# *LIFE CYCLE ASSESSMENT*

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***INNOREGIO: dissemination of innovation and knowledge management techniques***

by **LEIA Technological Development Center**

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# Contents

**LIFE CYCLE ASSESSMENT**

# 1. DESCRIPTION

## *1.1. What is the Life Cycle Assessment (LCA)?*

The heightened awareness of the importance of environmental protection, and the possible impacts associated with products manufactured and consumed, has increased the interest in the development of methods to better comprehend and reduce these impacts. One of the techniques being developed for this purpose is Life Cycle Assessment (LCA).

A LCA is a useful tool for the study of the environmental impacts relating to a product, activity or process, through the identification and quantification of the main raw materials and energy consumptions and the generated wastes.

The assessment includes the entire life cycle of the product, activity or process (cradle to grave analysis), and addresses environmental impacts of the system under study in the areas of ecological health, human health and resource depletion, therefore, it is always a simplification and cannot provide a complete representation of every environmental interaction.

An LCA encompasses, generally, the following steps:

- Extracting and processing raw materials
- Manufacturing
- Packaging
- Transportation and distribution
- Use and re-use
- Maintenance
- Final disposal or recycling

## *1.2. Objectives of the technique*

The prime objectives of carrying out a LCA are:

1. To provide a picture as complete as possible, of the interactions of an activity with the environment
2. To contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities
3. To provide decision-makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements.

Additionally, the systematic procedures for LCA facilitate constructive dialogue among different sectors in society concerned with environmental quality. The concept of LCA is also an important influence on a range of techniques and thought processes that guide decision-making and the selection of options for design and improvement.

LCA is only one of several techniques for environmental management: It complements other techniques such as environmental impact assessment, hazard identification, risk assessment, technology assessment, waste-audits and waste minimisation assessment of processes, design for the environment, product stewardship, and management systems standards.

LCA can assist in:

- Identifying opportunities to improve the environmental aspects of products at various points in their life cycle
- Decision-making in industry, governmental or non governmental organizations (strategic planning, priority setting, product or process design or redesign…)
- Selection of relevant indicators of environmental performance, including measurement techniques
- Marketing (environmental claim, ecolabelling scheme or environmental product declaration)

### *1.3. Description of the methodology*

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

- Compiling an inventory of relevant inputs and outputs of a product system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

The LCA methodology comprises the following steps:

✓ ***Goal definition and scoping*****:** It is required at an early stage in the study to gain a clear understanding of the purpose, to identify the system(s) to be studied, and to determine the relevant requirements and intended applications that influence the direction and depth of the study.

  - Purpose
  - Scope
  - Functional unit
  - Data quality assessment

✓ ***Inventory analysis*****:** Includes the identification and quantification of energy and materials used and wastes released into the environment along the entire life cycle of a product, package, material, process or activity.

- Defining system and system boundaries
- Process Flow-Charts
- Data
- Allocation procedures
- Treatment of Energy

✓ ***Impact assessment:*** It is necessary to place the inventory input and output data and information into perspective in order to understand the environmental relevance of the system's components. However this step is still at the development stage.

- Classification
- Characterization
- Valuation

✓ ***Improvement assessment*:** It is important to make sure that LCA is used to reduce the environmental impacts associated with the system and not only to justify the status-quo; as well as to be aware that all systems have some level of environmental impacts, which possibly can be reduced.

✓ ***Analyses and Interpretation of results:*** the report should include an analysis and interpretation of results and recommendations for improvements, in terms appropriate to the goal of the study. It should be taken into account that a LCA only provides data about environmental aspects and that for decision –making, information is also required about economy, product behaviour and public opinion. Finally, conclusions should consider the data variability and resulting variability of the findings.

✓ ***Reporting:*** Once the LCA has been completed and all the data processed, the next stage is the production of a full report. A complete report should contain tables of data used and should also ensure transparency and consistency of all the methodologies and data employed. The requirements of a full report are:

- Objectives of the study
- Scope of the study
- System boundaries
- Flow diagram
- Methodology
- Data presentation
- Conclusions
- Summary report
- Peer review

✓ **Critical Review:** The critical review process shall ensure that

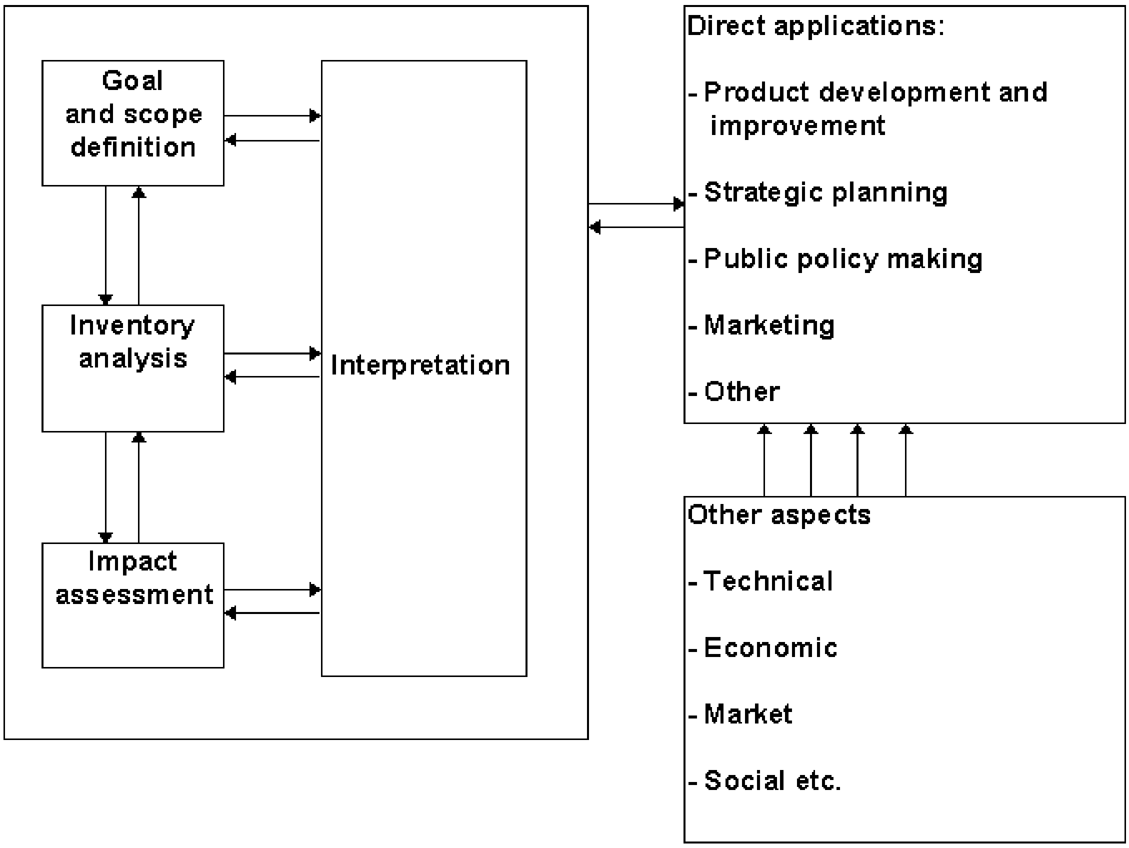
- The methods used to carry out the LCA are consistent with the International Standard ISO 14040 (Life Cycle Assessment-Principles and framework)

- Those methods are scientifically and technically valid
- The data used are appropriate and reasonable in relation to the goal of the study
- The study report is transparent and consistent.

A critical review may facilitate understanding and enhance the credibility of LCA studies, for example by involving interested parties. However, the fact that a critical review has been conducted should in no way imply and endorsement of any comparative assertion that is based on an LCA study.

A critical review may be carried out by an internal or external expert independent of the LCA study or by interested parties.

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



### *1.4. Expected results/benefits*

LCA may support decisions for a wide range of applications. Possible uses may include:

- Internal uses such as:
  - Strategic planning or environmental strategy development
  - Product and process design, improvement and optimization
  - Identifying environmental improvements opportunities and tracking improvement progress
  - Support the establishment of purchasing procedures or specifications
  - Environmental auditing and waste minimization
- External uses such as:
  - Marketing or support for specific environmental claims
  - Labelling, including setting criteria for eco-labelling
  - Public education and communication
  - Policy making
  - Supporting the establishment for purchasing procedures or specifications

In the case of internal uses, study information and results are not publicly release. However, when the sponsor proposes to communicate LCA results outside the organization, detailed and specific disclosure of information is necessary to ensure the credibility of the findings of the study. There is a requirement for transparent reporting of data sources and data handling, as well as methods used.

The application of the results varies depending on the kind of user. By the moment, benefits of the LCA studies application may be pointed out in the private sector and the public policy making.

#### 1.4.1. Private sector applications

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

Commodity producers (chemicals, plastics, metals) most often perform life cycle inventories to be used in comparative assertions or for assessing waste management and recycling options. Producers of intermediates and components provide data for their customers, and producers of final goods combine the knowledge from upstream and downstream processes to design and manufacture products with the least environmental impact. Time in this context, is an important factor in LCA. For companies producing final goods in a competitive market, the product development cycles are short and accordingly, comprehensive LCAs are not feasible with the presently available data bases because the analysis are time consuming.

Some of the main applications in the private sector are:

- Product development
- Marketing
- Strategic planning

Product development

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

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

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

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

Several research programs on how to incorporate environmental issues in product development have been conducted. Some of these programs are presented in the table. Information on other programs can be found in reports from industry sector conferences (e.g. the packaging, automotive and electromechanical industries) and from meetings in LCA-orientated societies (e.g. SETAC’s annual meetings and symposia for case studies).

- The Product Ecology Project (Sweden)
- The NEP project (Scandinavia)
- The Eco-Design programme (The Netherlands)
- The Milion and the Promise programmes (The Netherlands)
- The Eco-Indicator Programme (The Netherlands)
- The Materials Technology Programme (Denmark)
- The EDIP project (Denmark)
- Quality Function Deployment (Denmark)
- The Life Cycle Design Project (U.S.A.)
- Strategies for Industrial Production in the 21st Century (Germany)

Marketing

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

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

- *Environmental labelling (ISO Type I-labelling):* defined by ISO 14024, establishes the principles and procedures for developing Type I environmental labelling programmes, including the selection of product categories, product environmental criteria and product function characteristics; and for assessing and demonstrating compliance.

- *Environmental claims (ISO Type II-labelling);* defined by ISO (ISO/DIS 14021 and ISO/CD 14022) as a label or declaration that indicates the environmental aspects of a product or service that may take the form of statements, symbols or graphics on product or packaging labels, product literature, technical bulletins, advertising, publicity or similar applications.

- *Environmental declarations (ISO Type III-labelling):* This is the most recent ISO-proposal for communication of a product environmental claim that may take the form of statements, symbols, or graphics on product or package labels, product literature, technical bulletins, advertising, publicity, etc. The concept is in principle similar to that of declaration on food products, but is not yet fully developed. The main difference in relation to ecolabels is that environmental declarations are neutral, i.e. they contain no information on whether the product is worse or better than other products fulfilling the same service.

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

- *Organization marketing:* The classical marketing of environmental performance has mainly been orientated towards products as described above. However, with the increasing number of companies being certified according to ISO 14001, EMAS or BS 7750, some marketing initiatives are being directed towards the environmental capabilities of the company per se. As organizations implement the necessary policies for certification they are also encouraged to formalize the implementation of LCA procedures and life cycle thinking through the environmental management system. The process is intended to identify significant environmental activities associated with activities, products and services, and is not intended to require a detailed life cycle assessment. Organisations do not have to evaluate each product, component or raw material input. They may select categories, products or services to identify those aspects most likely to have a significant impact.

Strategic planing

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

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

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

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

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

LCA information can provide decision-makers with an understanding of the environmental pros and cons of their products and services.

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

### 1.4.2. Public policy making

The main applications in this sector are:

- Environmental labelling
- Green procurement
- Other governmental application

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

The main governmental applications are:

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

The government's role in product publicity is mainly to facilitate and support, and this can be done by increasing the available information to both individual consumers and institutional and governmental buyers. The present chapter focuses on the product-oriented policy as this is the most promising area in relation to LCA and the life cycle approach. A broader survey of life cycle based government policies can be found in Curran (1997) and Allen *et al* (eds), 1996.

### 1.4.3. Future applications

It is anticipated that LCA or the life cycle approach can and will be integrated with other decision support tools in almost all areas where environmental issues are important. The amount of LCA-relevant information is increasing, giving the possibility of extending LCA into new production areas.

LCA should also be an integral part in the development of extended producer responsibility (EPR) as suggested by OECD. EPR can for instance be employed by governments as a strategy to transfer the costs of municipal waste management from local authorities to those actors most able to influence the characteristics of products that can become problematic at the post-consumer stage. In this context, Design for Environment, Risk Assessment and LCA can give input from different angles to the decision-makers.

Finally, the integration of life cycle approaches and environmental management systems is seen as a potentially key area for further development.

The ability to apply and use LCA in the future is critically dependent upon the ability to actually do authentic LCAs. This sould be suported by the development of ISO LCA-standards, together with more precise and better documented data and methodologies.

### *1.5. Characteristics of service providers for this IMT*

The necessity for external consultors is relevant in order to set the methodology and steps of a LCA, although the goal and scope definiton has to be well stablished by the final user of the study.

Consultors have to show a good knowledge of the LCA technique as well as of the main environmental management tools, being desirable some familiarity with the sector activity and related environmental impacts.

The leading role of the consultors has to be focused in the organization of the methodology and the training of the working-shifts, until these reach the knowledge to apply the technique to any other product/process in their activity sector.

## 2. APPLICATION

### *2.1. Where the technique has been applied*

Nowadays, many sectors of the society are aware of the necessity of including environmental considerations into management tasks. As previously said, LCA can be considered as a useful decision tool concerning environmental aspects. There are two main kinds of decisions: the operational and the strategic ones.

Strategic decisions produce changes in the organisation (strategic analysis of a business, optimisation and elaboration of wastes, packaging, energy or transport policies, marketing, sales or purchasing policy establishment), whereas operational decisions are those related to activities that are in progress, like ecolabelling criteria determination, ecodesign, improvement and optimisation of processes.

Some examples of LCA application as decision tool by several social sectors are exposed in the following table:

| SOCIAL SECTOR | Strategic decisions | Operational decisions |
|---|---|---|
| Administration | Legislation support<br>Wastes management, energy production…<br>Research areas | Ecolabelling<br>Information to consumers |
| Enterprises | Production processes selection<br>Business strategies | Material selection<br>Processes improvement<br>Suppliers selection<br>Marketing information |
| NGOs | Political survey | Public opinion |

In the last 10 years, the number of companies using LCA studies, is increasing gradually, specially in the polymer industry (70% LCA), due to a heavy social pressure. However, several inquiries made during the last decade in the Nordic countries, showed that LCA was used by less than the 10% of the inquiried companies, being Ecodesign and Eco-redesign the most emerging applications in the industrial sector.

Some examples of LCA utilization in the industry sector are the following:

- Agro-food industry: packaging, cotton, potato, wheat, tomato, margarine, ketchup, grains.. (Danone, Nestlé, Astra Calve…)
- Automobile industry: NedCar, Renault, Audi…
- Electronics and electrical appliances: Computers and periferics (IBM, Hewlett Packard), optical fiber wires (Nokia, Siemens, Philips…)
- Construction: paints, coatings, windows…
- Chemical sector: textile dyes and chemical products (CIBA, Dow Chemical, Rhone Poulenc, Procter & Gamble, Shell…)

In relation to the Public Administration, the EU uses LCA as a tool for environmental legislation (packaging, ecolabelling, chemical substances control, environmental mangement and auditing or impact assessment.

In practise, LCA is mainly used for ecolabelling, public services management (water, wastes…) and technology evaluation. Some important users are The USA Defence Department., The Environmental Protection Agency of Denmark, The Netherlands Government, The Belgium Ministry of Environment, …

NGOs, like unions, consumers associations, political parties and environmental protection associations, have, however, a less knowledge about LCA and his applications possibilities, although they agree in considering LCA as a useful tool for improving workers health, information to consumers or political decision taking.

### 2.2. Types of firms/organisations concerned for the application

The organisations concerned with LCA studies and software development include:

- *Consultants.* Environmental consultants play a key role in promoting the use of LCA. They are some of the main methodologies and softwares makers.

- *Standards setting organisations.* They are responsible for the development of the principles, procedures and methods of LCA, based on the terminology and structure of the ISO Environmental Mangement Systems. The existing standards for LCA are:
  - ✓ EN/ISO 14040: Environmental management – Life cycle assessment – Principles and framework
  - ✓ FDIS/ISO 14041: Environmental management – Life cycle assessment – Goal and scope, definition and inventory analysis.
  - ✓ CD/ISO 14042.34: Environmental management – Life cycle assessment – Impact assessment.
  - ✓ CD/ISO 14043.2rev: Environmental management – Life cycle assessment – Life cycle interpretation.

- *Ecolabelling boards.* LCA is one of the most important tool for ecolabelling criteria development although there are still problems in its implementation.

- *Consumer associations.* Consumers often have the ultimate say in which products survive and which do not. To date, however, most consumer associations and campaigners have paid little attention to LCA. Many have also paid surprisingly little attention to ecolabelling, although it is expected to gain interest in the next years.

- *Industry associations.* Industry associations are expected to play an increasingly important role with respect to the provision of sectoral data, as well as in helping industry to understand the true value of LCA and assisting small and medium-sized enterprises (SMEs).

- *Finantial institutes.* Financial institutions and analysts can use LCA to compare and benchmark, for investment purposes.

- *Governments.* Through regulations and ecolabelling initiatives, governments clearly have an important role to play. Increasingly, too, some government agencies will require LCA data in support of their decision-making processes.

- *NGOs.* They can play a critical role in relation to LCA bringing a greater transparency and adding weight to the public acceptabilityof the results.

- *Research Institutes and Universities.* They are responsible, along with consultants, for the promotion of the use of LCA among industry and government bodies.

Some of the most important organisms concerned with LCA development are the following:

- ✓ United Nations Environmental Technological Centre
- ✓ Gil Friends and Associates (Berkeley, California-USA)
- ✓ The Flemish Institute for Technological Research (Belgium).
- ✓ The Netherlands Organization for Applied Scientific Research, TNO, (The Netherlands).
- ✓ Ecobalance Inc.(USA)
- ✓ Ecosite (UK)
- ✓ EcoDesign Gallery
- ✓ SB Young Consulting (Canada)
- ✓ Franklin Associates (USA)
- ✓ Centre for Design at RMIT (Austria)
- ✓ Tellus Institute (USA)
- ✓ IVAM Research Institute (The Netherlands)
- ✓ Environment Canada's National Office of Pollution Prevention
- ✓ US Environmental Protection Agency
- ✓ Pré: Product Ecology Consultants (The Netherlands)
- ✓ Batelle (USA)

### *2.3. Implementation costs*

By the moment, LCA utilization by MSE has been very limited, due to high investment requeriments, in time and money, leading to a great demand of more symplified methods.

Exact illustrations of costs and times are difficult to provide as they can vary substantially from product to product. Indeed the difficulty of estimating such costs is itself a problem for companies planning on LCA - based developments. Companies that have established their own internal LCA research are generally reluctant to publicise the costs associated with such work. Still some information is available and it can be quite instructive.

Comparative LC analyses of white goods (such as washing machines and refrigerators) which have been carried out (with differences in the range of comparative products and the level of detail in the inventory data) seemed to put the cost somewhere between \$20,000 and \$80,000. One large project in the Netherlands for a copying machine company is said to be costing around \$8 mill, although that cost includes the development of design, engineering and management tools as well as an exhaustive LCA inventory of all materials and components used by the company. A joint Scandinavian research program - the Nordic project on Environmentally sound Product development (NEP) - is reported to have an overall budget of greater than \$7m to develop data tools for use in LCA based product development' and produce systems for participating companies to develop products with better environmental performance. Various presentations by the research team for that project have confirmed that the collection of LC data for the six companies was by far the major cost component of the overall program.

The length of time to conduct a full LCA is obviously partly a function of the budget, but the really time consuming work is generally in tracking materials back through the supply chain. This often means dealing with component suppliers (sometimes component suppliers to component suppliers) and an extensive array of raw material suppliers.

The increasing availability of public databases of environmental impacts of materials and processes has helped reduce costs and time for LCA work. But these general databases bring with them some problems of accuracy and reliability. Materials extraction, transport and processing can vary greatly from place to place and factory to factory and averages can sometimes produce substantial inaccuracies if applied to particular - specific - products.

In many cases the difficulties and limitations of LCA for strategic planning - whether it be ecodesign, business planning, or policy development - stem not from the costs and time but the complexity of the results.

***Simpler Life-Cycle oriented methodologies***

There has been a lot of attention to the development of simpler methods and approaches which would preserve the life-cycle orientation of LCA whilst avoiding its more intricate difficulties.

This has led to the development of various guidelines, or sets of rules, by which the design of new products can be deliver minimal LC environmental impact. Some of these rules are:

- Reduce total material content ( eg: by thinning out the walls of a container, introducing soft refills with reusable hard containers)
- Minimise the total number of different materials
- Eliminate all toxic materials
- Use only materials that can be recycled, or, where that is not possible, use biodegradable materials to replace non-biodegradable materials
- Make maximum use of recycled materials
- Ensure that all different materials are physically separated and permanently labelled
- Utilise as few components as possible
- Ensure that all components and materials are easily separated (disassembled) at end of life
- Minimise the use of energy-intensive materials
- Minimise energy consumed in use
- Where there is a choice of energy supply, go for the form of energy with the lowest contribution to greenhouse gases.

### *2.4. Conditions for implementation (infraestructures)*

The required infraestructures for LCA implementation are:

- General databases that could be easily updated and amplified
- Databases of public access and with data fiability
- Adaptable and easy to use softwares
- Possibility of results conversion to economic data
- Guidelines for LCA results interpretation

Nowadys there are a number of commercial softwares and methodology guidelines that can be used as a base for LCA implementation, acording to EN/ISO 14040. In many cases, data collecting for Life Cycle Inventory is the most difficult step in LCA studies, so good databases availability for specific products or processes is critical to reduce time and costs.

### *2.5. European organisations supporting the implementation*

As previously said, the principles, procedures amd methods of LCA are collected in ISO standard series. However, a great effort is being made by several european organisations in order to contribute to the knowledge and development of LCA methodologies. Between the most important ones, we can include:

- ✓ Society of Environmental Toxicology and Chemistry (SETAC)-Europe, founded in 1990, with more than 1000 members.
- ✓ Society for the Promotion of LCA Development (SPOLD), founded in 1992 by important european companies.
- ✓ EC Groupe des Sages on LCA and Ecolabelling (1993), founde by the Eurpean Comission.
- ✓ European Network for Strategic Life Cycle Assessment Research and Development (LCANET), promoted by the GDXII Climate and Environment Programe.
- ✓ Spanish Association for the Development Promoting of LCA (APRODACV), 1995.

However, standards on impact assessment and interpretation are still under development and discussion and are supplemented by other literature references on LCA, such as:

- ✓ Nordic Guidelines on Life Cycle Assessment and Technical Reports (Linforrs et al. 1995)
- ✓ Report from HankØ, Norway on LCA in: Strategic management, Product development and improvement, Marketing and Ecolabelling, and Government Policies (Christiansen et al. 1995)
- ✓ SETAC Working Group Reports 1996-97: Simplifying LCA, enhancing inventory methodology, Impact assessment, Case studies and Conceptually related programmes.
- ✓ LCANET workshop background and summary papers 1996 on: Positioning and application of LCA, Goal and scope definition and inventory analysis, Impact assessment and interpretation, and Databases and software.

# 3. IMPLEMENTATION

## *3.1. Steps/phases*

### 3.1.1. Goal and scope definition

The definition of the goal and scope is the critical part of an LCA due to the strong influence on the result. It contains the following main issues:

- *Goal*
- *Scope*
- *Functional unit*
- *System boundaries*
- *Data quality*
- *Critical review process*

<u>Goal</u>

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

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

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

The goal definition determines the level of sophistication of the study and the requirements to reporting. It can be redefined as a result of the findings throughout the study e.g. as a part of the interpretation.

<u>Scope</u>

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

In defining the scope of an LCA study, the following items shall be considered and clearly described:

- the functions of the system, or in the case of comparative studies, systems;
- the functional unit;
- the system to be studied;
- the system boundaries;
- allocation procedures;
- the types of impact and the methodology of impact assessment and subsequent interpretation to be used;
- data requirement;
- assumptions;
- limitations;
- the initial data quality requirements;
- the type of critical review, if any;
- the type and format of the report required for the study

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal.

LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

<u>Functional unit</u>

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

One of the main purposes for a functional unit is to provide a reference to which the input and output data are normalised. A functional unit of the system shall be clearly defined and measurable. The result of the measurement of the performance is the reference flow.

<u>The system boundaries</u>

The *system boundaries* define the processes/operations (e.g. manufacturing, transport, and waste management processes), and the inputs and outputs to be taken into account in the LCA. The input can be the overall input to a production as well as input to a single process - and the same is true for the output.

Any omission of life cycle stages, processes or data needs should be clearly stated and justified. Ultimately, the sole criterion used in setting the system boundaries is the degree of confidence that the results of the study have not been compromised and that the goal of a given study has been met.

Quality of data

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

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

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

Further descriptions which define the nature of the data collected from specific sites versus data from published sources, and whether the data should be measured, calculated or estimated shall also be considered.

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

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

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

Critical review

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

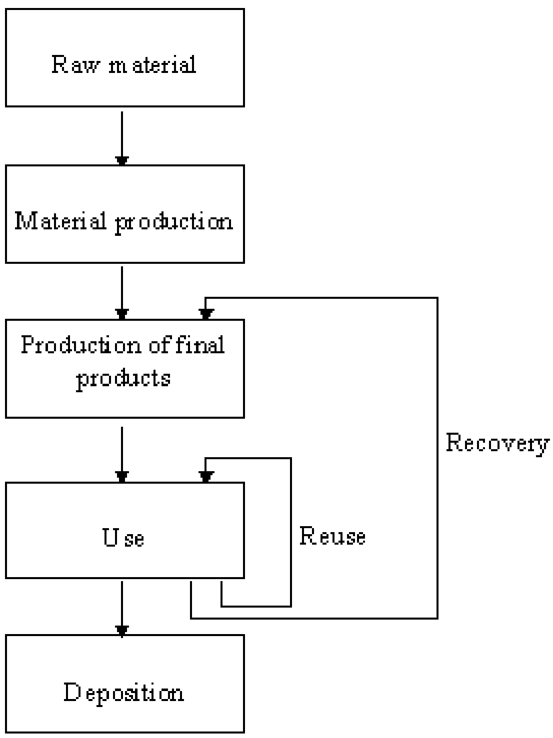
- the methods used to carry out the LCA are consistent with this international standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations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

### 3.1.2. Inventory analysis

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

- *Data collection*
- *Refining system boundaries*
- *Calculation*
- *Validation of data*
- *Relating data to the specific system*
- *Allocation data*

The inventory analysis and the tasks to be fulfilled can obviously be supported by a flow sheet for the considered product. An example of a flow sheet can be seen in the figure.



Each of the different phases can be made up from different single processes, e.g. production of different kinds of raw material to be combined in the material production phase. The different phases are often connected by transport-processes. Reuse do often involve a cleaning process.

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

<u>Data collection</u>

The inventory analysis includes collection and treatment of data to be used in preparation of a material consumption, waste and emission profile for all the phases in the life cycle, but also for the whole life cycle. The data can be *site specific* e.g. from specific companies, specific areas and from specific countries but also more *general* e.g. data from trade organisations, public surveys etc. The data have to be collected from all single processes in the life cycle and can be quantitative or qualitative.

The quantitative data are important in comparisons of processes or materials, but often they are missing or their quality is poor (too old or not technologically representative etc.). The more descriptive qualitative data can be used for environmental aspects or single steps in the life cycle that cannot be quantified, or if the goal and scope definition allow a non-quantitative description of the conditions.

The process of conducting an inventory analysis is iterative. Sometimes, issues may be identified that require revisions to the goal or scope of the study.

Allocation procedures are needed when dealing with systems involving multiple products (e.g. multiple products from petroleum refining). The materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified;

The calculation of energy flow should take into account the different fuels and electricity sources used, the efficiency of conversion and distribution of energy flow as well as the inputs and outputs associated with the generation and use of that energy flow.

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

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

The result of the data collection can be presented in an inventory table. An example from the material data published by the Association of Plastic Manufacturers of Europe (APME) is shown in the following table:

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

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

| | | | |
|---|---|---|---|
| **Solid waste** | Industrial waste | mg | 1800 |
| | Mineral waste | mg | 66000 |
| | Slags and ash | mg | 47000 |
| | Inert chemicals | mg | 14000 |
| | Regulated chemicals | mg | 1200 |

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

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

Refining system boundaries

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

- the exclusion of life cycle stages or sub-systems when lack of significance can be shown by the sensitivity analysis
- the exclusion of material flows which lack significance to the outcome of the results of the study
- the inclusion of new unit processes that are shown to be significant in the sensitivity analysis

The results of this refining process and the sensitivity analysis shall be documented. This analysis serves to limit the subsequent data handling to those input and output data which are determined to be significant to the goal of the LCA study.

Calculation procedures

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

Validation of data

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

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

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

<u>Relating data</u>

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

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

<u>Allocation and recycling</u>

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

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

When avoiding allocation by e.g. expanding the system boundaries there is a risk of making the system too complex. Allocation may be a better alternative, if an appropriate method can be found for solving the actual problem.

Allocation can be necessary when dealing with:

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

- Open-loop recycling, where a waste material leaving the system boundaries is used as a raw material by another system, outside the boundaries of the studied system.

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

1. Wherever possible, allocation should be avoided or minimised. This may be achieved by subdividing the unit process into two or more sub-processes, some of which can be excluded from the system under study. Transport and materials handling are examples of processes which can sometimes be partitioned in this way.

2. Where allocation cannot be avoided, the system inputs and outputs should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they must reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

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

Any deviation from these procedures shall be documented and justified.

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

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

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

Recycling of products implies that the environmental inputs and outputs associated with the manufacturing of a product and its recycling are to be shared by more than one product system. Claims regarding recycling shall be documented and justified and be based on actual practice rather than theoretical possibilities.

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

### 3.1.3. Life cycle impact assessment

Life Cycle Impact Assessment (LCIA) is the third phase in a life cycle assessment containing the following mandatory and optional elements as described in the Draft ISO standard CD 14042.33 (ISO, 1998b):

A) Mandatory elements:

- *Selection of impact categories, category indicators, and models;*
- *Assignment of LCI results (Classification) to the impact category.*
- *Calculation of category indicator results (Characterisation).*

B) Optional elements:

- *Calculating the magnitude of category indicator results relative to reference value(s) (Normalisation).*
- *Grouping; sorting and possibly ranking of the indicators.*
- *Weighting; aiming at converting and possibly aggregating indicator results across impact categories.*
- *Data quality analysis; better understanding the reliability of the LCIA results.*

The impact assessment can be expressed as a "quantitative and/or qualitative process to characterise and assess the effects of the environmental interventions identified in the inventory table" (Heijungs & Hofstetter, 1996). According to these authors, "the impact assessment component consists in principle of the following three or four elements: classification, characterisation, (normalisation,) and valuation"; normalisation and valuation are sometimes merged. Valuation is proposed changed to weighting by ISO (ISO, 1998b) and this terminology has been adapted by the SETAC-Europe working group (Udo de Haes, 1996).

Selection of impact categories

This step includes the dentification of the impact categories, related indicators and models, category endpoints and associated LCI results that the LCA study will address. For example, the global warming impact category represents emissions of greenhouse gases using infrared radiative forcing as an indicator.

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

- Completeness - all environmental problems of relevance should be covered by the list
- Practicality - the list should not contain too many categories
- Independence - double counting should be avoided by choosing mutually independent impact categories

- Relation to the characterisation step - the chosen impact categories should be related to available characterisation methods

Assignment of LCI results (Classification)

The life cycle impact assessment includes as the second mandatory element classification of the inventory input and output data (ISO, 1998a).

Assignment of LCI results to impact categories should consider the following, unless otherwise required by the goal and scope:

- assignment of LCI results which are exclusive to one impact category;
- identification of LCI results which relate to more than one impact category, including distinction between parallel mechanisms e.g. $SO_2$ is allocated between the impact categories of human and acidification and
- allocation among serial mechanisms, e.g. NOx may be assigned to ground level ozone formation and acidification.

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

The impact categories can be placed on a scale dividing the categories into three (four) different space groups: global impacts, (continental impacts,) regional impacts and local impacts. The grouping is not unequivocal for all the impact categories exemplified by e.g. environmental toxicity which can be global, continental, regional as well as local. The impact categories is often related directly to exposure i.e. global exposure is leading to global impacts, continental exposure is leading to continental impacts. Some of the impact categories are strongly correlated with continental, regional or local conditions i.e. some localities are more predisposed to certain impacts than other localities. Certain lakes in Scandinavia can be mentioned as examples of localities that are more predisposed to acidification than lakes in other parts of Europe. The time aspect is also important when considering certain impact categories e.g. global warming and stratospheric ozone depletion with time horizons on 20 to 500 years.

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

Selected lists of impact categories; references are given in the list. (SETAC Europe, ISO and Lindfors *et al*., 1995**)**

| **The "Leiden list"**<br>**SETAC-Europa (1992)** | **SETAC "default list"[1]**<br>**Udo de Haes (1996)** | **"Nordic list"**<br>**Lindfors et al. (1995)** | **ISO preliminary list. ISO (1998)** | **Scale/comments** |
|---|---|---|---|---|
| non-renewable | abiotic resources | energy and materials | abiotic resources | global |
| scarce, renewable | biotic resources | | biotic resources | global |
| | | water | | |
| | land | land | land use | local |
| global warming | global warming | global warming | global warming/ climate change | global |
| | depletion of stratospheric ozone | depletion of stratospheric ozone | stratospheric ozone depletion | global |
| human toxicity | human toxicological impact | human health, toxicological excl. work environment | human toxicity | global, continental, regional, local |
| | | human health, non-toxicological excl. work environment | | |
| occupational safety | | human health impacts in work environment | | local |
| environmental toxicity | ecotoxicological impacts | ecotoxicological impacts | ecotoxicity | global, continental, regional, local |
| photo-oxidant formation | photo-oxidant formation | photo-oxidant formation | photochemical oxidant formation (smog) | continental, regional, local |
| acidification | acidification | acidification | acidification | continental, regional, local |
| eutrophication | eutrophication (incl. BOD and heat) | eutrophication | eutrophication | continental, regional, local |
| COD (chemical oxygen demand) discharge | | | | local |
| effects of waste heat on water | | | | local |
| nuisance (smell, noise) | odour | | | local |
| | noise | | | local |
| | radiation | | | local, regional |
| space requirement | | | | local |
| final solid waste (hazardous) | | | | regional, local |
| final solid waste (non-hazardous) | | | | regional, local |
| | casualties | | | local |
| | | habitat alterations and impacts on biological diversity | | local |

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

Calculation of category indicator results (Characterisation).

Characterisation is the step in which analysis/quantification, and ,where possible, aggregation of the impact within the given impact categories take place. This step should be based on scientific knowledge about environmental processes.

One method is to relate the data from the inventory table to, for instance, No-Observable-Effect Concentrations or to environmental standards. Presently, much attention is given to the development and use of equivalency factors for the different impact categories, such as the Global Warming Potential (GWP) and the Ozone Depletion Potential (ODP).

Calculating the magnitude of category indicator results relative to reference value(s) (Normalisation)

A further development of the characterization step is to normalize the aggregated data per impact category in relation to the actual magnitude of the impacts within this category in some given areas. The reason is to increase the comparability of the data from the different impact categories and thus provide a basis for the next step.

Grouping

This step consists on the sorting and possibly ranking of the indicators.

Weighting or valuation

This step is aiming at converting and possibly aggregating indicator results across impact categories, so that they can be compared among themselves and the relative importance of the impact categories can be assessed.

Data quality analysis; better understanding the reliability of the LCIA results.

There is considerable value and interest in producing quantitative estimates of quality. However, there is at present, no aceptable methodology for computing such estimates. The selection and application of quality data indicators for specific data sould be made by the practitioner based on the nature of the data  and on the uses to which it will be put.

Interpretation

Interpretation is the fourth phase in life cycle assessment containing the following main issues:

- Identification of significant environmental issues
- Evaluation
- Conclusions and recommendations

Life cycle assessment interpretation is a systematic procedure to identify, qualify, check, and evaluate information from the conclusions of the inventory analysis and/or impact assessment of a system, and present them in order to meet the requirements of the application as described in the goal and scope of the study.

Life cycle interpretation is also a process of communication designed to give credibility to the results of the more technical phases of LCA, namely the inventory analysis and the impact assessment, in a form which is both comprehensible and useful to the decision maker.

Interpretation is performed in interaction with the three other phases of the life cycle assessment. If the results of the inventory analysis or the impact assessment is found not to fulfil the requirements defined in the goal and scoping phase, the inventory analysis must be improved by e.g. revising the system boundaries, further data collection etc. followed by an improved impact assessment.

Identification of significant environmental issues

The first step in the identification is the selection of key results in a prudent and justifiable manner. The objective of this step is to structure the information from the inventory analysis and - if additionally conducted - from the life cycle impact assessment phase in order to determine the significant environmental issues in accordance with the goal and scope definition.

Environmental issues are inputs and outputs i.e. results of the inventory phase and environmental indicators i.e. the results of the life cycle impact assessment phase if LCIA is conducted.

Significant environmental issues are found to represent the most important results of the study in accordance with the goal and scope definition.

The identification step include structuring and presentation of relevant information:

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

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

Evaluation

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

The objective of this step is to establish confidence in the result of the study, based on the preceding LCA phases, and on the significant environmental issues identified in the first step of the interpretation. The results should be presented in such a form as to give the commissioner or any interested party a clear and understandable view of the outcome of the study.

The evaluation shall be undertaken in accordance with the goal and scope, and should take into account the final use of the study.

The interpretation made at this stage shall be reinforced by the facts and calculations brought forward in at least the three following elements:

- *completeness check*: The completeness check has to decide whether it is necessary to complete the data set. If the data set is important according to the defined environmental issues, the data collection can be improved or the goal and scope definition can be revised.
- *sensitivity check*: Sensitivity check involves a systematic procedure for estimating the effects of variations in parameters to the outcome of the study with the aim to establish a required degree of confidence in the results of the study relative to its overall goal.
- *consistency check*: The objective is to conduct a thorough check on the consistency of methods, procedures and treatment of data used throughout the study. The procedure has to test whether methods etc. have been used consistently and especially within comparative studies.

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

<u>Conclusions and recommendations</u>

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

The aim of this third step of the interpretation is to reach conclusions and recommendations for the report of the LCA study or life cycle inventory study.

This step is important to improve the reporting and the transparency of the study. Both are essential for the readers of the LCA report. The results of the critical review of the study shall also be included when presenting the conclusions and recommendations

### *3.2. Related software*

Many institutions and companies have developed software for use in LCA. The obvious reason for this is that large amounts of data have to be stored and processed in any LCA and that computers are the natural tool for this. Some programmes have been developed to perform a "complete" LCA, i.e. both *Inventory*, *Impact Assessment*, and some kind of *Interpretation* is performed, whereas others are only able to perform the *Inventory* part of the LCA.

Most of the developed software tools are commercially available at prices ranging from about 1500 € to more than 10.000 €. Free demo versions are available for many programs, but they are most often of limited value for potential buyers due to limitations in capacity. As the software represents a substantial investment, potential buyers are advised to collect as much information as possible from the developers and compare this to their own needs.

List of commercially available life cycle assessment tools (Adopted from Menke, Davis and Vigon , 1996)

| Name | Vendor | Version | Cost, $K | Data Location |
|---|---|---|---|---|
| 1. Boustead | Boustead<br>Phone +44 403 864 561<br>Fax +44 403 865 284 | 2 | 24 | Europe |
| 2. CLEAN | EPRI<br>Phone +1 415 960 5918<br>Fax +1 415 960 5965 | 2 | 14 | U.S.A. |
| 3. CUMPAN | Univ. of Hohenheim | Unknown | Unknown | Germany |
| 4. EcoAssessor | PIRA | Unknown | Unknown | UK |
| 5. EcoManager | Franklin Associates, Ltd.<br>Phone: +1 913 649 2225<br>Fax +1 913 649 6494 | 1 | 10 | Europe/U.S.A. |
| 6. ECONTROL | Oekoscience | Unknown | Unknown | Switzerland |
| 7. EcoPack2000 | Max Bolliger | 2.2 | 5.8 | Switzerland |
| 8. EcoPro | EMPA<br>Phone +41 71 300101<br>Fax +41 71 300199 | 1 | Unknown | Switzerland |
| 9. EcoSys | Sandia/DOE | Prototype | Unknown | U.S.A |
| 10. EDIP | Danish Environmetal Protection Agency (http://www.mst.dk) | Prototype | 1 | Denmark |
| 11. EMIS | Carbotech | Unknown | Unknown | Switzerland |
| 12. EPS | IVL<br>Fax +46 314 82180 | 1 | Unknown | Sweden |
| 13. GaBi | IPTS<br>Phone +49 7021 942 660<br>Fax +49 7021 942 661 | 2 | 10 | Germany |
| 14. Heraklit | Fraunhofer Inst.<br>Phone +49 89 149009 89<br>Fax +49 89 149009 80 | Unknown | Unknown | Germany |
| 15. IDEA | IIASA (A)/VTT (SF)<br>Fax +358 (0) 456 6538 | Unknown | Unknown | Europe |

| | | | | |
|---|---|---|---|---|
| 16. KCL-ECO | Finnish Paper Inst.<br>Phone +358 9 43 711<br>Fax +358 9 464 305 | 1 | 3.6 | Finland |
| 17. LCA1 | P&G/ETH | 1 | Not Avail. | Europe |
| 18. LCAD | Battelle/DOE | Prototype | < 1 | U.S.A. |
| 19. LCAiT | Chalmers Industriteknik<br>Phone +46 31 772 4237<br>Fax +46 31 82 7421 | 2.0 | 3.5 | Sweden |
| 20. LCASys | Philips/ORIGIN | Unknown | Unknown | Netherlands |
| 21. LIMS | Chem Systems<br>+1 914 631 2828<br>+1 914 631 8851 | 1 | 25 | U.S.A. |
| 22. LMS Eco-Inv. Tool | Christoph Machner | 1 | Unknown | Austria |
| 23. Oeko-Base II | Peter Meier<br>Phone +41 1 277 3076<br>Fax +41 1 277 3088 | Unknown | 5.5 | Switzerland |
| 24. PEMS | PIRA<br>Phone +44 0 1372 802000<br>Fax +44 0 1372 802238 | 3.1 | 9.1 | Ave. European |
| 25. PIA | BMI/TME<br>Phone +31 70 346 4422<br>Fax +31 70 362 3469 | 1.2 | 1.4 | Europe |
| 26. PIUSSOECOS | PSI AG | Unknown | Unknown | Germany |
| 27. PLA | Visionik ApS<br>Fax +45 3313 4240 | Unknown | Unknown | Denmark |
| 28. REGIS | Sinum Gmbh<br>Phone +41 51 37 61 | Unknown | Unknown | Switzerland |
| 29. REPAQ | Franklin Associates, Ltd.<br>Phone +1 913 649 2225<br>Fax +1 913 649 6494 | 2 | 10 | U.S.A. |
| 30. SimaPro | Pré Consultants BV<br>Phone +31 33 455 5022<br>Fax +31 33 455 5024<br>e-mail: info@pre.nl<br>Web site: www.pre.nl | 5.0 | Depend on version | Europe/U.S.A. |
| 31. ECO-It | Pré Consulting<br>Phone +31 33 461 1046<br>Fax +31 33 465 2853 | 1 | 0.25 | Netherlands |
| 32. Simbox | EAWAG | Unknown | Unknown | Switzerland |
| 33. TEAM | Ecobalance<br>+1 301 548 1750<br>+1 301 548 1760 | 1.15 & 2.0 | 10 | Europe/U.S.A. |
| 34. TEMIS | Oko-Institut<br>Phone +49 761 473130<br>Fax +49 761 475437 | 2 | 0.3 | Europe |
| 35. TetraSolver | TetraPak | Unknown | Unknown | Europe |
| 36. Umberto | IFEU<br>+49 40 462033<br>+49 40 462034 | Unknown | Unknown | Germany |
| 37. Umcon | Particip Gmbh | Unknown | Unknown | Germany |
| 38. Öekobilanz von Packstoffen | BUWAL | EXCEL-files | 0.25 | Switzerland |

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