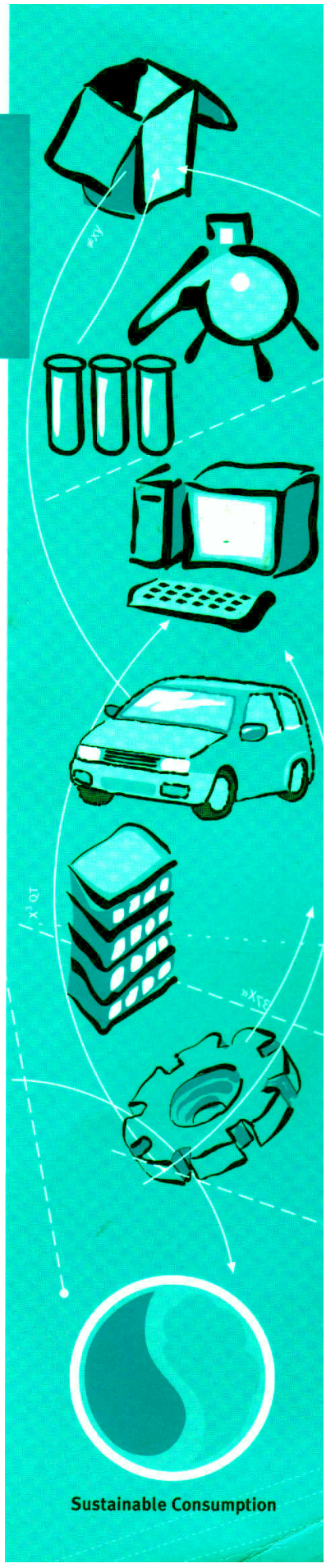
United Nations Environment Programme
Division of Technology, Industry and Economics
Production and Consumption Branch

# Evaluation of Environmental Impacts in Life Cycle Assessment




## Meeting report

**Brussels, 29-30 November 1998, and**
**Brighton, 25-26 May 2000**

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# EVALUATION OF ENVIRONMENTAL IMPACTS IN LIFE CYCLE ASSESSMENT

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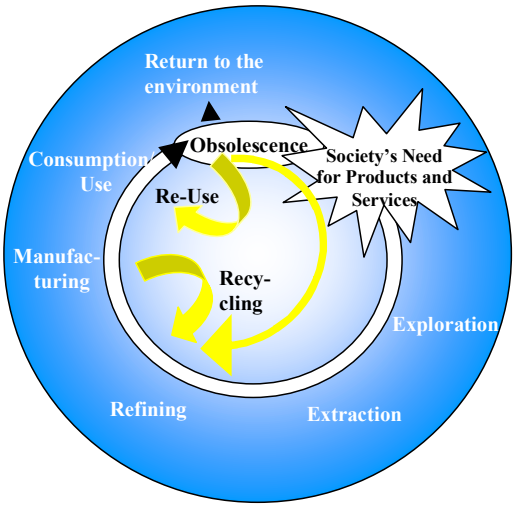
"We have at our disposal the human and material resources to achieve sustainable development, not as an abstract concept but as a concrete reality". Our efforts "must be linked to the development of cleaner and more resource efficient technologies for a life cycle economy".

Malmö Declaration, 1st Global Ministerial Environment Forum

"Consumers are increasingly interested in the world behind the product they buy. Life cycle thinking implies that everyone in the whole chain of a product's life cycle, from cradle to grave, has a responsibility and a role to play, taking into account all the relevant external effects. The impacts of all life cycle stages need to be considered comprehensively when taking informed decisions on production and consumption patterns, policies and management strategies."

Klaus Toepfer, Executive Director, UNEP



# Foreword

In 1998 and 2000, UNEP joined forces with US-EPA and CML to facilitate an international discussion forum on two specific issues of scientific development in the field of Life Cycle Assessment - first, the level of sophistication in impact assessment and second, the type of environmental indicators to use. To this end, two international expert workshops were held. The present document provides an introduction to the workshop topics, a report of these two workshops, and some resources for further information. It has been published with the kind support of US-EPA. Our goal with this publication is to bring the overall issues, and the specific discussions and outcomes of both workshops to a broader audience.

In 2002, UNEP continued to facilitate an international forum for life cycle approaches with the launch of the UNEP/ SETAC Life Cycle Initiative, also with the involvement of US-EPA and CML. This new initiative responds to the call of the "Malmö Declaration", the agreement signed by the world's environment ministers at the 1st Global Ministerial Environment Forum, for a life-cycle economy. The relevance of life cycle analysis for changing unsustainable consumption and production patterns was emphasized in the plan of implementation emanating from the World Summit of Sustainable Development in 2002.

UNEP hopes to foster the application of life cycle assessment in public and private decision making for the benefit of the consumer and the sake of the environment. Therefore, UNEP is promoting supply chain responsibility and sustainable procurement to business and governments in order to create a need for life cycle information. Capacity building on life cycle approaches will be undertaken via regional programmes falling under the UNEP/SETAC Life Cycle Initiative.

The development of a consistent methodology framework, internationally accepted, is a priority to promote Life Cycle Assessment. Environmental Product Declarations would stand to benefit from such an approach. We also know that it is important to develop Life Cycle Management approaches. Finally sharing information and results obtained from Life Cycle Assessment studies is crucial to progress towards a life cycle economy. These are also subjects that will be addressed by the UNEP/ SETAC Life Cycle Initiative.

We in UNEP hope that this publication, as well as our other activities, will help to raise awareness of life cycle approaches around the world and assist in their effective implementation.

Jacqueline Aloisi de Larderel
Assistant Executive Director, UNEP
Director, DTIE

# Contents

# Guidance for readers

The mission of UNEP's Division of Technology, Industry and Economics (UNEP DTIE) is to help decision makers in governments, industry and local authorities develop and adopt policies, strategies and practices that are cleaner and safer, and make efficient use of natural resources; ensure adequate management of chemicals; incorporate environmental costs, and reduce pollution risks to people and the environment.

Within the Division, the Production and Consumption Unit aims to reduce the environmental consequences of industrial development and the pollution arising from the ever-increasing consumption of goods and services. The Unit's sustainable consumption activities apply a life cycle approach to consumer's needs. The focus is on understanding the driving forces behind consumption – using them to inspire cost-effective improvements, thereby raising the quality of life and reducing environment damage.

In the Malmö declaration more than 100 Ministers of Environment, gathered at the first Global Ministerial Environment Forum in the year 2000, emphasized the importance of the life-cycle economy as the overall objective for the development of cleaner and more resource efficient technologies. Life Cycle Assessment (LCA) has proved itself a valuable quantitative tool to support the way towards a life cycle economy by documenting the environmental considerations that need to be part of decision making for a sustainable development, which here is understood as satisfying the needs of the present generation without compromising the needs of future generations. Sustainability includes taking into account three aspects:

1. Economic: we need economic growth; to assure our material welfare;
2. Environmental: we need to minimize environmental damage, pollution, and exhaustion of resources;
3. Social: this is equity; the world's resources should be better shared between the rich and the poor.

There is evidence that LCA is not being utilized to its full potential, even in those countries that are most involved in its development and application. A major goal is therefore to increase worldwide the availability of information on LCA and to foster its use.

In 1996, UNEP published *Life Cycle Assessment: What it is and How to do it* to provide background information on the LCA concept and examples of current practice. In 1999, UNEP published *Towards the Global Use of Life Cycle Assessment,* connected to the workshop held in San Francisco the previous year.

This present meeting report – *Evaluation of environmental impacts in Life Cycle Assessment* – is based on workshops held in Brussels, 29-30 November 1998, and Brighton, 25-26 May 2000. It has been produced with the support of the United States Environmental Protection Agency (US-EPA). Its four main sections elaborated in cooperation among AGA, CML, US-EPA and UNEP provide a concise overview of the current status of the theory and practice of Life Cycle Impact Assessment (LCIA), document the improvements in the evaluation of impacts in Life Cycle Assessment, and discuss the challenges and opportunities for its wider application. LCIA provides a framework standardized by ISO 14042 for the systematic evaluation of environmental impacts in LCA. In this report, evaluation is meant in its broad sense; unlike ISO, here evaluation includes not only the formal step weighting, but the whole topic of assessing environmental stressors in a life cycle perspective. Several approaches for different types of environmental impacts have been developed in recent years.

Guidance for readers

## Readers's guide

This report is divided into four parts:

**Part One** provides a brief overview of the concept of life cycle thinking and LCA methodology with focus on Life Cycle Impact Assessment for those not familiar with the approach and identifies the potential users of LCA.

**Part Two** gives an introduction to the evaluation of environmental impact in LCA and describes the basic elements in Life Cycle Impact Assessment (LCIA) presenting a brief definition of the main concepts and steps in the LCIA based on ISO 14042. This chapter analyses as well the concept of sophistication in LCIA and the factors involved in its determination. An important aspect within sophistication is the definition of midpoints and endpoints and their different approaches. Both concepts will be presented and analyzed in this chapter providing different examples, theories and approaches.

**Part Three** analyses the results of the international expert workshops held in Brussels and Brighton under the umbrella of UNEP. The first was held to give an opportunity for international experts to address the issues related to Life Cycle Impact Assessment sophistication in an open format. The second addressed issues on the implications of midpoints versus endpoints indicators in LCIA with respect to uncertainty, transparency and the ability to subsequently resolve trade-offs across impact categories using weighting techniques.

**Part Four** reviews the main challenges in the current state of LCA and recommends ways to overcome them. The special aim is to reach a more widespread use of the Life Cycle Impact Assessment phase in the LCA studies.

**Appendices** to this report comprise a thematic bibliography, main internet resources, existing software and a list of key institutions involved in Life Cycle Assessment, as well as the lists of participants in the Brussels and Brighton workshops.

This report is written for both those unfamiliar with the LCIA framework and the LCA community familiar with the different aspects of the evaluation of environmental impacts in LCA.

Readers who are totally unfamiliar with LCA should start with Part One and the section of the appendix "LCA for beginners." Based on this information they should be able to understand Part Two and Part Four. Moreover, they will find interesting resources for further information on LCA in the appendix that could be a necessary support to completely follow the ongoing scientific discussions of the LCIA community researchers presented in Part Three.

LCA commissioners and practioners who want to know about LCIA can start with Part Two which gives a trouble-free insight into the issues related to the evaluation of environmental impacts in LCA. Part Three may, or may not, be attractive for them, depending on their interest in the more detailed questions of LCIA development.

LCIA experts are referred to Part Three and Four in order to learn about the scientific discussions and recommendations regarding the topics of the two international workshops on LCIA. Additonally two articles of workshop summaries published in a scientific journal are added in the appendix.

# Acknowledgements

This publication is based on the material provided by the speakers of the international expert workshops held in Brussels on November 29-30, 1998 and in Brighton on May 25-26, 2000 under the umbrella of UNEP, the workshop summaries prepared by Jane C. Bare (US-EPA), Patrick Hofstetter (ORISE Research Fellow, US-EPA), David W. Pennington (former ORISE Research Fellow, US-EPA; now EPFL) and Helias A. Udo de Haes of the Centre of Environmental Science (CML) at the Leiden University in the Netherlands (Bare et al., 1999; Bare et al., 2000 and EPA, 2000) and a background report provided by Guido W. Sonnemann and Francesc Castells of the Environmental Analysis and Management Group (AGA) at the Fundació URV – STQ of the University Rovira i Virgili in Tarragona/ Spain.

The Editorial board of the production comprised Jacqueline Aloisi de Larderel, Bas de Leeuw and Anne Solgaard of UNEP DTIE as well as Jane Bare of US-EPA. Thanks are also to Patrick Hofstetter (former ORISE Research Fellow, US-EPA) Helias A. Udo de Haes (CML), Olivier Jolliet (EPFL) and David W. Pennington (former ORISE Research Fellow, US-EPA; now EPFL) for their advice and comments.

Financial support for the project was provided by the US-EPA who also edited the text.

Part One

# The Framework of Life Cycle Assessment (LCA)

## Life Cycle Thinking

Life cycle thinking is a way of addressing environmental issues and opportunities from a system or holistic perspective. In this way of thinking, a product or service is evaluated or designed with a goal of reducing potential environmental impacts over its entire life cycle. Life cycle thinking does not generally normalize the results to a functional unit, as is done as part of a Life Cycle Assessment study. The concept of life cycle thinking implies the linking of individual processes to organized chains starting from a specific function.

Life cycle thinking implies that everyone in the whole chain of a product's life cycle, from cradle to grave, has a responsibility and a role to play, taking into account all relevant external effects. From the extraction of the raw material through refining, manufacturing, use or consumption to its reuse, recycling or disposal, individuals must be aware of the impact that this product has on the environment and try to reduce it as much as possible. The impacts of all life cycle stages need to be considered when taking informed decisions on the production and consumption patterns, policies and management strategies. This is also the idea behind the global aim of the life cycle economy mentioned in the Malmö declarations of more than 100 Ministers of Environment on 31 May 2000.

## Overview of LCA methodology

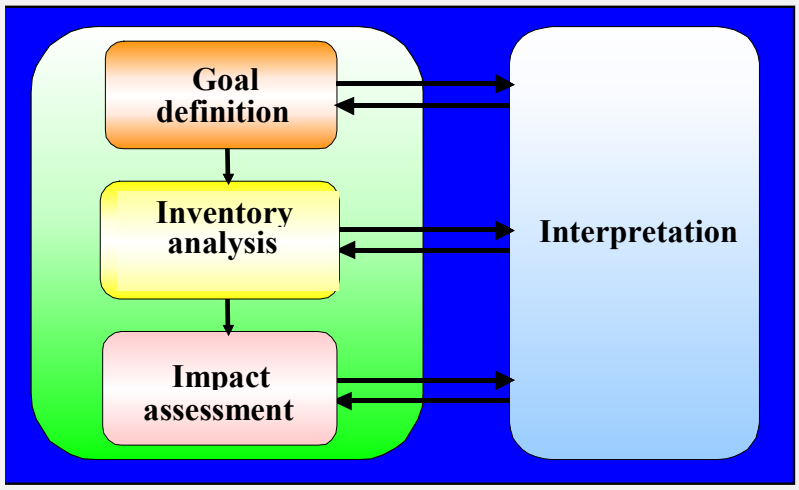
The technical framework for the Life Cycle Assessment methodology has been standardized by the International Standards Organization (ISO). According to ISO 14040, LCA consists of four phases, as presented in Figure 1:

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

These phases are not simply followed in a single sequence. This is an iterative process, in which subsequent iterations (rounds) can achieve increasing levels of detail (from screening LCA to full LCA), or lead to changes in the first phase prompted by the results of the last phase. Life Cycle Assessment has proven to be a valuable tool to document and analyze environmental considerations of product and service systems that need to be part of decision making towards sustainability.

ISO 14040 provides the general framework of LCA. ISO 14041 provides guidance for determining the goal and scope of an LCA study, and for conducting a life cycle inventory. ISO 14042 is about the life cycle impact assessment phase, and ISO 14043 provides guidance for the interpretation of results from an LCA study. Technical guidelines exist that illustrate how to apply the standards.

# Part One




**Goal and scope definition:** the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined.

**Inventory analysis:** the energy carriers and raw materials used, the emissions to atmosphere, water and soil, and different types of land use are quantified for each process, then combined in the process flow chart and related to the functional basis.

**Impact assessment**: the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance.

**Interpretation**: the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

FIGURE 1: THE PHASES OF LIFE CYCLE ASSESSMENT ACCORDING TO ISO 14040

## LCA USERS

LCA can be used by: industry and other types of commercial enterprises, governments at all levels, non-governmental organizations such as consumers organizations and environmental groups, and consumers. The motivations for use vary among the user groups.

An LCA study may be carried out for operational reasons, as in the assessment of individual products, or for strategic reasons, as in the assessment of different policy scenarios, waste management strategies or design concepts. LCA may be used for internal or external applications.

Part Two

# Introduction to Life Cycle Impact Assessment (LCIA)

## BASIC ELEMENTS IN LCIA

Life Cycle Impact Assessment (LCIA) is the third phase of Life Cycle Assessment described in ISO 14042 and further outlined with examples in ISO TR 14047. The purpose of LCIA is to assess a product system's Life Cycle Inventory to better understand its environmental significance. It also provides information for the interpretation phase.

The LCIA phase provides a system-wide perspective of environmental and resource issues for product system. It assigns Life Cycle Inventory results via characterization to impact categories. Characterization of emissions, resources extractions and land use means the aggregation by adequate factors of different types of substances or other interventions in a selected number of environmental issues, or "impact categories" such as resource depletion, climate change, acidification or human toxicity. For each impact category the indicators are selected and the category indicator results are calculated. The collection of these results provides information on the environmental impact of the resource use and emissions associated with the product system.

The general framework of the LCIA phase is composed of several mandatory elements that convert LCI results to indicator results. In addition, there are optional elements. The LCIA phase is only one part of a total LCA study and shall be coordinated with other phases of LCA. An overview of the mandatory and optional elements is given in Figure 2.

Separation of the LCIA phase into different elements is necessary for several reasons:

1. Each LCIA element is distinct and can be clearly defined.
2. The LCA study goal and scope definition phase can consider each element.
3. A quality assessment of the LCIA methods, assumptions and other decisions can be conducted for each LCIA element.
4. LCIA procedures, assumptions, and other operations within each element may be transparent for critical review and reporting.
5. Values and subjectivity – value choices – within each element have to be made transparent for critical review and reporting, if applied.

The mandatory LCIA elements are listed below:

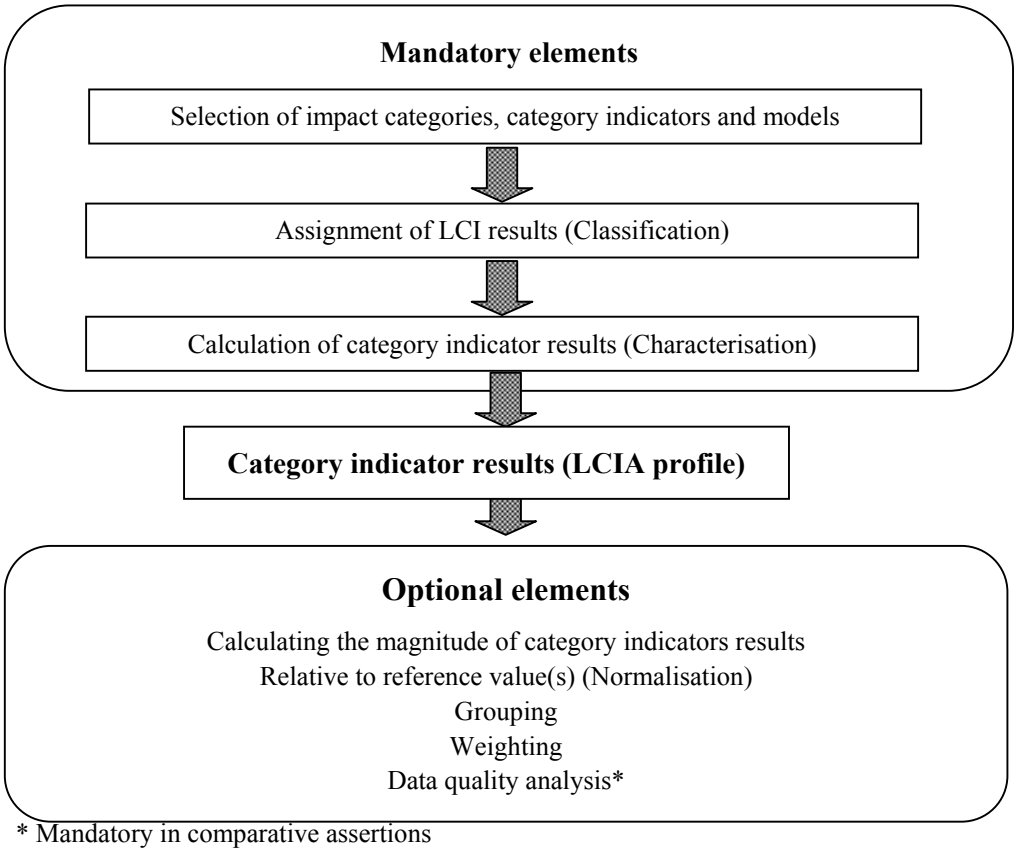
- Selection of impact categories, category indicators, and models.
- Assignment of LCI results (Classification) to the impact category. That is, the data from the inventory table are grouped together into a number of impact categories.
- Calculation of category indicator results (Characterization). Analysis and estimation of the magnitude of the impacts on the ecological health, human health, or resource depletion for each of the impact categories.

The indicator results for different impact categories together represent the LCIA profile for the product system.

There are optional elements and information that can be used depending on the goal and scope of the LCA study:

# Part Two

- Calculating the magnitude of category indicator results relative to reference value(s) (Normalization). All impact scores–contribution of a product system to one impact category–are related to a reference situation.
- Grouping; sorting and possibly ranking of the indicators.
- Weighting; aiming at prioritizing and possibly aggregating indicator results across impact categories. It is a quantitative comparison of the seriousness of the different impact potentials of the product systems, in general with the aim to obtain a single index of environmental performance.
- Data quality analysis; understanding better the reliability of the LCIA results.




* Mandatory in comparative assertions

FIGURE 2: MANDATORY AND OPTIONAL ELEMENTS OF LCIA ACCORDING TO ISO 14042

The use of models is necessary to derive the characterization factors. The applicability of the characterization factors depends on the accuracy, validity and characteristics of the models used. For most LCA studies no models are needed because existing impact categories, indicators and characterization factors will be selected from available sources. As can be seen in Figure 3 models reflect the cause-effect chain (environmental mechanism) of an impact category by describing the relationship between the LCI results, indicators and if possible category endpoint(s), i.e. the receptors that are damaged. For each impact category, the following procedure is proposed in ISO 14042:

Part Two

- Identification of the category endpoint(s).
- Definition of the indicator for given category endpoint(s).
- Identification of appropriate LCI results that can be assigned to the impact category, taking into account the chosen indicator and identified category endpoint(s).
- Identification of the model and the characterization factors.

This procedure facilitates an adequate inventory analysis and the identification of the scientific and technical validity, assumptions, value choices and the degree of accuracy of the model. The resulting indicators may vary in precision among impact categories due to the differences between the model and the corresponding environmental mechanism. The use of simplifying assumptions and available scientific knowledge influences the accuracy of the indicators.

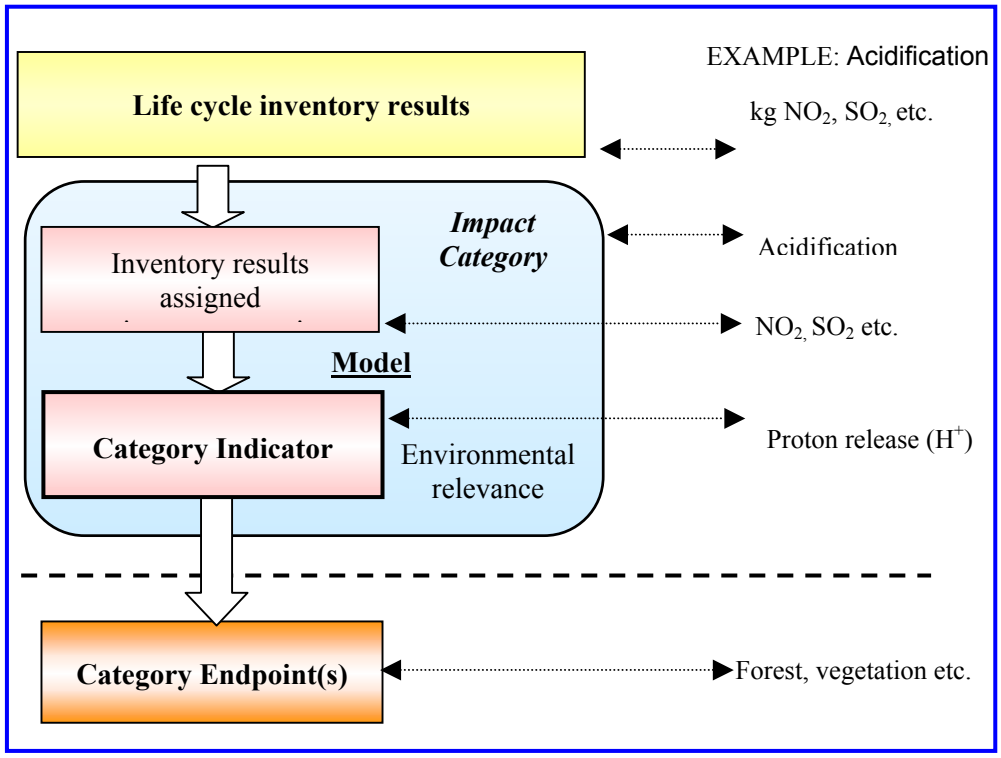



FIGURE 3: THE CONCEPT OF INDICATORS (ISO 14042). THE RELATIONSHIP BETWEEN THE LIFE CYCLE INVENTORY RESULTS, CATEGORY INDICATORS AND CATEGORY ENDPOINT(S) IS ILLUSTRATED FOR THE EXAMPLE OF ACIDIFICATION. THE INVENTORY RESULTS RELEVANT FOR ACIDIFICATION AS $NO_2$ AND $SO_2$ ARE ASSIGNED TO THIS CATEGORY. THEY ARE THEN RELATED TO THE CATEGORY INDICATOR (PROTON RELEASE) BY THE CHARACTERIZATION FACTORS CALCULATED BASED ON A MODEL. THE CLOSENESS OF THE INDICATOR TO THE CATEGORY ENDPOINTS DETERMINES ITS ENVIRONMENTAL RELEVANCE.

The relationship of the category endpoints as physical elements to the societal values behind them has been contemplated in the concept of Areas of Protection (AoP). In the first report of the Second SETAC Working Group on Life Cycle Impact Assessment (Udo de Haes et al., 1999), an AoP is defined as a class of category endpoints. In ISO 14042 three of such classes are mentioned, be it in a rather implicit way: human health, natural environment and natural resources.

Part Two

Another term used is the expressive term "safeguard subject", introduced by Steen and Ryding (1992). It is important to note that these two terms exactly convey the same message: they relate to the category endpoints as physical elements, not to the societal values behind.

AoPs enable a clear link with the societal values which are the basis for the protection of the endpoints concerned. Table 2 gives an overview of the AoPs with underlying societal values as presented by Udo de Haes et al. (1999), including man-made environment, i.e. damages to crops and materials. AoPs are the basis for the determination of relevant endpoints, their definition implies value choices. Thus, there is not one correct way to define a set of AoPs.

TABLE 2: AREAS OF PROTECTION AND UNDERLYING SOCIETAL VALUES (UDO DE HAES ET AL., 1999)

| **Areas of Protection** | **Societal values** |
|---|---|
| 1. Human Health | Intrinsic value of human life, economic value |
| 2. Natural Environment | Intrinsic value of nature (ecosystems, species), economic value of life support functions |
| 3. Natural Resources | Economic and intrinsic values |
| 4. Man-made Environment | Cultural, economic and intrinsic values |

Normally damages to elements within the economy that do not involve environmental processes are excluded from LCIA. An example concerns material damage caused by car accidents. In fact, these types of impact are part of the product system itself. A product system therefore not only fulfils a function, but also can lead to internal damage within the product system itself without any involvement of processes in the environment. In principle, LCA can include also the analysis of these types of impact, but in general these are considered to be additional to the environmental impacts that are part of the scope of an environmental management tool.

## LEVEL OF SOPHISTICATION IN LCIA

### What does sophistication mean?

The level of sophistication corresponds to the level of detail used in the impact assessment. In accordance with Bare et al. (1999) sophistication in LCIA can be considered as the ability to provide very accurate and comprehensive reports to help decision making in each particular case. In language more consistent with recent ISO publications, the practitioners of LCA are faced with the task of trying to determine the appropriate level of sophistication in order to provide a sufficiently comprehensive and detailed approach to assist in environmental decision-making. Sophistication has many dimensions and, dependent upon the impact category, may simulate the fate and exposure, effect and temporal and spatial dimensions of the impact. It has the ability to assess the validity and accuracy of the models used in LCIA (Udo De Haes et al., 1999; Owens et al., 1997; Udo de Haes, 1996; Fava et al., 1993).

Part Two

Traditionally LCIA uses linear modeling, takes the effects of the substances into account, but not their background concentrations and the geographical dependency on fate, and aggregates the environmental consequences over:

- time,
- locations, ⇨ "potential impact"
- chemicals.

All this only allows calculating potential impact scores, not actual damages.

Therefore, the appropriate level of sophistication of LCIA involves quite a number of issues. An overview of these different levels of detail in the characterization step of LCIA is given in Figure 4. A major point concerns the extension of the characterization modeling to include the dispersion or fate of the emitted substances as well as their exposure, and not only the physical damages to endpoints by dose-response functions. Exposure is the concentration increase due to the emission plus the background. More sophisticated possibilities arise which use multimedia modeling, take background levels of substances into account and make use of non-linear dose-response functions in the effect analysis. An important question for the quantification of the effect is whether there are real science-based thresholds that can be exceeded, or whether these thresholds are always of a political origin. Another issue concerns a possible differentiation in space and time. Studies can include impact models that use data just at world level and do not specify time periods; in contrast, more recent options involve spatial details of impacts and distinguish between different time periods.

A further question relates to the role and practicality of including uncertainty and sensitivity analysis. According to Bare et al. (1999) sensitivity analysis is increasingly included in LCA studies; but this is not yet the case for uncertainty analysis. Finally, there is the question of how to apply these different options for sophistication of LCIA, which applications can afford to keep it simple, and for which applications a more detailed analysis is needed.

## Factors involved in the determination of the level of sophistication

The important issue of deciding the appropriate level of sophistication is not typically addressed in LCA. Often, the determination of sophistication is based on considerations that may, or may not, be appropriate, but which may include practical reasons for limiting sophistication (e.g., the level of funding). A discussion of the most appropriate ways of determining sophistication will include (Bare et al., 1999):

- Study objective
- An uncertainty and/ or sensitivity analysis
- The inventory data and their specifications
- Depth of knowledge and comprehension in each impact category
- The quality and availability of modeling data
- Available supporting software
- The level of financial resources

### WHAT IS THE MEANING OF MIDPOINTS AND ENDPOINTS?

Although the terms "midpoints" and "endpoints" have yet to be clearly defined, in line with Bare et al. (2000) midpoints are considered to be points in the cause-effect chain (environmental mechanism) of a particular impact category, between stressors and endpoints. For midpoints characterization factors can be calculated to

Part Two

reflect the relative importance of an emission or extraction in a Life Cycle Inventory (e.g., global warming potentials defined in terms of radioactive forcing and atmospheric half-life differences). That is, midpoints are located anywhere between the stressors and the endpoints and allow calculation in a relative way the environmental impact of any stressor defined in the Life Cycle Inventory. Historically, the midpoint approaches have set the scene in LCIA, taken as prominent examples the CML thematic approach (Heijungs et al., 1992), the Sandestin workshop on LCIA (Fava et al., 1993), the Nordic LCA guide (Lindfors et al., 1995), the Eco-indicator 95 method, (Goedkoop, 1995), and the EDIP model (Wenzel et al., 1997). They also have mostly structured the thinking and examples chosen in ISO 14042.

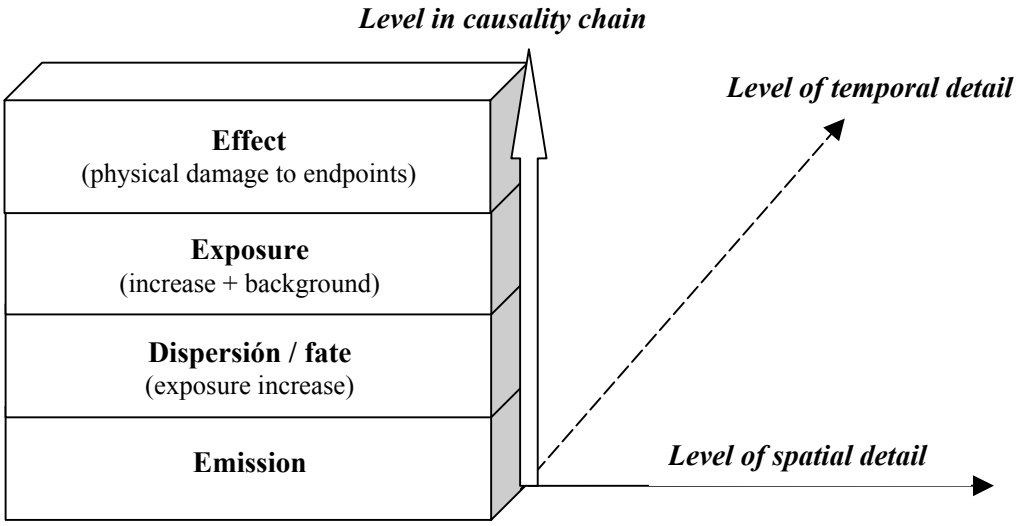



FIGURE 4: LEVELS OF DETAIL IN IMPACT CHARACTERISATION (POTTING, 2001)

According to Udo de Haes and Lindeijer (2001), endpoints are those elements of an environmental mechanism that are in themselves of value to society. ISO 14042 mentions forests and coral reefs as examples; this in contrast to ambient concentrations of hazardous substances. Other examples are physical aspects of human health, like lifetime or bodily functions; plant or animal species; or natural resources like fossil fuels and mineral ores.

Since the middle of the nineties the endpoint approach has been on the agenda Particularly in LCA studies that require the analysis of tradeoffs between and/ or aggregation across impact categories, endpoint-based approaches are gaining popularity. They already had a history, particularly in the EPS approach from Steen and Ryding (1992) and Steen, (1999), but got strong impetus from Switzerland (Mueller-Wenk, 1997) and again from the Netherlands in the Eco-indicator 99 approach (Goedkoop and Spriensma, 1999). In Japan, impact assessment models are currently developed according this approach (Itsubo and Inaba, 2000). This approach starts from the main values in society, connected with Areas of Protection, or Safeguard Subjects. From these values and connected endpoints the modeling goes back to the emissions and resources consumptions.

In Figure 5, Bare et al. (2000) show the steps that can be involved if a practitioner wishes to take an LCA study from the inventory stage, via impact assessment, to a single comparison metric using weighting techniques (both economic and/ or panel

approaches). Two different routes are presented, representing the routes taken when using midpoint and endpoint approaches. One of the key differences between midpoint and endpoint approaches is the way in which the environmental relevance of category indicators is taken into account. In midpoint approaches, the environmental relevance is generally presented in the form of qualitative relationships, statistics and review articles; however, it could similarly be quantified using endpoint methods to provide insights to the decision maker. In endpoint approaches there is no need to deal separately with the environmental relevance of the category indicators, because the indicators are chosen at an endpoint level and are generally considered more understandable to the decision makers.

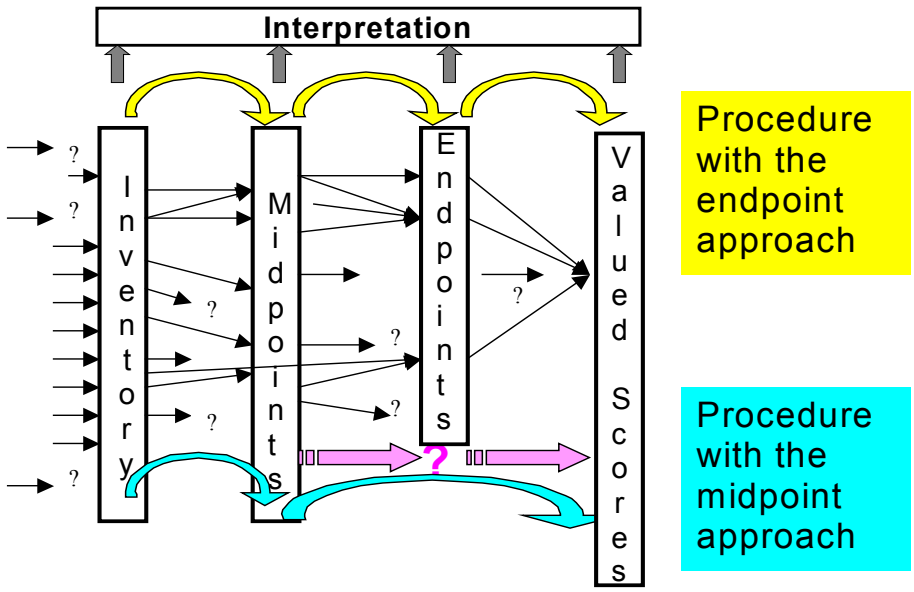



FIGURE 5: SOME BASIC DIFFERENCES BETWEEN THE MIDPOINT (LOWER ROW OF SWINGING ARROWS) AND THE ENDPOINT APPROACH (UPPER ROW OF SWINGING ARROWS). THE SMALL ARROWS REPRESENT MODELS THAT ADD INFORMATION IN A CAUSE-EFFECT FRAMEWORK. THE QUESTION MARKS INDICATE INFORMATION THAT WAS AVAILABLE BUT COULD NOT BE FURTHER MODELLED. SUCH CASES INCLUDE UNMEASURED EMISSIONS, UNCONSIDERED TYPES OF RELEASES SUCH AS OCCUPATIONAL ACCIDENTS, AND SUBSTANCES WHERE ENDPOINT MODELS HAVE STILL TO BE ESTABLISHED, E.G. NEUROTOXIC EFFECTS ON HUMAN HEALTH. (BARE, BRIGHTON WORKSHOP 2000)

Endpoint modeling may facilitate more structured and informed weighting, in particular science-based aggregation across categories in terms of common parameters (for example, human health impacts associated with climate change can be compared with those of ozone depletion using a common basis such as DALYs – Disability Adjusted Life Years).

As said by Bare et al. (2000) proponents of midpoint modeling believe, however, that the availability of reliable data and sufficiently robust models remains too limited to support endpoint modeling. In addition, many believe that extending the models to endpoints reduces their level of comprehensiveness and that such extensions will be based on a significant number of additional, unsubstantiated

Part Two

assumptions (which may not reflect the viewpoint of other experts and/or the user) to fill in missing knowledge gaps. One major concern is that uncertainties may be extremely high beyond well-characterized midpoints, resulting in a misleading sense of accuracy and improvement over the midpoint indicators when presented to weighting panels and decision makers. Many modelers believe that the additional complexity and detail of endpoint approaches is only warranted if they can be demonstrated to provide an improvement in the decision-making basis.

### EXAMPLES OF MIDPOINT AND ENDPOINT APPROACHES

In the previous sections we have introduced concepts such as classification and characterization as mandatory steps in any LCIA, and normalization and weighting as optional steps. These concepts are of crucial importance, but may not be completely clear for those unfamiliar with the field of Life Cycle Assessment. Hence, we now provide a brief introduction to midpoints indicators by the means of the example Global Warming Potential (GWP) to facilitate the understanding of classification, characterization, normalization and weighting. Moreover, we have chosen the Eco-indicator'99 as example for an endpoint method to illustrate the differences between the two approaches.

## Example of midpoint approach: Global Warming Potential (GWP)

Most of the energy that the earth receives from the sun in the form of short-wave radiation is reflected directly or re-emitted from the atmosphere, or the surface of the earth, as longer wave infrared (IR) radiation. The "man-made" greenhouse effect causes increases in temperature on top of the above natural greenhouse effect, caused by man-made emissions of substances or particles that can influence the earth's radiation balance.

Mandatory steps: Classification and Characterization

Many of the substances emitted to the atmosphere as a result of human activities contribute to this man-made greenhouse effect and have to be classified in this impact category. The most important are, in order, the following (Hauschild and Wenzel, 1998):

- $CO_2$ (carbon dioxide)
- $CH_4$ (methane)
- $N_2O$ (nitrous oxide or "laughing gas")
- Halocarbons (hyrdrocarbons containing chlorine, fluorine or bromine)

Moreover, a number of substances act indirectly, often with a positive effect, as greenhouse gases by influencing the efficiency of one or more of the above direct greenhouse gases (carbon monoxide, non-methane hydrocarbons, sulphur dioxide).

The potential contribution to global warming is computed with the aid of a procedure that expresses the characteristics of the substance relative to those of the other gases. For use in political efforts to optimize initiatives to counter man-made global warming, the Intergovernmental Panel of Climate Change (IPCC) has developed a characterization factor system that can weight the various substances according to their efficiencies as greenhouse gases.

The system allocates the various substances to GWP, which is calculated as the anticipated contribution to global warming over a chosen time period (20, 100 or 500 years) from a given emission of the substance divided by the contribution to warming from an emission of a corresponding quantity of $CO_2$. Multiplying a known emission of greenhouse gas by the relevant GWP yields the magnitude of

the $CO_2$ emission that, under the chosen conditions, will result in the same contribution to global warming, i.e. the emission of the greenhouse gas expressed on $CO_2$-equivalents.

$CO_2$ was chosen by the IPCC as reference substance because it is the substance that makes by far the most significant contribution to the man-made greenhouse effect. The expected contribution to warming from a greenhouse gas is calculated on the basis of knowledge of its specific infrared (IR) absorption capacity and expected lifetime in the atmosphere. The GWP is internationally accepted, well documented, and provides characterization factors for all substances encountered in a life cycle assessment. See Table 3 below with an example of GWP values for direct contribution of the three substances mentioned before ($CO_2$, $CH_4$ and $N_2O$).

TABLE 3: GWP FOR SOME SUBSTANCES DEPENDING ON TIME HORIZON (HOUGHTON ET AL., 1995)

| Substance | Formula | GWP (kg $CO_2$/kg substance) | | |
|---|---|---|---|---|
| | | 20 years | 100 years | 500 years |
| Carbon dioxide | $CO_2$ | 1 | 1 | 1 |
| Methane | $CH_4$ | 62 | 24.5 | 7.5 |
| Nitrous oxide | $N_2O$ | 290 | 320 | 180 |

Optional steps: Normalization and Weighting

The scores obtained for each impact category are compared to a specific reference. That means the relative contributions of the product system to the different impact categories are calculated. An impression is thus gained of which of the environmental impact potentials are relatively large and which are relatively small. This allows a comparison of the various environmental impacts from a product system.

Normalization has two objectives:

1. To provide an impression of the relative magnitudes of the environmental impact potentials.
2. To present the results in a form suitable for subsequent weighting

Weighting factors are used for the prioritization of one impact category (e.g. global warming) with other impact categories such (e.g. stratospheric ozone depletion). The prioritization of impact categories depends in general on subjective definitions of main concerns like political targets or business strategies.

Due to the subjective character of the weighting factors they are often obtained by means of an expert or policy-maker panel (Udo de Haes, 1996). In principle, public opinion can be asked, too. This is the idea behind the monetisation method based on Willingness-To-Pay (WTP), see for instance European Commission (1995).

## Other impact categories and proposed indicators (midpoints)

Table 4 gives an overview of some impact categories that are currently used in LCIA; for each impact category a possible midpont indicator is shown.

Part Two

TABLE 4: IMPACT CATEGORIES AND POSSIBLE INDICATORS (UDO DE HAES, 1996 AND UDO DE HAES ET AL., 1999)

| **Impact categories** | **Possible indicator** |
|---|---|
| *Input related categories* | |
| **Extraction of abiotic resources** | Scarcity of resource |
| **Extraction of biotic resources** | Scarcity of resource, considering replenishment rate |
| *Output related categories* | |
| **Climate change** | Kg $CO_2$ as equivalence unit for the Global Warming Potential (GWP) |
| **Stratospheric ozone depletion** | Kg CFC-11 as equivalence unit for the ozone depletion potential (ODP) |
| **Human toxicity** | Human Toxicity Potential (HTP) |
| **Eco-toxicity** | Aquatic Eco-Toxicity Potential (AETP). |
| **Photo-oxidant formation** | Kg ethene as equivalence unit for photochemical ozone creation potential (POCP) |
| **Acidification** | Release of $H^+$ as equivalence unit for the Acidification Potential (AP) |
| **Nutrification** | Stoichiometric sum of macro-nutrients as equivalence unit for the Nutrification Potential (NP) |

Udo de Haes et al. (1999) propose as input-related categories extraction of abiotic resources and extraction of biotic resources. Moreover, they suggest considering land use as an impact category consisting of three subcategories: increase of land competition, degradation of life support functions and bio-diversity degradation. As output related categories they propose climate change, stratospheric ozone depletion, human toxicity, eco-toxicity, photo oxidant formation, acidification and nutrification.

The impacts of the different categories have consequences on the environment and human welfare on different spatial scales. This has nothing to do with the importance of the categories, but with a need of spatial differentiation within the fate and exposure for some impact categories. Since economic processes are spread worldwide, local impacts have a global extension as well.

The climate change and the stratospheric ozone depletion are phenomena that affect the whole planet. In principle, this holds true also for the extraction of abiotic and biotic resources. However, not all regions of the world have the same need of all resources. Acidification, nutrification and photochemical oxidant formation are generally caused by pollutants whose residence time in the atmosphere permits a continental dispersion. The impact categories human and ecotoxicity can be considered to have a regional dimension. Depending on the characteristics of the pollutant and the medium where it is emitted, fate can be considered continental or local. Finally the impacts caused by photo-oxidant formation and land use are totally dependent on the local situation, meteorological conditions and land characteristics. The need for spatial differentiation in the fate and exposure analysis in different impact categories is illustrated in Figure 6.

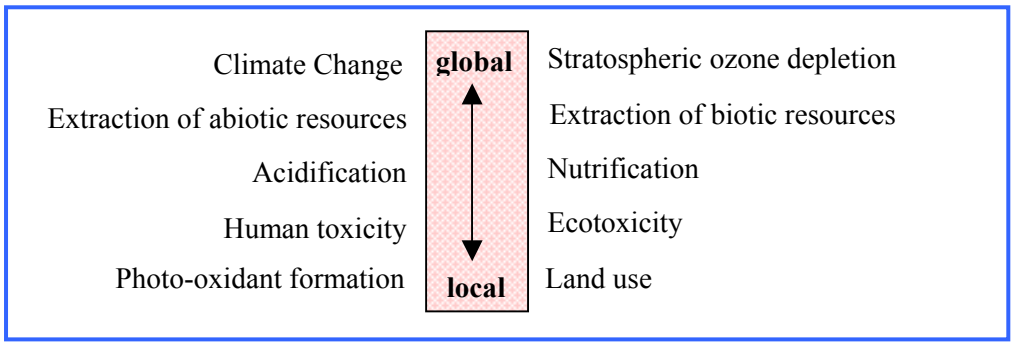



FIGURE 6: NEED FOR SPATIAL DIFFRENTIATION IN DIFFEREENT IMPACT CATEGORIES

## Example of endpoint approach: Eco-indicator 99

As an example of methods oriented to damage level, that is those focusing at endpoints level, we have chosen the Eco-indicator 99 method developed by a European team of experts from 1997 to 1999 (Goedkoop and Spriensma, 1999).

The Eco-indicator 99 method is a complete "top-down" impact assessment method with four clearly detailed steps: fate, exposure, effect and damage analysis. That means the methodology develops these further steps based on the values of the decision maker. This is in contrast with the "bottom up" approach that can be found in the more traditional midpoint methods, where the modeling starts with the release of the pollutant to the environment, the use of land and the extraction of resources.

Corresponding to this "top-down" approach the most fundamental problem is the definition of possible values of the decision maker To deal with the fact that in the valuesphere (value choices and weighting), a single truth simply does not exist, three perspectives are used: the hierarchist, the individualist and the egalitarian. The Table 5 specifies some different characteristics per perspectove.

The Eco-indicator 99 methodology allows for an analysis of the relative contribution of the different impact category indicators to one of the three endpoints without any weighting, using the values of the three perspectives. The methodology may include rather complex environmental models with possibly high uncertainties, but the developers of this method claim that the ease of interpretation compensates for this problem.

In the development of the Eco-indicator 99 methodology, the weighting step is considered to be the most difficult, controversial and uncertain, in addition to the uncertainty of the endpoint modeling. To simplify the weighting procedure, damage categories had to be identified, and as a result new damage models were developed that link inventory results into *three damage categories*:

Part Two

Part Two

TABLE 5: THE THREE CULTURAL PERSPECTIVES USED IN ECO-INDICATOR 99 (HOFSTETTER, BRUSSELS WORKSHOP 1998)

| Perspective | Time perception | Manageability | Required level of evidence |
|---|---|---|---|
| *Hierarchist* | Balance between short and long term | Proper policy can avoid many problems | Inclusion based on consensus |
| *Individualist* | Short time | Technology can avoid many problems | Only proven effects |
| *Egalitarian* | Very long term | Problems can lead to catastrophe | All possible effects |

Damage to Human Health

Damage models were developed for respiratory and carcinogenic effects, the effects of climatic change, ozone layer depletion and ionizing radiation. In these models for Human Health, four steps are used:

1. **Fate analysis**, linking an emission to a temporary change in concentration.
2. **Exposure analysis,** linking this temporary concentration change to a dose.
3. **Effect analysis,** linking the dose to a number of health effects, such as occurrence and type of cancers.
4. **Damage analysis,** links health effects to DALYs (Disability Adjusted Life Years) using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL); it includes a first weighting step.

Damage to Ecosystem Quality

Damages to Ecosystem Quality are expressed as percentage of species disappeared in a certain area due to environmental load (Potentially Disappeared Fraction or PDF). The PDF is then multiplied by the area size and the time period to obtain damage. This damage category consists of:

1. **Ecotoxicity** expressed as the percentage of all species present in the environment living under toxic stress.
2. **Acidification and Eutrophication** treated as one single category. Damage to target species in natural areas is modeled.
3. **Land use and land transformation** based on empirical data. Both damages related to land occupation and transitions in land use are taken into account.

Damage to resources

Damage to resources, minerals and fossils fuels, are expressed as surplus energy for the future mining of resources:

1. **For minerals,** geo-statistical models are used that relate availability of a resource to its concentration.
2. **For fossil fuels,** surplus energy is based on future use of oil shale and tar sands.

The Eco-indicator 99 methodology used basically three types of models:

1. Modeling in the technosphere for the inventory phase.
2. Modeling in the ecosphere for the impact assessment phase.
3. Modeling in the valuesphere as the all-encompassing sphere for weighting and ranking, as well as to deal with unavoidable value choices (Hofstetter, 1998)

Figure 7 gives an overview of the Eco-indicator 99 method.

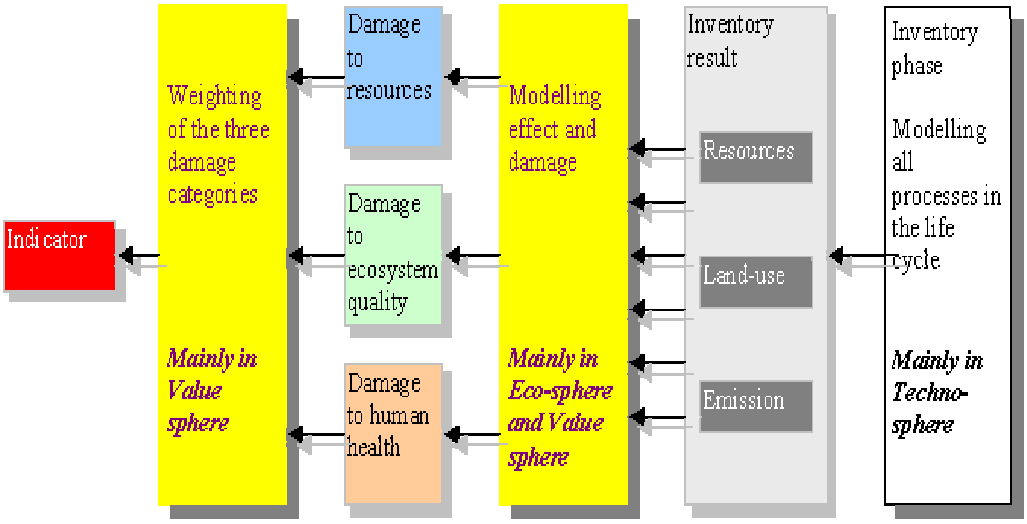



FIGURE 7: OVERVIEW OF THE ECO-INDICATOR 99 METHOD. THE TERM SPHERE IS USED TO INDICATE THAT THE METHOD INTEGRATES DIFFERENT FIELDS OF SCIENCE AND TECHNOLOGY (GOEDKOOP AND SPRIENSMA, 1999). THE MODELING OF THE DAMAGE TO HUMAN HEALTH INCLUDES A FIRST WEIGHTING STEP.

A similar method based on the same principles bas been developed by Steen (1999): A Systematic Approach to Environmental Priority Strategies in Product Development (EPS) - Version 2000.

## Other methods orientated at the damage level (endpoints)

Other endpoint approaches developed in recent years have their origin in the environmental risk assessment methodology and in the evaluation of external costs. The exposure assessment phase in the evaluation of human health risk estimates the probability that adverse effects to human health may occur as a consequence of the exposure to one or more substances. Environmental damages and resulting social costs are estimated by following the endpoint modeling approach called impact pathway analysis. This approach was used within the ExternE project (funded by the European Commission, 1995); it was expected to provide science-based estimates of environmental externalities by monetary valuation of welfare losses. ExternE should be used to design appropriate market based internalization instruments (like energy tax or emission tax).

Similar to some LCIA methods, ExternE aimed at quantifying the marginal impacts of an additional unit of electricity generation at a given site, which requires information on site-specific conditions (e.g. meteorology, distribution and sensitivity of receptors) and on background conditions (e.g. existing level of air pollution or acid deposition) to be considered in the impact assessment. Experience from ExternE shows that considerable resources are required to establish an operational set of relevant models and provide all the relevant site-specific input data. However, once such a model system is set up, it very much helps to

Part Two

understand, for example, the influence of site-specific parameters on the expected impacts, and also the potential influence of environmental policy measures (which might affect background conditions) on the impact (Udo de Haes and Lindeijer, 2001).

## Site-dependent impact assessment methods

The LCIA approaches have been adapted recently to allow site-dependent impact assessments. As in site-specific approaches fate, exposure and effect information are taken into account, but indicators are calculated that are valid for wider spatial areas. There is a trade-off between the accuracy of the impact assessment and the practicability of spatial desegregation for impact assessments in a life-cycle perspective.

Developments for site-dependent impact assessment have been made for acidification and eutrophication, such as Potting (2000) as well as Huijbregts and Seppälä (2000). Moreover, several approaches are presented for human health effects due to airborne emissions. Exemplary damage factors for a number of European sites are provided by Spadaro and Rabl (1999). Potting (2000) establishes impact indicators that take into account different release heights, population density and substance characteristics such as atmospheric residence time. The release height is statistically linked to several industrial branches. Moriguchi and Terazono (2000) present an approach for Japan where the meteorological conditions are set to be equal for all examples. Nigge (2000) presents a method for statistically determined population exposures per mass of pollutant that considers near-range and long-range exposure separately and allows addressing the local dispersion and population distribution systematically. Impact indicators are derived that depend on the settlement structure class and the stack height.

# Part Three

# Recent methodological discussions on the evaluation of environmental impacts in LCA

## BRUSSELS AND BRIGHTON WORKSHOPS

### The Brussels Workshop

On November 29 - 30, 1998 in Brussels, an international workshop was held to discuss Life Cycle Impact Assessment (LCIA) Sophistication. Approximately 50 LCA and Risk Assessment experts attended the workshop from North America, Europe, and Asia. Prominent practitioners and researchers were invited to present a critical review of the associated topics, including the current limitations of available impact assessment methodologies and a comparison of the alternatives in the context of uncertainty. Each set of presentations, organized into three sessions, was followed by a discussion session to encourage international discourse with a view to improving the understanding of these crucial issues. The discussions were focused around small working groups of LCA practitioners and researchers, selected to include a balance of representatives from industry, government and academia

At the beginning of this workshop Bare stressed that Life Cycle Impact Assessment can be effective in supporting environmental decision making, but only if the data and methods are sufficiently scientifically defensible. Scientifically defensible was defined as being dependent upon the level of sophistication, the level of certainty (including both data and model certainty), the level of comprehensiveness, and data availability. The participants were challenged to address several additional questions throughout the two days of discussions including: What is "scientifically defensible?" In the sphere of determining whether impact assessment is based on sound science, where does one draw the line between sound science and modeling assumptions? (EPA, 2000)

This workshop provided the first opportunity for international experts to address the issues related to LCIA sophistication in an open format. Among the topics addressed were (Bare et al., 1999):

1. Context of sophistication,
2. Necessity and practicality regarding the sophistication of the uncertainty analysis,
3. Role of various types of uncertainty analysis,
4. Difficulty of assessing and capturing the comprehensiveness of the environmental health impact category,
5. Implications of cultural/ philosophical views,
6. Meaning of terms like science-based and environmental relevance in the ISO 14042 LCIA standard,
7. Dichotomy of striving for consistency while allowing the incorporation of state-of-the-art research,
8. Implications of allowing impact categories to be assessed at "midpoint" versus at "endpoint" level, and
9. Role of supporting environmental analyses (e.g., risk assessments).

Many of these topics addressed the need for increased sophistication in LCIA, but recognized the conflict this might have in terms of the comprehensiveness and holistic character of LCA, and LCIA in particular.

Part Three

## The Brighton Workshop

On May 25 – 26, 2000 in Brighton (England), the second in a series of international workshops was held under the umbrella of UNEP addressing issues in Life Cycle Impact Assessment (LCIA). The workshop provided a forum for experts to discuss midpoint vs. endpoint modeling. The topics addressed in this workshop included the implications of midpoint versus endpoint indicators with respect to uncertainty (parameter, model and scenario), transparency and the ability to subsequently resolve trade-offs related to weighting across impact categories using weighting techniques. The Brighton workshop was conceived to present both sides of the midpoint versus endpoint argument to an international group of approximately 50 experts and to allow these participants adequate time to discuss the relative merits and limitations of the approaches.

Bare opened this workshop by suggesting that there are advantages and disadvantages to each approach and suggested that both midpoint and endpoint approaches might be used together to provide more information (Figure 8) than just the typical ensemble of midpoint indicator results (Figure 9) (Bare et al., 2000).

Figure 8 illustrates the additional information that is obtained by the combined use of midpoints and endpoints for the case of the Ozone Depletion Potential (ODP). The emissions of CFCs and Halons cause chemical reactions that release $Cl^-$ and $Br^-$. The ODP measures the potential of the released ions to destroy ozone. The endpoint approach provides information of the damages that correpond to the ODP. Less ozone in the stratosphere allows increased UVB radiation that can be related directly to damages at the endpoint. These damages are an increase of skin cancer, cataracts, crop damage, immune system suppression, damage to materials like plastics, and marine life damage.

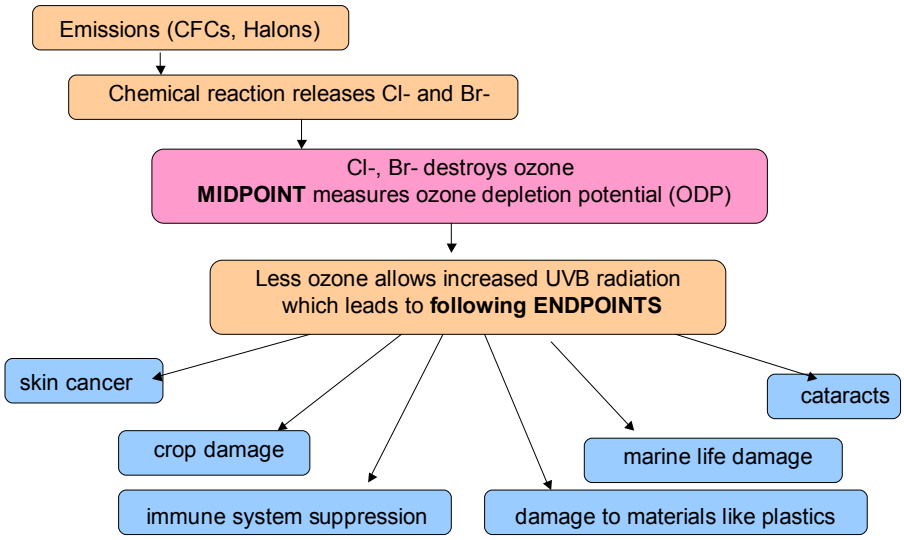



FIGURE 8: USING ENDPOINT AND MIDPOINT APPROACHES TOGETHER TO PROVIDE MORE INFORMATION, EXAMPLE OF OZONE DEPLETION POTENTIAL (BARE, BRIGHTON WORKSHOP 2000)

Figure 9 gives an overview of the ensemble of midpoints indicators in a way in which it is often used in LCA studies. Damage informaton related to the impacts behind the potentials is not available. Aggregations of damage values across the impact categories are not possible since category-specific potentials are presented.

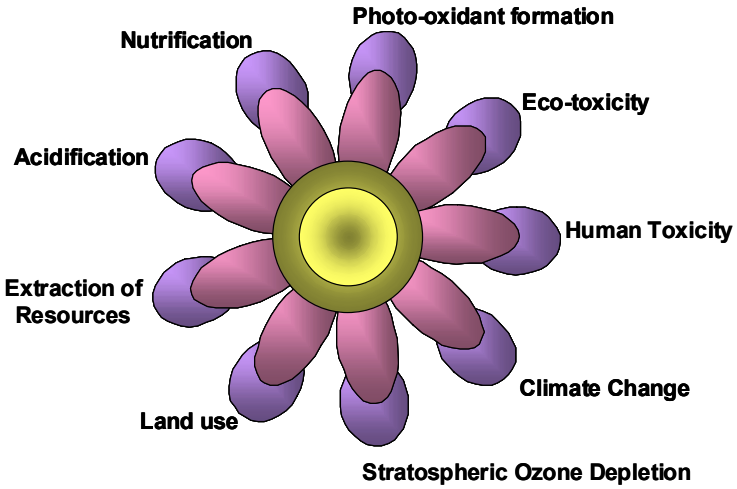



FIGURE 9: ENSEMBLE OF MIDPOINT INDICATORS (ADAPTED FROM VAN DE MEENT, BRIGHTON WORKSHOP 2000)

To use current midpoint and endpoint approaches together would require the use of models that have incompatible data sets, impact assessment methodologies, and modeling assumptions. Analogous to the idea of using midpoint and endpoint approaches in parallel, some practitioners suggested in the workshop conducting studies using available, multiple methodologies (and even inventory databases) to determine whether this affected the results. Others voiced frustration with available software and warned that decision makers will not accept conflicting models next to each other. Further investigation would then be required to resolve contradictory results.

As said in Bare et al. (2000), faced with the benefits and limitations of midpoint and endpoint approaches, the workshop closed with a consensus that both midpoint and endpoint methodologies provide useful information to the decision maker, prompting the call for developing one encompassing framework that includes both midpoint and endpoint indicators, so that the results of the two approaches can be compared with each other. The user could then see the comparative results at the midpoint level, as well as at the endpoint level. It was noted that this is analogous to the use of endpoint methodologies to provide a default basis for cross-comparison among midpoint category indicators.

## UNCERTAINTY AND COMPREHENSIVENESS

Uncertainties in LCIA remain high. There was a recognition that at least two types of uncertainty exist: model uncertainty and parameter uncertainty. Model uncertainty reflects the accuracy of the model, as determined through evaluation studies. Parameter uncertainty is the uncertainty associated with the input data, as commonly determined using tools like Monte-Carlo analysis. Many participants expressed concern that model uncertainties are often ignored in LCA, and the limited efforts to date have only focused on parameter uncertainty (Bare et al., 1999). Therefore, the aspect of scenario uncertainty was broadly discussed at the workshop.

In the Brussels workshop (EPA, 2000), Hertwich presented the purpose of uncertainty analysis: “to develop confidence in an analytical result, as an input to formal decision analysis techniques and as a tool to refine impact assessment methods.” He noted that uncertainty analysis includes:

Part Three

Part Three

- Parameter uncertainty (errors in the resolution of instrumentation, sampling errors of entire population model uncertainty, and biases introduced through experimental design or instruments);
- Decision rule uncertainty (whenever there is ambiguity about how to quantify or compare social objectives).

In the Brighton workshop, Hertwich derived from the concept of covariance that indicators for some products might be better distinguished at midpoint and for others at endpoint level. For some product systems a distinction might be even sufficient through the identifiable differences in the stressors of the inventory.

Norris stated in the Brussels workshop that the level of sophistication should be partially dependent upon the inventory data and its uncertainty, upon the appropriate models and upon decisions about weighting. He suggested using Input/ Output-based upstream LCI databases to answer many of the common questions that practitioners face, such as "How many sites, with how much geographic dispersion, contribute significantly to inventory totals?" And "What are the expected shapes of these distributions?" He also cautioned participants against trying to draw conclusions about the advantages of more detailed LCIA, based on a Probability Density Function diagrams, pointing out that further simulations may be required. Finally, he discussed the difference between analyzing uncertainty in weighting and in characterization modeling and the need to treat these issues jointly in the determination of the level of sophistication and decision support (EPA, 2000)

In the Brighton workshop Norris stressed the importance and decision support value of calculating and maintaining uncertainty information at each stage in the impact assessment, and suggested iterative tests for dominance at each impact assessment modeling stage. He pointed out the rapidly changing nature of modeling in LCIA, noting how quickly we have moved from midpoint potentials to endpoint models, and he predicted we would soon be using more sophisticated estimates of uncertainty within our models.

There was recognition that there is also uncertainty regarding the adequate level of relevance for the presentation of the results. This is referred to as scenario or decision rule uncertainty by some researchers. (This was also presented as "What we know" vs. "What we want.") There was an overall belief that endpoint models may be more relevant, but less certain (i.e., higher model and parameter uncertainty) but that midpoint modeling may be more certain (i.e., lower model and parameter uncertainty), but less relevant to what the decision makers really want to know.

During the Brighton workshop Krewitt said in his presentation "Advantages and limitations of endpoint modeling – experiences from the ExternE project" that is well acknowledged in ExternE (European Commission, 1995) that there is an increasing level of uncertainty when going from the quantification of stressors towards the assessment of impacts to the final weighting. Data uncertainty and model uncertainty basically are of scientific nature, and thus are amenable to analysis by statistical methods. Uncertainty due to a lack of knowledge (e.g. future change in background conditions) or subjective judgments (e.g. valuation of increased risk of death) should be addressed in a sensitivity analysis. Statistical uncertainty was analyzed by taking into account uncertainties resulting from all steps of the impact pathway, i.e. the quantification of emissions, air quality modeling, dose-effect modeling, and valuation (Rabl and Spadaro, 1999).

Then Krewitt asked how to treat impact categories that (currently) cannot be quantified. He pointed out that ExternE discussed a long list of 'un-quantifiable'

impacts, included the most important ones labeled as 'not quantified' in the result tables, and presented 'sub-totals' of external costs (rather than 'totals') in the summary tables, indicating that the reported external costs do not include all impacts. As ExternE was explicitly confined to the assessment of marginal damage costs by using individuals' willingness-to-pay, for the purpose of methodological consistency other valuation approaches were not considered. But in particular in the case of very uncertain impacts the use of society's revealed preferences is considered as a good alternative approach for economic valuation. Although the expected damage is not well known, there exist policy defined environmental targets (e.g. $CO_2$ reduction). The (known) costs for achieving these targets can be interpreted as society's willingness-to-pay to avoid the anticipated impacts.

In the Brussels workshop, Hofstetter addressed the question of "What is science?" in the presentation: "The Different Levels of Uncertainty Assessment in LCIA: The Case of Carcinogenic Effects." He stated that the development of models is dependent on the perspective of the modeler. The perspective is responsible for the respective attitude towards the manageability of unknown damage and unknown causalities in relation to the acceptable damage and the damage due to unknown causalities (Figure 10).

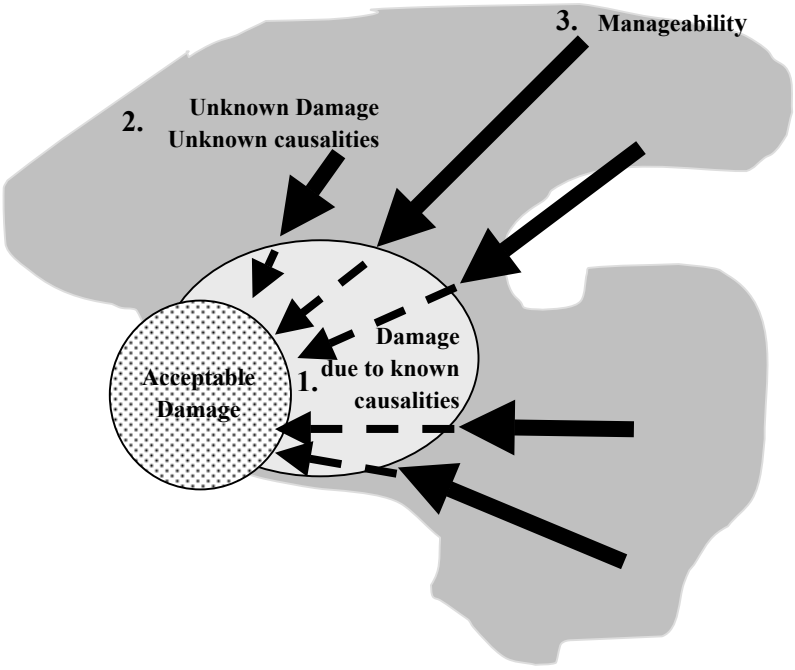



FIGURE 10: THE MODELING FRAMEWORK FOR THE ECOSPHERE. THE ARROWS – THE THIRD MODELING LEVEL OF 'MANAGEABILITY' – SYMBOLIZE THE DYNAMIC ASPECTS OF A DAMAGE REDUCTION TOWARDS AN ACCEPTABLE DAMAGE. (HOFSTETTER, BRUSSELS WORKSHOP 1998)

Part Three

The relative comprehensiveness of the midpoint and endpoint indicators was discussed. In general, midpoint indicators will be more comprehensive because they will be relevant for a wider variety of impacts at endpoint level, although these impacts on endpoint level are not modeled and may not be specified or known. Generally, endpoint models will focus on a smaller number of pathways because of the requirement to model them quantitatively. Although some "gaps" are qualitatively "known", the experts in the associated domains may not be confident about assessment beyond well-characterized midpoints up to endpoint effects. Pathways that carry significant knowledge gaps prohibiting quantification can be considered within endpoint modeling by making assumptions within the cause-effect chain modeling itself, by leaving pathways out of consideration, or by using parallel precautionary indices. In contrast, midpoint approaches do not address these knowledge gaps, but allow their consideration within the weighting and decision making phases. It was also noted that for both midpoint and endpoint approaches, participants in a weighting process may not even be qualitatively aware of all of the primary or secondary effects associated with each impact category (Bare et al., 2000).

### Areas of Protection

During the Brighton workshop, Udo de Haes suggested, Life Support Functions (LSF) might be seen as having intrinsic value in their own right (see Figure 11). The Life Support Functions concern the major regulating functions of the natural environment, which enable life on earth (both human and non-human). These particularly include the regulation of the earth climate, hydrological cycles, soil fertility and the bio-geo-chemical cycles. Like the Natural Resources, the Life Support Functions are of functional value for society. From a value perspective, these two are therefore of a fundamentally other nature than the AoPs with intrinsic value to society, such as in particular those connected with human health, with biodiversity and with works of art.

Starting from the distinction between intrinsic and functional values it is proposed to differentiate within the AoP Natural Environment between Biodiversity and Natural Landscapes and Life Support Functions. Now there are two ways to deal with this. One is to define two new AoPs instead of one, each with their own indicators. The other is to regard it still as one AoP, within which different indicators are defined related to the different societal values. Udo de Haes and Lindeijer (2001) see the latter as the most generally applicable structure; therefore they follow this line, also in order to keep the result simple. But then there is indeed little reason to keep the Natural Resources as a separate AoP. Rather it can be seen as a third sub-category within the AoP Natural Environment. The links between these three sub-categories are quite strong and the boundaries not sharp.

According to Udo de Haes and Lindeijer (2001), the question, whether or not to include the Life Support Functions as a separate sub-AoP, is not only of academic significance. Suppose, one wants to choose the category indicators at endpoint level (i.e., at the level of physical damage) in direct relationship to societal values. If one would only include AoPs that have intrinsic value to society, then it would suffice to select indicators for Human Health and for Biodiversity, just as for instance is done in the Eco-indicator 99 approach (Goedkoop and Spriensma, 1999). But if one also wants to include functional values, then it becomes relevant to also include indicators for the Natural Resources and the Life Support Functions.

Part Three

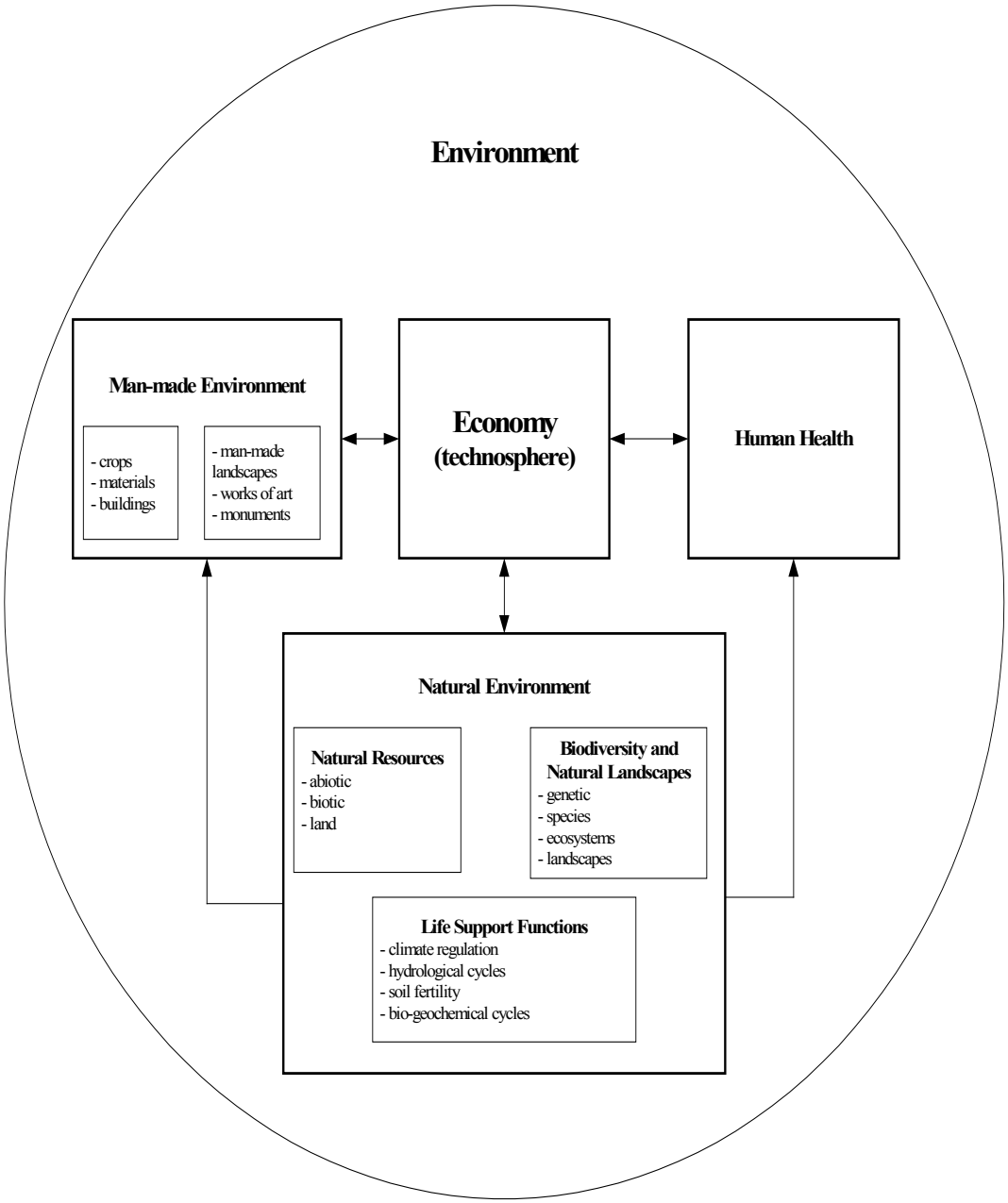



FIGURE 11: CLASSIFICATION OF AREAS OF PROTECTION ACCORDING TO SOCIETAL VALUES. ARROWS POINTING BOTH WAYS EXPRESS INTERACTIONS BETWEEN ECONOMY AND AOPS. OTHER ARROWS INDICATE MAIN RELATIONSHIPS BETWEEN AOPS. (UDO DE HAES AND LINDEIJER, 2001)

A few remarks should be added about the possible sub-AoP Life Support Functions. Firstly, it should be clear that it is in the same way as other sub-AoPs composed of a number of subclasses, which cannot easily be represented with one indicator, thus giving further shape to a hierarchical set-up. To be more precise, this sub-AoP may well cover more impact categories, each with its own category indicator. Secondly, it is interesting to compare this sub-AoP with the "Unknown Damage," as introduced by Hofstetter (1998). Although there is resemblance, there are also differences. Hofstetter's "Unknown Damage" is in fact based on a negative definition; it shrinks with increasing knowledge. Here a positive description is

used, based on the natural regulation functions, and of comparable value as the natural resources. Thirdly, it should be recognized that the inclusion of a sub-AoP Life Support Functions implies, that the elements involved are to be regarded as endpoints.

For example, the Global Warming Potential is a midpoint measure in the context of impacts to humans and ecosystems in the event of climate change. The GWPs also relate to the integrity of the global climate as a LSF - an area of protection in its own right, being supportive to life on earth in a broad sense; still the GWPs may be regarded as midpoint indicators, but now with a high environmental relevance (Udo de Haes and Lindeijer, 2001).

### TRANSPARENCY

The more complex the model, the harder it is to maintain transparency and the greater the level of required documentation. For example, it is not always obvious which toxicological effects are taken into consideration in some endpoint methodologies or which assumptions and value choices are made in the associated chemical fate and exposure models. It may be clarifying to learn that human health effects on endpoint level due to climate change are considered to be mainly due to the expected increase of malaria. A specific problem may be that the value choices encoded into the methodology may not reflect those of the decision maker. Similar arguments may exist in the context of midpoint indicators, including ozone depletion potentials and global warming potentials, but are probably less abundant. It was suggested that methodologies should be as transparent as possible whilst still providing the desired level of accuracy. In the case of complex models, there has to be sufficient consensus within the scientific community that the approaches are acceptable and that the general user does not require detailed documentation. De Leeuw stated for UNEP, "It is not necessary to know how the engine works to drive a car."

Based on the level of modeling alone, the level of transparency associated with midpoint indicators can be considered higher than in endpoint approaches. However, when weighting is required to compare and aggregate across impact categories, the implicit links between the midpoint indicators and the endpoint effects may not always be expressed clearly or represented in a structured fashion. This may impact the robustness of the weighting exercise and the final result. This is another reason to support the use of midpoint and endpoint indicators in one consistent framework (Bare et al., 2000).

Part Three

## Human Health and Ecotoxicity

A chemical's fate in the media is the result of numerous complicated processes. Fate models have been developed to simulate transport among and within multiple environmental media. These models are referred as multi-media fate models and are used to evaluate possible damages due to human and ecotoxicity in risk assessment. The cause-effect chain for impacts to ecosystems and human health is presented in Figure 12. This figure shows the influence of human activities on the environment. It illustrates the different paths that cause the total exposure.

In the Brussels workshop, Hertwich opened the session on human and ecotoxicity with his presentation: "A Framework for the Uncertainty Analysis of the Human Toxicity Potential." A framework for uncertainty analysis, which was originally developed for risk assessment (Finkel, 1990) is applied to the exposure modeling component of the Human Toxicity Potential (HTP) (Hertwich, 1999). The HTP is a characterization factor, similar to that goal warming potential, that is used to multiply emissions in a life cycle inventory to obtain a single metric representing the human health hazard (Heijungs et al., 1992). The HTP presents evaluations of hazard based on the toxic potency of a substance and the potential dose in a so-called unit world. In this example, the exposure is calculated using CalTOX (McKone, 1993; Maddalena et al., 1995), a risk assessment model that integrates a multimedia l fate model with a multiple pathway exposure model. He presented various examples of uncertainty analysis as they might pertain to modeling for human toxicity impact assessment in LCIA. He pointed out that simply conducting a sensitivity analysis can often provide valuable insights about the significance of the multiple uncertainties involved in the decision and can help refine impact assessment techniques (Hertwich, 1999).

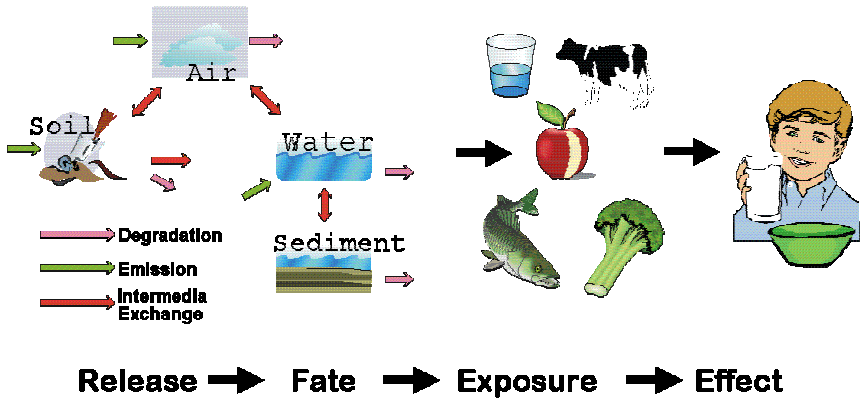



FIGURE 12: CAUSE EFFECT CHAIN FOR ECOSYSTEM AND HUMAN HEALTH (PENNINGTON, BRIGHTON WORKSHOP 2000)

According to EPA (2000), McKone presented "Midpoint vs. Endpoint Modeling of Human Health." McKone compared the two levels by saying that one represented greater relevancy (endpoints) while the other represented greater reliability (midpoints). He pointed out that the field of human health modeling is much more complex than most LCA researchers might realize. Human effects can be deterministic (i.e., effect and severity directly related to exposure, as in a sunburn) or stochastic (i.e. the severity is a question of probability in relation to the effect caused by exposure, as in cancerous effects). He stated that there is a dearth of information in this area - fewer than 30 chemicals have human carcinogenic data

Part Three

available, while only approximately 200 chemicals have animal carcinogenic test data. For other chemicals and other types of health effects we have to make highly uncertain estimates of dose-response relationships. He concluded that midpoint models provide more opportunities for scientific validation than endpoint models (e.g., for acidification it is easier to measure pH than to measure affected species) and eventually, midpoint models could be extrapolated into endpoint approaches so long as the resulting loss of reliability is addressed.

Pennington presented "Midpoint vs. Endpoint Issues: Toxicological Burden on Aquatic Ecosystems" in the Brighton workshop. He opened with a discussion that some straightforward approaches based on indicators of implicit concern (usually midpoint indicators such as persistence, bioaccumulation and toxic potency scores) could be used to double check the results of models in LCA that attempt to more explicitly represent the fate and exposure mechanisms of a chemical in the environment, similar to the parallel precautionary index used to check for gaps by Hofstetter (1998). In one cited case study, the limited representation of the aquatic food web in a multimedia model (example Figure 12) had resulted in misleadingly low characterization factors for some chemicals. He concluded that uncertainties (parameter, model and scenario) must be stated before distinctions among alternatives can be expressed and that extreme caution is required when adopting complex LCIA methodologies, as they may not be scientifically robust and can be built on assumptions that add little additional information, or even increase uncertainty.

According to Bare et al. (1999) Jolliet discussed "Human Toxicity and Ecotoxicity Modelling vs. Scoring" in the Brussels workshop. He started by saying, "Tell me your results and I will tell you who paid you!" Then he called for the identification of best available practice regarding impact assessment methods to reduce the ability to provide LCAs that support such malpractice. He also proposed that this process should try to meet the ISO 14042 requirements to be "scientifically and technically valid" and "environmentally relevant." After comparing different human toxicity modeling efforts, he pointed out parameters and model characteristics that are important in human and ecotoxicity modeling, including exposure and fate uncertainties, that can be responsible for significant uncertainty and which open options for reduction of modeling uncertainty by proper empirical or experimental validation. He concluded by saying that modeling comparisons should be made based on model characteristics, consistent data and field validation.

In the Brussels workshop Huijbregts presented a paper on "Priority Assessment of Toxic Substances in LCA: A Probabilistic Approach" (Huijbregts et al., 2000). Citing previous publications (e.g. Guinée et al., 1996 and Hertwich et al., 1998), he suggested that the following specific improvements are needed: a review of default values with the possibility of using more realistic values, an inclusion of all relevant environmental compartments through multimedia models, like (E)USES (Guinée et al., 1996 and Berding et al., 1999), and use of a Monte Carlo type of uncertainty analysis. He presented a probabilistic simulation of weighted human, aquatic and terrestrial Risk Characterization Ratios (RCRs) for 1,4-dichlorobenzene and 2,3,7,8-TCDD (dioxins) and demonstrated that only a few substance-specific parameters are responsible for the uncertainty in results. Finally, Huijbregts concluded that variability is not of significance if it is identical for all options being compared and asked that researchers continue to explore the issue of when data uncertainty/ variability cancel out in relative comparison applications.

Part Three

One of the basic limitations of the current state-of-the-science of LCIA of human and ecotoxicity is the inability to effectively deal with potential combinatory effects of chemical mixtures. Toxicologists operate under the assumption that chemicals acting on the same organ can be considered to have an additive effect, but often LCIA impact categories are much broader than a focus on target organs. Therefore, the same assumptions used in risk assessment are not applicable to LCIA. This is especially an issue when practitioners try to incorporate threshold levels for individual chemicals into LCIA. Because mixtures are not well characterized in LCIA, effects may be occurring at much lower levels than the accepted threshold levels of the individual chemicals. Practitioners often try to compensate for these and other model deficiencies by adopting the precautionary principle.

Particularly in human and ecotoxicity, availability and quality of both inventory and chemical data to support the modeling of a large number of chemicals can be frustrating. These impact categories are a good example of where less sophisticated screening techniques may, with an appropriate degree of caution, prove to be useful (Bare et al., 1999).

## Acidification and Eutrophication

A highly simplified example for an acidification environmental mechanism is shown in the Figure 13. $SO_2$ and NOx are converted, by sunlight or hydrolysis, into acids that then are transported in the air and cause acid rain. Depending on the soil neutralizing capacity a lake is or is not acidified. Finally, the acidification of the lake kills fishes what is considered as one or the endpoints of this environmental mechanism.

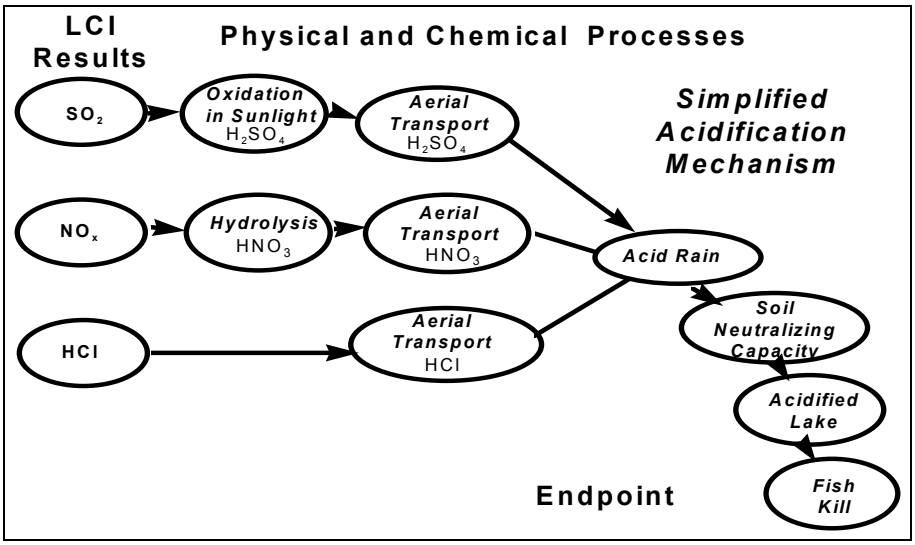



FIGURE 13: EXAMPLE FOR AN ENVIRONMENTAL MECHANISM: ACIDIFICATION (OWENS, BRUSSELS WORKSHOP 1998)

In the Brighton workshop, Norris presented "Midpoint -> Endpoint: Changes in Relative Importance of Pollutant, Location, and Source." Using acidification as an example, he pointed out an analysis in which the location was even more important than the pollutant characteristics. He indicated source class as a possible indicator of location discussed its correlation with other important factors including exposure efficiency. He suggested that source class related information might be used to fill in some of the existing holes in LCA (Bare et al., 2000).

# Part Three

Potting spoke about different levels of sophistication in Life Cycle Impact Assessment both in the Brussels and the Brighton workshop, taking especially acidification as an example. She suggested a combination of the spatial differentiated or site-dependent midpoint modeling with the site-generic endpoint modelling. Presenting a case study she demonstrated the potential need for site-specific simulations, including emission dispersion and deposition patterns, background depositions on receiving ecosystems, and the sensitivity of receiving ecosystems. She announced that easy-to-use acidification factors had been established for 44 European regions and suggested that utilizing this site dependent approach for acidification resulted in a significant reduction in uncertainty. The level of sophistication in impact assessment can, as mentioned few times during the Brussels workshop, be understood in two ways (see also Potting et al., 1997):

1. The extent to which relevant parameters in the causality chain are taken into account in the characterization factors (i.e. whether the characterization factors are based on no, some or full fate and exposure modeling).
2. The extent to which spatial (and temporal) variation is allowed in each parameter of the modeling underlying the characterization factors

The acidification factors from Potting et al. (1998) are sophisticated in both senses. They cover all the relevant parameters in the causality chain, and they allow a high degree of spatial variation. The application of these acidification factors in life cycle impact assessment is quite straightforward. Each emission is multiplied with the acidification factor for the relevant substance and region. Next the product from all emissions times acidification factors are summed-up to arrive at the total acidifying impact from the analyzed product. Application of the acidification factors from Potting et al. (1998) requires data additional to current impact assessment: The geographical site or region where an emission takes place. The requirement of this additional data is often put forward as an objection against spatial differentiation. However, the geographical site or region where an emission takes place is often provided by current life cycle inventory analysis. Nevertheless, this spatial differentiation may not always be possible or desired. While forehand processes might need a certain degree of site-dependency, this is generally not the case for backhand processes. The mentioned acidification factors can be used also to establish default value per substance and region. It is necessary to adapt LCA software for the application of such factors.

Another approach for region-specifc fate factors was proposed by Huijbregts and Seppälä (2000). Their approach establishes European fate factors for airborne nitrogen compounds that cause aquatic eutrophication.

In the Brussels workshop, in accordance with EPA (2000), Finnveden presented two topics – “Eutrophication – Aquatic and Terrestrial – State of the Art,” and “Thresholds/ No Effect Levels/ Critical Loads.” First, he showed the site dependency of eutrophication in three models, developed since 1993. Then, in his second presentation, Finnveden proposed that thresholds may, at the macro-level, have no scientific basis and in fact may just be “acceptable” levels of risk and thus constitute value choices. Acidification and human toxicity were used as examples of impact categories that should not ignore “below threshold values.” In line with this, he proposed that threshold values should not exist in LCIA for any impact category.

As said in Bare et al. (1999) practitioners have tried to incorporate background levels in LCA studies in the past but there was a lot of discussion that this practice may or may not be appropriate. In line with the point raised by Finnveden, thresholds do exist and if so, one of the questions at hand is whether emissions do

occur above or below thresholds. Another issue concerned the fear that defining backgrounds and thresholds will lead to treating certain environments as infinite sinks when in reality nature's ability to absorb the impact may be exceeded in the future. The distinction was also made that thresholds may be less strict, because of the presence of very sensitive species or human individuals. Thresholds may also not be protective enough in environments in which the combined effects of chemicals may cause impacts at a level lower than the threshold. On the other hand, some participants believed that thresholds might be valuable indicators of relative potency for many chemicals and that thresholds had been derived with statistically sound methods. Further clarification of the decision-making context may be necessary to determine the value of thresholds in particular LCIA applications.

## APPLICATION DEPENDENCY OF LCIA

The reason to perform an LCA study is essentially to use it in support of a decision. A decision gives rise to a change somewhere in society compared to a scenario in which this decision was not taken. The key requirement for LCA in any application is, therefore, that it shall reflect the environmental change caused by the decision. It is found that the need to differentiate LCA methodology for the use in different applications is born by a few key characteristics of the decision to be supported. LCA may have several applications including life cycle management, strategic planning, product development, process design, green procurement and public purchasing, product comparison and marketing.

Life Cycle Impact Assessment as part of an overall LCA can be used to:

- Identify and assist the prioritization of product system improvements,
- Characterize or benchmark a product system and its unit processes over time,
- Make relative comparisons among product systems based on selected category indicators, or
- Indicate environmental issues where other techniques can provide complementary environmental data and information useful to decision makers.

According to Wenzel in his presentation during the Brussels workshop (EPA, 2000) the three governing dimensions of LCIA applications are its time scale, its spatial scale and the need for certainty, transparency and documentation (Figure 14). For instance, eco-labelling is an application that needs certainty, transparency and documention due to the social and economic consequence of the decision, but no time- or site-diferentiation, while for product development the time scale is very important and the spatial scale plays a role. The need for certainty, transparency and documention depends on the specific product.

Furthermore, a key characteristic of the application dependency of LCIA is the environmental consequence of the decision, i.e. the nature and extent of the environmental change caused by the decision, thus giving rise to different requirements, primarily for the scoping of the LCIA. Another key characteristic is the context in which the decision is taken, including the decision maker and interested parties, implicitly influencing impact assessment and weighting.

Goedkoop discussed "Impact Assessment for Ecodesign" in the Brussels workshop (EPA, 2000). He pointed out that the point of conducting an LCA study is typically to determine whether A is better than B. He then presented three problems with LCA and ecodesign:

1. LCA studies are too time consuming;

Part Three

2. LCA studies are hard to interpret; and
3. Designers never become LCA experts, but remain dependent upon experts.

His proposed solution for these problems was to calculate pre-defined single scores for the most commonly used materials and processes, and to incorporate uncertainty into the modeling. He also discussed the sometimes hidden role of societal values in characterization modeling, even for internationally agreed upon models. As an example, he presented the three classes of carcinogenics (proven, probable and possible) and pointed out that the practitioner must make a decision about whether to include one, two, or all three classes. He proposed that a single truth does not exist and that modeling is dependent upon the chosen perspective.

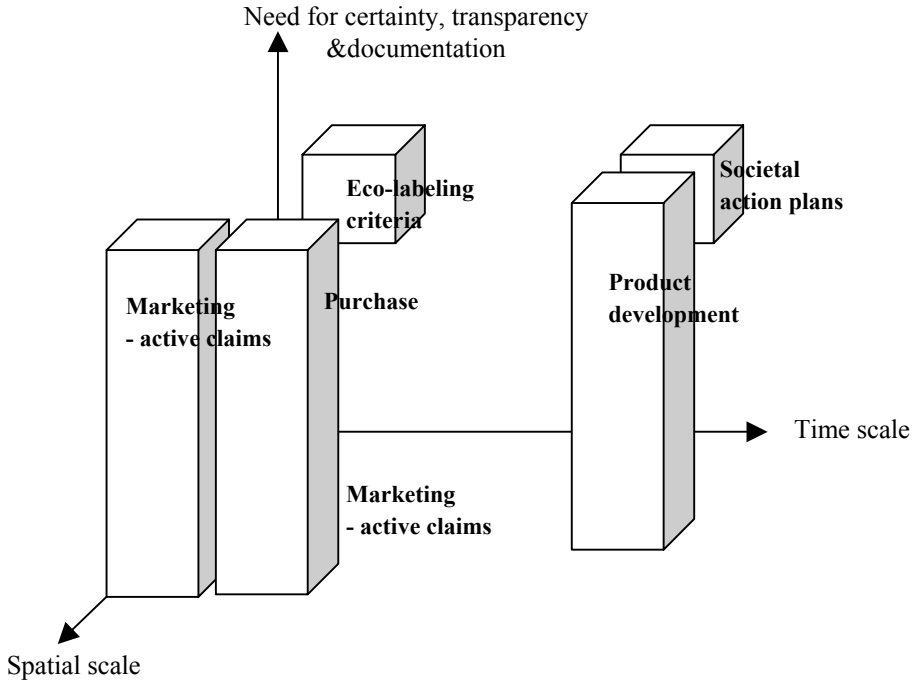



FIGURE 14: LCIA APPLICATIONS IN THREE GOVERNING DIMENSIONS (WENZEL, BRUSSELS WORKSHOP 1988)

Pennington discussed two extremes of LCIA sophistication in the Brussels workshop (EPA, 2000). One extreme he called the "Contribution or Burden" approach, which is comparable to what has been historically used in LCIA (reflecting the precautionary principle and the combinatory potential to cause impacts). As the other extreme, he noted the "Consecutive Risk Assessment" approach, as being particularly recommendable for use in areas with high stakes, such as comparative assertions, but as often limited to the assessment of chemicals in isolation.

## COMPARATIVE ASSERTIONS AND ENVIRONMENTAL CLAIMS

In the Brussels workshop (EPA, 2000), Owens spoke about comparative assertions (i.e., public comparisons between product systems) and the requirements for LCIA under ISO 14042. He stated that ISO 14042 requires a sufficiently comprehensive set of internationally accepted category indicators, a comparison conducted indicator by indicator (i.e. no weighting) and that LCIAs should not be the sole basis for comparative assertions. Current language in ISO 14042 states that

subjective scores, such as weighting across categories, shall not be used for comparative assertions, that category indicators shall be scientifically defensible and environmentally relevant and that sensitivity and uncertainty analyses shall be conducted.

ISO 14040 defines a comparative assertion as an environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function. The ISO 14020 series establishes several principles for any environmental claim, including comparative assertions: information will be accurate, verifiable, relevant, and non-deceptive; scientific methods will be used to generate the results; the process is open and participatory; the information is transparent and available to all (e.g., purchasers, interested parties, etc.); any claim is based on measurable differences including consideration of variations and uncertainty; and clear explanatory statements justify and qualify the claim. The 14040 LCA standards and draft standards include these principles.

According to ISO, public comparative assertions have to be based on a full LCA, including an impact assessment phase. They require equivalence between compared systems for functional unit, methodological considerations, performance, system boundaries, data quality, allocation procedures, decision rules on inputs and outputs, and the presence of an impact assessment phase. Together, these requirements establish a fair comparison in the inventory phase that is technically sound, transparent, and non-deceptive.

Each of the mandatory steps used to derive an indicator must be scientifically and technically valid: grouping into impact categories (Classification), converting LCI results (1$^{st}$ Characterization step), and aggregating converted LCI results within an impact category (2$^{nd}$ step). This may present difficulties for several current practices such as aggregation of different types of effects, aggregation of a similar effect from different places and times, and the use of subjective scores. For example, an expert panel to toxicologists of the International Life Science Institute states that it is inherently impossible to make a purely scientific comparison of qualitatively or quantitatively different toxicity impacts (ILSI, 1996). Instead, they suggested explicitly weighing the severity of the different types of impact.

For environmental relevance, ISO 14042 establishes key criteria to meet: the indicator will reflect the actual consequences of the system operation on the category endpoint(s), at least qualitatively. In addition, the category model must incorporate environmental data or information, including: environmental condition of the category endpoint(s); intensity of environmental changes; spatial and temporal aspects such as duration, residence time, persistence, timing, etc.; reversibility; and uncertainty.

ISO also established the requirements for a critical review of any study used for public comparative assertions so that methods used will be consistent with ISO, all methods are scientifically and technically valid, the data are appropriate and reasonable, study interpretations reflect the limitations, and the study report is transparent and consistent. The panel members should be familiar with ISO and have scientific/ technical expertise to address the impact categories covered. There are also extensive reporting requirements for the conduct of a study to ensure transparency, the critical review panel report must be included in the study report, and the report must be made available to all upon request.

In the Brussels workshop (EPA, 2000) there was a belief that the ISO standard on LCIA, specifically for the comparative assertions to be disclosed to the public, is too demanding in the areas of scientific validity and certainty. Examples were given of some other modeling arenas that face the same challenges (e.g., economic modeling, risk assessment studies). In these fields large uncertainties or agreed-

upon value choices are accepted, expected and (sometimes) clearly documented. There was also a concern that the rigor expected of the impact categories without a working international acceptance (e.g., human toxicity) exceeds the rigor and certainty requirements compared with the impact categories that benefit from having international consensus (e.g., global warming potentials).

In the Brighton workshop, Hertwich began his presentation "Judging Environmental Harm: What Evidence should be included?" by stating that all environmental concerns are public and pointed out that statements about the relative or absolute importance of environmental stressors contain three different types of truth claims (Table 6): factual claims, which are based on natural science; normative claims, which refer to preference values; and relational claims, which address the proper relation between factual knowledge and values. Objective arguments can be made about each type of claim. The distinction among different types of claims is important because the methods used to evaluate the credibility of each type differ. Factual truth claims can be assessed using the scientific method. Normative claims can be based on ethical arguments. The values of individuals or groups can be assessed using various social science methods. Relational claims must follow the rules of logic (Herwich et al., 2000).

TABLE 6: THE TYPES OF TRUTH CLAIMS IN LCA AND THEIR ASSOCIATED VALIDITY REQUIREMENTS (HERTWICH, BRUSSELS WORKSHOP 2000)

| | **Factual truth claim** | **Normative claim** | **Relational claim** |
|---|---|---|---|
| **Description** | relates to the correctness of the data and scientific models used in LCA | relates to the representativeness, consistency and appropriateness of (preference) values in LCA | relates to the appropriate use of scientific data and models as well as elicited values to represent our concern about something (relevance, consistency of aggregation) |
| **Example** | The persistence of $CO_2$ in the atmosphere is higher than that of $CH_4$. | We are more concerned about the near-term effects of climate change than about the long-term effects. | Our concerns about climate change are appropriately reflected by the increased infrared absorption resulting from the emissions of a unit of a greenhouse gas integrated over the next 100 years. |
| **Requirement** | Scientific validity<br>An LCA method is scientifically valid if the factual claims contained in it are scientifically valid. | Normative validity<br>An LCA method is normatively valid if the preference values contained in it represent the preferences of actual persons and can be shown to be acceptable in a discussion. | Technical validity<br>An LCA method is technically valid if it combines scientific data and models and preference values in a way that is appropriate, logically correct, consistent, and in agreement with the intentions of LCA. |

According to Hertwich, from the presence of normative elements in LCA, it follows that there exists no unique best impact assessment method. There are different, legitimate sets of preference values and alternative, logically consistent ways of making judgments about facts (Ran, 1998). In addition, our concerns about the environment demand that we include issues about which no scientific consensus exists, e.g. about the causes of observed forest damage. In cases of scientific uncertainty, alternative, legitimate scientific hypotheses may become the factual basis for the assessment (Casman et al., 1999). Contextual and constitutive values will influence the method choice (Shrader-Frechette, 1991).

LCA can be seen as a systematic approach to judging the environmental consequences of consumption (Scheringer, 1999). It is based on factual evidence, but also on a careful consideration and weighting of competing interests and values. The question of the Brighton workshop, whether to model impacts at the midpoint or the endpoint levels, is hence according to Hertwich, ultimately a question about the standard of evidence, but it also concerns the assessment approach and the underlying philosophical perspective (Bare et al., 2000). In contrast to this, Udo de Haes pointed out the need for identifying best available practice, both regarding the factual and the normative aspects. This includes its dependence on the type of application and its time and space characteristics.

### RELATIONSHIP WITH DECISION SUPPORT

The LCIA terminology rather closely connects with terminology used in decision analysis (Keeney, 1992; Hertwich and Hammit, 2001), which starts from the values which are affected. In the framework of these authors the terms stressor, insult, stress, consequence and value lost are used, and in addition the terms attribute and means-ends objective network. In Table 7 the correspondence is given with the terms used in LCIA.

TABLE 7: CORRESPONDENCE BETWEEN TERMS FROM DECISION ANALYSIS WITH THE TERMINOLOGY USED IN LCIA (KEENEY, 1992; HERTWICH AND HAMMITT, 2001).

| Terms used in decision analysis | Corresponding terms used in LCIA |
|---|---|
| Stressor | Environmental intervention (emissions and resources consumption) |
| Insulta and stress | Midpoint |
| Consequence | Endpoint |
| Value lost | Area of Protection |
| Attribute | Category indicator |
| Means-ends objective network | Environmental relevance |

Moreover, according to Bare et al. (2000), communication of the results was recognized as an important factor. For example, indicators at a midpoint level may be preferred for specific communication purposes (e.g. it may be politically preferable to speak in terms of global warming potentials rather than in terms of DALYs.). In general, indicators at endpoint level are often considered to lead to more understandable results; in fact this is connected with the environmental relevance of the indicators, already discussed above. However, indicators at a midpoint level may be more readily communicated in the sense that they will less readily lead to unwarranted conclusions. For instance, global warming potentials

will not lead to an unproven suggestion that malaria will increase in certain regions, in contrast to results in DALYs, which do assume this. In contrast, other practitioners liked the idea of increased specificity of the modeling of associated effects, stating that it may result in increased awareness of the implications of consumption patterns.

When aggregation was considered desirable, there was recognition that conducting comparisons across categories is difficult. Three examples of weighting strategies were discussed at the Brighton workshop:

1. Using normalized midpoint indicators,
2. Using normalized midpoint indicators and in addition using endpoint measures to provide default insights into the relative importance of certain midpoint categories, or
3. Using endpoint indicators.

Many supported the use of both midpoint and endpoint approaches when conducting a weighting exercise.

As also said in Bare et al. (2000) Hofstetter in his presentation during the Brighton workshop pointed to the complications associated with panel methods and the severe limitations in current LCA practices related to their use with both midpoint and endpoint factors. Consequently, during the larger group discussions, the present quality of default weighting factors between impact categories was questioned. Hofstetter stated that endpoint indicators would in general be better understandable to the public. However, he suggested at the same time that it was rather the coverage in the mass media that counts. Therefore, both midpoint and endpoint results can in principle be useful by non-experts, depending on attention they obtain in the mass media.

A far-reaching remark by Hofstetter was that in the weighting stage quantitative and readily available information will have much more influence than qualitative or not-presented information. This would affect both midpoint and endpoint modeling in the moment that they provide qualitative information on environmental relevance (with the midpoint models) or on the gaps of current modeling capacities (in the endpoint models). Norris went even one step further, arguing that non-quantified information cannot and should not be included in a weighting process because it will influence the decision in an uncontrollable way. In order to get clarity on this important issue there is a high need to learn more from experiences in related science fields (Bare et al., 2000).

# Challenges in the current state of LCA and especially LCIA and recommendations on how to overcome them to broaden its use

Part Four

## CHALLENGES

The potential of LCA and therefore also of LCIA as a decision-supporting tool is constrained by a number of barriers both within and outside the LCA community. UNEP identified the costs of LCA studies, the need for methodological expertise and a lack of communication strategies as basic barriers for a broader use of LCA (UNEP, 1999). The relative importance of the barriers differs between countries, between diverse users and between different applications. Countries with less LCA practice are first of all confronted with the absence of any perceived need for LCA, while countries with more extensive LCA experience suffer more from the shortage of data and methodology sharing.

The lessons learned from the workshops demonstrate that in the area of Life Cycle Impact Assessment generally agreed methodological choices would enhance the inclusion of this phase in LCA studies. This is going further than the ISO standard and technical guideline in that field. A framework for the combination of both midpoints and endpoints and an inadequate detailing of questions with respect to time and space is missing. Moreover, there is a lack of easy assessable high-quality LCI data that would also improve the reliability of LCIA outcomes. Finally, guidance is required on the interactions and interfaces of LCIA with other tools as environmental risk assessment, since various experiences in companies have shown that the use of LCA as a stand alone tool is limited to some applications in environmental management and that the results of the application of different tools might even be contradictory.

To overcome these barriers, action is needed in education and communication, in public policies, and in the further scientific clarification and development of Life Cycle Impact Assessment, LCA in general and related "ecotools." Therefore recommendations have been elaborated for appropriate actions based on the outcomes of the UNEP workshops, further discussions within the LCA community and cooperation with the Society of Environmental Toxicology and Chemistry (SETAC), particularly the working group on LCIA (Udo de Haes et al., 1999). This working group expressed a clear need for best or recommended practice regarding LCIA.

### Absence of a perceived need for LCA

A general lack of environmental awareness and a lack of drivers for chain management are the most fundamental barriers to the use of LCA. The level of the driving forces also differs considerably among countries, and among organizations and companies. The lack of commitment to LCA, or more generally to environmental chain management, at the top of these institutions and the lack of a procedural incorporation of LCA in policy strategies are major barriers.

Political problems may arise in the case of policies based on life-cycle considerations, for example in the shape of eco-labels or ecotaxes on products. One major impediment for life-cycle-based policies is the "Stockholm Principle," which states that every country is responsible for its own resources, as long as it causes no harm to any other country. Life-cycle considerations may thus be regarded as undue meddling in other countries' internal affairs. A related complication is the

Part Four

World Trade Organization agreement that forbids discrimination – especially when domestic production is favored, either intentionally or unintentionally, for instance on the basis of environmental information.

### Scarcity of LCA expertise/ know-how

The scarcity of expertise for performing and understanding LCA studies is a particular problem in developing countries, as well as for Small and Medium-sized Enterprises (SMEs) and policy makers. Communication about the LCA methodology and the LCA outcome is also a problem. The complexity of the LCA model often makes decision makers lose sight of the overall picture because they cannot follow how the outcomes are reached and what the implications are of some particular choices. Also the small number of participants from the Southern hemisphere in the UNEP workshops on LCIA demonstrates the need for a global technology transfer.

### Costs of LCA studies

The high level of expert knowledge required by the method complexity (including LCIA issues), the large data demand, and the related costs for the experts and the purchasing of data from commercial databases (intellectual property) creates a picture of LCA as a very costly affair. In addition, the ISO requirements on review procedures increase the cost burden of LCA. This may result in the perception that the cost/ benefit ratio for carrying out an LCA is too high.

### Difficult access to high-quality data

Data quality and availability is one of the major practical bottlenecks in LCA studies. This is especially true for developing countries and SME's. Some data for LCA studies is in the public domain, others not; their value depends on their quality and on their relevance to the user's needs and options. Especially, there is a lack of consistent and peer reviewed international level databases of Life Cycle Inventories on a wide range of processes, materials and products, since in the present globalized economy the products are traded worldwide. Also for improving the reliability of the applications of LCIA methods in LCA studies the availability of high-quality data is an indispensable requirement.

### Lack of user-friendly and widely recognized LCIA methodologies

Methodological barriers in LCIA are related to the lack of generally agreed methodological choices, an inadequate detailing of available methods with respect to time and space, and the complexity of the method itself. This may imply that subjective choices are made, which may influence the outcome. The ISO standardization does not solve this problem. Moreover, scientific knowledge from related multidisciplinary fields as collected and discussed in SETAC (e.g. Udo de Haes et al., 1999), is insufficiently incorporated into Life Cycle Impact Assessment methods.

The workshops showed that the uncertainties are high in the current models and derived factor, which does not stimulate decision makers in relying on them. In general, there is a trade-off between the accuracy of impact assessment and the practicability of spatial differentiated methods for use in a life cycle perspective. A minimum requirement is transparency. The need has been identified for international guidance on levels of sophistication and for a consistent and encompassing framework of environmental processes and Areas of Protections enabling the choice of category indicators at different midpoint and endpoint levels.

## Unclear perception of the applications of LCA in relation to other tools

There is an unclear perception of the applicability of LCA and its relationship to other tools. Sophisticated LCIA methods for example are frequently compared to environmental risk assessment studies. Only a few integrated approaches have been proposed so far. Expectations of LCA as a universal tool may lead to disappointments, which can be a drawback for the general acceptance of the LCA tool. Furthermore, the adoption of LCA for investment- and strategy-oriented decisions requires broadening the scope of LCA. These types of decisions often deal with multiple functions not yet specified, and concern long-term questions with changing surrounding technologies. An international agenda for companies to orient their life cycle related activities is missing. This would also put LCIA in a broader picture (Wrisberg et al., 2002).

### RECOMMENDATIONS

The fundamental barrier is the absence of a perceived need for LCA and hence also for LCIA. The easiest way to address this would be by developing a broader market for LCA, recognizing that LCA does not always serve the objectives of prospective users. A distinction can be made between the following necessary steps: raising environmental awareness, understanding LCA, acceptance of LCA, and creating incentives. This implies activities such as the launching of communication and education programmes; the diffusion of LCA studies and experiences to make decision makers aware of the benefits; the involvement of stakeholders in LCA processes to improve their acceptance of the LCA outcome, and the procedural incorporation of LCA in policies to stimulate its use in the public arena.

Furthermore, one should aim at a targeted promotion. The ecological gatekeepers, the intermediate actors between industry and consumers, should advocate environment orient chain management. LCA is a decision-supporting tool, but its role in the decision making process is not sufficiently developed. LCA should be incorporated into procedures such as Environmental Management Systems, and policy makers should start to incorporate LCA into environmental policy making. A further point is that the economic incentives can be enhanced by subsidies to developing countries and SMEs to enhance LCA capacity.

In the purpose of stimulating the global use of LCA and overcoming the identified challenges, in April 2002, UNEP and SETAC, the Society of Environmental Toxicology and Chemistry, the leading scientific association in the field of LCA, launched the Life Cycle Initiative on approaches and best practice for a life cycle economy. Folllowing the ideas of the initative the focus in the area of Life Cycle Impact Assessment should be on best practice with regard to the characterization of emissions, resources extractions and land use, that means on the aggregation by adequate factors of different types of substances in a selected number of environmental issues, or impact categories such as resource depletion, climate change, acidification or human toxicity. The methodology should be adapted in general to fulfill also the requirement of developing countries.

# Conclusions

There have been a number of advances made in the evaluation of environmental impacts in Life Cycle Assessment in recent times:

- The framework for Life Cycle Impact Assessment has become standardized in ISO, enhancing the comparability and avoiding unnecessary variation between studies.
- The fate of substances is increasingly taken into account, in particular using multimedia modeling as a basis for characterization.
- The results of different characterization procedures for the same category are compared among each other and they show convergence.
- Better distinctions are being made between scientific information and value choices.

These developments are leading to advances in the practice of LCIA, but the major limitations and uncertainties cannot be expected to go away in the near future. Instead, practitioners must learn how to best address the concerns and limitations of the methodologies. As in risk assessment, there is great attention to being true to the science, but in the interest of practicality, a great need for simplifying assumptions. An increasing level of sophistication can increase model certainty, but, in some cases, may reduce the comprehensiveness.

There is a general agreement that one cannot validate the results of a single LCIA study, because of the lack of temporal and spatial specification associated with the inventory data, and an inability to accurately model complex interactions in the environment, including the combinatory effects of chemical mixtures. However, input data can be quality checked, and elements in the models can be compared with models developed in the context of other applications such as environmental risk assessment. Thresholds reflect value choices about what is regarded acceptable, rather than science based parameters.

A consensus was reached by the LCIA experts that both midpoint and endpoint level indicators have complementary merits and limitations:

- Both types of approaches have their specific value.
- Midpoint approaches give results which are relatively certain (although sometimes still quite uncertain), but which generally are less environmentally relevant because they focus on variables that are generally far removed from the endpoints, which directly matter to society.
- Endpoint approaches on the other hand give results that are expressed in very relevant terms, but are relatively (to extremely) uncertain.
- It would be an important step further if one encompassing framework could be developed, including the most important variables of both types of approaches, thus enabling modeling along the two approaches and comparing the results with each other.

The level of sophistication might depend upon the type of application and the availability of data; a consistent internationally accepted methodology framework would help to make easier the comparability between studies. However, the establishment of methods as basis for best practice should not discourage further research efforts. Besides, certain studies may only require life cycle thinking and therefore, are not subject to sophisticated methodologies.

# Appendices

Appendix 1: LCA for beginners

# LCA for Beginners

LCA methodology according ISO 14040 consists of the following phases:

The **Goal and Scope Definition** phase is designed to obtain the required specifications for the LCA study: what questions do we want to answer and who is the intended audience? The following steps must be taken:

1. *Defining the purpose of the LCA study*, ending with the definition of the functional unit, which is the quantitative reference for the study.
2. *Defining the scope of the study,* which includes the drawing up of a flowchart of the unit processes that constitute the product system under study, taking into account a first estimation of their inputs from and outputs to the environment (the elementary flows or burdens to the environment).
3. *Defining the data required*, which includes a specification of the data required both for the Inventory Analysis and for the subsequent Impact Assessment phase.

The **Inventory Analysis** collects all data of the unit processes of the product system and relates them to the functional unit of the study. The following steps must be taken:

1. *Data collection*, which includes the specification of all input and output flows of the processes of the product system, both product flows (i.e. flows to other unit processes) and elementary flows (from and to the environment).
2. *Normalization* to the functional unit, which means that all data collected are quantitatively related to one quantative output of the product system under study, most typically 1 kg of material is chosen, but often other units like a car or 1 km of mobility are preferable.
3. *Allocation*, which means the distribution of the emissions and resource extractions of a given process over the different functions which such a process, e.g. petroleum refining, may provide.
4. *Data evaluation*, which involves a quality assessment of the data, e.g. by performing sensitivity analyses.

The result of the Inventory Analysis, consisting of the elementary flows related to the functional unit, is often called the "Life Cycle Inventory (LCI) table".

The **Impact Assessment** phase aims to make the results from the Inventory Analysis more understandable and more manageable in relation to human health, the availability of resources, and the natural environment. To accomplish this, the inventory table will be converted into a smaller number of indicators. The mandatory steps to be taken are:

1. *Selection and definition of impact categories*, which are classes of a selected number of environmental such as global warming or acidification.
2. *Classification*, comprising the assignment of the results from the Inventory Analysis to the relevant impact categories.
3. *Characterization*, which means the aggregation of the inventory results in terms of adequate factors, so-called characterization factors, of different types of substances in the impact categories, therefore a common unit is to be defined for each category, the results of the characterization step are entitled the environmental profile of the product system.

The **Interpretation** phase aims to evaluate the results from either Inventory Analysis or Impact Assessment and to compare them with the goal of the study defined in the first phase. The following steps can be distinguished:

1. *Identification* of the most important results of the Inventory Analysis and of the Impact Assessment.

2. *Evaluation* of the study's outcomes, consisting of a number of the following routines: completeness check, sensitivity analysis, uncertainty analysis and consistency check.

3. *Conclusions, recommendations and reporting*, including a definition of the final outcome; a comparison with the original goal of the study; the drawing up of recommendations; procedures for a critical review, and the final reporting of the results.

The results of the Interpretation may lead to a new iteration round of the study, including a possible adjustment of the original goal.

**Users** of the LCA methodology are:

### Industry

At present, LCA is primarily used by companies (company internal use) to support their environmental decision making. The most frequent applications are related to:

- design, research and development,
- comparison of existing products with planned alternatives, and
- providing information and education to consumers and stakeholders.

Companies first of all use LCA for incremental product improvements and not for real product innovation, i.e. so far LCA is barely used for the complete redesign of existing concepts and even less for alternative fulfillment of functionality.

**Case Study. Higher materials and transport efficiency by compact detergents (UNEP, 1999)**

In Germany in 1994, Procter & Gamble compared conventional and compact detergents, and were able to show that compact detergents yearly save 815,000 tones (30%) of raw materials, 40,700 tours of trucks and 53 million MJ of energy. The company fosters the production and marketing of compact detergents.

Increasingly, the manufacturer of a product is held responsible for its manufacturing operations as well as for the uses of the product and how it is disposed. This chain responsibility has been formalized in some countries as an obligation to 'take back' the product and its packaging (electrical and electronic industry in EU, for example). This responsibility can also extend to the upstream process of a product. Companies are increasingly looking at supply chain management as a way to improve environmental performance. For a producer to address these concerns, an LCA can play a critical role in helping them to identify and quantify the issues involved.

### Government

At present the main role of LCA in policy development is in environmental labeling and the formulation of regulations on product policy and waste management. However, there are high expectations of its future significance in a number of other policy areas – such as green government purchasing, eco-

management, green design guidelines and awards, and sector benchmarking. The significance of LCA will increase when it is a part of a standard decision-making procedure.

The public sector is undertaking LCAs in relation to policy development, for example in product and waste policy (UK and Germany); for procurement of environmentally preferable products (USA); in directives for waste management (EU waste directive) and cleaner production (EU IPPC- Integrated Pollution Prevention and Control). Furthermore, LCA has been used in sector covenants between the public and industrial sectors, such as the Dutch packaging covenant

Overall, governments are seen to have a responsibility in promoting LCA because of its potential to achieve environmental improvements for a sustainable development. LCA is one of the few tools that can be applied to both the economic and environmental aspects of a product. The use of a well-developed LCA framework will allow governments to address social and economic sustainability indicators on a product level.

### Consumers and consumers organizations

Consumers and consumer organizations express their need for environmental information in order to make (ecological) product choices and to establish guidelines for how to achieve a more sustainable consumption pattern. However, consumers do not make environmental assessments entirely by themselves, but rely to a large extent on consumer organizations and on other organizations issuing ecolabels. The use of LCA by consumer organizations is not very widespread due to their limited resources and access to data: however, when LCAs are available, their results are used to support decisions related to products, investments or strategy development. LCA may indirectly, through ecolabeling and comparative publications by consumer organizations, support consumers in their decision-making in relation to product- and investment-oriented decisions.

**Case Study. Successful application of LCA by a public body: The Dutch Packaging Covenant (UNEP, 1999)**

A number of LCA studies comparing one-way packaging systems with recycling systems have been carried out in the context of the Dutch packaging covenant, involving different actors in the packaging chain. The results were quite different for various application situations. For instance, hybrid systems consisting of one-way packaging in combination with a durable container at home, scored relatively well. Moreover, the LCA studies identified environmental weak points in packaging, which have lead to product improvements in a number of cases.

Besides the standards related to Life Cycle Assessment there are other environmental management ISO 14000 standards that are valid for product systems. These are especially ISO 14020 and 14021 as well as ISO 14024 and 14025 that are defining standards for using environmental labels. An overview of relevant ISO 14000 standards for evaluating product systems is given in the Table.

TABLE: ISO 14000 STANDARDS RELATED TO PRODUCT SYSTEMS

| Using environmental declarations and claims  | Conducting life cycle assessment (LCA)  | Understanding the standards  |
|---|---|---|
| **ISO 14020**<br>This document provides general principles which serve as a basis for the development of ISO guidelines and standards on environmental claims and declarations. | **ISO 14040**<br>This document provides the general principles, framework and methodological requirements for the LCA of products and services. | **ISO 14050**<br>This document helps an organization to understand the terms used in the ISO 14000 series standards. |
| **ISO 14021**<br>This document provides guidance on the terminology, symbols and testing and verification methodologies an organization should use for self-declaration of the environmental aspects of its products and services. | **ISO 14041**<br>This document provides guidance for determining the goal and scope of an LCA study, and for conducting a life cycle inventory. | |
| | **ISO 14042**<br>This document provides guidance for conducting the life cycle impact assessment phase of an LCA study. | |
| **ISO 14024**<br>This document provides the guiding principles and procedures for third-party environmental labeling certification programs. | **ISO 14043**<br>This document provides guidance for the interpretation of results from an LCA study. | |
| **ISO/ TR 14025**<br>This document provides guidance and procedures on a specialized form of third-party environmental labeling certification using quantified product information labels. | **ISO /TR 14047**<br>This document provides illustrative examples on how to carry out Life Cycle Impact Assessment. | |
| | **ISO /TR 14048**<br>This document provides information regarding the formatting of data to support life cycle assessment. | |
| | **ISO /TR 14049**<br>This document provides examples that illustrate how to apply the guidance in ISO 14041. | **ISO Guide 64:1997**<br>This document helps the writers of product standards to address environmental aspects in those standards. |

Appendix 2: Bibliography

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This bibliography covers recent LCA publications and is divided into the following sections:

- References for citations in the text
- Introductory Reading
- General Methodology and Development
- Software and Life Cycle Inventory data
- Life Cycle Impact Assessment
- Possible Applications
- Case Studies
- Regional Activities on LCA

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Appendix 3: Internet Resources

# Internet Resources

CHAINET - European network on chain analysis for environmental decision support.
http://www.leidenuniv.nl/interfac/cml/chainet/

ECOCYCLE, A newsletter that shares information on policy and technical issues related to product environmental life-cycle management (LCM). Last issue Fall/Winter 1999.
http://www.ec.gc.ca/ecocycle/

Ecosite - The self acclaimed "World Wide Resource for LCA" that has not been updated since 1997.
http://www.ecosite.co.uk/

European Environment Agency - Use Search to find LCA information
http://www.eea.eu.int/

Global Development and Environment Institute at Tufts University
http://ase.tufts.edu/gdae/

International Network for Environmental Management
http://www.inem.org/

LCANET European Network for Strategic Life Cycle Assessment Research & Development. Last update 1997.
http://www.leidenuniv.nl/interfac/cml/lcanet/hp22.htm

Life Cycle Assessment Links – Broad spectrum of information for further details
http://www.life-cycle.org

Official ISO Technical Committee (TC) 207 site
http://www.tc207.org/home/index.html

SPOLD - The Society for Promotion of Life-cycle Assessment
http://www.spold.org/

Sustainable Development - Large index of Sustainability web sources.
http://www.ulb.ac.be/ceese/meta/sustvl.html

The Global LCA Village An electronic conference that serves as an intelligent platform for discussing leading topics in the area of LCA.
http://www.ecomed.de/journals/lca/village/aboutLCAvillage.htm

The L C A hotlist - A comprehensive list of LCA sources.
http://www.unite.ch/doka/lca.htm

The LCA Website - Steve Young's not so old LCA website updated in January of 1998:
http://www.trentu.ca/faculty/lca

WWW site associated with LCA and ecodesign - Another site that has not been updated since 1998:
http://love.kaist.ac.kr/~kcr/links.htm

Appendix 4: LCA based electronic Tools

# LCA based electronic Tools

The tools have been divided into four sections:

## Life Cycle Inventory Tools:

- ***The Boustead Model***

  A basic MS DOS based software package with one of the largest database available. All information is collected from industry through questionnaires. Data from over 23 countries is available which makes Boustead a very international oriented tool.

  Contact details:

  Tel: +44 1403 864561
  Boustead Consulting
  Fax: +44 1403 865284
  http://www.boustead-consulting.co.uk

- ***Euklid***

  The Euklid developers limit the process to an inventory. The software package is based on SQL Database with object oriented program structure.

  Contact details:

  Frauenhofer-Institut für Lebensmitteltechnologie und Verpackung
  Tel: +49 8161 491 300
  Fax: +49 8161 491 33
  http://www.ilv.fhg.de

- ***JEM-LCA***

  Inventory tool aimed at the electronics sector with a limited database developed at NEC. Software system based on an inventory and process tree principle.

  Contact details:

  Ecology based Systems Research Laboratory, NEC Corporation
  Tel: +81 3 38327085
  Fax: +81 3 38327022
  http://www.nec.co.jp

## Full LCA:

- ***EDIP LCV tool:***

  Developed for use in product development, EDIP is a software tool based on three groups: database, modeling tool and calculation facilities. Available in English and Danish.

  Contact details:

  Institute for Product Development (IPU)
  Tel: +45 45 932522
  Fax: +45 45 932529
  http://www.dtu.dk/ipu

# Appendix 4: LCA based electronic Tools

- ***LCAiT:***

  Simple graphics based software that allows the user to set up a product life cycle graphically and allows material and input/output balances. Because of a windows-type drop and drag system, copying cards between different studies is possible and easy to do.

  Contact details:

  Chalmers Industriteknik CIT
  Tel: + 46 31 7724000
  Fax: + 46 31 827421
  http://www.lcait.com

- ***GaBi:***

  Software system designed to create Life Cycle balances, covering both environmental and economical issues. The structure can be set up to support the ISO 14040 standards. Two possible databases and further add-on modules.

  Contact details:

  Institut für Kunststofprüfung und Kunststofkunde & Product Engineering GmbH (IKP), Universität Stuttgart
  Tel: +49 711 6412261
  Fax: +49 711 6412264
  http://www.ikp.uni-stuttgart.de

- ***KCL ECO:***

  KCL ECO operates on a process of modules and flows, each flow consists of a number of equations that represent masses and energies moving between two modules. The software works especially well when applied to small products and has a clear presentation style.

  Contact details:

  The Finnish Pulp and Paper Research Institute KCL
  Tel: +358 9 43711
  Fax: +358 9 464305
  http://www.kcl.fi

- ***LCAdvantage:***

  The software system consists of a graphical interface based on links, representing material and energy flows between modules that represent components out of products. The software also has a report generator, and contains a high degree of transparency and documentation on the information provided.

  Contact details:

  Pacific Northwest National Laboratory
  Tel: +1 509 3724279
  Fax: +1 509 3724370
  http://www.battelle.com

- ***PEMS:***

  It is based on graphical flowcharts representing a product life cycle in four units: manufacture, transportation, energy generation and waste management. The database is transparent and allows the user to insert new information.

Contact details:
PIRA International
Tel: +44 1372 802000
Fax: +44 1372 802245
http://www.pira.co.uk

- ***Simapro:***

  The database is transparent and the program allows the results to be displayed in different formats such as after classification or characterization. Simapro is a software package that comes with extensive instruction material, which includes an operating manual for the program, the database and the methodology itself.

  Contact details:
  Pré Consultants BV
  Tel: +31 33 4555022
  Fax: +31 33 4555024
  http://www.pre.nl

- ***TEAM:***

  TEAM is a software package with an extensive database and a powerful and flexible structure that supports transparency and sensitivity analyses of studies. Ecobalance offers to insert company data into the database.

  Contact details:
  The Ecobilan Group / Pricewaterhouse Coopers
  Tel: +44 1903 884663
  Fax: +44 1903 882045
  http://www.ecobalance.com

- ***Umberto:***

  Umberto is a multi-purpose Life Cycle Assessment package capable of calculating material flow networks. Uses a modular structure and offers clear transparent results. User starts by setting up a life cycle model after which the process units and materials can be selected.

  Contact details:
  IFEU Institut für Energie und Umweltforschung Heidelberg GmbH
  Tel: +49 6221 47670
  Fax: +49 6221 476719
  http://ourworld.compuserve.com/homepages/ifeu_heidelberg/ifeu_eng.htm

## Abridged LCA:

- ***Eco-indicator:***

  It is a manual for designers with background information on life cycle assessment. It contains a limited amount of data but allows simple Life Cycle Impact evaluation studies and helps designers understand the fundamentals of life cycle thinking.

  Contact details:
  PRé Consultants BV
  Tel: +31 33 4555022
  Fax: +31 33 4555024
  http://www.pre.nl

# Appendix 4: LCA based electronic Tools

- ***MET Matrices Method:***

  The MET matrices are a simple method of assessing and prioritizing environmental impacts of products or processes. By filling in two simple 4X4 matrices, the main causes of environmental impact can be determined (a reasonable level of background knowledge is required).

  Contact details:

  See: Brezet, H & van Hemel, C. Ecodesign: a promising approach to sustainable production and consumption , ISBN 928071631X, UNEP, Paris.

- ***AT&T product improvement matrix and target plot:***

  It is similar to the MET matrices, but it is more systematic. The matrix consists of questions and a scoring system, requiring the user to grade certain aspects of a product or process design. The scoring system produces a target plot that indicates the areas most suited for improvement.

  Contact details:

  Method available in book "Industrial Ecology" by T.E. Graedel, 1995, New Jersey: prentice Hill.

- ***Ecoscan 2.0:***

  Ecoscan is a software tool that produces LCA studies of products and processes only in evaluated format. This simplified approach allows evaluation and comparison of products through evaluation methods only and provides no information on characterization or classification level.

  Contact details:

  Martin Wielemaker
  Tel: +31 10 2651178
  Fax: +31 10 4651591
  http://www.luna.nl/turtlebay

## Specialized LCA tools:

Specialized LCA tools are basically the same as normal LCA tools, but the databases are oriented towards a particular product. The majority is for the packaging sector and waste management, but they can be used and adapted for other products (most of them have an interactive database that you can add to yourself).

- ***Ecopack 2001-06-22:***

  The successor of Ecopack 2000, based on the data sets created by the Swiss EPA, BUWAL. The sets SRU 133 and SRU 250 are based on material production, energy carriers and transportation, all used in packaging industry.

  Contact details:

  Max Bolliger Consulting
  Tel: +41 41 6722477
  Fax: +41 41 6722477

- ***Ecopro 1.4:***

  Software based on flow chart principle, systems can be built out of either process or transport modules. The user can add own information to the database and several methods of impact assessment are available.

# Appendix 4: LCA based electronic Tools

Contact details:
EMPA / Sinum GmbH
Tel: +41 71 2747474
Fax: +41 71 2747499
http://www.empa.ch

- ***Repaq:***

  Life Cycle Inventory tool with database containing information on packaging materials from US. User can set up functional unit type description of packaging system, specify materials/ fabrication method and insert additional information.

  Contact details:
  Franklin Associates Ltd.
  Tel: +1 913 6492225
  Fax: +1 913 6496494
  http://www.fal.com/

- ***EIME:***

  It has been developed for the design of electronic products. By using a network set-up, the tools allows environmental managers to select priority issues which will be enforced by "to do" and "do not" reminders during the design process.

  Contact details:
  The Ecobilan Group / Pricewaterhouse Coopers
  Tel: +33 1 53782347
  Fax: +33 1 53782379
  http://www.ecobalance.com

- ***WISARD:***

  WISARD is an LCA software tool combined with waste management priorities. It is equipped with LCI capabilities but also allows comparison of different waste management scenarios.

  Contact details:
  The Ecobilan Group / Pricewaterhouse Coopers
  Tel: +44 1903 884663
  Fax: +44 1903 882045
  http://www.ecobalance.com

**Facilitating communication of LCA information**

Exchange of LCA information is increasing. The Global LCA Village, an independent Internet forum provides a continuous flow of information among LCA scientists and practitioners, highlighting 'hot' current topics. A joint initiative of the International Journal of Life Cycle Assessment and SETAC, the forum has been addressing also the use of LCA in developing countries since April 1999.

For more in formation: http://www.ecomed.de/journals/lca/

Appendix 5: Scientific Articles

# Scientific Articles

## Life Cycle Impact Assessment Sophistication – International Workshop

**Jane C. Bare[1], David W. Pennington[2], and Helias A. Udo de Haes[3]**

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### Abstract

On November 29 - 30, 1998 in Brussels, an international workshop was held to discuss Life Cycle Impact Assessment (LCIA) Sophistication. Approximately 50 LCA experts attended the workshop from North America, Europe, and Asia. Prominent practitioners and researchers were invited to present a critical review of the associated factors, including the current limitations of available impact assessment methodologies and a comparison of the alternatives in the context of uncertainty. Each set of presentations, organized into three sessions, was followed by a discussion session to encourage international discourse with a view to improving the understanding of these crucial issues. The discussions were focused around small working groups of LCA practitioners and researchers, selected to include a balance of representatives from industry, government and academia.

This workshop provided the first opportunity for International experts to address the issues related to LCIA Sophistication in an open format. Among the topics addressed were: 1) the inclusion or exclusion of backgrounds and thresholds in LCIA, 2) the necessity and practicality regarding the sophistication of the uncertainty analysis, 3) the implications of allowing impact categories to be assessed at "midpoint" vs. at "endpoint" level, 4) the difficulty of assessing and capturing the comprehensiveness of the environmental health impact category, 5) the implications of cultural/philosophical views, 6) the meaning of terms like science-based and environmental relevance in the coming ISO LCIA standard, 7) the dichotomy of striving for consistency while allowing the incorporation of state-of-the-art research, 8) the role of various types of uncertainty analysis, and 9) the role of supporting environmental analyses (e.g., risk assessments). Many of these topics addressed the need for increased sophistication in LCIA, but recognized the conflict this might have in terms of the comprehensiveness and holistic character of LCA, and LCIA in particular.

### Introduction

A UNEP Workshop titled "Towards Global Use of LCA" was held on June 12 - 13, 1998 in San Francisco. The purpose of the San Francisco workshop was to develop recommendations and an action plan that would lead towards a greater use

of LCA in the context of sustainable development. At the end of the San Francisco workshop, each of the participants was asked what actions could lead to greater development and use of LCA in sustainable development decision making. One of the many ideas suggested was to provide a forum for an International discussion of the appropriate practice of LCIA. LCIA Sophistication was taken up as subject of the workshop held in Brussels, which was attended by approximately fifty LCA practitioners and experts from various countries.

Practitioners of LCA are faced with the task of trying to determine the appropriate level of sophistication in order to provide a sufficiently comprehensive and detailed approach to assist in environmental decision making. Sophistication has many dimensions and dependent upon the impact category, may simulate the fate and exposure, effect and temporal and spatial dimensions of the impact. (Udo De Haes, 1999a, Owens, et al., 1997, Udo de Haes, 1996, Fava, et al., 1993) In the context of the Brussels workshop, sophistication was considered to be the ability of the model to accurately reflect the potential impact of the stressors, or in language more consistent with recent ISO publications, the ability to reflect the environmental mechanism with scientific validity. (ISO, 1999)

The impact assessment phase of LCA, termed LCIA, helps decision-makers interpret inventory data in the context of a number of impact categories and to bring them into a more surveyable format. Ideally, an LCIA would be based on high quality data. All impact categories and processes in the environmental mechanism of each of these categories would be considered using state-of-the-art techniques, which would fully account for spatial and temporal variation. In such an Ideal World, decisions would be made based on these assessments with a high level of confidence and certainty. However, real world practitioners have to deal with limitations (e.g., budget, and poor quality data) and simplifications are made. Some modifications may include: 1) reduction in spatial and temporal discrimination (or ignoring these dimensions altogether), 2) ignoring fate, 3) assuming linear dose-response curves and/or 4) eliminating an impact category because appropriate data or assessment methodologies do not exist.

While ideally an impact assessment should be sophisticated in all dimensions, this high level of sophistication requires exhaustive time, data, and resources and generally cannot be reached due to limitations in methodology and data available. Hence, the scope of the assessment needs to be defined, possibly iteratively, to provide the appropriate level of sophistication, including the required level of detail and accuracy, together with an uncertainty analysis practical for individual studies, and the specification of value choices within the framework of the LCA. Appropriate definition of this scope, including sophistication, uncertainty analysis, and comprehensiveness is the key to effective environmental decision making.

Many practitioners in the past have attempted to evaluate impacts to support broad LCA-based decisions, but have oversimplified the impact assessment step. Unfortunately, limitations in simulation sophistication lead to a reduced ability of the study to answer the questions at hand with a high degree of certainty. In the absence of accompanying uncertainty analysis, and validation (which addresses model uncertainty) many LCAs are conducted at such a low level of simulation sophistication that they are ineffectual in differentiating the very options they are trying to evaluate. (Coulon, 1997; Potting, 1997, Udo de Haes, 1996) Workshop participants also discussed the dichotomy of sophistication and comprehensiveness. As an example, very simplistic methods such as relying solely on toxicity data may allow a larger chemical database set than a more sophisticated approach which would require additional chemical and physical properties to determine the relative human health potentials.

More recently, researchers are recognizing the many types of uncertainty involved in environmental decision making. Two types of uncertainty discussed at this workshop were model uncertainty and data uncertainty. Data uncertainty may be estimated by the propagation of uncertainty and variability of the input parameters. Model uncertainty can only be characterized by comparison of the model prediction with the actual response of the system being addressed. As data uncertainty is relatively easy to characterize, whereas model uncertainty is difficult, especially in a field like LCIA, the presentation of data uncertainty alone may not appropriately be used to compare two methodologies. For example, a simplistic approach utilizing only persistency, bioaccumulation, and toxicity data may appear to be more certain when compared in terms of data uncertainty to a more complex multimedia/human exposure approach, but the unaddressed model uncertainty may significantly overshadow the data uncertainty.

The specification of value choices has a bearing on the level of sophistication and has been the subject of many recent papers. (Owens, 1998, Finnveden, 1997, Volkwein, 1996a, Volkwein, 1996b, Powell, 1996, and Grahl, 1996) Some practitioners are uncomfortable with the subjectivity of the Valuation Process, but fail to recognize the role of subjectivity in other phases of the LCA framework. All LCAs are conducted under the influence of subjective decisions. In fact, subjective decisions, value choices, or scientific or engineering judgements are made throughout the LCA process. Thus, the selection, aggregation, or disaggregation of impact categories and the determination of the methodologies to quantify the potential impacts are all influenced by value choices. The Brussels workshop was chosen to explicitly address the incorporation of value choices within the LCA process.

Unfortunately, the important issues of deciding the appropriate level of sophistication often remain unaddressed in LCIA. The determination of the level of sophistication is often not based on sound and explicit considerations, but on practical reasons (e.g. the level of funding, level of in-house knowledge). The workshop was therefore formulated to allow a more explicit discussion of the many factors outlined above that can influence the choice of the level of sophistication of a study, including:

- The project objective
- The perceived value placed on the specific impact categories
- The availability of inventory data and accompanying parameters
- The depth of knowledge and comprehension in each impact category
- The quality and availability of modeling data
- The uncertainty and sensitivity analyses
- The level of validations
- The available supporting software
- The level of funding

This paper provides a summary of the results of this workshop, including discussion on many of the above topics. An attempt is made to provide short reviews of the presentations and discussions. However, in documenting the workshop it was not possible to capture the full detail of the many points raised. For a more detailed coverage including overheads and summary papers, the reader is encouraged to e-mail the corresponding author.

Appendix 5: Scientific Articles

## Workshop Logistics

On the 29th and 30th of November, 1998 in Brussels, Belgium an international workshop was held to discuss Life Cycle Impact Assessment (LCIA) Sophistication. Approximately 50 LCA experts attended the workshop, coming from Europe, Asia and the USA. Several prominent practitioners and researchers were invited to present a critical review of the associated factors, including the current limitations of available impact methodologies and a comparison of the alternatives in the context of uncertainty. Each set of presentations, organized into three sessions, was followed by a discussion session to encourage international discourse with the aim to improve the understanding of these crucial issues. The discussions were focused around small working groups of LCA practitioners and researchers, deliberately selected to include a balance of representatives from industry, government and academia. Each group was given the charge to address the questions that most interested them, as opposed to assigning specific groups with specific questions.

## Introductory Session

Jane Bare of the U.S. Environmental Protection Agency (EPA) opened the workshop noting that many of the participants had been involved in previous meetings as LCIA experts, sometimes even discussing related issues in the development of ISO 14000 series and SETAC Working Groups on LCA and LCIA. Requirements are being developed under ISO 14042 to specify a high level of sophistication for Comparative Assertions, including language concerning the scientific validity, environmental relevance, and the role of value choices. Within SETAC-Europe efforts are on going to develop a document related to the selection of the "state-of-the-art" impact assessment methodologies. Bare asked that participants consider the present workshop as a more open format than either of these settings to allow a completely uninhibited technical exchange. She stressed that Life Cycle Impact Assessment can be effective in supporting environmental decision making, but only if the data and methods are sufficiently scientifically defensible. Scientifically defensible was defined as being dependent upon the level of sophistication, the level of certainty (including both data and model certainty), the level of comprehensiveness, and data availability. The participants were challenged to address several additional questions throughout the two days of discussions including: What is "scientifically defensible"? In the sphere of determining whether impact assessment is based on sound science, where does one draw the line between sound science and modeling assumptions?

Garrette Clark from the United Nations Environment Programme (UNEP) then provided a short history of UNEP's involvement in the area of LCA, which includes providing technical assistance to developing countries and the development of an associated guidance document for LCA (UNEP, 1996). She stated that LCA is considered by UNEP to be an important tool for achieving cleaner production and consumption. She also summarized findings from the recent LCA workshop in San Francisco in June 1998 (UNEP, 1998).

David Pennington discussed two extremes of LCIA sophistication. One extreme he called the "Contribution or Burden" approach, which is comparable to what has been historically used in LCIA (reflecting the Precautionary Principle and the combinatory potential to cause impacts). The other extreme, the "Consecutive Risk Assessment" approach, he noted as being particularly recommendable for use in areas with high stakes, such as comparative assertions, but as often limited to the assessment of chemicals in isolation. He introduced the question concerning the need for spatial differentiation and asked when site-specific differentiation was

appropriate. He also pointed out that the category indicators are chosen at different points in the environmental mechanism (or cause-effect chain), and stated that the U.S. EPA has been using the term of "midpoint" to address indicators that stop short of expected effects on the final "endpoint" of the environmental mechanism. He presented acidification as an example of a category with the indicator at "midpoint" level and human health as a possible example of a category with the indicator at "endpoint" level. He concluded by asking about the different levels of sophistication. What is possible? What is required? When to use the various levels of sophistication?

## Session One: Overview

Willie Owens of Procter and Gamble spoke about comparative assertions (i.e., public comparisons between product systems) and the requirements for LCIA under ISO 14042. He stated that ISO 14042 requires a sufficiently comprehensive set of category indicators, a comparison conducted indicator by indicator (i.e. no weighting) and that LCIAs should not be the sole basis for comparative assertions. Current language in ISO 14042 states that subjective scores, such as weighting across categories, shall not be used for comparative assertions; that category indicators be scientifically defensible and environmentally relevant and that sensitivity and uncertainty analyses shall be conducted.

Mark Goedkoop of Pré Consultants discussed LCIA for ecodesign. He pointed out that the point of conducting an LCA is typically to determine whether A is better than B. He then presented three problems with LCA and ecodesign: 1) LCA studies are too time consuming, 2) LCA studies are hard to interpret, and 3) Designers never become experts, but remain dependent upon experts. His proposed solution for these problems was to calculate pre-defined single scores for the most commonly used materials and processes, and to incorporate uncertainty into the modeling. He also discussed the sometimes hidden role of societal values in characterization modeling, even for internationally agreed models. As an example, he presented the three classes of carcinogens (proven, probable and possible) and pointed out that the practitioner must make a decision about whether to include one, two, or all three classes. He proposed that a single truth does not exist and that modeling is dependent upon the chosen perspective. He then introduced three different views of the world based on values: egalitarian, hierarchical and individualist. (A topic discussed later in more detail by Patrick Hofstetter.) He pointed out that if A is not better than B in all three cases then the result is dependent upon the perspective.

Henrik Wenzel of the Technical University of Denmark discussed the application dependency of LCIA. He mentioned several applications including life cycle management, strategic planning, product development, process design, green procurement and public purchasing, and marketing. In addition, he discussed three main variables governing application dependency: the environmental consequence of the decision (including spatial and temporal scale), the socio-economic consequence and the decision context. He discussed the application dependency of uncertainty, transparency, documentation and the inclusion of temporal and spatial resolution. He stated that the need for sophistication of LCIA is largest in decisions with the highest requirements for certainty. He also stated that the decision-maker might impact the choice of normalization and weighting. (Wenzel, 1998)

Helias Udo de Haes wrapped up this first session by providing a summary of some of the key points covered and challenging the participants to address the questions provided during the small group discussions. Workshop participants were asked to

address the following questions and to provide additional questions to aid discussion:

1. What are the most common methods by which the level of sophistication is determined?
2. Which methods are considered more acceptable? Why?
3. What are the barriers to using the acceptable methods? What can be done to overcome these barriers?
4. To what extent should LCIA be application dependent?
5. What are the expectations regarding the level of sophistication for the various LCA applications (e.g., by government, by industry, for public communication, and for internal use)?
6. When should LCIAs be as detailed as possible, aiming at the maximum level of accuracy? And when is it better to limit the scope of LCA to addressing questions on a macroscopic scale, leaving spatial and threshold considerations to other analytical tools?
7. How do practitioners deal with the trade-offs necessary when sophistication and comprehensiveness are "at odds" (e.g., choosing a detailed modeling approach that may limit the comprehensiveness vs. a scoring approach that may limit the sophistication)?
8. What case studies are available using uncertainty analyses within LCIA? And what are the major findings to date (levels of uncertainty discovered)? When is the uncertainty determined to be unacceptable?

Questions Added at Workshop:

9. What is scientifically and technically valid, as included in the requirements of ISO 14042?
10. If LCIA is an iterative process, what drives the decision on the level of sophistication (e.g., uncertainty analysis, relevance, and existence of trade-offs)?
11. Define uncertainty in the context of LCIA. What parameters must be analyzed?
12. How do we incorporate background levels into LCIA? Should we define working points (as in Mark Goedkoop's presentation)? Should this be done for individual chemicals or combined?
13. What is the best currently available method to represent the combined effect of chemicals without double counting, or inappropriately allocating?
14. How do we incorporate (or should we incorporate) the differing philosophical views in characterization?

### First Session Discussion Summary

An aggregation of the resultant views is presented below:

*Determination of Sophistication* – Many different groups commented on the appropriate level of impact assessment sophistication. One group commented that some sound decisions may be/have been made on the basis of LCA studies, which did not have very sophisticated LCIAs, but these tended to be more obvious cases. They recommended using the most sophisticated impact assessment models that provide information closest to the endpoint. Another group commented that sophistication is dependent upon a number of things including: inventory data availability, the availability of characterization models and data to support these models, objective, the application dependency, the decision maker's sphere of

influence and the impact category. A third group stated that the choice of sophistication depends upon an iterative process, where the iterations may be dependent upon uncertainty, the environmental relevance of the results and the minimum level of certainty required to support a decision. Several participants commented that sophistication is often limited by budget, inventory data availability, ease of use of impact assessment methods and in-house knowledge.

These participants stressed the practical side of LCA and recognized the difficulty in data collection and the structuring of public databases to support more sophisticated analyses.

*Application Dependency* - There was a general belief that LCIA sophistication is application dependent, according to the type of application and not the individual user. For example, screening level LCA studies may not require the rigorous use of sophisticated impact assessment techniques but final comparative assertions may require much more rigor, particularly if the benefits are not apparent. LCIA studies should be performed based on the type of question or decision at hand and the purposes that the LCIA may be serving.

*Validating the Results of LCIAs* – There was agreement that one cannot validate the results of a single LCIA study, because of the lack of temporal and spatial specification associated with the inventory data, and an inability to accurately model complex interactions in the environment, including the combinatory effects of chemical mixtures. However, input data can be quality checked, and elements in the models can be compared with models developed in the context of other applications such as environmental risk assessment. It was also noted that validation might not be as important in the context of LCIA since models simply reflect a relative comparison as opposed to an absolute assessment.

*Backgrounds and Thresholds* - Practitioners have tried to incorporate background levels in LCA studies in the past but there was a lot of discussion that this practice may or may not be appropriate. One of the questions at hand is whether emissions do occur in above or below threshold situations. Another issue concerned the fear that defining backgrounds and thresholds will lead to treating many environments as infinite sinks (e.g., for acidic chemicals) when in reality nature's ability to absorb the impact may be exceeded at some future time. The distinction was also made that thresholds may be less strict, because of the presence of very sensitive species or human individuals. Thresholds may also not be protective enough in many environments in which the combined effects of chemicals may cause effects at a level much lower than the threshold effect. Finally, practitioners were cautioned not to use LCIA to the exclusion of recognizing the problem of hot spots surrounding facilities. (See the following point for more information on mixtures). On the other hand, some participants believed that thresholds might be valuable indicators of relative potency for many chemicals and that thresholds had been derived with statistically sound methods. Further clarification of the decision-making context may be necessary to determine the value of thresholds and backgrounds in particular applications of LCIA.

*Mixtures* - One of the basic limitations of the current state-of-the-science of LCIA of human and ecotoxicity is the inability to effectively deal with potential combinatory effects of chemical mixtures. Toxicologists operate under the assumption that chemicals acting on the same organ can be considered to have an additive effect, but often LCIA impact categories are much broader than a focus on target organs. Therefore, the same assumptions used in risk assessment are not applicable to LCIA. This is especially an issue when practitioners try to incorporate threshold levels for individual chemicals into LCIA. Because mixtures are not well characterized in LCIA, effects may be occurring at much lower levels

than the accepted threshold levels of the individual chemicals. Practitioners often try to compensate for these and other model deficiencies by adopting the Precautionary Principle.

*Data Gaps* – There was a concern that data gaps can be significant. Particularly in human and ecotoxicity, availability and quality of both inventory and chemical data to support the modeling of a large number of chemicals can be frustrating. These impact categories are a good example of where less sophisticated screening techniques may, with an appropriate degree of caution prove useful.

*Uncertainty Analysis* - LCIA still faces great challenges before fully addressing uncertainty analysis. Some of these challenges include the lack of awareness, lack of associated methodology, and the perceived difficulty of presenting the results to decision-makers. Specifically, practitioners need better knowledge of uncertainties in existing methods within the different impact categories and of the potential for improvement, if any, by using methods with greater sophistication. Many participants acknowledged a need for a better understanding of the uncertainty involved in each of the impact assessment methodologies for each of the impact categories, noting that uncertainty is associated with the models as well as the input data. The potential trade-off in available models between increased sophistication (i.e., detail) and reduced comprehensiveness (e.g., number of stressors simulated) was again noted.

*Unnecessary Rigor?* – There was a belief that the ISO standard on LCIA, specifically for the comparative assertions to be disclosed to the public, is too demanding in the areas of scientific validity and certainty. Examples were given of some other modeling arenas that face the same challenges (e.g., economic modeling, risk assessment studies). In these fields large uncertainties are accepted, expected and (sometimes) clearly documented. There was also a concern that the rigor expected of the impact categories without a working international acceptance (e.g., human toxicity) exceeds the rigor and certainty requirements compared with the impact categories that benefit from having international consensus (e.g., global warming potentials).

*Model uncertainty vs. data uncertainty* – Some participants commented that the current disparity in levels of uncertainty analysis may have lead to the false impression that the more sophisticated models have increased uncertainty when compared to less sophisticated techniques. Typically this is not the case. Usually, with a more sophisticated model the model uncertainty has decreased and the ability to model data certainty quantitatively has increased. Deceptively (since model uncertainty is not typically characterized) the increased characterization of data certainty may have seemed to increase total uncertainty. (Additional details on uncertainty analysis may be found in Edgar Hertwich's presentations.)

*Standardization* – While it was recognized that the level of sophistication might depend upon the type of application and the availability of data, there was a belief that consistency of approach or methodology may be an important priority to allow comparability between studies. Some participants pointed out that certain studies may only require Life Cycle Thinking and therefore, should not be subject to the standardized methodologies. Others addressed the idea of approach hierarchies that differentiate between screening and more intensive techniques but noted that the approaches could be consistent within these tiers. It was similarly noted that there could be a trade-off between sophistication and comprehensiveness, while one approach provides a more complete picture but with low level of detail, another may provide a higher level of detail but at the expense of comprehensiveness. It was further noted that there is continual development of methods and standardization should not discourage further research efforts.

*More Focused Research* - More energy needs to be expended to ensure that LCA research is focused on areas that will have the greatest impact. Research needs to be conducted in deriving better methodologies for more relevant indicators. Specifically, land use, habitat alteration, and environmental toxicity were mentioned as examples of impact categories requiring much more research.

## Session Two: Human Health and Ecotoxicity

Edgar Hertwich of the University of California, Berkeley opened the session on Human and Ecotoxicity with his presentation: "A Framework for the Uncertainty Analysis of the Human Toxicity Potential". He presented the purpose of uncertainty analysis: “to develop confidence in an analytical result, as an input to formal decision analysis techniques and as a tool to refine impact assessment methods.” He noted that uncertainty analysis includes: parameter uncertainty, model uncertainty, decision rule uncertainty and variability. He then presented various examples of each of these as they might pertain to modeling for human toxicity impact assessment in LCIA. Finally, he pointed out that simply conducting a sensitivity analysis can often provide valuable insights about the significance of the multiple uncertainties involved in the decision and can help refine impact assessment techniques. (Hertwich, et al., 1993; Hertwich, 1999)

Patrick Hofstetter of the Swiss Federal Institute of Technology in Zurich addressed the question of “What is science?” in the presentation: “The Different Levels of Uncertainty Assessment in LCIA: The Case of Carcinogenic Effects.” He stated that the development of models is dependent on the perspective of the modeler. Three perspectives were described: hierarchist, individualist and egalitarian. An individualist optimizes the spending of resources based upon the known or certain types of harm that can be modeled (e.g., only choosing to include IARC Group 1 Carcinogenics in an analysis). A hierarchist could be closest to the operating positions typically held by government and international organizations and would include Group 1 and Group 2 Carcinogens. Egalitarians tend to take a more risk aversive and preventive standpoint and thus would include Groups 1, 2, and 3 in a carcinogenic analysis. Similarly, these different perspectives would derive different discount rates for use within an assessment in terms of the Disability Adjusted Life Years (DALY). An illustration showed the combination of the assumptions of all three cultural perspectives in an eco-index probability graph. Finally, he concluded that LCIA could be made simple to use and yet robust by incorporating the values associated with various perspectives and allowing an analysis of the related technical, methodological and epistemological uncertainties. (Hofstetter, 1998)

Olivier Jolliet of the Swiss Federal Institute of Technology in Lausanne discussed “Human Toxicity and Ecotoxicity Modeling vs. Scoring.” He opened by saying “Tell me your results and I will tell you who paid you!” Then he called for the identification of best available practice regarding impact assessment methods to reduce the ability to provide LCAs that support such malpractice. He also proposed that this process should try to meet the ISO 14042 requirements to be “scientifically and technically valid” and “environmentally relevant.” After comparing different human toxicity modeling efforts, he pointed out parameters and model characteristics that are important in human and ecotoxicity modeling, including exposure and fate uncertainties, that can be responsible for significant uncertainty and which open options for reduction of modeling uncertainty by proper empirical or experimental validation. He concluded by saying that modeling comparisons should be made based on model characteristics and consistent data.

Mark Huijbregts of the University of Amsterdam presented a paper on "Priority Assessment of Toxic Substances in LCA: A Probabilistic Approach." Citing previous publications (e.g., Guinée, et al., 1996 and Hertwich, et al., 1998), he suggested that the following specific improvements are needed: a review of default values with the possibility of using more realistic values, an inclusion of all relevant environmental compartments and inclusion of a Monte Carlo type of uncertainty analysis. He presented a probabilistic simulation of weighted human, aquatic and terrestrial Risk Characterization Ratios (RCRs) for 1,4-dichlorobenzene and 2,3,7,8-TCDD and demonstrated that only a few substance-specific parameters are responsible for the uncertainty in results. Finally, Huijbregts concluded that variability is not of significance if it is identical for all options being compared and asked that researchers continue to explore the issue of when data uncertainty/variability cancel in relative comparison applications.

**Second Session Discussion Summary**

Workshop participants were asked to address the following questions and to provide additional questions to aid discussion.

1. In human toxicity and ecotoxicity, when is spatial and/or temporal differentiation necessary? If necessary, what spatial and/or temporal details are recommended (e.g. indoor/outdoor, height of emission point)?
2. With respect to ecotoxicity what is the best approach to addressing multiple species? If suggested, what are recommended representative species?
3. With respect to human toxicity and ecotoxicity, what are the greatest barriers to conducting uncertainty analysis?
4. What are recommendations for research and development in these impact categories?

An aggregation of the groups' views is presented below:

*Standardization* – Again the question of standardization was discussed. Specifically, if the practitioner or study commissioner can have such a strong influence on the final results of the study, then perhaps some standardization would be useful to provide comparability between studies. However, what perspective or aggregation of perspectives should be represented in a standardized approach? Should central tendency assumptions or worst-case assumptions be used? Some participants stated that additional time was needed to ferment an opinion in this area. Others contended that "allowing" for too many methods and approaches could undermine the credibility of LCIA. However, many believed that now is the time to capture the state-of-the art in a document, while still allowing room for advances in the future. Several participants expressed interest in being involved in the current SETAC-Europe Working Group on Life Cycle Impact Assessment. (Udo de Haes, et al, 1999a and Udo de Haes, et al, 1999b).

*Midpoint vs. Endpoint Level* – In further discussion of the concepts of midpoints vs. endpoints, many participants discussed the advantages of making all impact assessment models as close as possible to the final endpoints of the environmental mechanism of the impact categories (e.g., quantifying fish kills and trees lost as opposed to the acidification potential of the substances). One benefit of this approach would be to allow more common endpoints for the valuation process, perhaps even opening the door to allowing more economic valuation of endpoints. Others pointed out that this might be unnecessary in a relative comparison context. They stated that extending the models to the endpoints will narrow down the comprehensiveness of the impacts considered, and will include many more assumptions and value judgements into the assessment. This may subsequently

increase the uncertainty of the results and reduce credibility by further mixing "science and value judgements."

*Ecotoxicity* – There was a strong call for research in this area. There was a recognized need to extrapolate ecotoxicity in a manner similar to human toxicity with representative species but also a realization that representative species may vary within different areas. However, there was also some discussion that LCA is a very macroscopic tool and, can not be expected to accurately model local issues. Perhaps, ecotoxicity is so specific to the locality affected that an attempt should not even be made to include it as an impact category. The most widely held view on this topic seemed to be that ecotoxicity should continue to be included, for the sake of providing a more holistic picture, and that the potential for more site-specific approaches should be considered further.

*Potentially Affected Fraction of Species (PAFs)* – Mark Goedkoop gave an impromptu presentation on PAFs. He stated that PAFs are different from PNECs in that they take the background level of the substances into account and thus enable non-linear modeling of impact on the species composition. Many in principle liked the idea of PAFs and combined PAFs that represent the combined effect of chemicals. However, there were concerns related to the possibility of identifying PAFs, due to the limited availability of dose response curves and of background concentration data for so many chemicals. A discussion of Eco-Indicator 98's relationship to PAFs was held. (Goedkoop, 1998)

*Borrowing from Risk Assessment* - Concern was voiced that LCIA for human toxicity is often based on typical risk assessment practice (e.g., the use of toxicological benchmarks). Caution was particularly high in the context of deterministic safety factors used in the toxicity component of the characterization factors, many of which compensate for low test species numbers. As this reduces the equity and comparability of chemicals, participants suggested that LCIA must be careful when adopting deterministic risk assessment perspectives.

*Research into Increasing Sophistication and the Role of Other Assessment Techniques* – One group asked for increasing temporal modeling, real ground concentration measurement, incorporation of population density into simulations and better representation of food webs. In this group, there was a concern that the current direction of research in multimedia modeling would not address these areas. However this must be viewed in the context of the aims which are to be met by LCA as opposed to the types of analytical tools. Thus, another group stressed that perhaps practitioners are too concerned with detail. Perhaps the focus should remain on macro differentiation of substances in terms of their persistent bioaccumulative and toxic (PBT) properties. This could be subsequently complimented (if required) by local scale analysis using other tools, and would help to include a larger set of chemicals at a sufficient level of differentiation.

## Session Three: Acidification, Eutrophication and Inventory

Greg Norris of Sylvatica, North Berwick, Maine, USA, presented a "Value-of-Information Approach." [He pointed out that uncertainty analysis allows some additional information (e.g., confidence intervals associated with data uncertainty) within the decision-making framework.] Norris stated that the level of sophistication should be partially dependent upon the inventory data and its uncertainty, upon the appropriate models and upon decisions about weighting. He suggested using Input/Output-based upstream LCI databases to answer many of the common questions that practitioners face, such as "How many sites, with how much geographic dispersion, contribute significantly to inventory totals?" And "What are the expected shapes of these distributions?" He also cautioned

participants against trying to draw conclusions about the preferability of more detailed LCIA, based on a Probability Density Function (PDF) or Cumulative Density Function (CDF) diagram, pointing out that further simulations may be required. Finally, he discussed the difference between analyzing uncertainty in weighting and in characterization modeling and the need to treat these issues jointly in the determination of the level of sophistication and decision support.

José Potting of the Technical University of Denmark presented "Levels of Sophistication in Life Cycle Impact Assessment of Acidification." Potting presented a case study comparing alternative locations for copper production and demonstrated the potential need for site-specific simulations, including emission dispersion and deposition patterns, background depositions on receiving ecosystems, and the sensitivity of receiving ecosystems. [She used the Regional Air pollution INformation System (RAINS) model (from IIASA) with calculations based on Critical Loads provided by the National Institute of Public Health and the Environment (RIVM) in the Netherlands and transfer-matrices from EMEP MSC-W at the Norwegian Meteorological Institute.] She announced that easy-to-use acidification factors had been established for 44 European regions and suggested that utilizing this site dependent approach for acidification resulted in a significant reduction in uncertainty.

Göran Finnveden of Stockholm University presented two topics - "Eutrophication – Aquatic and Terrestrial – State of the Art," and "Thresholds/No Effect Levels/Critical Loads." Finnveden discussed the site dependency of eutrophication in three models, developed since 1993. He presented additional topics for discussion and research related to eutrophication. In his second presentation, Finnveden proposed that thresholds may, at the macrolevel, have no scientific basis and in fact may just be "acceptable" levels of risk and thus constitute value choices. Acidification and human toxicity were used as examples of impact categories that should not ignore "below threshold values." In line with this, he proposed that threshold values should not exist in LCIA for any impact category.

The third session was concluded with the large group documenting some of the earlier topics and discussing the value of conducting future similar workshops. An on-site workshop summary was presented by two of the co-chairs.

## Conclusions

In meetings and journals world wide, practitioners have debated the utility of conducting Life Cycle Assessment studies. The debate has often hinged on the appropriate level of sophistication. While some have advocated abandoning LCA altogether, since it is not achievable in its most sophisticated form, others have supported the concept of conducting LCA studies at a more holistic level, while making the limitations and uncertainties transparent. This workshop discussed many of the issues of dealing with the appropriate level of sophistication in the Life Cycle Impact Assessment phase of an LCA study.

A number of prominent practitioners and researchers presented a critical review of the associated factors, including the current limitations of available impact methodologies and a comparison of alternatives in the context of model and data uncertainty. On the one hand the workshop addressed the various factors which are connected with an increase of sophistication in LCIA. Examples include the need for better fate and effect models and the role of spatial and temporal differentiation therein; the identification of background levels and thresholds, but also the need to specify value-laden aspects such as connected with different cultural perspectives. On the other hand, the holistic and comparative character of LCA was stressed. In this context, many questioned whether LCA should aim to conduct sophisticated

site specific risk assessments, particularly when this high level of detail may give a false impression of great confidence, especially when it is not presented with a stringent uncertainty analysis. Moreover, it was recognized that thresholds reflect value choices about what is regarded acceptable, rather than science based parameters. And finally, increasing level of detail can increase model certainty, but, in some cases, may reduce the comprehensiveness.

Workshop speakers and participants discussed the way that philosophical views may affect not only the valuation process, but also the impact assessment phase by including assumptions that include values based on the differing perspectives. This further complicates the question of what is "science-based" and what are "reasonable" modeling assumptions. Arguments were raised both for and against striving for consistency at this time in the effort to standardize some of the methods and assumptions to allow comparability between studies.

There was much discussion about the decision-making framework and the role of other environmental analyses, such as risk assessment. From the sophisticated uncertainty analyses presented it was obvious that great advances are being made, but there are many very basic principles that still lack consensus (e.g., the use of threshold values and background concentrations). As in risk assessment, there is great attention to being true to the science, but in the interest of practicality, a great need for simplifying assumptions.

There was consensus that the workshop was very valuable and that this exchange should be continued through e-mail discussions and periodic workshops (next target workshop in Brighton, U.K. in May 2000). Several topics were mentioned for future workshops, including: LCIA at strategic levels of decision making (including sustainable development decision support), community planning using LCIA-type indicators, the role of value choices in characterization modeling, and the state-of-the-science for characterizing ecotoxicity in LCIA.

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# Appendix 5: Scientific Articles

Appendix 5: Scientific Articles

# LIFE CYCLE IMPACT ASSESSMENT WORKSHOP SUMMARY - MIDPOINTS VERSUS ENDPOINTS: THE SACRIFICES AND BENEFITS

**Jane C. Bare[1], Patrick Hofstetter,[2] David W. Pennington,[3] and Helias A. Udo de Haes[4]**

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## Abstract

On May 25 – 26, 2000 in Brighton (England), the third in a series of international workshops was held under the umbrella of UNEP addressing issues in Life Cycle Impact Assessment (LCIA). The workshop provided a forum for experts to discuss midpoint vs. endpoint modeling. Midpoints are considered to be links in the cause-effect chain (environmental mechanism) of an impact category, prior to the endpoints, at which characterization factors or indicators can be derived to reflect the relative importance of emissions or extractions. Common examples of midpoint characterization factors include ozone depletion potentials, global warming potentials, and photochemical ozone (smog) creation potentials. Recently, however, some methodologies have adopted characterization factors at an endpoint level in the cause-effect chain for all categories of impact (e.g., human health impacts in terms of disability adjusted life years for carcinogenicity, climate change, ozone depletion, photochemical ozone creation; or impacts in terms of changes in biodiversity, etc.). The topics addressed at this workshop included the implications of midpoint versus endpoint indicators with respect to uncertainty (parameter, model and scenario), transparency and the ability to subsequently resolve trade-offs across impact categories using weighting techniques. The workshop closed with a consensus that both midpoint and endpoint methodologies provide useful information to the decision maker, prompting the call for tools that include both in a consistent framework.

## Introduction

In June 1998 in San Francisco (USA), the workshop "Towards Global Use of LCA" was held to develop recommendations and an action plan that would lead towards greater use of LCA in the context of sustainable development, including its use in developing countries. (UNEP, 1999) In November 1998 in Brussels participants of the "Life Cycle Impact Assessment Sophistication" workshop addressed the need for increased sophistication in LCIA, whilst recognizing the conflict that this might have in terms of the comprehensiveness and holistic character of LCIA, as well as the increase in data need in the LCI phase. (Bare, et al., 1999) One of the key issues raised – midpoint versus endpoint modeling – became the focus of the third international workshop, held in Brighton on May 25 – 26, 2000, and summarized in this paper.

Although the terms have yet to be rigorously defined, midpoints are considered to be a point in the cause-effect chain (environmental mechanism) of a particular impact category, prior to the endpoint, at which characterization factors can be calculated to reflect the relative importance of an emission or extraction in a Life Cycle Inventory (LCI) (e.g., global warming potentials defined in terms of radiative forcing and atmospheric half-life differences). Examples of methodologies based on midpoint characterization factors include Heijungs et al. (1992) and EcoIndicators '95 (Goedkoop, 1995). However, particularly in LCA studies that require the analysis of tradeoffs between and/or aggregation across impact categories, endpoint-based approaches are gaining popularity. Such methodologies include assessing human health and ecosystem impacts at the endpoint that may occur as a result of climate change, ozone depletion, as well as other categories traditionally addressed using midpoint category indicators. Examples of endpoint methodologies include Steen et al. (1992), ExternE (1995), ESEERCO (1995), and EcoIndicators '99 (Goedkoop & Spriensma 1999).

Figure 1 shows the steps that can be involved if a practitioner wishes to take an LCA study from the inventory stage, via impact assessment, to a single comparison metric using weighting techniques (both economic and/or panel approaches). Two different routes are presented, representing the routes taken when using midpoint and endpoint approaches. One of the key differences between midpoint and endpoint approaches is the way in which the environmental relevance of category indicators is taken into account. In midpoint approaches, the environmental relevance is generally presented in the form of qualitative relationships, statistics and review articles; however, it could similarly be quantified using endpoint methods to provide insights to the decision maker. In endpoint approaches there is no need to deal separately with the environmental relevance of the category indicators, because the indicators are chosen at an endpoint level and are generally considered more understandable to the decision makers. As a result different types of results are presented to the decision maker.

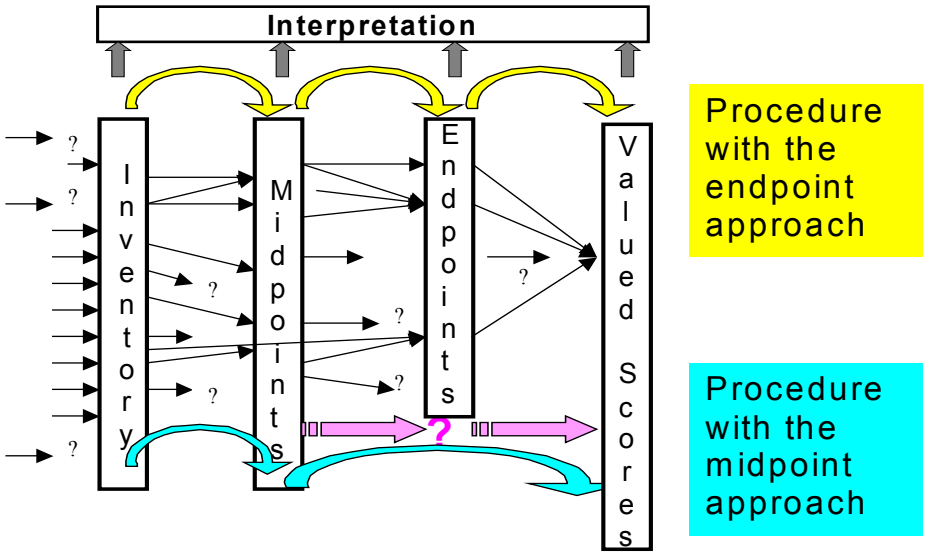



FIGURE 1. GRAPHICAL REPRESENTATION OF SOME BASIC DIFFERENCES BETWEEN THE MIDPOINT (LOWER ROW OF SWINGING ARROWS) AND THE ENDPOINT APPROACH (UPPER ROW OF SWINGING ARROWS). THE SMALL ARROWS REPRESENT MODELS THAT ADD INFORMATION IN A CAUSE-EFFECT FRAMEWORK. THE QUESTION MARKS INDICATE INFORMATION THAT WAS AVAILABLE BUT COULD NOT BE FURTHER MODELED. SUCH CASES INCLUDE UNMEASURED EMISSIONS, UNCONSIDERED TYPES OF RELEASES (OCCUPATIONAL, ACCIDENTAL), AND SUBSTANCES WHERE ENDPOINT MODELS HAVE STILL TO BE ESTABLISHED (E.G. NEUROTOXIC EFFECTS ON HUMAN HEALTH).

Endpoint modeling may facilitate more structured and informed weighting, in particular science-based aggregation across categories in terms of common parameters (for example, human health impacts associated with climate change can be compared with those of ozone depletion using a common basis such as DALYs – Disability Adjusted Life Years). Proponents of midpoint modeling believe, however, that the availability of reliable data and sufficiently robust models remains too limited to support endpoint modeling. Many believe that extending the models to endpoints reduces their level of comprehensiveness (the number of pathways and endpoints in the cause-effect chains that are represented beyond well characterized midpoints) and that such extensions will be based on a significant number of additional, unsubstantiated assumptions and/or value choices, (which may not reflect the viewpoint of other experts and/or the user) to fill in missing gaps. One major concern is that uncertainties (model, scenario and parameter) may be extremely high beyond well-characterized midpoints, resulting in a misleading sense of accuracy and improvement over the midpoint indicators when presented to weighting panels and decision makers. Many modelers believe that the additional complexity and detail is only warranted if it can be demonstrated to provide an improvement in the decision-making basis.

The Brighton workshop was conceived to present both sides of the midpoint versus endpoint argument to an international group of approximately 50 experts and to allow these participants adequate time to discuss the relative merits and limitations

of the approaches. A summary of the presentations, discussions and the outcome is presented below.

## 1 Presentations

This section provides short summaries of each platform presentation. Extended abstracts and slides will be available later in a full report.

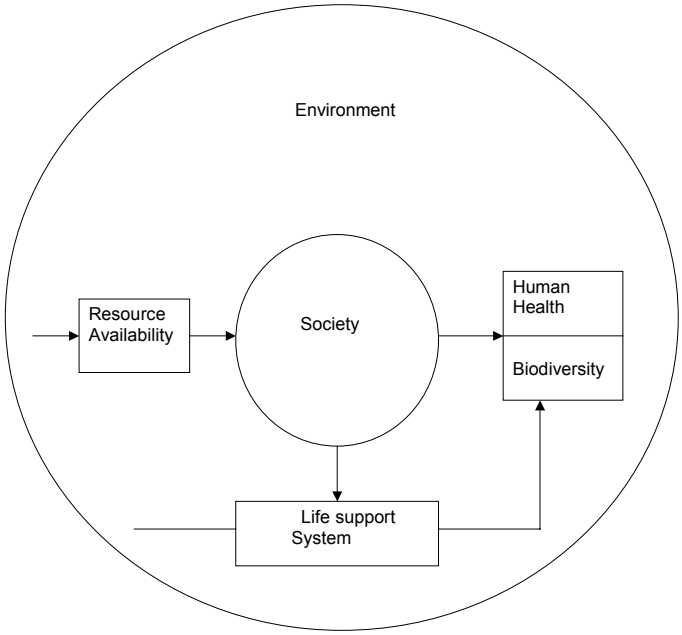
**Jane Bare** of the U.S. Environmental Protection Agency (EPA) opened the workshop with the presentation entitled: Midpoints vs. Endpoints – How Do We Decide? She pointed out that there are several reasons for conducting LCIAs, including LCIAs for enlightenment (which she defined as LCIAs which are used within a larger decision making framework and do not require impact category consolidation) and comparative LCIAs (which may be presented with the desire to determine which of two or more options is more environmentally friendly). Within LCIAs for enlightenment there may be no desire to consolidate the information of the LCIA into a single score. Decision makers may select the LCIA impact categories that are most closely related to their environmental values or ethics, and/or LCIA impact categories they wish to use for communication. In this case, a midpoint and an endpoint approach may be equally desirable. In comparative LCIAs consistency is important and to provide a consistent decision making framework in situations where trade-offs are necessary, a single score or weighted result may be the goal of the study. Bare then outlined some of the issues with midpoint and endpoint modeling. She proposed that endpoint modeling may facilitate a more structured and informed weighting process, which may include economic techniques, but she also stated that a high level of knowledge, data quality, and expert involvement was LCIA, are not transparent to the user and may conflict with the values necessary in forecasting specific endpoint effects. She used the example of ozone depletion. While the midpoint modeling of ozone depletion characterization factors may in principle encompass the consideration of crop damage, immune system suppression, marine life damage, and damage to materials, currently, these endpoints are not included in popular endpoint methodologies such as EcoIndicator'99. She also noted that endpoint modeling may introduce assumptions that are not always compatible with and/or wishes of the decision maker (e.g., human health may not include all possible endpoints.) Bare concluded her talk by suggesting that there are advantages and disadvantages to each approach and suggested that both midpoint and endpoint approaches might be used together to provide more information.

**Bas de Leeuw** of the United Nations Environment Programme (UNEP) presented "LCA: Untapped Potential for Sustainable Consumption and Production Policies." Within this talk he presented the analogy of a car and driver - challenging researchers to determine the "best science" and build software that would enable practitioners to use these models with a very low level of knowledge. He presented the role of UNEP in the LCA process, including: encouraging the use of LCA, helping to build consensus, and bringing LCA to developing countries. He stated that he believed that the production side has embraced LCA application, but the application of LCA to the consumption side of the problem has not been well studied despite the growing awareness among the public (and hence policy makers) about the "world behind the product".

**Mark Goedkoop** of Pré Consulting presented "The Benefit of Endpoints." Instead of discussing what is best, he stressed the focus on what is the most appropriate level of aggregation to communicate with the audiences in a company. As many audiences, especially decision makers, cannot relate to rather abstract midpoints, endpoint modeling is required, as well as midpoint modeling. He noted that an

attempt had been made to incorporate all possible value perspectives in the models by allowing endpoint calculation based on Hierarchist, Individualist, and Egalitarian viewpoints. He stated that the weighting process is difficult enough without expecting the panelists to model endpoints. He discussed some of the issues with the weighting process including panelists' incorporation of observed, perceived, and predicted damages. He suggested that fewer endpoints were better than too many. EcoIndicators '99 has human health, ecosystem quality, and resources. He suggested that the weighting process may take a different form if panelists are able to use the weighting triangle instead of estimating deterministic weighting factors. Goedkoop acknowledged the many assumptions and large data uncertainty in endpoint modeling and acknowledged the incomprehensive nature of the endpoints at this time. Goedkoop concluded by answering some of the questions written by the workshop chairs prior to the workshop. He believed there are gaps in endpoint modeling, but that these gaps are not a fundamental problem. He also felt that there is a need to avoid bias within all types of models. He recommended more weighting panels using both endpoint and midpoint modeling, and recommended that research continue for both approaches, preferably as one consistent system that can supply data at both midpoint and endpoint level.

**Helias Udo de Haes** of the Centre of Environmental Science (CML) presented "The Advantages of Midpoint Modeling." He considered endpoint modeling to be scientifically challenging, but with a much smaller reach, (i.e., much less encompassing) and much higher uncertainty compared with midpoint modeling. He referred to midpoint modeling as the traditional approach with a relatively good level of (model parameter) certainty at the level of characterization modeling, and quite encompassing with respect to the reach of the endpoints involved. However, in midpoint models a lot of the uncertainty is not included in the characterization modeling but is in the environmental relevance of the category indicators providing information about the links between the midpoint indicators and the respective endpoints (e.g. uncertainty associated with missing pathways in the cause-effect chain and not taking the indicator to an endpoint measure). Udo de Haes then proposed a new framework (Figure 2) for the areas of protection in LCIA, which distinguishes four areas of protection: resources, human health, biodiversity, and life support system. Individual impact categories are related to one or more of these areas of protection. The newly included area of protection, the life support system, deals with the supporting role of processes in the environment that enable sustainable life on earth. The use of characterization factors at the midpoint level is desirable for this category, not as a second best option as long as endpoint modeling is not yet feasible, but because these midpoint indicators reflect the impacts on the life support system itself. Categories for which this is pertinent include: climate change, ozone depletion, acidification and eutrophication.




| Resource Availability | Life Support System | Human Health |
|---|---|---|
| abiotic resources | climate change | trop.oxidant form |
| biotic resources | strat. ozone depletion | human toxicity |
| land competition | acidification | radiation |
| nutrification | noise, odour | |
| soil erosion | work environment | |
| hydrological change | Biodiversity | |
| | land productivity | ecotoxicity |
| | hunting | |
| | introd. new species | |
| | land use: species loss | |

FIGURE 2. PROPOSED FRAMEWORK FOR FOUR AREAS OF PROTECTION BASED ON BOTH MIDPOINT AND ENDPOINT INDICATORS.

**Patrick Hofstetter** of the U.S. EPA presented "Looking at the Full Picture – Implications Associated with Valuation." He restricted his presentations to cases where trade-offs between category indicators are needed and focused on methods that use stated preferences to do so (panel methods, WTP etc.). Based on descriptive decision analysis literature, he explained how important the selection of impact categories is on the final weighting step. Confronted with the question of how to allocate 100 importance points to a number of impact categories human beings tend to anchor their answers around 100 points divided by the number of impact categories. A review of recent panel studies in LCA confirmed that anchoring may have biased the studies. One step (among others) to avoid anchoring is to present category indicators that are perceivable and have a meaning, i.e., preferences may exist. Although endpoint approaches can potentially fulfill this requirement better than midpoint-based methods this is not yet the actual case. Both, midpoint and endpoint indicators are presently not based on a careful selection procedure that reflects societal consensus or the involvement of decision makers. Further research may well show that the way mass media and communication deals with environmental problems is finally decisive for the selection of the modeling level. Based on criteria like the 'perceivability of

indicators' and the 'possibility to provide more detailed information' Hofstetter also showed how the level of modeling influences the type of weighting methods that can be used. He concluded this evaluation with the finding that midpoint approaches appear not to fit with stated preference methods that elicit societal preferences.

In contradiction to Udo de Haes, Hofstetter claimed that from a decision support perspective the modeling at the endpoint level does not have more gaps than midpoint approaches. He suggested that true gaps in knowledge and understanding should rather be captured by a parallel precautionary index than by unstructured lists of suspected effects due to environmental mechanisms captured by midpoint indicators.

**Dik van de Meent** of RIVM (National Institute of Public Health and the Environment) presented "Ecological Impact Assessment of Toxic Substances: All the Way to the Endpoint?" He discussed the four steps to endpoint modeling as follows: 1) from functional unit to release inventory, 2) from emissions to concentrations, 3) from concentrations to "toxic pressure," and 4) from "toxic pressure" to "environment stress." He discussed ways to deal with unavailable data through estimation techniques, and the high level of correlation among chemicals with the same toxic mode of action. He provided greater detail in the fourth step for specific circumstances within the Dutch environment. He concluded by answering the chair's questions. He stated that some of the key assumptions included are: 1) Is vegetation representative of the ecosystems? 2) Are heavy metals representative of toxic environment stress? 3) And was a proper extension made to specific midpoint categories such as ozone depletion and climate change? Finally, he listed the primary uncertainties involved in the extension from midpoint to endpoint in this case.

**David Pennington** of the U.S. EPA presented "Midpoint vs. Endpoint Issues: Toxicological Burden on Aquatic Ecosystems." He opened with a discussion that some straightforward approaches based on indicators of implicit concern (usually midpoint indicators such as persistence, bioaccumulation and toxic potency scores) can be used to double check the results of models in LCA that attempt to more explicitly represent the fate and exposure mechanisms of a chemical in the environment (similar to Hofstetter's parallel precautionary index used to check for gaps). In one cited case study, the limited representation of the aquatic food web in a multimedia model had resulted in misleadingly low characterization factors for some chemicals. The error was spotted through such a crosscheck. Moving from this methodological overview, he then discussed the relative merits and complexities of the linear versus the tangential gradient as the measure of toxicological potency used in the calculation of characterization factors. It was stressed that both gradients are endpoint measures (change in percentage of stressed species in the case of ecosystems; the percentage of individuals in the case of human health), that there are limitations associated with this endpoint basis (e.g., increases in stress on an already stressed group of species and for the potential extinction are not measured), and that a common midpoint in the cause-effect chain of toxicological impacts does not exist to support comparisons in LCA. He concluded that uncertainties (parameter, model and scenario) must be stated before distinctions amongst alternatives can be expressed and that extreme caution is required when adopting complex LCIA methodologies, as they may not be scientifically robust and can be built on assumptions that add little additional information, or even increase uncertainty.

**Tom McKone** of the University of California Berkeley presented "Midpoint vs. Endpoint Modeling of Human Health." McKone compared the two levels by

saying that one represented greater relevancy (endpoints) while the other represented greater reliability (midpoints). He pointed out that the field of human health modeling is much more complex than most LCA researchers might realize. Human effects can be deterministic (i.e., effect and severity directly related to exposure, as in a sunburn) or stochastic (i.e., effect, but not severity related to exposure, as in cancerous effects). He stated that there is a dearth of information in this area - fewer than 30 chemicals have human carcinogenic data available, while only approximately 200 chemicals have animal carcinogenic test data. For other chemicals and other types of health effects we have to make highly uncertain estimates of dose-response relationships. He concluded that midpoint models provide more opportunities for scientific validation than endpoint models (e.g., for acidification it is easier to measure pH than to measure affected species) and eventually, midpoint models could be extrapolated into endpoint approaches so long as the resulting loss of reliability is addressed.

**Wolfram Krewitt** of the University of Stuttgart, presented ”Advantages and Limitations of Endpoint Modeling – Experiences from ExternE.” Krewitt pointed out that all models should fit the goal and scope of the study, and in the case of ExternE the context was presented. He gave an example of ExternE endpoint modeling to the Years of Life Lost (YOLL) due to ozone formation per 1000 tons of NOx and pointed out that it is possible to have both negative and positive effects in this example. He discussed uncertainty in many different categories including those of a scientific nature which can be quantified with statistical methods including some data and model uncertainty. He also noted that there were uncertainties related to policy and ethical choices, uncertainty about the future, and idiosyncrasies of the analysis (e.g., interpretation of ambiguous information). For impacts that currently cannot be quantified on the endpoint level (e.g. global warming, impacts on biodiversity), Krewitt suggested to use the costs for achieving environmental targets (‘standard-price approach’) as a measure of society’s preferences towards the expected, but unknown impacts. He concluded his talk by supporting endpoint modeling to enhance weighting and increase the understanding of the environmental mechanisms.

**José Potting** of Institute for Product Development at the Danish Technical University presented “Acidification and Terrestrial Eutrophication – Comparison of Different Levels of Sophistication.” She compared a number of midpoint approaches, all based on spatially resolved modeling with the RAINS model, but defined increasingly closer towards the endpoint. She showed that spatial differentiation into source regions (and subsequent effects) becomes more important as modeling comes closer to the endpoint. In other words, the uncertainties posed by refraining from spatial differentiation increase by orders of magnitude as modeling comes closer to the endpoint. She identified the lack of differentiation in source regions as a main drawback of the endpoint-approach in Ecoindicator’99 that is based on a model confined to the – relatively small – Dutch territory. Aggregation of acidification and terrestrial eutrophication (already implemented) together with ecosystem effects (not yet fully implemented) was on the other hand appreciated by Potting as one of the strong features of Ecoindicator’99. She therefore suggested a combination of the spatial differentiated or site-dependent midpoint modeling with the site-generic endpoint modeling (for instance by extrapolating the midpoint modeling with RAINS to endpoint by calibrating on Ecoindicator’99). Potting stressed that the state-of-the-art modeling is for some regions (like Europe) closer towards endpoint than in other regions (like North America). She therefore recommended, in line with ISO14042, to limit characterization to modeling at the point for which accurate – spatially resolved –

modeling is available (often midpoint modeling), and to consider the extrapolation to endpoint as a part of weighting.

**Greg Norris** of Sylvatica presented "Midpoint -> Endpoint: Changes in Relative Importance of Pollutant, Location, and Source." He pointed out the rapidly changing nature of modeling in LCIA, noting how quickly we have moved from potentials to models, and he predicted we would soon be using more sophisticated estimates of uncertainty within our models. He stressed the importance and decision support value of calculating and maintaining uncertainty information at each stage in the impact assessment, and suggested iterative tests for dominance at each impact assessment modeling stage. In the second portion of Norris's talk he stressed that location is important for some impact categories and should be considered during the inventory stage. Using acidification as an example he pointed out analyses in which location was even more important than pollutant. He pointed to source class as a possible indicator of location and noted that source class correlated with other important factors including exposure efficiency. He suggested that source class related information may be used to fill in some of the existing holes in LCA.

**Edgar Hertwich** of the LCA Laboratory presented "Judging Environmental Harm: What Evidence should be Included?" Edgar began his presentation by stating that all "Environmental concerns are public." And "There is no satisfactory way to determine social preferences from individual preferences." He also stated that he thought some expression of uncertainty was imperative, perhaps including uncertainties about mechanisms, magnitudes, and relevance. He stated that within midpoints analysis we know things with more certainty, but within endpoints analysis we know things with more relevance. Hertwich warned against compounding uncertainty, i.e., introducing the same uncertainty in additional steps of impact assessment that change a clear preference order of a comparative LCA to overlapping indicator results. Instead he recommended that to maximize the differentiability, one should operate with differences at the inventory level, and again operate with differences at the midpoint level. He recommended keeping both midpoint and endpoint analysis for a number of reasons. He noted that endpoint modeling allows for an easier evaluation of the magnitude of effects, while midpoint modeling allowed higher confidence and lower uncertainty.

## 2 Group Discussions

A summary of the issues discussed within the small break-out groups and then during a moderated discussion session is presented below.

### 2.1 Definition of the terms Midpoint and Endpoint

A midpoint indicator can be defined as a parameter in a cause-effect chain or network (environmental mechanism) for a particular impact category that is between the inventory data and the category endpoints. Although in general this definition will hold true, such as in categories like climate change and acidification, it may not be fully adequate in others. In particular, this definition was questioned in relation to many impact categories (e.g., human health and some ecosystem effects) that were considered to have no common midpoint in the cause-effect chain at which characterization factors could be adequately defined. The parallel role of midpoint measures, such as the overall persistence of a chemical, as a check of endpoint characterization factors was however stated.

Endpoint characterization factors (or indicators) are calculated to reflect differences between stressors at an endpoint in a cause-effect chain and may be of direct relevance to society's understanding of the final effect, such as measures of

biodiversity change. In some impact categories, more than one endpoint measure exists. For example, in the context of ecosystem effects, measures include the Potentially Affected Fraction (PAF) of species and the Potentially Disappeared Fraction (PDF) of species.

## 2.2 Uncertainty, Comprehensiveness and Environmental Relevance

Uncertainties in LCIA remain high. There was a recognition that at least two types of uncertainty exist: model uncertainty and parameter uncertainty. Model uncertainty is reflects the accuracy of the model, as determined through evaluation studies. Parameter uncertainty is the uncertainty associated with the input data, as commonly determined using tools like Monte-Carlo analysis. Many participants expressed concern that model uncertainties are often ignored in LCA, and the limited efforts to date have only focused on parameter uncertainty.

There was a recognition that there is also uncertainty regarding the relevance of the results. This is referred to as scenario or decision rule uncertainty by some researchers. (This was also presented as “What we know” vs. “What we want”.) There was an overall belief that endpoint models may be more relevant, but less certain (i.e., higher model and parameter uncertainty) but that midpoint modeling may be more certain (i.e., lower model and parameter uncertainty), but less relevant to what the decision makers really want to know.

In the context of relevance, Udo de Haes suggested, "Life Support Systems" may be seen as having intrinsic value in their own right. For example, GWPs are a midpoint measure in the context of impacts to humans and ecosystems in the event of global warming. The GWPs also relate to the integrity of the global climate as a LSS - an area of protection in its own right, being supportive to life on earth in a broad sense; hence, the GWPs in this context may still be regarded as midpoint indicators, but now with a high environmental relevance.

One group stated that the inventory was truly the “starting point” in the model and that one could make some decisions at this level, but the hidden uncertainty would be very high, in fact maximal. In some cases it makes sense to stop at the midpoint level from an uncertainty standpoint (no additional differentiation is added by modeling further along the cause-effect chain and, in general, the uncertainty will be increased). A dissenting opinion stressed that some endpoint models may include additional information, which is generally left out of consideration at the midpoint (e.g., endpoint models may more easily include the precise time pattern of the emission of ozone depleting gases).

The relative comprehensiveness of the midpoint and endpoint indicators was discussed. In general, midpoint indicators will be more comprehensive because they will be relevant for a wider variety of impacts at endpoint level, although these impacts are not modeled and may not be specified or known. Generally, endpoint models will focus on a smaller number of pathways because of the requirement to model them quantitatively. Although some “gaps” are qualitatively "known", the experts in the associated domains may not be confident about assessment beyond well-characterized midpoints up to endpoint effects. Pathways that carry significant knowledge gaps prohibiting quantification can be considered within endpoint modeling by making assumptions within the cause-effect chain modeling itself, by leaving pathways out of consideration, or by using parallel precautionary indices. In contrast, midpoint approaches do not address these knowledge gaps, but allow their consideration within the weighting and decision making phases. It was also noted that for both midpoint and endpoint approaches, participants in a weighting process may not even be qualitatively aware of all of the primary or secondary effects associated with each impact category.

Faced with the benefits and limitations of midpoint and endpoint approaches, it was suggested that both sets of results should be presented, either in parallel or in a tiered approach, within one consistent framework. The user could then see the comparative results at the midpoint level, as well as at the endpoint level. It was noted that this is analogous to the use of endpoint methodologies to provide a default basis for cross-comparison amongst midpoint category indicators.

### 2.3 Transparency

The more complex the model, the harder it is to maintain transparency and the greater the level of required documentation. For example, it is not always obvious which toxicological effects are taken into consideration in some endpoint methodologies or which assumptions and value-choices are made in the associated chemical fate and exposure models. It may be clarifying to learn that human health effects on endpoint level due to climate change are considered to be mainly due to the expected increase of malaria. A specific problem may be that the value choices encoded into the methodology may not reflect those of the decision-maker. Similar arguments may exist in the context of midpoint indicators, including ozone depletion potentials and global warming potentials, but are probably less abundant. It was suggested that methodologies should be as transparent as possible whilst still providing the desired level of accuracy. In the case of complex models, there has to be sufficient consensus within the scientific community that the approaches are acceptable and that detailed documentation is not required by the general user. De Leeuw stated, “It is not necessary to know how the engine works to drive a car”.

Based on the level of modeling alone, the level of transparency associated with midpoint indicators can be considered higher than in endpoint approaches. However, when weighting is required to compare and aggregate across impact categories, the implicit links between the midpoint indicators and the endpoint effects may not always be expressed clearly or represented in a structured fashion. This may impact the robustness of the weighting exercise and the final result. This is another reason to support the use of midpoint and endpoint indicators in one consistent framework, where the endpoint indicators provide structured insights to be used at the midpoint level.

### 2.4 Relationship with decision support

Many of the issues addressed in the Brighton workshop were related to the decision support process.

Communication of the results was recognized as an important factor. For example, indicators at a midpoint level may be preferred for specific communication purposes (e.g. it may be politically preferable to speak in terms of global warming potentials rather than in terms of DALYs.). In general, indicators at endpoint level are sometimes considered to lead to more understandable results; in fact this is connected with the environmental relevance of the indicators, already discussed above. However, indicators at a midpoint level may be more readily communicated in the sense that they will less readily lead to unwarranted conclusions. (For instance, global warming potentials will not lead to an unproven suggestion that malaria indeed will increase in certain regions, in contrast to results in DALYs which indeed give such a suggestion.) In contrast, other practitioners liked the idea of increased specificity of the modeling of associated effects, stating that it may result in increased awareness of the implications of consumption.

As endpoint approaches were seen to be most valuable in those cases where aggregation was desired, there was a considerable discussion about the value of aggregating results. Some participants pointed out that the degree of aggregation

across categories may be dependent upon the point at which one alternative can be demonstrated to be an improvement over the other. Other participants suggested that it can be desirable to determine the relative importance of an indicator in one impact category compared to another (e.g., global warming compared to ozone depletion), or even to fully aggregate all impact categories into a single number. Still other participants questioned whether it was necessary to strive for a single number; they argued that it would be sufficient to compare options within categories like human health, ecosystem health, and resources, without aggregating these disparate measures. Related to the "single number approach" some participants cautioned others to spend significant time analyzing the value of the LCIA within the decision making process. They pointed out that these decisions are often not independent of other information, but are simply informative within a larger picture. Similar to the ISO 14042 admonition not to use LCIA as the sole basis for comparative assertions, these participants warned against isolating the results of the LCIA in the single number approach and advocated using specific environmental impact categories as independent indicators along with other types of information, such as economic and social considerations.

When aggregation was considered desirable, there was a recognition that conducting comparisons across categories is difficult. Three examples of weighting strategies were discussed: 1) using normalized midpoint indicators, 2) the same, but in addition using endpoint measures to provide default insights into the relative importance of certain midpoint categories, or 3) using endpoint indicators. Many supported the use of both midpoint and endpoint approaches when conducting a weighting exercise.

Hofstetter in his presentation, summarized earlier, pointed to the complications associated with panel methods and the severe limitations in current LCA practices related to their use with both midpoint and endpoint factors. Consequently, during the larger group discussions, the present quality of default weighting factors between impact categories was questioned. Participants were challenged to come up with a single example of well conducted, well documented, and bias-free panel results available within the literature. The general conclusion that midpoint results can only be weighted by experts, whereas endpoint results can also be evaluated (or weighted) by non-expert stakeholders, was further questioned by a number of experts. Hofstetter stated that more important than the modeling level is the way environmental issues are covered in mass media because mass media information will influence at which levels individuals develop preferences. In that respect both present midpoint and endpoint approaches may need to be adjusted to the level of actual perception by the public. If non-perceivable indicators are offered in a weighting exercise it is likely that preferences do not exist and answers will be biased by the provided information and the question format. Therefore, both midpoint and endpoint results can in principle be useful by non-experts, depending on attention they obtain in the mass media.

A far reaching remark by Hofstetter was that in the weighting stage quantitative and readily available information will have much more influence than qualitative or not presented information. This would affect both midpoint and endpoint modeling in the moment that they provide qualitative information on environmental relevance (with the midpoint models) or on the gaps (in the endpoint models). Norris went even one step further, arguing that non-quantified information cannot and should not be included in a weighting process because it will influence the decision in an uncontrollable way. In order to get clarity on this important issue there is a high need to learn more from experiences in related science fields.

## 2.5 Using both midpoint and endpoint indicators

Theoretically, providing they are developed using a consistent framework, midpoint and endpoint characterization factors within some impact categories may display linear proportionality (e.g., the midpoint measure "ozone depletion potentials" and the endpoint measure of "DALYs" related to ozone depletion may be linearly proportional). In cases in which there is essentially just a multiplication factor between the midpoint and endpoint measures there is still value in communicating, and perhaps utilizing both approaches because different endpoint impacts will use different factors (and also evidenced in the arguments for Life Support Systems, and the issue of communication needs). This remained a presupposition, however, since there are currently no examples of models which allow consistent analyses to occur at both levels.

To use current midpoint and endpoint approaches together would require the use of models that have incompatible data sets, impact assessment methodologies, and modeling assumptions. Analogous to the idea of using midpoint and endpoint approaches in parallel, some practitioners suggested conducting studies using available, multiple methodologies (and even inventory databases) to determine whether this affected the results. Others voiced frustration with available software and warned that decision makers will not accept conflicting models next to each other. Further investigation would then be required to resolve contradictory results.

In order to overcome the above stated problems, the aim may well be to develop one framework which includes both midpoint and endpoint approaches in a consistent way. Then for a particular study a choice can be made which level or levels to use for the modeling, depending on the requirements set by the given application. Such a perspective could be considered within the presently envisaged SETAC/UNEP program, aiming at the identification of best available practice.

## 3 Conclusions

A consensus was reached by the LCIA experts at the Brighton workshop that both midpoint and endpoint level indicators have complementary merits and limitations. Decisions can be made using the midpoint indicators, which are more certain but can have a lower relevance for decision support in some cases, or using the endpoint indicators, which were argued to often have a higher relevance but lower certainty.

Some practitioners suggested that the midpoint and endpoint indicators should be available in parallel. An interesting perspective would be to provide both sets of information to decision makers within a consistent framework (midpoint and endpoint indicators provided from a given model of the cause-effect network). In line with this, strong support was expressed for the use of tiered approaches within LCA, where, for example, preliminary comparisons using midpoint approaches are followed by more detailed approaches at endpoint level. However, the form of such a tiered approach was not identified.

The present workshop has played an important role in clarifying the difference between the two approaches regarding comprehensiveness and gaps, uncertainty (model and parameter), relevance (or scenario uncertainty), the degree of transparency, value-choices, and an improved understanding of the limitations of panel-based weighting methods for comparing across impact categories. However, this can only be seen as a step in a process, because on all these issues further information and discussion is needed.

Participants finally expressed a desire to hold future workshops on these and on related issues in the field of LCIA, such as the treatment of ecosystem effects and environmental quality as it relates to land use issues, the different forms of uncertainty, issues in weighting, and the interaction between risk assessment and LCIA.

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About UNEP DTIE

# UNEP - Division of Technology, Industry and Economics

The mission of UNEP's Division of Technology, Industry and Economics (DTIE) is to help decision-makers in government, industry and local authorities develop and adopt policies and practices that:

- Are cleaner and safer;
- Make efficient use of natural resources;
- Ensure adequate management of chemicals;
- Incorporate environmental costs;
- Reduce pollution, and risks to humans and the environment

The Division is based in Paris and comprises one center and four units.

- **The International Environmental Technology Centre (Osaka**), which promotes the adoption and use of environmentally sound technologies which focus on the environmental management of cities and freshwater basins in developing countries and countries in transition.
- **Production and Consumption Unit (Paris),** which fosters the development of cleaner and safer production and consumption patterns that lead to increase efficiency in the use of natural resources, and reduction in pollution.
- **Chemicals Unit (Geneva)**, which promotes sustainable development by catalyzing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide, with a priority on Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC, jointly with FAO).
- **Energy and Ozone Action Unit (Paris),** which supports the phase-out of ozone-depleting substances in developing countries and countries with economies in transition, and promotes good management practices and use of energy, with a focus on atmospheric impacts. The UNEP/RISØ Collaborating Centre of Energy and Environment supports the work of the Unit.
- **Economics and Trade Unit (Geneva)**, which promotes the use and application of assessment and incentive tools for environmental policy, and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development.

UNEP DTIE activities focus on raising awareness, improving the transfer of information, building capacity, fostering technology co-operation, partnerships and transfer, improving understanding of environmental impacts of trade issues, promoting integration of environmental considerations into economic policies, and catalyzing global chemical safety.

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# About EPA, CML & AGA

**The U.S. Environmental Protection Agency** was established in 1970 to consolidate in one agency a variety of federal research, monitoring, standard-setting and enforcement activities to ensure environmental protection. EPA's mission is to protect human health and to safeguard the natural environment - air, water, and land - upon which life depends. For 30 years, the EPA has been working for a cleaner, healthier environment for the American people.

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**The Centre of Environmental Science** (CML) is an inter-faculty department of Leiden University, providing education and research on social and environmental processes relevant to progress towards a sustainable society. Its four sections deal with Substances and Products, Ecosystems and Environmental Quality, Environment and Development, and Education. The center has a staff of 40.

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**The Environmental Management and Analysis Group AGA** (Grup d'Anàlisi i Gestió Ambiental) of the University Rovira i Virgili URV has the mission to carry out environmental research on a European level and to satisfy, from the university background, technology and outsourcing requirements of industry and public administration by means of technology and knowledge transfer actions. The group is located in the Technology Transfer Service STQ and the Chemical Engineering Department of the School for Chemical Engineering ETSEQ. Since 1994 AGA's research group has developed different projects and courses, has participated in several national and international meetings and has published more than 50 reports as well as publications related to the subjects mentioned above.

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## Why use Life Cycle Assessment? (UNEP, 1996)

There are three reasons for using LCA:
It is **product and service** oriented; it is **integrative**; and it is **scientific and quantitative**.
LCA thus has a unique role to play in furthering the environmental aspects of sustainable development.

**Products and services** are extremely important in an industrial society. All economic activities depend on the use and consumption of products and services. Products and services are the axis around which industrial activity turns. Policies on products and services in business and governments are an important means of making economic activities environmentally more sustainable.

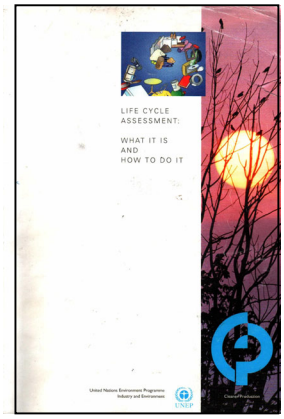
By its **integrative** approach, LCA can be used to prevent three common forms of pollution problem shifting:

- from one stage of the life cycle to another;
- from one environmental medium to another; and
- from one location to another.

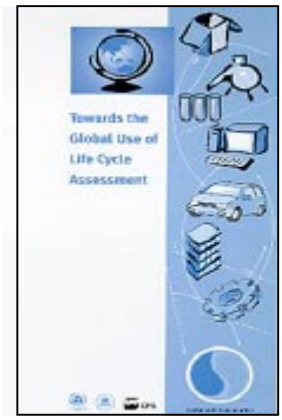
LCA is designed to provide the most **scientific and quantitative** information possible to support decision-making. Other types of criteria – economic, social and political – enter the discussion when decision-makers use the overall information furnished by LCA to analyze the information at stake.

### PREVIOUS UNEP REPORTS ON LIFE CYCLE ASSESSMENT

UNEP Industry and Environment, 1996.
*Life cycle assessment: what is it and how to do it.*
United Nations Publication Sales No. 9C-III-D.2, Paris.




UNEP Division of Technology, Industry and Economics, 1999. *Towards the Global Use of Life Cycle Assessment*. United Nations Publication, ISBN 82-807-1704-5, Paris.



# Life Cycle Initiative

## UNEP/ SETAC cooperation
## on approaches and best practice for a Life Cycle Economy

### Objectives and Deliverables

The Life Cycle Initiative builds on the ISO 14040 standards and intends to establish approaches and best practice for a Life Cycle Economy. The overall objective is to ***develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs associated with products over their entire life cycle to achieve sustainable development***. This includes the sharing of information between existing bodies of life cycle knowledge and the stimulation of multidisciplinary work.

An important tool concerns Life Cycle Assessment (LCA); to establish ***best practice in LCA*** the following deliverables have been identified:

- **Information system with Life Cycle Inventory databases** peer reviewed and regularly updated.
- **Set of rules for the setting of system boundaries and for allocation** as a basis for the elaboration of consistent data.
- **Set of best available Life Cycle Impact Assessment methods,** models and factors.

To facilitate a framework ***for incorporating Life Cycle Thinking and the social, economical and environmental aspects of sustainability in management systems*** the following elements have been proposed:

- **Integration of various existing tools and concepts** for decision-making on sustainable products and services.
- **Set of adequate indicators** for benchmarking.
- **Strategies for the communication** with relevant stakeholders about life cycle information.

The ***initiative will be driven by*** the implementation and dissemination of life cycle thinking with:

- **Demonstration studies** on life cycle approaches and best practice in different industry sectors and world regions.
- **Training modules** for SMEs and developing countries.

### Expected benefits

Expected benefits concern the development of practical tools for governments, industry and consumers that ***translate life cycle thinking into practice*** with:

- **Avoiding duplication of work and arbitrariness**
- **Providing reliable information in accessible format**
- **Preparing industry for increasingly aware consumers**
- **Supporting good business practices**
- **Contributing to continuous improvement**
- **Ensuring global applicability and dissemination**

For more information contact the Sustainable Consumption Group of UNEP DTIE at sc@unep.fr.

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