapeseed oil or rapeseed oil methyl ester as substitute for diesel fuel. Friedrich A, Glante F, Schlüter C et al. (1993). UBA, Berlin.

Green products by design. Choices for a cleaner environment. U.S.Congress (1992). OTA-E-541. OTA, Washington, DC.

Integrated substance chain management. VNCI - Association of the Dutch Chemical Industry (1991). Leidschendam.

Resource and environmental profile analysis of

high-density polyethylene and bleached paperboard gable milk containers. Sellers VR, Sellers JD, Rolander ST et al. (1990). Franklin Associates, Kansas.

5.3 LCA Software

Many institutions and companies have developed software for use in LCA. The obvious reason for this is that large amounts of data have to be stored and processed in any LCA and that computers are the natural tool for this. Some programmes have been developed to perform a "complete" LCA, i.e. both Inventory, Impact Assessment, and some kind of Interpretation is performed, whereas others are only able to perform the Inventory part of the LCA.

Most of the developed software tools are commercially available at prices ranging from about 1500 ECUs to more than 10.000 ECUs. Free demo versions are available for many programs, but they are most often of limited value for potential buyers due to limitations in capacity. As the software represents a substantial investment, potential buyers are advised to collect as much information as possible from the developers and compare this to their own needs. An overview of commercial software tools is presented in Table 5-1. Some essential issues to consider are discussed in the following.

- The database should contain life cycle information on a large amount of raw materials, chemicals, energy scenarios and transportation modes. Consideration should be given to system boundaries (do they describe the same system as you are going to investigate?), representative ness (average or site-specific data), specificity (e.g. number of emissions), and data quality (e.g. age). The database should also have the possibility of storing and using own data as well as a future common data format. Please note that the many software databases are solely based on paper reports which are considerably cheaper.

- Inventory calculations. How are the life cycle modelling facilities? Is the software able to use different kinds of allocation rules in the calculation?

- Impact assessment. Which method(s) are used for impacts assessment?. Are they in accordance with the requirements in the ISO standard?. Do the evaluation methods need any transformation before they can be used to investigate a different geographic scenario?

- Interpretation. Can the software help you in the interpretation of the LCA, e.g. by performing a "hot-spot" or sensitivity analysis. Is a statistical module included?

- Reporting. Do the reporting facilities meet your needs, e.g. exporting to other programmes for further treatment (word processing, spreadsheet).

For a discussion of data quality and databases, the following paper is of interest:

Life cycle assessment: data quality and databases practitioner survey. Vigon BW and Jensen AA (1995). J.Cleaner Prod. 3(3):135-41.

An overview of LCA data sources (both paper and software) tools can be found in:

Directory of life cycle inventory data sources. Hemming C (1995). SPOLD, Brussels.

Two reports have evaluated some of the commercially available software tools:

LCA software review. Rice G (1996). A review of commercial LCA software, with specific emphasis on European industrial applications. University of Surrey.

Evaluation of life cycle assessment tools. Menke D, Davis GA and Vigon BW (1996). Environment Canada, Ottawa. This report can be downloaded for free from http://www.ec.gc.ca/ecocycle.

Commercial software programs

The thirty-seven software tools for life cycle assessment in the table were identified by Menke et al. (1996). With the rapid development in this LCA area, new models may have emerged, and some of the listed models may have been released in newer versions. For more specific information on price, data content and methodology please refer to the vendor or the reports mentioned previously.

5.4 Internet addresses

The amount of information on the World Wide Web is increasing with an incredible speed. This is also true for information on LCA, and the Internet facilities listed below will in a short time only contain a fraction of all relevant addresses on WWW. Users of

Table 5-1
List of commercially available life cycle assessment tools (Adopted from Menke et al., 1996)

Name	Vendor	Version	Cost, $K	Data Location
1. Boustead	Boustead Phone +44 403 864 561 Fax +44 403 865 284	2	24	Europe
2. CLEAN	EPRI Phone +1 415 960 5918 Fax +1 415 960 5965	2	14	U.S.
3. CUMPAN	Univ. of Hohenheim	Unknown	Unknown	Germany
4. EcoAssessor	PIRA	Unknown	Unknown	UK
5. EcoManager	Franklin Associates, Ltd. Phone: +1 913 649 2225 Fax +1 913 649 6494	1	10	Europe/U.S.
6. ECONTROL	Oekoscience	Unknown	Unknown	Switzerland
7. EcoPack2000	Max Bolliger	2.2	5.8	Switzerland
8. EcoPro	EMPA Phone +41 71 300101 Fax +41 71 300199	1	Unknown	Switzerland
9. EcoSys	Sandia/DOE	Prototype	Unknown	U.S.
10. EDIP	Inst. for Prod. Devel. Phone +45 4295 2522	Prototype	Unknown	Denmark
11. EMIS	Carbotech	Unknown	Unknown	Switzerland
12. EPS	IVL Fax +46 314 82180	1	Unknown	Sweden
13. GaBi	IPTS Phone +49 7021 942 660 Fax +49 7021 942 661	2	10	Germany
14. Heraklit	Fraunhofer Inst. Phone +49 89 149009 89 Fax +49 89 149009 80	Unknown	Unknown	Germany
15. IDEA	IIASA (A)/VTT (SF) Fax +358 (0) 456 6538	Unknown	Unknown	Europe
16. KCL-ECO	Finnish Paper Inst. Phone +358 9 43 711 Fax +358 9 464 305	1	3.6	Finland
17. LCA1	P&G/ETH	1	Not Avail.	Europe
18. LCAD	Battelle/DOE	Prototype	< 1	U.S.
19. LCAiT	Chalmers Industriteknik Phone +46 31 772 4237 Fax +46 31 82 7421	2.0	3.5	Sweden
20. LCASys	Philips/ORIGIN	Unknown	Unknown	Netherlands
21. LIMS	Chem Systems +1 914 631 2828 +1 914 631 8851	1	25	U.S.
22. LMS Eco-Inv. Tool	Christoph Machner	1	Unknown	Austria
23. Oeko-Base II	Peter Meier Phone +41 1 277 3076 Fax +41 1 277 3088	Unknown	5.5	Switzerland
24. PEMS	PIRA Phone +44 0 1372 802000 Fax +44 0 1372 802238	3.1	9.1	Ave. European

Name	Vendor	Version	Cost, $K	Data Location
25. PIA	BMI/TME Phone +31 70 346 4422 Fax +31 70 362 3469	1.2	1.4	Europe
26. PIUSSOECOS	PSI AG	Unknown	Unknown	Germany
27. PLA	Visionik ApS Fax +45 3313 4240	Unknown	Unknown	Denmark
28. REGIS	Sinum Gmbh Phone +41 51 37 61	Unknown	Unknown	Switzerland
29. REPAQ	Franklin Associates, Ltd. Phone +1 913 649 2225 Fax +1 913 649 6494	2	10	U.S.
30. SimaPro	Pré Consulting Phone +31 33 461 1046 Fax +31 33 465 2853	3.1	3	Netherlands
31. SimaTool	Leiden Univ.	Prototype	Unknown	Netherlands
32. Simbox	EAWAG	Unknown	Unknown	Switzerland
33. TEAM	Ecobalance +1 301 548 1750 +1 301 548 1760	1.15 & 2.0	10	Europe/US
34. TEMIS	Oko-Institut Phone +49 761 473130 Fax +49 761 475437	2	0.3	Europe
35. TetraSolver	TetraPak	Unknown	Unknown	Europe
36. Umberto	IFEU +49 40 462033 +49 40 462034	Unknown	Unknown	Germany
37. Umcon	Particip Gmbh	Unknown	Unknown	Germany
38. Öekobilanz von Packstoffen	BUWAL	EXCEL-files	0.25	Switzerland

WWW will quickly be able to browse for additional information sources, and at the same time the number of links will increase.

The following addresses have been chosen because they contain a number of links specifically related to LCA, or because the organisations are central in distributing LCA knowledge.

Centre of Environmental Science, CML, Leiden (NL): http://www.leidenuniv.nl/interfac/cml/lcanet/hp22.htm.

EcoSite (UK): http://www.ecosite.co.uk.

Environment Canada. http://www.doe.ca/ecocycle/.

SB Young Consulting (CA): http://www.io.org/~lca.

Society of Environmental Toxicology and Chemistry, SETAC (US): http://www.setac.org/fndt.html.

Thomas Gloria, Tufts University (US): http://www.tiac.net/users/tgloria/LCA/lca.html.

Appendix 5.1:

Database on LCA Organisations

A database has been developed in Access 2.0 by dk-TEKNIK and the information referred to is version 2.0 c Beta. The database is available on EEA homepage: http://www.eea.eu.int

Content
The database contains information on more than 180 organisations and on more than 410 contact persons working with life cycle assessment.

The building of the database is in five parts for each organisations:

- Organisation Information
- LCA Contact Persons
- LCA Publications
- LCA Projects
- LCA Software

Beneath each of the five part are shortly described.

Organisation Information
Each organisation is given by name and address including phone and fax number, e-mail and homepage address. The type of organisations are in the categories: Academic, Consultancy, Governmental, Industry, Institute and Non Governmental Organisation (NGO).

There is a searching facility on name and address of the organisation.

For each organisation there is a short description called Organisation Profile. There is information on the type of LCA's the organisations work with and their experiences. In this part the date of the latest updating is noted.

LCA Contact Persons
This section contains information on the full name, titles, direct phone and fax numbers and e-mail address. For each person there is a short Curriculum Vitae on key qualifications, experiences and memberships relevant for LCA.

Furthermore there is a total list of LCA contact persons for each organisation.

LCA Publications
Publications on LCA by the organisations, during the last five years, are listed in this section.

LCA Projects
Projects on LCA, which the organisation has participated in, are described by titles, content, possible partners and funders and period for the project.

LCA Software
In this section LCA software developed or used by the organisation is shortly described.

Other user possibilities
There is a printing function for each of the five sections and one for all the information in the database.

There is a search function on organisation and the list is alphabetic on names.

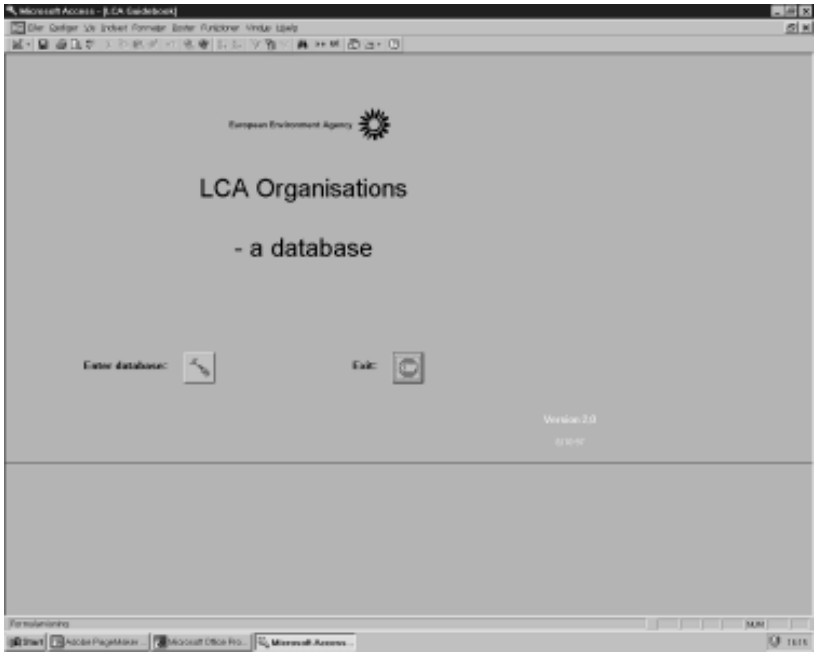
Furthermore each organisation has an internal number and it is possible to go to the previous and the next organisation number and thereby find the wanted organisation.

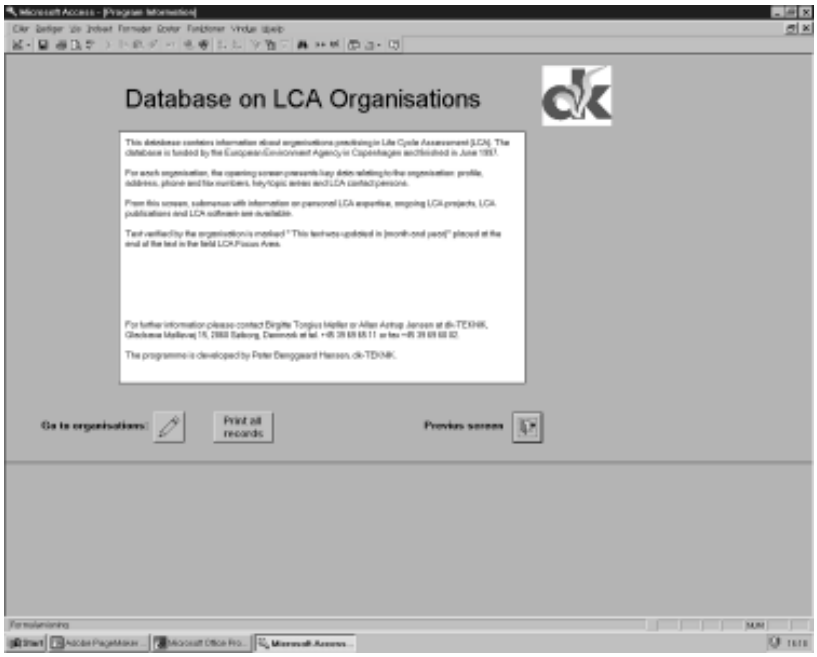
Updating
There will probably be an updating of the database version 1.0, but at the present time there is no agreement on the updating.

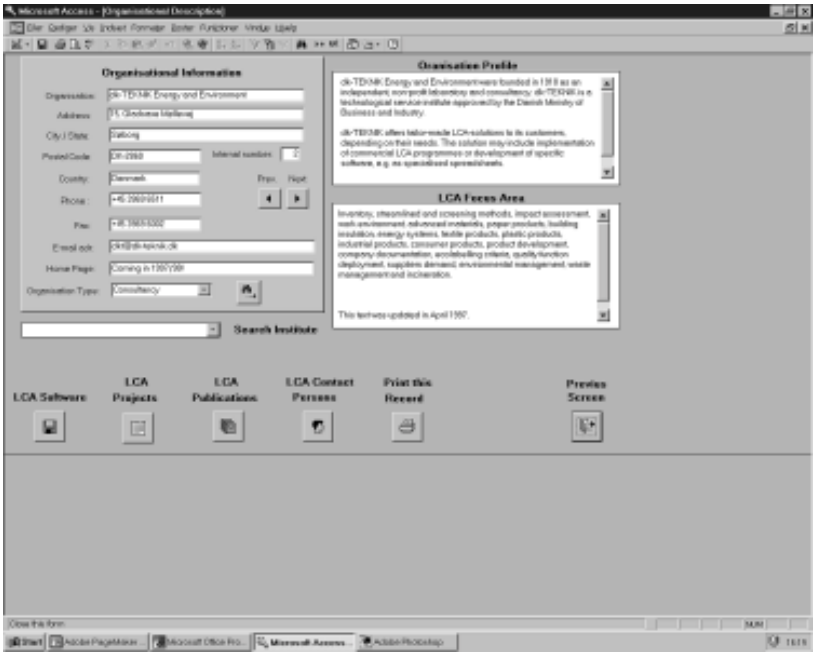
Enclosed
Screen prints from the database.

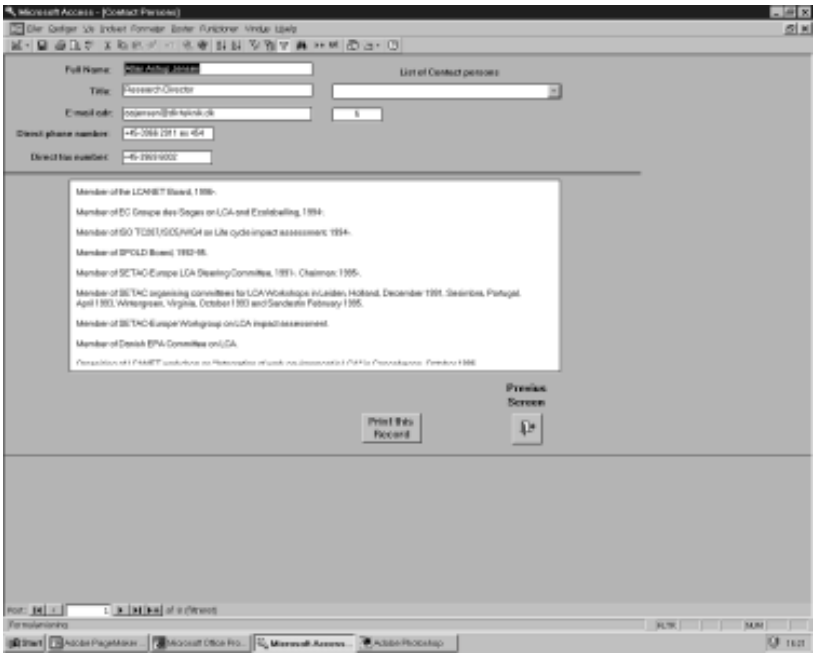
Appendix 5.1.1:

Screen prints from the database






Organisational Information
Organisation Profile
LCA Focus Area
Search Institute
LCA Software
LCA Projects
LCA Publications
LCA Contact Persons
Print this Record
Previus Screen


List of Contact persons
Previus Screen
Print this Record

Appendix 5.1.2:

Print examples on organisations

Organisation Name:
dk-TEKNIK Energy and Environment

Address:
15, Gladsaxe Møllevej

City:
Søborg

Postal Code:
DK-2860

Country:
Denmark

Phone Number:
+45 3969 6511

Fax Number:
+45 3969 6002

E-mail Adress:
dkt@dk-teknik.dk

Homepage Adress:
Coming in 1997/98!

Organisation Profile:
dk-TEKNIK Energy and Environment were founded in 1918 as an independent, non-profit laboratory and consultancy. dk-TEKNIK is a technological service institute approved by the Danish Ministry of Business and Industry.

dk-TEKNIK offers tailor-made LCA-solutions to its customers, depending on their needs. The solution may include implementation of commercial LCA programmes or development of specific software, e.g. as specialised spreadsheets.

dk-TEKNIK is internationally active in harmonisation and standardisation of LCA.

dk-TEKNIK is hosting the Danish Boilers Owners Association and is part of the Danish Centre for Biomass Energy. Main activities are: Energy management and auditing, fuel efficiency, combustion and cleaning technology, measurements of air quality, air emissions, odour and noise, air pollution modelling, environmental management, environmental impact assessment, product life-cycle assessment and ecolabelling.

Focus Area:
Inventory, streamlined and screening methods, impact assessment, work environment, advanced materials, paper products, building insulation, energy systems, textile products, plastic products, industrial products, consumer products, product development, company documentation, ecolabelling criteria, quality function deployment, suppliers demand, environmental management, waste management and incineration.

This text was updated in April 1997.

Contact Name:
Allan Astrup Jensen

E-mail Adress:
Research Director

Title:
aajensen@dk-teknik.dk

Direct Phone No.:
+45-3966 2011 ext. 454

Direct Fax No.:
+45-3969 6002

Personal CV:
Member of the LCANET Board, 1996-

Member of EC Groupe des Sages on LCA and Ecolabelling, 1994-

Member of ISO TC207/SC5/WG4 on Life cycle impact assessment, 1994-.

Member of SPOLD Board, 1992-95.

Member of SETAC-Europe LCA Steering Committee, 1991-. Chairman: 1995-.

Member of SETAC organising committees for LCA Workshops in Leiden, Holland, December 1991, Sesimbra, Portugal, April 1993, Wintergreen, Virginia, October 1993 and Sandestin February 1995.

Member of SETAC-Europe Workgroup on LCA impact assessment.

Member of Danish EPA Committee on LCA.

Organizing of LCANET workshop on „Inte-

gration of work environment in LCA“ in Copenhagen, October 1996.

Organizer of LCA sessions at SETAC-Europe annual Congress in 1994 and 1996.

Participated in SETAC Life cycle impact assessment workshops in Sandestin, Florida, February 1992.

LCA Publications:

Schmidt A. (1996). Environmental Guidance to public buyers. Photocopying machines. Information and background. Project for the danish EPA. December 1996.

Møller B. Torgius (1996). Environmental Guidance to public buyers. Copying paper. Information and background. Project for the danish EPA. December 1996.

Jensen A.A., Møller B.T., Søborg L. and Potting J. (1996) Work Environmental Issues in Life Cycle Assessment, LCANET Summary Report, Draft, Copenhagen.

Potting, J., Møller, B.T. and Jensen, A.A. (1996) Work environment and LCA, LCANET Theme Report. Draft, dk-TEKNIK, November.

Jensen A.A. and Vigon B.W. (1995) Life cycle assessment: Data Quality and Databases Practitioner Survey. J. Cleaner prod. 3(3): 135-41.

Fava J, Jensen A.A., Lindfors L., Pomper S., De Smet B., Warren J., Vigon B., eds. (1994) SETAC, Life-cycle assessment data quality: a conceptual framwork. Workshop report, Wintergreen, October, 1992. Pensacola: SETAC.

Grisel L., Jensen A.A., Klöpffer W., Lindfors L-G., eds. (1994) Integrating impact assessment into LCA. Brussels: SETAC-Europe.

Schmidt, A. and Drabæk, I. In: Midtgaard, U. (editor) (1994). Integrated environmental and occupational assessment of new materials - the Danish Materials Technology Programme (MUP). National Institute of Occupational Health, Copenhagen.

Udo de Haes H.A., Bensahel J-F, Clift R., Fussler C.R., Griesshammer R., Jensen A.A. (1994) Guidelines for the application of life-cycle assessment in the European Union ecolabelling programme. Leiden: CML, September.

Jensen A.A., Hansen L.E., Jensen O.K. and Werther, I. (1993)Textile products. Keyfeatures 3. Draft version - Restricted use. dk-TEKNIK June.

Jensen O.K., Hansen L.E. and Jensen A.A. (1993) Textile products. Impact assessment and criteria for eco-labelling. Draft. dk-TEKNIK for the Danish EPA, December.

Schmidt, A., Jelnes, J.E., Hansen, L.E. et al. In: Lindfors, L.G. (editor) (1992) Health Impacts and Life Cycle assessment. Product life cycle assessment - principles and methodology. Nord 1992:9. Nordic Council of Ministers, Copenhagen.

Stranddorf H.K., Schmidt A., Hansen L.E., Jensen A.A., Thorsen M. (1995) Thermal Insulation Products for Walls and Roofs.

Stranddorf H.K., Hansen L.E., Schmidt A., Jensen A.A et al. Establishing fo Key Features (and Criteria) Covering Full Life Cycle for Thermal Insulation Products for Walls and Roofs Based on LCA. dk-TEKNIK, Soeborg.

LCA Projects:

LCA Guidebook for European Environment Agency (EEA) 1996 - 1997. LCA database and a LCA Guidebook Report. dk-TEKNIK. In co-operation with SustainAbility (United Kingdom).

LCANET Theme report on Work Environment and LCA. Report on workshop in Copenhagen, October 1996.

An Environmental Informative label based on Life-Cycle Assessment. Project for the Danish EPA. 1996-1997.

Environmental assessment of selected garments. In co-operation with Danish Technological Institute, Clothing and Textile. A project for the Danish EPA. 1996-

LCA Software:

The database for the LCA Guidebook is

developed by dk-TEKNIK. 1996-1997

dk-TEKNIK offers tailor-made LCA-solutions to its customers, depending on their needs. The solution may include implementation of commercial LCA programmes or development of specific software, e.g. as specialised spreadsheets.

Organisation Name:
SustainAbility Ltd

Address:
49-53 Kensington High Street

City:
London

Postal Code:
W8 5ED

Country:
United Kingdom

Phone Number:
+44 171 937 9996

Fax Number:
+44 171 937 7447

E-mail Adress:
info@sustainability.co.uk

Homepage Adress:
-

Organisation Profile:
SustainAbility Ltd. was formed in 1987 and is an internationally respected, award-winning environmental management and sustainable development consultancy - offering specialist services in corporate environmental policy, strategy, management systems, product life-cycle management, auditing and verification, communications and reporting and training. Throughout, SustainAbility focuses on the „Triple Bottom Line“ of sustainable development: economic prosperity, environmental quality, and social equity.

Focus Area:
Applications, business usage, ecolabelling, stakeholders views.

This text was updated in March 1997.

LCA Publications:
Engaging Stakeholders (1996). The second international progress report on company environmental reporting. SustainAbility and UNEP.

Who Needs it? Market implications of sustainable Lifestyle (1995). SustainAbility and Dow Europe.

Company Environmental Reporting (1994). SustainAbility and UNEP

The LCA Sourcebook (1993). A European Business Guide to Life-Cycle Assessment, SustainAbility, SPOLD, and Business in the Environment. ISBN 0-9521904-0-0

Organisation Name:
Tauw Milieu bv

Address:
11 Handelskade, PO Box 133

City:
Deventer

Postal Code:
NL-7400 AC

Country:
The Netherlands

Phone Number:
+31 5700 99911

Fax Number:
+31 5700 99666

E-mail Adress:
-

Homepage Adress:
-

Organisation Profile:
Independent consultancy in the field of environmental research, with approximately 500 people employed. The organisation was founded in 1928. The company houses one of the largest environmental laboratories in the Netherlands. Tauw milieu is a full daughter of the Tauw Holding group, which employs approximately 1000 people.

Tauw Milieu has carried out a number of projects in the field of environmental management, like EIA (Environmental Impact Assessment), environmental auditing and LCA.

Focus Area:
The department for environmental management has performed LCA´s on a wide variety of subjects, for example catering systems, packaging, copying paper, water treatment techniques, soil sanitation techniques, waste

treatment, etc. Also a lot of ecolabelling projects were carried out, both for the Dutch ecolabelling body (e.g. paper products, cat litter, floor coverings and refrigerators) and the EU (e.g. cleaning products, cat litter and paper products).

This text was updated in December 1996.

LCA Publications:
Nijdam D.S. (1996) Ecolabel Converted Paper Products. Feasibility Study. R 3449165.W02/DSN.

LCA of zinc roof gutters, review and update (I English, German and Dutch) (1996). Client: The Dutch zinc industry.

Product study Dyes „Dyes, How green are they?“ (1994/95) (In Dutch). Client: Ministry of VROM1, Directorate IBPC (Industry, Building, Products and Consumers).

Product study „Dyes and Pigments“ (1990/1991) (In Dutch). Client: Ministry of VROM1, Directorate Substances and Risk Control.

LCA of water treatment techniques (In Dutch and English) (1995). Client: Norit NV (producer of granular activated carbon).

LCA of watersoil remediation techniques (1994) (In Dutch). Client: RIZA2.

LCA of gutter systems (1994) (In Dutch). Client: RIZA 2

LCA for a starch product vs polypropene (1993/1994) (In Dutch). Client: Ministry of VROM1, Directorate IBPC.

Product study into plastic water bank reinforcement materials (1994) (In Dutch). Client: Ministry of VROM1, Directorate IBPC.

Product study into xerographic paper (LCA and environmental performance indicator case study) (1992/1993) (In Dutch)

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European Ecolabel toilet cleaning products. Client: The European Commission.

European Ecolabel floor cleaning products. Client: The European Commission.

Dutch Ecolabel offsetpaper. Client: Stichting Milieu (Dutch competent body for ecolabelling).

Dutch Ecolabel papertowels. Client: Stichting Milieu (Dutch competent body for ecolabelling).

Dutch Ecolabel cotton towel dispensers. Client: Stichting Milieu (Dutch competent body for ecolabelling).

LCA of waste treatment systems. Client: A large waste treatment company.

Appendix 5.1.3:

Total list of organisations in the database version 1.0
(next 5 pages)

5 sider tabel i separat dokument

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