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Environmental life cycle assessment of products: guide and backgrounds (Part 1)

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ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF PRODUCTS

Guide – October 1992

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The NOH cannot guarantee either the correctness or completeness of information, designs, constructions, products or production methods referred to or described in this report nor their suitability for any particular purpose.

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The report consists of two related parts, the Guide and the Backgrounds document, which are only available as a set. Further copies of this report can be ordered from the library of the Centre of Environmental Science (tel. +31 71 277 485). The price is NLG 90.00 per set.

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PREFACE TO THE ENGLISH EDITION

This is a translation of the original report in Dutch, dated October 1992. Only obvious printing errors have been corrected; new developments have not been included. This preface gives an overview of some developments in the state-of-the-art of LCA since the conception of the original report.

The *Society of Environmental Chemistry and Toxicology* (SETAC) is the current leading international organization in the coordination of the methodological development of life cycle assessment. In April 1993, an expert workshop was held in Sesimbra, Portugal, with the aim of establishing an internationally agreed *Code of Practice*. This included the definition of a technical framework for LCA consisting of components (as in Figure 0.1) and a uniform terminology.

The framework and terminology developed in this report differ slightly from that provisionally developed by SETAC. To avoid confusion we have provided an overview of the main differences here. This is followed by a comparison of the framework and terminology used in this report and that in the *Code of Practice*.

The framework in this report consists of five components. The draft *Code of Practice* consists of four components. The main difference concerns the components *classification* and *evaluation* in the present report. These are part of the *impact assessment* in the SETAC framework. Classification as used in this report is subdivided into *classification* and *characterization* in the *Code of Practice*, where the former denotes the labeling of inputs and outputs according to the effect categories they contribute to, and the latter amounts to the weighting and aggregation into scores for these effect categories. The similarities and the differences between the two approaches are summarized in the table below.

	Code of Practice Sesimbra – April 1993	Guide + Backgrounds LCA – October 1992
	goal definition and scoping	goal definition
	inventory analysis	inventory analysis
	classification	classification
impact assessment	characterization	
	valuation	evaluation
	improvement assessment	improvement analysis

In this study the term *impact* has been avoided. *Interventions* indicate human interference in the environment, e.g. resource extraction and emissions (environmental releases). *Effects* indicate the resulting environmental problems, e.g. resource depletion and acidification. Further differences in terminology are minor.

FOREWORD

The Netherlands National Environmental Policy Plan Plus (NEPP-plus) proposes to accelerate targeted product policy measures. According to the plan this acceleration "is dictated by the need to manage the waste chain as a whole. This covers not only the effects at the waste stage, but also emissions and diffusion of substances." It continues as follows: "Viewed against the background of integrated chain management, it goes without saying that product policy extends over the whole life cycle of a product. Good product policy is not only important to producers. Naturally it also benefits consumers."

The acceleration of the product policy measures has now been implemented in several places in the Netherlands. The concept that good product policy is based on an approach in which the entire life cycle of a product is assessed in relation to all aspects of the environment has been highly significant in gaining broad acceptance in society. The reason for this is that everyone considers it undesirable for environmental effects to be shifted to other stages in the life cycle or other aspects of the environment.

Life cycle assessment is not just an instrument to support the product policy; it is also a philosophy. Consumers in the shops will become aware that there is such a thing as a "life cycle"; a highly polluting process may have been used to manufacture an apparently "environmentally-friendly" (e.g. biodegradable) product. A life cycle assessment provides information about such hidden aspects. As a result the chain concept may become widely accepted.

The method described in this manual for the environmental assessment of product life cycles can be used to implement a product policy as referred to in the NEPP-plus. The method can also be used as a tool for ecological product development and improvement in industry, as a regulatory instrument for government and as an instrument to inform consumers. Hence both the Netherlands Ministry of Environment (VROM) and the Ministry of Economic Affairs have contributed to the funding of this study which was carried out as part of the National Reuse of Waste Research Programme (NOH). It is expected that both the public and private sectors, environmental and consumer organizations will be able to use the results of this method in the next few years.

The ultimate aim of the environmental policy is to bring about sustainable development. The NEPP-plus contains the following statement: "The objective of not leaving environmental problems to be solved by future generations can only be achieved if our present patterns of production and consumption are altered. This requires a departure from the existing trend in our behaviour." This means that the outcome of an environmental life cycle assessment can never legitimize our consumption. There are no environmentally-friendly products, some products however, are more environmentally-friendly than others.

CONTENTS

SUMMARY

This chapter provides a summary which can be used in the implementation of environmental life cycle assessments for product studies. It includes a short *document guide* which explains the structure and relationship of the various parts of this report and a *guidelines* section which lists all the guidelines.

Document guide

The report comprises two integral volumes. Both volumes are entitled *Environmental Product Life Cycle Assessment*. Their subtitles, however, are different: one volume is the *Guide* while the other volume is the *Backgrounds* document. The target groups for these documents and the relationships between them are described below.

Guide
The guide describes a method which can be used to carry out an environmental assessment of the life cycle of one or more products. Hence, it is largely aimed at those *who actually undertake environmental product assessments*. These are likely to be consulting engineers, scientific institutes and departments of large companies.

Backgrounds
This document discusses the reasoning behind the method described in the guide. The reasons for certain choices are explained and compared to methods used elsewhere. This volume is largely aimed at *scientists in research institutes*.

The guide (i.e. this volume) which is intended for the implementation of life cycle assessments, is divided into three sections:

- the summary which includes all guidelines;
- the report itself;
- the appendices.

The guidelines section gives a concise description of the method, concentrating purely on the procedures. It is clear from the structure that these are guidelines to assist those carrying out an environmental life cycle assessment. Initially, or if in any doubt, a researcher will need more than these guidelines. The number of each step in the summary corresponds with the section numbers and explanations in the document. The report itself explains terms, identifies parallels between actions described in the guide and gives examples. It also gives references to the backgrounds document. The appendices contain information essential to carry out a life cycle assessment but which does not belong in a summary guide.

Guidelines

This section combines the guidelines for all stages. It cannot be used without practical experience of life cycle assessments. For further information about the guidelines you are referred to the corresponding section of the guide, the backgrounds document and the list of terms on page 91.

Component 1 – goal definition

STEP 1.1 – DETERMINING THE APPLICATION

- The type of application is determined; examples include:
  - information about existing products;
  - innovation of existing products or prototypes;
  - legislation affecting product policies;
  - assessing policy strategies through the use of scenarios;
  - ...
- The application depends on the choice of target group or groups:
  - consumers;
  - producers;
  - government bodies;
  - ...
- List those concerned:
  - those undertaking the study;
  - the client and the funding body;
  - the steering committee;
  - those providing (and possibly verifying) the information required;
  - ...
- Such a full explanation will not be required if the LCA is only to be used internally e.g. to optimise a design.

STEP 1.2 – DETERMINING THE DEPTH OF THE STUDY

- A complete LCA should first be considered: covering all processes and environmental effects and at least the following components: goal definition, inventory analysis, classification and evaluation. At this stage it would not be sensible to omit any elements, this can only be done once an inventory analysis has provided sufficient information to justify this.
- Identical elements may be excluded when products are being compared. However, this can only be done after defining the process tree in step 2.1.
- When improving a product it may well be feasible to make recommendations for a redesign at the inventory analysis level. However, the new design will have to undergo a complete LCA to assess any shift to other environmental effects.
- In all cases reliability and validity will have to be assessed (step 4.2).

STEP 1.3 – DEFINING THE SUBJECT OF THE STUDY

- Select a functional unit which is clearly defined in detail and covers an activity to the greatest possible extent.
- Provide an accurate specification of the products being assessed. The extent to which the information is representative (in time and space) and the functional properties are particularly important.
- Indicate any product alternatives which meet the specifications fully or almost fully that were not included in the assessment, and the reasons for this.

Component 2 – inventory analysis

STEP 2.1 – DRAWING UP THE PROCESS TREE

- A process tree is drawn up for each alternative under consideration, i.e. the processes which form part of the product life cycles are determined. The process tree is best laid out as a diagram, often with a summary process tree and separate trees for individual parts of the summary process tree.

- The extraction of raw materials from the environment is considered as the start of the life cycle.
- Although waste processing is considered as the end of the life cycle it is treated as an economic process which affects the environment through the consumption of raw materials, emissions and in other ways. Similarly, waste treatment steps carried out before a substance is introduced into the environment are included as part of the product system.
- The process tree is made up of economic processes.
- Economic processes have at least one economic output – goods (materials, components, products, etc.) or services (transport, energy, waste processing, etc.) – which forms the goal of the process.
- Each economic output of a process is the economic input of another process, with the exception of the service provided by the overall product system which is related to the functional unit.
- There is no need to extend the process tree by following the processes related to associated products and their production or the useful application of residual and waste materials.
- If the life cycle includes open loop recycling extraction and production are fully allocated to the primary application. Collection and upgrading are fully allocated to the secondary application while waste processing is only allocated to the last application in the cascade.
- This allocation system for open loop recycling will result in some of the consequences being shifted elsewhere. In some situations this shift may well be undesirable. In this event the reuse will not be interpreted as recycling in the LCA. The initial proposal for those situations in which there is no open loop recycling but where the rest of the life cycle has to be followed is as follows:
  — reuse of incinerator flue gas scrubbing residue;
  — reuse of incinerator fly ash;
  — application of combustible waste obtained from different, highly varied combustible waste fractions as RDF;
  — reuse of sewage sludge.
- Reuse which is considered to be open loop recycling must be identified.
- All branches of the process tree must be extended to include processes whose inputs are auxiliary environmental sources or whose outputs are emissions, unless they end in processes which are not considered in detail (i.e. indicated as *p.m.* processes).
- When drawing up a process tree the processes which have been excluded should be clearly indicated, where possible with a semi-quantitative estimate of the significance of these processes.

STEP 2.2 – ENTERING THE PROCESS DATA

- The data for all processes is collected and presented as shown in Table A.1. This includes both the input from and the output into other economic processes: the use and production of goods, materials, energy, services and waste to be processed. Other data includes flows to and from the environment in terms of raw materials, space use, and emissions of substances, noise, heat, etc.
- The nature and quality of the process data will be specified for each process. Data whose quality or representativeness does not match the general standard may have to be identified separately.
- Some processes have non-quantifiable aspects. These should also be included; the format makes special provision for them.
- Preferably, the long-term marginal process data should be collected. In many cases this data will be similar to the average process data during normal operations.
- Whenever possible numerical process data should be specified in SI units.
- Space use is a process parameter which requires a special conversion. It is expressed as a relationship between the area of the plant, its annual production and the consumption of a product or material. For a material whose quantity is expressed in kg this could be calculated as follows:

$$\textit{space use}\,(\mathrm{m^2{\cdot}yr}) = \textit{material use}\,(\mathrm{kg}) \times \frac{\textit{area}\,(\mathrm{m^2})}{\textit{annual production}\,(\mathrm{kg{\cdot}yr^{-1}})} \qquad (1)$$

  Thus space use is expressed in $m^2{\cdot}s$ or $m^2{\cdot}yr$.
- Noise is treated similarly:

$$noise\,(\mathrm{Pa^2 \cdot yr}) = material\ \ use\,(\mathrm{kg}) \times \frac{4 \cdot 10^{-10}\,(\mathrm{Pa^2}) \times 10^{sound\ pressure\ level\,(\mathrm{dB})/10}}{annual\ production\,(\mathrm{kg \cdot yr^{-1}})} \tag{2}$$

The unit is $Pa^2 \cdot s$ or $Pa^2 \cdot yr$.

STEP 2.3 – APPLICATION OF THE ALLOCATION RULES

- Allocations are made to outputs with a positive economic value (or, where there is no external market, which have a useful application). The other flows (flows to and from the environment, economic inputs and economic outputs of zero or negative value) are the items which are allocated.
- Whenever possible the causal links should be determined first in an analysis. In this way part of the allocation problem may be neatly solved.
- The remaining allocation problems are solved by overall apportioned allocation.
- If the outputs to which the allocations are made have different units the allocation has to be made on the basis of economic value.
- For co-production allocation is generally made to the relevant physical unit. Normally this will be the unit in which the outputs, to which the allocation is made, are expressed. Generally, this will be mass, although area is not unusual.
- If the economic values of the outputs differ greatly for each physical unit, the allocation is made on the basis of economic value.
- If the allocation key could be open to dispute, it is advisable to use two or more variations of the allocation and consider the difference between the results as a measure of the reliability (see step 4.2).

STEP 2.4 – CREATING THE INVENTORY TABLE

- The quantitative occurrence of all processes in the process tree can be determined by drawing up mass and energy balances for each economic input: the sum of all occurrences in each process must be zero for each economic unit, with the exception of the process producing the functional unit.
- Thereafter the inventory table for the functional unit can be determined by calculating, for each environmental intervention, the sum of all the occurrences of these interventions.
- Additionally, all unquantified interventions for each process are combined and included in the inventory table of the functional unit.
- When a number of products are being compared and a conclusion can clearly be drawn by comparing the inventory tables, the classification and evaluation steps will not have to be carried out. However, the reliability and sensitivity of the result (step 4.2) will need to be determined.

Component 3 – classification

STEP 3.1 – SELECTION OF THE PROBLEM TYPES

- The provisional classification system is shown in Table 3.1. It indicates the environmental effects under consideration and which are to be used in step 3.2.
- If necessary, a different set may be chosen provided the reasons for this are given.

STEP 3.2 – DEFINITION OF THE CLASSIFICATION FACTORS

- The depletion of abiotic raw materials is assessed by comparing the nett quantity used of each raw material with the reserves (Table B.1 on page 65) of that raw material. This produces a dimensionless expression:

$$abiotic\ \ depletion = \sum_i \frac{material\ use_i\,(\mathrm{kg})}{reserves_i\,(\mathrm{kg})} \tag{3}$$

- The depletion of biotic raw materials is assessed by comparing the nett quantity used of each raw material with its reserves and its reserves/production-ratio. These two together provide a *biotic depletion factor* (BDF; Table B.2 on page 65). The result is an expression in yr^{-1}:

$$biotic\ \ depletion\,(\mathrm{yr^{-1}}) = \sum_i BDF_i\,(\mathrm{kg^{-1} \cdot yr^{-1}}) \times material\ use_i\,(\mathrm{kg}) \tag{4}$$

- For some substances which contribute to the enhancement of the greenhouse effect parameters have been developed in the form of a *global warming potential* (GWP; see Table B.3 on page 66). These parameters can be used to express the potential direct* contribution to the greenhouse effect in a single effect score. The GWP is a relative parameter which uses CO_2 as a reference†: the extent to which a mass unit of a given substance can absorb infrared radiation compared with a mass unit of CO_2. In this way atmospheric emissions (in kg) can be converted to CO_2 emissions (in kg) with an equivalent greenhouse effect:

$$\textit{greenhouse effect}(\mathrm{kg}) = \sum_i GWP_i \times \textit{emission}_i \textit{ to the air}(\mathrm{kg}) \tag{5}$$

- For some substances which contribute to the depletion of the ozone layer parameters have been developed in the form of an *ozone depletion potential* (ODP; see Table B.4 on page 67). These parameters can be used to express the potential contribution which these substances make to the depletion of the ozone layer in a single effect score. The ODP is a relative parameter which uses CFC-11 as a reference: the *steady state* ozone depletion per mass unit of gas emitted to the atmosphere per year is calculated relative to that of a mass unit of CFC-11. In this way atmospheric emissions (in kg) can be converted to CFC-11 emissions (in kg) resulting in an equivalent depletion of the ozone layer:

$$\textit{ozone depletion}(\mathrm{kg}) = \sum_i ODP_i \times \textit{emission}_i \textit{ to the air}(\mathrm{kg}) \tag{6}$$

- Human toxicity is assessed by relating the emissions‡ to the *tolerable daily intake* (TDI), the *acceptable daily intake* (ADI), the *tolerable concentration in air* (TCL), the *air quality guidelines*, the *maximum tolerable risk level* (MTR) or the *C-value for soil based on human toxicology considerations*. This is data from toxicological experiments about the maximum daily intake or concentration which is considered acceptable. A conversion is made so that emissions to water, the atmosphere and soil can be combined in an acceptable way. This results in the definition of *human toxicological classification factors* which depend on the substance and the environmental medium concerned (see Table B.5 on page 68): for the atmosphere (HCA), for water (HCW) and for soil (HCS). The unit of the effect score is kg: the part of the body weight in kg exposed to the toxicologically acceptable limit. This is calculated as follows:

$$\begin{aligned} \textit{human toxicity}(\mathrm{kg}) = \sum_i & HCA_i(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission}_i \textit{ to the air}(\mathrm{kg}) + \\ & HCW_i(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission}_i \textit{ to water}(\mathrm{kg}) + \\ & HCS_i(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission}_i \textit{ to the soil}(\mathrm{kg}) \end{aligned} \tag{7}$$

- The assessment of substances with an ecotoxic effect on species in the ecosystem is based on *maximum tolerable concentrations* (MTCs) determined according to the EPA-method. This results in the definition of two groups of *ecotoxicological classification factors*: one for aquatic ecosystems (ECA) and one for terrestrial ecosystems (ECT); see Table B.6 on page 77. The unit of aquatic ecotoxicity is m^3 polluted water:

$$\textit{aquatic ecotoxicity}(\mathrm{m3}) = \sum_i ECA_i(\mathrm{m^3{\cdot}mg^{-1}}) \times \textit{emission}_i \textit{ to water}(\mathrm{mg}) \tag{8}$$

and for terrestrial ecosystems, it is kg polluted soil:

$$\textit{terrestrial ecotoxicity}(\mathrm{kg}) = \sum_i ECT_i(\mathrm{kg{\cdot}mg^{-1}}) \times \textit{emission}_i \textit{ to the soil}(\mathrm{mg}) \tag{9}$$

- *Photochemical ozone creation potential* parameters (POCP; see Table B.7 on page 83) have been

* The indirect contribution is included as a qualitative aspect, see §3.3.1.

† In addition to CO_2 another reference gas which is commonly used is CFC-12. As CFC-11 is also used occasionally the term GWP should be used with some caution.

‡ In the context of this study it was proposed that the properties of toxic substances in the environment be included in the assessment. This has already been done with some other effect scores; for GWP for example, the degradation of the substance in the environment has also been considered. For human toxicity this results in the definition of a *human toxicity potential* (HTP) and a reference substance. However, HTP has not yet been implemented.

developed* for some substances† which contribute to the formation of photochemical oxidants. These values can be used to express the potential contribution made by these substances to this problem as a single effect score. The POCP is a relative measure which uses ethylene (C_2H_4) as a reference: the extent to which a mass unit of a substance forms oxidants compared with a mass unit of ethylene. In this way atmospheric emissions (in kg) can be converted to ethylene emissions (in kg) with equivalent oxidant formation:

$$\textit{oxidant formation}(\text{kg}) = \sum_i POCP_i \times \textit{emission}_i \textit{ to the air}(\text{kg}) \qquad (10)$$

- The contribution to acidification made by various forms of intervention in the environment can be determined by weighting with *acidification potentials* (AP; see Table B.8 on page 86) which are a measure of the propensity to release H^+ compared with sulfur dioxide (SO_2). Atmospheric emissions (in kg) are converted, using the AP, to sulfur dioxide emissions (in kg) resulting in equivalent acidification:

$$\textit{acidification}(\text{kg}) = \sum_i AP_i \times \textit{emission}_i \textit{ to the air}(\text{kg}) \qquad (11)$$

- The contribution to nutrification made by various forms of intervention in the environment can be determined by weighting with *nutrification potentials* (NP; see Table B.9 on page 87) which are a measure of the capacity to form biomass, compared with phosphate (PO_4^{3-}). Emissions to the atmosphere, water or soil (in kg) are converted, using the NP, to an equivalent phosphate emission (in kg) in terms of nutrification:

$$\textit{nutrification}(\text{kg}) = \sum_i NP_i \times \textit{emission}_i(\text{kg}) \qquad (12)$$

- Until the consequences of waste heat have been sufficiently determined, the release of heat, as a form of environmental intervention, can only be taken directly from the inventory analysis and aggregated. Only waste heat emissions into water are included:

$$\textit{aquatic heat}(\text{MJ}) = \textit{energy-emissions}_{\text{water}}(\text{MJ}) \qquad (13)$$

- The odour threshold values in air (OTV; see Table B.10 on page 87) which have been determined for the most important substances can be used to assess odours. Atmospheric emissions are converted to the volume of air polluted up to the odour threshold:

$$\textit{malodourous air}(\text{m}^3) = \sum_i \frac{\textit{emission}_i \textit{ to the air}(\text{kg})}{OTV_i(\text{kg}\cdot\text{m}^{-3})} \qquad (14)$$

- To assess noise, sound production data from the inventory analysis are aggregated:

$$\textit{noise}(\text{Pa}^2\cdot\text{s}) = \textit{sound}(\text{Pa}^2\cdot\text{s}) \qquad (15)$$

- As the exhaustive effects of space use are inextricably bound up with displacement effects, they are combined in a single effect score. A maximum of ten forms of intervention of this nature are collected during the inventory. At present categories I, II and III are considered "natural" and categories IV and V as "unnatural". Thus the ten forms of intervention are combined in a single effect score with the unit $m^2\cdot s$:

* As the use of the POCP for this purpose is disputed, a further indication could be obtained by adding the quantities of VOC and NO_x without further weighting; see step 4.2.

† No POCP has yet been defined for nitrogen oxides hence the quantity of NO_x emitted is included separately as a "flag", see §3.3.1.

$$\begin{aligned} damage\,(m^2{\cdot}s) = \; & space\ use_{I\rightarrow IV}(m^2{\cdot}s) + \\ & space\ use_{I\rightarrow V}(m^2{\cdot}s) + \\ & space\ use_{II\rightarrow IV}(m^2{\cdot}s) + \\ & space\ use_{II\rightarrow V}(m^2{\cdot}s) + \\ & space\ use_{III\rightarrow IV}(m^2{\cdot}s) + \\ & space\ use_{III\rightarrow V}(m^2{\cdot}s) \end{aligned} \tag{16}$$

- In the inventory analysis processes hazards were determined as the number of fatalities directly attributable to an accident. This parameter is included in the classification without further weighting:

$$victims = number\ of\ victims \tag{17}$$

.... STEP 3.3 – CREATING THE ENVIRONMENTAL PROFILE ....

- The standard classification model (possibly amended or extended) is applied to the quantitative part of the inventory table.
- Forms of intervention which may contribute to more than one effect (CFC emissions for example contribute to the greenhouse effect as well as to ozone depletion) are included more than once.
- The qualitative aspects of the inventory table appear as a qualitative part of the environmental profile, wherever possible in the form of effects.
- It is preferable not to use graphs at this stage as they may give the wrong impression or depend solely on the choice of scale used in the graphs.
- Caution is advised when discussing the environmental profile, otherwise the classification could include an implicit evaluation.
- When products are being compared it may happen that all effect scores and all qualitative aspects point in the same direction. In such an event there will be no need to take steps 3.4 and 4.1. However, the reliability and validity will have to be considered; see step 4.2.

.... STEP 3.4 – NORMALIZATION OF THE EFFECT SCORES ....

- To make the effect scores of the environmental profile more meaningful they can be normalized by relating them to the magnitude of the problem in a given period. For this purpose the same classification model should be used as that used to draw up the environmental profile; the difference being that the magnitude of the environmental intervention in one year, for example, is used as the input data rather than the magnitude of the environmental intervention of a single functional unit. This results in a normalized environmental profile, comprising a number of normalized effect scores all with the unit yr. For an effect score expressed in kg this results in:

$$normalized\ effect\ score\,(yr) = \frac{effect\ score\,(kg)}{annual\ volume\,(kg{\cdot}yr^{-1})} \tag{18}$$

- Although these normalized effect scores have the same unit they should never be added to each other in the classification.
- While information about the global magnitude of the effect scores is not available, the magnitude in e.g. the Netherlands alone will have to be used.
- As it will continue for some time to be difficult to obtain all the required information for the normalization this step will often have to be dispensed with.

Component 4 – evaluation

.... STEP 4.1 – EVALUATION OF THE ENVIRONMENTAL PROFILE ....

- There are two methods for the evaluation of environmental profiles: quantitative and qualitative multi-criteria analyses. Quantitative multi-criteria analysis is preferable as it provides greater transparency but at present it is only used to a limited extent, if at all.
- As the evaluation will, for the time being, mostly be undertaken through qualitative multi-criteria analysis, the highest possible level of transparency should be aimed for. Hence, the reasons for preferring one product alternative over another will have to be specified in discussion.

...... STEP 4.2 – EVALUATION OF THE VALIDITY AND RELIABILITY ......

- The functional unit may be formulated differently in the goal definition. For example, in a comparison of plastic coffee cups and porcelain cups, the calculations could be performed for cups with and without saucers.
- During the inventory analysis the exact definition of the system boundary in step 2.1 should not be relevant, so the inclusion of capital goods, for example, should not change the conclusion.
- In step 2.2 – when the process data are collected – there are generally some uncertainties included in the data. The aim is to provide a clear presentation by using the format and by estimating the quality of the data. However, the data will often be obtained from indefinite sources. In this step the estimate of the quality of individual process data, which in step 2.2 was converted to an estimate of the reliability of the complete data set, is extended to provide an estimate of the reliability of the inventory table or the environmental profile.
- The allocation rules used will also affect the outcome. Wherever possible it may be useful to assess the influence of alternative allocation rules.
- Soundly-based scientific knowledge about the effects of emissions, etc. is used for the classification. In practice, there is often a problem in that substances are released for which there is no information available about their harmful effects. In such cases a value may be determined by analogy with related substances. Alternatively, the magnitude of the harmful effect may be determined at which the conclusion of the study changes, after which the acceptability of this value can be discussed.
- This method can also be used in the evaluation of the weighting factors. By determining the magnitude of the weighting factors at which the conclusion changes, the sensitivity of the results to these factors can be assessed.
- For some of the process data there are estimates of its uncertainty in the form of margins, e.g. 12 ± 2. The range of the data is also known for some classification factors. The backgrounds document discusses a method requiring extensive calculations to determine the effects of these uncertainties on the inventory table, the environmental profile and the environmental index.
- A method of determining the influence of marginal changes in the process data has been developed for the improvement analysis (step 5.2). This method provides information about changes in the inventory table, environmental profile or environmental index as a function of such changes in the process data. However, this method can also be used to investigate which process data must be most accurately defined because a marginal change could have such a major impact.
- In view of the reliability analysis, it is better to estimate an unknown data item than to omit it. The reliability analysis may well show that the item is of minor importance but the insignificance of the actual value of the item can then be demonstrated even more clearly.

Component 5 – improvement analysis

.... STEP 5.1 – DOMINANCE ANALYSIS ....

- The "true origin" of the environmental interventions or effects is determined in the dominance analysis which makes it possible to take a considered approach to solving a problem.
- During a dominance analysis it is useful to provide an overview in the form of a matrix of all process data based on their occurrence. This matrix approach is developed in the backgrounds document. It is illustrated in the example with this step.

.... STEP 5.2 – MARGINAL ANALYSIS ....

- In theory marginal analysis is a powerful tool in determining the options for product improvement. The method has yet to prove itself in practice. It is a new development which has still to be applied and assessed. The approach is described in detail in the backgrounds document.
- An effective method of handling the large quantity of numbers is to make a list in which the calculated numbers are listed in order of decreasing magnitude (in absolute terms).
- There is a close link with the reliability analysis in step 4.2: process data in which small changes may have major consequences are also process data which have to be calculated extremely accurately. Hence marginal analysis should also be used carefully.

CHAPTER 0

INTRODUCTION

This chapter describes the contents of this guide, its target group and structure. It provides an introduction to the report itself.

0.1 Orientation

First we will describe some terms*. This guide describes the implementation of a *product assessment*. This is limited to the potential effect on the *environment* of the functioning of a given product. The assessment is not restricted to any particular stage in the life of a product: the entire *life cycle* is considered, from production and use to disposal. Hence the term *environmental product life cycle assessment*, which is abbreviated as LCA†. An environmental life cycle assessment, possibly together with the results of other analyses e.g. an economic analysis, may result in an application. LCA applications include product information, product innovation and government regulation. Information provides support when a choice has to be made between alternative products, innovation might include the development of more environmentally-friendly products and regulation might include awarding approvals (*ecolabelling*). When used like this an environmental life cycle assessment can be employed as an instrument to support policy making.

This report describes a method for environmental life cycle assessment. The method is described in general terms in §0.2. Chapters 1 to 5 serve as a practical guide and give *guidelines* for carrying out an LCA. The guidelines in the summary (page 2) list all the guidelines.

When determining the target groups addressed by the method there is a difference with the policy target groups in the Netherlands NEPP‡ (National Environmental Policy Plan) as the policy officials are now one of the target groups. There are four main target groups:

- *those implementing* LCAs, i.e. large companies, consulting engineers and consumer organisations;
- *users* of the results of LCAs, i.e. consumers, the public and private sectors and other organizations;
- *policy officials*, for product policy in the widest sense of the word (including environmental approvals, waste policy and innovation policy);
- *companies and designers*, for design decisions.

The guide described in this section is only intended for *those implementing* LCAs. The aim was to find a compromise between brevity and completeness: everything required to implement an LCA is included in this guide. The reasons behind the choice of methods are included in the backgrounds document.

* A short list of definitions is included in Appendix C.1.

† LCA has slowly developed from an instrument for analysis into one for assessment. This explains the the confusion on the meaning of the abbreviation: is it life cycle analysis or life cycle assessment?

‡ A list of abbreviations is included in Appendix C.2.

None of the practical studies currently available fulfils all the requirements of this method. Thus the method does not reflect current practice, but rather the desired situation. Given the present, limited, level of development of the methods and the lack of complete basic data practical studies are unlikely to meet all the desired requirements in the near future. However, it is possible to indicate the extent to which they meet certain requirements, the methodological status and quality of each step, as well as the quality of the data in these steps. Hence the method is provisional and requires further development, possibly through international cooperation. For this reason the most recent developments should form the basis of each study and the method used as well as its date should be specified.

The wide variety of product assessments created in the past was one of the reasons for the development of this method. Variety is undesirable for all target groups: trade and industry (the private sector), consumers and the public sector. Decisions about investment, procurement, creating the right conditions and the provision of information are not taken on a clear basis. The method presented here aims to provide uniform guidelines for the implementation of an LCA. As progress is made practical studies will continue to be faced with problems and disagreements. A *code of conduct* will have to be created to deal with the remaining problems.

0.2 Structure

The following elements are included in the method:
- components;
- steps.

The components are built up into a logical structure which is developed in more detail in each of the steps. The components will be discussed within this structure. The detailed development of the components, as well as their steps, is included in Chapters 1 through 5, i.e. one component per chapter. Each step is discussed in a separate subsection.

0.2.1 Structure in components

An environmental life cycle assessment is made up of five *components* which together form a comprehensive structure. These components are:
- goal definition (page 17);
- inventory analysis (page 25);
- classification (page 41);
- evaluation (page 51);
- improvement analysis (page 57).

The concept behind these components will be explained here. The precise nature of the components will be described later. The logical progression of these five components is illustrated in the bold frame in Figure 0.1.

The assessment of a product is concerned with more than just environmental aspects. Financial, social and functional aspects may also be relevant. These other aspects are beyond the scope of this report. The figure shows the position of environmental life cycle assessment compared with other forms of analysis. Applying the results of an environmental life cycle assessment, possibly in combination with other analyses, also lies beyond the scope of providing a description of a method for environmental life cycle assessment.

Each component of an environmental life cycle assessment provides a result which can be used on its own. Hence there is an outward arrow from each component in Figure 0.1. The results of the various components are known as *environmental indicators*. An environmental indicator is a number which provides information about the properties of the product concerned with respect to the environment. The environmental indicators will be included as part of the discussion of the relevance of the components. There are many potential environmental indicators. However not all of them are equally useful or practical. Some of these environmental indicators will be examined in this report. There is some interdependence between the environmental indicators as the outcome of the various components. Environmental indicators should only be used at the same level to obtain useful

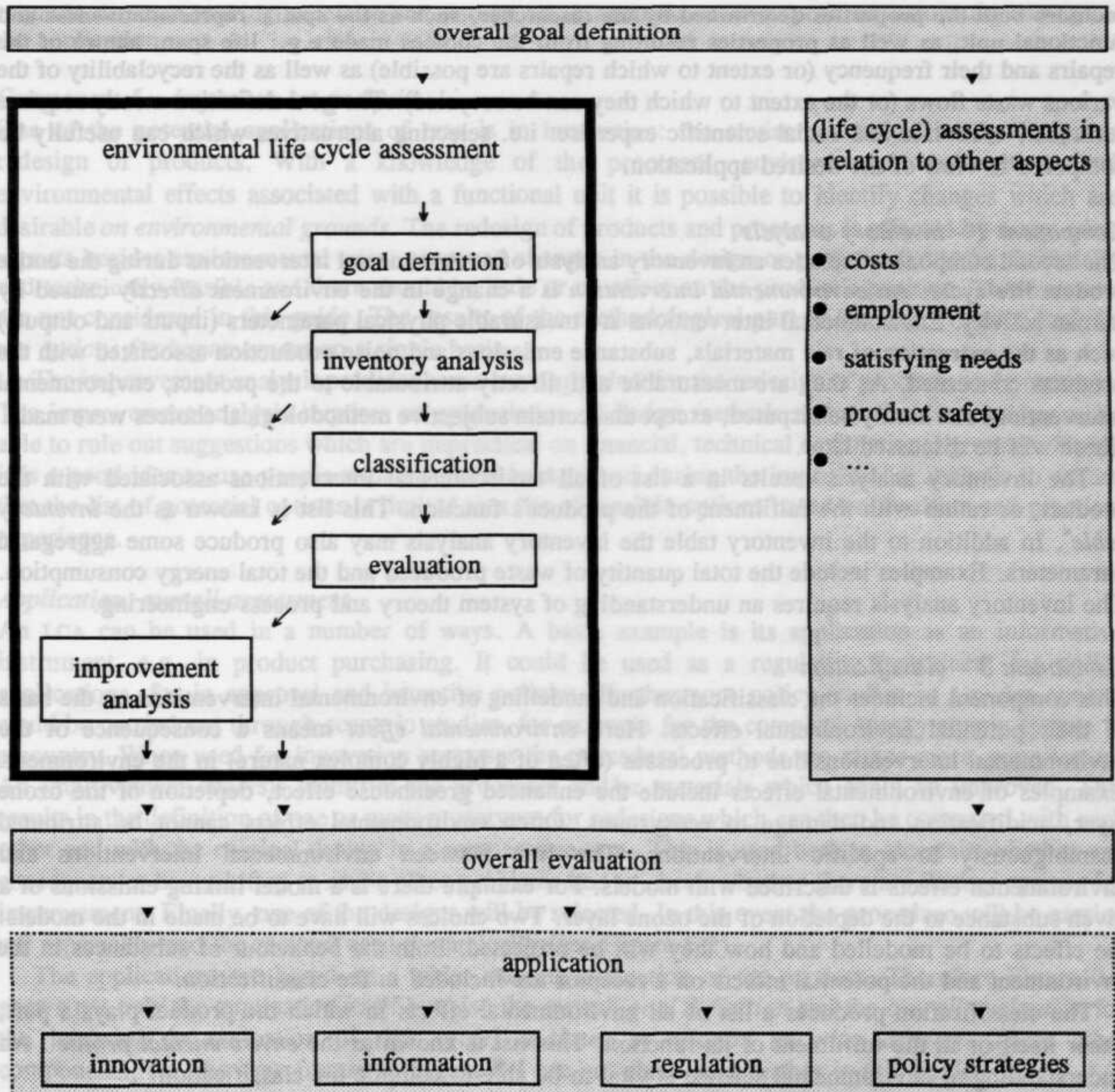

FIGURE 0.1. An LCA comprises the components goal definition, inventory analysis, classification, evaluation and improvement analysis and, with an assessment on other aspects, leads to an application.

information about the properties of a given product.

Component 1 – goal definition
The LCA begins with a definition of the goal. The actual goal of the LCA in question is determined. This includes a consideration of the type of decision required for a potential application. The actual application however is beyond the scope of the LCA. The depth of the study will also be determined at this time. Finally, the object of the study is accurately defined. The goal definition produces a fairly accurate specification of the product or products to be investigated. It will also specify the time and place covered by the LCA, and for which the processes should be representative. At this stage the core criterion in the comparison of the relevant product variations or the product is also determined as a *functional unit*. The choice of the numerical value is irrelevant: there is no difference, other than in scale, between 1 kilometre or 1000 kilometres by car.

The goal definition produces an overview of the *product properties* of the products concerned. This includes both the properties determined by the researcher, such as the spatial representativeness and functional unit, as well as properties resulting from the choices made e.g.: life span, nature of the repairs and their frequency (or extent to which repairs are possible) as well as the recyclability of the various waste flows (or the extent to which they can be recycled). The goal definition mostly requires technical, economic and social scientific expertise: i.e. selecting alternatives which can usefully be compared in view of the desired application.

Component 2 - inventory analysis

The second component includes an inventory analysis of environmental interventions during the entire product life cycle. An *environmental intervention* is a change in the environment *directly* caused by human activity. Environmental interventions are measurable physical parameters (inputs and outputs) such as the extraction of raw materials, substance emissions and noise production associated with the products concerned. As they are measurable and directly attributable to the product, environmental interventions can hardly be disputed, except that certain subjective methodological choices were made. These will be discussed later.

The inventory analysis results in a list of all environmental interventions associated with the product, or rather with the fulfilment of the product's function. This list is known as the *inventory table*[*]. In addition to the inventory table the inventory analysis may also produce some aggregated parameters. Examples include the total quantity of waste produced and the total energy consumption. The inventory analysis requires an understanding of system theory and process engineering.

Component 3 - classification

This component includes the classification and modelling of environmental interventions on the basis of their potential environmental effects. Here *environmental effect* means a consequence of the environmental interventions due to processes (often of a highly complex nature) in the environment. Examples of environmental effects include the enhanced greenhouse effect, depletion of the ozone layer, acidification and damage to ecosystems. Often environmental effects cannot be attributed unambiguously to specific interventions. The link between environmental interventions and environmental effects is described with models. For example there is a model linking emissions of a given substance to the depletion of the ozone layer. Two choices will have to be made in the models: the effects to be modelled and how they will be projected. Both the behaviour of substances in the environment and the potential effects on a receptor are included in the classification.

The classification produces a list of all environmental effects in which the product plays a part, either itself or in the fulfilment of its function. This list is known as the *environmental profile*[†]. An understanding of environmental science is vital to be able to compile the classification.

Component 4 - evaluation

During the evaluation an overall assessment of the product is made based on its potential environmental effects. A single, uniform, parameter is often required when comparing the environmental profiles of two products as in many cases an unweighted comparison will not lead to a clear conclusion. This means that the scores for the various environmental effects of the environmental profiles could be weighted and combined to provide an *environmental index*. Considerations about which environmental effects are most important depends rather more on the situation and personal opinion than considerations made in other components. Hence the value judgements made here are subjective. Apart from a valuation of the environmental effects the assessment is also based on an estimate of the reliability and validity of the analysis.

The result of the evaluation, therefore, will be a set of formally constructed environmental indices or a comparative judgement in which reliability and validity are also considered. The evaluation

[*] The usual term *inventory* comprises both inventory analysis and inventory table. To make a clear distinction between the procedure and the result, the words analysis and table have been included here, although the authors realize that they will often be omitted in practice.

[†] Other terms include eco-profile, environmental balance and eco-balance.

requires decision making expertise and will be of an administrative or political nature depending on the application.

Component 5 – improvement analysis
One of the potential applications of LCA is in innovation: the environmentally-friendly design or redesign of products. With a knowledge of the processes, environmental interventions and environmental effects associated with a functional unit it is possible to identify changes which are desirable *on environmental grounds*. The redesign of products and processes is affected by many other aspects besides environmental ones: proposed changes in the design or process should be financially and technically feasible and there should be little or no effect on the product's position. These aspects are not considered in this guide. The results of the methodological part of the improvement analysis are *options for improvement* on a single basis.

The improvement analysis provides some *starting points* for the redesign of products and processes. The improvement analysis requires an appreciation of design methods and process technology to be able to rule out suggestions which are impractical on financial, technical or functional grounds. Hence it is a good idea to use people with a general background during the improvement analysis to ensure that the list of potential options is limited to a list of feasible options based on intuition and practical experience.

Application; overall assessment
An LCA can be used in a number of ways. A basic example is its application as an informative instrument, e.g. in product purchasing. It could be used as a regulating instrument for policy applications, for in approval and incentive policies. Furthermore policy studies in a wider context could be carried out through scenario studies, for example for the complete energy supply system in a country. When used for innovation purposes the procedural methods are rather more complicated. An improvement analysis identifies the processes and/or materials which could be improved. This results in the definition of one or more prototypes for redesigns which can then be compared with each other and with the original design in a comparative LCA. This is used both to ascertain whether any consequences have shifted to cause other problems and to check whether there are further options for improvement. Finally, one of the designs will be selected. In this event the procedure will be carried out repeatedly and the method used dynamically (see Figure 5.2).

The applications are based on a wider ranging evaluation of the product. Therefore Figure 0.1 shows not only the application itself but also the *overall goal definition* and the *overall evaluation* for the initiation or evaluation of *(life cycle) analyses in relation to other aspects*. These other components, i.e. the grey frames in Figure 0.1 are not elaborated further in this guide.

0.2.2 Structure in steps

During an LCA a number of sequential actions is carried out in each component. A set of associated actions is referred to as a *step*. A step can be seen as a specific implementation in each individual LCA which is supported by a theoretical background (see Figure 0.2).

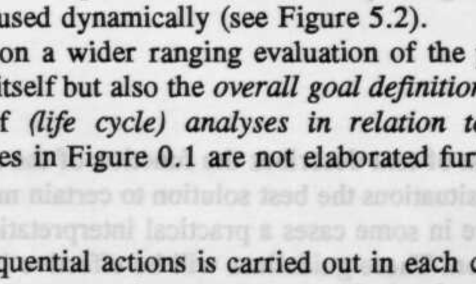

FIGURE 0.2. Structure of a step. The method provides the theoretical basis for the specific development in each situation.

Each step is supported by theoretical considerations which are not essential to the implementation of an LCA. However, these considerations are relevant for other purposes and are discussed in the other volume of the report, the backgrounds document. The chapter numbering of that document is the same as in this guide but the structure, in sections, differs. Chapters 1 to 5 of this guide cover the components goal definition, inventory analysis, classification, evaluation and improvement analysis. In these chapters each component is also divided into steps. Table 0.2 lists the five components and their constituent steps.

TABLE 0.2. The five components of an environmental LCA: the constituent steps, results and discipline.

component	step	indicator	expertise
goal definition	determining the application determining the depth of the study defining the subject of the study	product properties: life span, recyclability, etc.	technical, economic, social scientific
inventory analysis	drawing up the process tree entering the process data application of the allocation rules creating the inventory table	inventory table with environmental interventions; energy, waste, etc.	system theory, process engineering
classification	selection of the problem types definition of classification factors creating the environmental profile normalization of the effect scores	environmental profile with effect scores	environmental science
evaluation	evaluation of the environmental profile evaluation of the reliability and validity	environmental index or judgement	decision-making
improvement analysis	dominance analysis marginal analysis	starting points for redesign	process engineering

Each section of text describing a step includes a number of standard items:

- introduction;
- guidelines;
- example;
- backgrounds.

The *introduction* of each section of text describes the function of the step within the method and that component. In certain steps or situations the best solution to certain methodological problems may be impractical. The *guidelines* give in some cases a practical interpretation of the principle itself and in other cases a provisional solution. These guidelines will be effective in most cases in practice but not in all situations, e.g. where data is lacking or the application of the guideline leads to conclusions which are clearly unlikely. Therefore the exceptions are always discussed. Examples of exceptions are included together with the way to handle them. However, it is possible to deviate from the guidelines, even if this option is not explicitly stated. This will always have to be clearly stated and supported with reasons. Figure 0.3 shows the link between backgrounds, guidelines and exceptions.

Each step concludes with an *example*. These examples are only illustrative. Particularly as none of the practical studies available meets the requirements laid down here, it is difficult, if not impossible, to provide realistic examples which are not in conflict with the method itself. The last part of each step refers to the relevant passages in the backgrounds document.

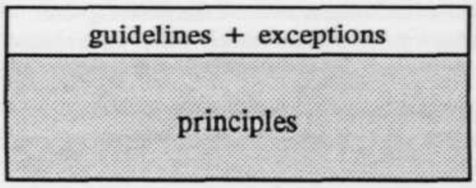

Figure 0.3. This report provides guidelines for implementing an LCA, based on the principles in the backgrounds document. If necessary, these guidelines may be departed from if the reasons are stated.

CHAPTER 1

GOAL DEFINITION

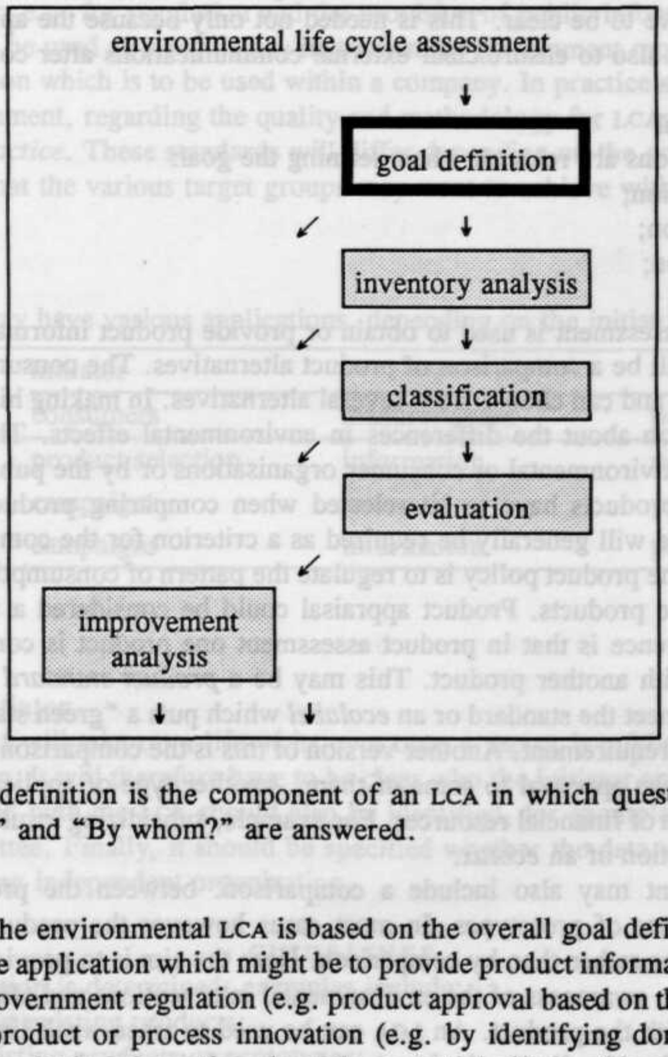

FIGURE 1.1. The goal definition is the component of an LCA in which questions such as "What?", "Why?", "For whom?" and "By whom?" are answered.

The goal definition of the environmental LCA is based on the overall goal definition. The overall goal definition anticipates the application which might be to provide product information (e.g. by comparing product alternatives), government regulation (e.g. product approval based on the results of comparison with a standard), for product or process innovation (e.g. by identifying dominant processes in the environmental profile to obtain information about the potential effects of innovation), or as a tool for strategic studies based on policy scenarios. The depth of the study is also determined at this stage, depending on the time available and intended application. Finally the products to be investigated are defined. Thus, the goal definition comprises three steps:

- **determining the application (page 18);**
- **determining the depth of the study (page 20);**
- **defining the subject of the study (page 21).**

The result of the goal definition includes an accurate description of the products to be investigated. This includes a number of product properties which may be related to effects on the environment. These could include the technical or economic life span, the nature and frequency of repairs, recyclability, the number of times the product is reused, etc. However, the relationship between these product properties and the level of environmental-friendliness is not clear.

1.1 Determining the application

INTRODUCTION

During the goal definition component certain decisions are taken which determine the subject of the assessment and its further implementation. As the intended application will determine the course of the LCA the first step is to determine the application. When carrying out an LCA the goal, the target group and the initiator need to be defined. This is to provide the basis for the LCA: the reasons for undertaking a study have to be clear. This is needed not only because the application will affect the course of the study but also to ensure clear external communications after completion of the study.

1.1.1 Defining the goal

The following applications are relevant when defining the goal:

- product information;
- product innovation;
- product regulation;
- policy strategies.

When a life cycle assessment is used to obtain or provide product information it is likely that the practical application will be a comparison of product alternatives. The consumer expects a particular function to be provided and can choose from several alternatives. In making his decision the consumer can consider information about the differences in environmental effects. This information may be provided by industry, environmental or consumer organisations or by the public sector. At least two product variations or products have to be selected when comparing products (see §1.3.5), and a common functional base will generally be required as a criterion for the comparison (see §1.3.4).

One of the aims of the product policy is to regulate the pattern of consumption. The results of LCAs can be used to appraise products. Product appraisal could be considered a special case of product comparison. The difference is that in product assessment one product is compared with a standard product, rather than with another product. This may be a *product standard* which aims to exclude products which fail to meet the standard or an *ecolabel* which puts a "green stamp" on products which meet a given minimum requirement. Another version of this is the comparison of a range of variations in order to award such an approval to some of them. Another type of application is the use of LCAs to manage the allocation of financial resources. For example, subsidizing insulation or energy-efficient lighting or the introduction of an *ecotax*.

Product improvement may also include a comparison: between the product before and after redesign, or of a number of prototypes. In most cases however the product improvement will be defined in absolute terms rather than by comparison. Here the aim is to provide recommendations for the redesign based on an awareness of the environmental interventions and effects of all materials and processes associated with the product. An LCA can be used to trace weak links in the life cycle, for example by indicating that the dispersal of toxic substances is largely due to cadmium emissions in a particular process. By selecting a different process or by taking environmental hygiene measures for that process, the environmental profile of the product may be drastically improved. The dynamic and iterative nature of LCAs will be emphasized by this type of application in particular: after inclusion of the recommendations in a new design the new product can be compared with the old in a comparative LCA. In this way environmental effects are not shifted to other stages in the life cycle nor to other environmental effects. All in all, product improvement also includes a comparison albeit that the options for improvement are determined only for one product.

Consideration of scenario studies is also important when defining the government policy, which can affect the market shares of products through levies or public information campaigns. An LCA may help when carrying out these scenario studies. This method can also be used to set priorities in the policy. This is one of the few examples where it may be useful to compare product groups which are not functionally identical. For example, is encouraging the use of energy-efficient lighting more urgent than encouraging the purchase of high-efficiency central heating boilers, given the limited availability of government funds?

Any secondary objectives which limit the scope of the study should also be considered when defining the goal.

1.1.2 Defining the target group

It is important to define who undertakes or commissions an LCA, and for whom. The results of an LCA may be aimed at three separate target groups, i.e.:

- consumers, for information (e.g. for purchasing decisions);
- manufacturers, for innovation and information (e.g. for advertising);
- the public sector, e.g. for regulation and the provision of public information.

A decision which is to be used as a regulatory instrument by government requires a higher degree of reliability than a decision which is to be used within a company. In practice standards will have to be set, possibly by government, regarding the quality and methodology for LCAs. This could be done by means of a *code of practice*. These standards will differ depending on the goal and the target group.

Table 1.1 shows what the various target groups may want to achieve with LCAs.

TABLE 1.1. An LCA may have various applications, depending on the initiator and target group.

	initiator		
target group	consumers	manufacturers	public sector
consumers	product selection	information	provision of information
manufacturers	campaigns	innovation	provision of information
public sector	campaigns	information	policy strategies

1.1.3 Defining the initiator

A life cycle assessment will take on a life of its own once a report is published, which may extend beyond the target group. It will therefore have to be clear who the initiator and funding body are. The organizations concerned with the LCA should also be identified, for example by listing the members of any steering committee. Finally, it should be specified whether the data used was provided by an interested party or by an independent organization.

GUIDELINES

- The type of application is determined; examples include:
  - — information about existing products;
  - — innovation of existing products or prototypes;
  - — legislation affecting product policies;
  - — assessing policy strategies through the use of scenarios;
  - — ...
- The application depends on the choice of target group or groups:
  - — consumers;
  - — producers;
  - — government bodies;
  - — ...
- List those concerned:

— those undertaking the study;
— the client and the funding body;
— the steering committee;
— those providing (and possibly verifying) the information required;
— ...

■ Such a full explanation will not be required if the LCA is only to be used internally e.g. to optimise a design.

EXAMPLE

This study was carried out to compare different types of window frames. The study was commissioned by Alukoz BV whose product range includes aluminium window frames. The study was estimated to require 250 hours. The client was closely involved in directing the project, particularly in selecting the product alternatives to be compared and provided the process data. Before publication the report was submitted for comment to Ecobouw BV, an independent firm of consulting engineers.

BACKGROUNDS

§0.1 – product assessments
§0.4 – premises
§1.1 – LCA applications

1.2 Determining the depth of the study

INTRODUCTION

Normally, a product assessment will require considerable time and funds. A detailed life cycle assessment may be justified for important applications such as government approvals or bans. However, when only a general outline is required a *streamlined method* could be used. Examples of this include applications within a company for product improvement. The streamlining may be achieved by:

- concentrating on the differences between product alternatives;
- excluding some components of the life cycle assessment;
- limiting the number of processes;
- limiting the number of environmental effects;
- ...

The decision to apply some streamlining may imply a reduction in reliability, particularly when it is decided to limit the number of processes or environmental effects considered. This reduction should correspond with the importance of the application. The level of detail will also affect the course of the following steps to some extent. The method described in this guide is based on the assumption that the highest level of detail has been selected. The streamlined methods have not been developed in sufficient detail to be considered as accepted methods.

Besides lack of time, a lack of data may also be one reason to opt for a limited LCA. Information about the use of capital goods, CO_2 emissions, distinction between different PAHs, etc. is not always available. This may require the exclusion of certain processes or environmental effects.

Apart from a limitation due to a lack of time or data the relevance to certain applications may lead to a reduction, or even an increase, in the level of detail of an LCA. For example, depending on the occupational hygiene regulations in a particular country, it may be decided to include or exclude occupational hygiene considerations. Alternatively the study could be limited to global environmental problems.

GUIDELINES

■ A complete LCA should first be considered: covering all processes and environmental effects and at least the following components: goal definition, inventory analysis, classification and evaluation. At this stage it would not be sensible to omit any elements, this can only be done once an inventory analysis has provided sufficient information to justify this.

- Identical elements may be excluded when products are being compared. However, this can only be done after defining the process tree in step 2.1.
- When improving a product it may well be feasible to make recommendations for a redesign at the inventory analysis level. However, the new design will have to undergo a complete LCA to assess any shift to other environmental effects.
- In all cases reliability and validity will have to be assessed (step 4.2).

EXAMPLE

An assessment of certain environmental effects has not been specifically excluded from this study of the environmental effects of different types of curtains. However, certain identical elements (i.e. the curtain rail and fixings) in the life cycles have not been considered.

BACKGROUNDS

§0.2 – structure
§1.2 – streamlined LCA methods

1.3 Defining the subject of the study

INTRODUCTION

Selecting the subject means:

- defining the product group;
- defining spatial representativeness;
- defining temporal representativeness;
- defining the functional unit;
- defining the product or products.

These elements are closely related. The order in which they are dealt with may differ. For these reasons they are included as a single step made up of sub-steps. However, the five items will be considered separately below where their interrelations will allow this.

1.3.1 Defining the product group

The function for which a set of products may be used is selected. This set of products and product variations is known as the *product group*. An example of a product group is "light sources", whose function is "lighting a space". There is no product group if it was decided when determining the type of application, to study policy strategies, in which event it is only necessary to define clearly the functional unit (see §1.3.4).

1.3.2 Defining spatial representativeness

The spatial representativeness of the products to be studied must be specified unless it is clear from the specification of the functional unit (§1.3.4). This could be global, continental (e.g. European), regional (e.g. EC), national (e.g. the Netherlands) or at company level (e.g. brand *X*).

1.3.3 Defining temporal representativeness

The temporal representativeness has to be determined in a similar manner to spatial representativeness. Generally, a rough indication will suffice, for example, "the '70s", "1991" or (for innovation) "2010".

1.3.4 Defining the functional unit

The concept of equal value, as referred to above, is based on the *functional unit*. The functional unit describes the main function performed by a product and indicates how much of this function is considered. Quantitative terms can be included in the process tree once a functional unit has been selected. When comparing products the functional unit forms the basis for the comparison. A functional unit will also be required for an assessment or any other application. Strictly speaking, the choice of functional unit will consist of a unit and a quantity; the quantity is irrelevant.

Examples of functional units include: "drinking 1 (or 1000) litres of fresh milk", "1 person-transport-kilometre" and "watching TV for one hour". In practice this will be expressed less carefully, for example in functional units such as "1 notepad", which do not express the use-function and the disposal-structure although these are included in the assessment.

Sometimes it is easy to choose the functional unit. However, it is often necessary to choose the main function which is used as the basis for the comparison. Examples include functional units such as "transport kilometres per car" and "person-transport-kilometres by car". In the first example the number of passengers in the car is not relevant, which it is in the second. The definition of the functional unit also defines the alternatives which could be considered. The more strictly the functional unit is described the fewer alternatives there are for it. The functional unit "watching TV for 1 hour" may be specified in greater detail as "watching colour TV for 1 hour", "watching large-screen colour TV for 1 hour", "watching large-screen colour TV with remote control for 1 hour", etc., until there are no product alternatives to compare. The contradiction between an accurate definition of something and allowing for slightly different alternatives means that the accuracy of the definition of the functional unit cannot be cast iron. This is particularly relevant when LCAs are used to plan policy strategies. For example, the functional unit chosen to compare energy-efficient lighting and high efficiency central heating boilers as referred to in §1.1 could be "an energy saving of x MJ per capita" or „providing y guilders subsidy for energy conservation".

1.3.5 Defining the product or products

One or more products are selected from the product group (see §1.3.1) which meet the representativeness criteria in §1.3.2 and §1.3.3. The final outcome of the goal definition will be a list stating the product or products which have to be investigated for a particular purpose, linked by the functional unit. An existing product need not be chosen: it could be a product to be developed. In practice it is advisable to provide an accurate description of the products to be investigated.

GUIDELINES

- Select a functional unit which is clearly defined in detail and covers an activity to the greatest possible extent.
- Provide an accurate specification of the products being assessed. The extent to which the information is representative (in time and space) and the functional properties are particularly important.
- Indicate any product alternatives which meet the specifications fully or almost fully that were not included in the assessment, and the reasons for this.

EXAMPLE

Two light sources will be compared in this investigation:

- incandescent lamp (60 HV ed 51);
- SL-type compact fluorescent lamp (SL-18W prisma).

Table 1.2 gives the functional differences between these lamp types. As both are suitable for providing electric light in living rooms they are considered as product alternatives.

Both types relate to the Netherlands market for light sources. Data from 1986 was used. The functional unit selected was 10^6 lm·hr light production. The TL-20/x fluorescent tube was not considered as it is soon to be discontinued. The TL-7/c was also excluded as its colour is generally not used for domestic applications.

BACKGROUNDS

§1.3 – the functional unit

TABLE 1.2. Product properties of the two types of light source investigated.

product property	incandescent lamp (60 HV ed 51)	SL-type fluorescent lamp (SL-18W prisma)	unit
light-related properties			
total power drawn	60	18	W
light flux	650	900	lm
colour temperature	2600	2700	K
colour rendition	100	82	ra
life span	1000	5000	hr
reduction in light flux	10	20	%
average light flux	617.5	810	lm
total light emitted	617,500	4,050,000	lm·hr
other properties			
weight	30	540	g
operating time	2000	2000	$hr \cdot yr^{-1}$
life of fitting	20	20	yr
depreciate fitting over	40	8	lamps

CHAPTER 2

INVENTORY ANALYSIS

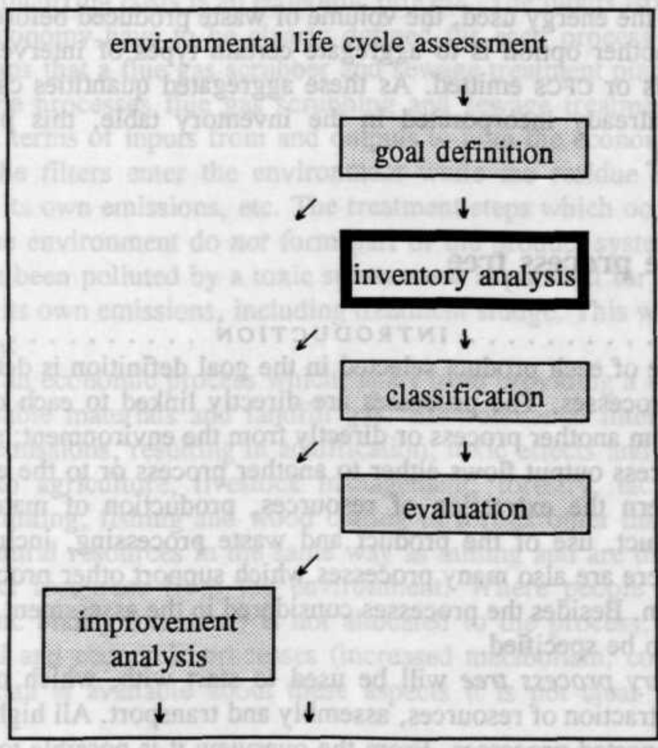

FIGURE 2.1. The product system is central to the inventory analysis of an LCA. The process tree is drawn up and process data entered which can be used to draw up the inventory table.

The inventory analysis is a survey of the interaction between the life cycles of the products under investigation and the environment. The life cycle of a product, which includes all processes required for the functioning of the product "from cradle to grave", is referred to as the *product system*. The product system affects the environment. The interventions have an effect throughout the system made up of all environmental processes (degradation, accumulation, etc.). These processes form the *environmental system*. The sequence from intervention to effect or potential effect is the subject of the classification component (Chapter 3).

The inventory analysis is based on the functional unit of the product defined in the goal definition and the selected products* which provide this function. The functional unit is realized through a product†, and the product is associated with past and future processes‡. Hence, the first action in an inventory analysis is to draw up an overview of the processes through which the life cycle is implemented in each of the product systems under investigation, which is known as a *process tree*§. Next the process data have to be collected and entered. The aggregation of this data throughout the process tree will ultimately provide a list of all interventions in the environment which are associated with the product system, this is the *inventory table*. There are four separate steps:

- drawing up the process tree (page 26);
- entering the product data (page 29);
- applyication of the allocation rules (page 35);
- creating the inventory table (page 37).

These four steps will be discussed separately.

Instead of using an inventory table the outcome of the inventory analysis could be presented in another form; for example by aggregating quantities (at the process level) which are of particular individual interest, e.g. the energy used, the volume of waste produced before or after processing, or the total space use. Another option is to aggregate certain types of interventions such as the total quantity of heavy metals or CFCs emitted. As these aggregated quantities cannot be assessed in the classification and are already incorporated in the inventory table, this procedure has not been elaborated in this report.

2.1 Drawing up the process tree

.... INTRODUCTION ....

In step 2.1 the life cycle of each product selected in the goal definition is determined. The life cycle consists of economic processes. The processes are directly linked to each other: each input into a process comes either from another process or directly from the environment; see also figure 2.3 (page 31). Similarly each process output flows either to another process or to the environment.

The processes concern the extraction of resources, production of materials and components, manufacturing the product, use of the product and waste processing, including the processes for recycling and reuse. There are also many processes which support other processes, such as transport and electricity generation. Besides the processes considered in the assessment, the processes that have been omitted should also be specified.

In practice a *summary process tree* will be used to start with, which only includes high-level processes such as the extraction of resources, assembly and transport. All high-level processes consist of a number of interconnected processes. From the overview it is possible to zoom in on each high-level process in the summary process tree which will then reveal the *partial process trees* of the process concerned.

To determine the life cycle of a product more information is required than just the processes to be included in the process tree. The product system also has to be delineated. This step includes the definition of three boundaries:

- delineating the boundary between the product system and the environmental system;

* These could also be product design specifications.

† In many cases there will be one core product performing the function, while the contribution made by other products is less clear. For example, let us consider a functional unit of vacuum cleaning: the vacuum cleaner is the core product while the dust collection bags are essentially a different product based on their function. In this case the different types of vacuum cleaners can be compared, including the relevant type of bag. This is not as clear in other cases. For example, when writing a letter both the paper and the writing implement play equal level roles and various combinations of wood-free paper and recycled paper or ballpoint pen, fountain pen and typewriter may be analysed. Although there is no core product which performs the functional unit the rest of the inventory analysis can be easily discussed using a core product.

‡ In the inventory analysis a process is always taken to mean an economic process. This generally refers to an action under human control. Examples include ore extraction, electricity generation, cleaning a carpet and waste water treatment.

§ When more than one product is studied several process trees will be drawn up.

- delineating the boundary between relevant and irrelevant processes;
- delineating the boundary between the product system and the other product systems.

2.1.1 Delineating the boundary between the product system and the environmental system

The complete process tree has to provide the links between the economic inputs and outputs and the environmental inputs and outputs. In this way all economic inputs linking two processes in the product system are traced back to inputs from and outputs to the environment. In this way they are reduced to the system boundary between the economic system and the environmental system. Starting from the process which provides the function defined in the functional units all processes have to be traced back to their origin and followed through to their completion. The chain is only broken if there is recycling to or from other product systems (this is known as *open loop recycling*; see §2.1.3). When going back to the origin each process with multiple inputs from other processes will branch to those processes, which have their own inputs from previous processes which also have their own branches.

Almost any activity incurring costs is an economic process. The inputs from and the outputs to the environment and the economy have to be clearly defined for each process in the process tree*. In practical terms this means that a flue gas scrubber and sewage treatment plant have to be included in the product system. The processes flue gas scrubbing and sewage treatment have to be known as economic processes, in terms of inputs from and outputs to both the economy and the environment. The flue gases from the filters enter the environment while the residue is dealt with in another economic process with its own emissions, etc. The treatment steps which occur after a substance has been introduced into the environment do *not* form part of the product system causing the emission. After surface water has been polluted by a toxic substance it is purified for consumption. This is an economic process with its own emissions, including treatment sludge. This will only be relevant in an LCA of the water supply.

Landfilling waste is an economic process which, apart from providing a waste processing service, may also produce reusable materials and landfill gas. Environmental interventions of this process include space use and emissions, resulting in acidification, toxic effects and odours.

Processes relating to agriculture, livestock management, forestry, etc., are considered to be economic processes. Hunting, fishing and wood cutting in forests other than production forests are processes which use natural resources in the same way as mining and are therefore considered to be processes which extract resources from the environment. Where people are used their presence (including all their basic bodily functions) is not allocated to the process. However, including the additional physiological and economic processes (increased metabolism, commuting, etc.) could be considered. As little data is available about these aspects it is not clear to what extent they are relevant.

After processing waste a material may be reused or find a useful application. This means that the life cycle has not come to an end at the material level. However, after this step the product life cycle is considered complete. A similar approach is taken in relation to the beginning of the life cycle: it starts when the raw material is extracted.

2.1.2 Delineating the boundary between relevant and irrelevant processes

When a process tree is drawn up a problem arises which could be described as *infinite regression*: each process refers to a previous or a subsequent process. The hammer used to make a machine was itself made and the waste processing plant used to process the product will itself have to be demolished. A boundary has to be drawn somewhere.

There is a similar problem regarding the delineation within a process: it has to be decided to what extent capital goods and matters such as the canteen for production staff should be included in the assessment.

In practice only the most relevant processes will be considered, particularly in a quick LCA, and

* The actual implementation will only become clear after step 2.2. In essence steps 2.1 and 2.2 are carried out as part of an iterative process; certain parts of the process tree can only be drawn up once the nature of the processes concerned is known.

many processes which could be relevant are excluded. The start of a series of processes to be excluded is always an omitted or dead-end economic input or output of a process already defined. The most important excluded processes will have to be identified, preferably with a qualitative or semi-quantitative estimate of the relative contribution to their expected environmental effects. For example, the production of capital goods required for a particular production process is often excluded. Whether to allocate these and other processes or not to a functional unit of product will be an important decision in a study.

At present it is difficult to say which processes may be excluded and when*. However, an initial indicator is that if the costs of maintenance and depreciation are a substantial part of the product price the environmental intervention of capital goods should not be excluded *a priori*†. In other cases it will usually suffice to include the operation of a capital good and to exclude its production, maintenance and disposal processes. However, such processes cannot be simply left out but should be identified. In this document they are indicated by the term *p.m.*‡ e.g.: "production of capital good *x*: *p.m.*". For energy supply however, Boustead's studies show that the inclusion of these other process does have an effect. Two solutions are possible in this situation. The first is the "proper" method in which all these processes are included and quantified. In the alternative method corrected data is used in which losses due to use anywhere in the chain are considered as a reduction in efficiency.

2.1.3 Delineating the boundary between the product system and the other product systems

Many processes produce more than one marketable output. A common example in LCAs is the combined production of chlorine and caustic soda from NaCl. If only one of these outputs is used as the input into another process in a given process tree then only part of the process has to be included in the product system: part of the environmental intervention as well as part of the inputs from earlier processes. This problem is not discussed as part of the compilation of a process tree as it concerns the extent to which a process is included, rather than whether or not to include it. There are three main categories of multiple processes: co-production, combined waste processing and open-loop recycling§. This distribution is known as *allocation* and is carried out in step 2.3 (page 35).

One of the problems associated with allocation can be included in step 2.1. This is the choice whether to include earlier processes in the use of recycled material and later processes in the production of recyclable materials. If a secondary resource such as scrap metal is used in a product system, the complete product system which provided the scrap need not be investigated. This would make the process tree much bigger. In this event the assessment would not be limited to the product systems under consideration but it would be extended to include a number of other product systems, one for each flow of secondary materials. The same problem occurs when material is reused in a following product system. A *cascade* of applications is also common: a primary resource is used in a number of products, one after another. The quality of the material may decline gradually until it is treated as final waste.

When drawing up the process tree it will have to be decided at what point products obtained from another product system become reusable waste. Similarly, when reusable waste is produced the point at these which products are to be included in the product system will have to be defined. To limit the discussion to the central product system the guidelines propose interrupting the materials cascade at a sensible place. As the quality required for the secondary application will determine the collection and reprocessing methods the complete collection and reprocessing process is allocated to the secondary use. The waste stage is eventually allocated to the final product system in the cascade. The

* Practical studies (see e.g. the discussion about streamlined methods in the backgrounds document) will have to demonstrate whether rules of thumb can be given for this.

† This does not imply that the use of capital goods with a low depreciation per functional unit of product need not be included. This is because the price is not proportional to the consequences to the environment.

‡ Abbreviation of the Latin phrase *pro memoria* (as a reminder).

§ Closed loop recycling involves the reuse of materials or products within the same product system. In the definition of the process tree this type of recycling is included through the proper definition of the processes: if a milk bottle is used forty times a functional unit of 1000 litres of milk requires 25 bottles.

primary use has the benefit of waste prevention, however this is offset by the extraction and production which are fully allocated to the primary use.

GUIDELINES

- A process tree is drawn up for each alternative under consideration, i.e. the processes which form part of the product life cycles are determined. The process tree is best laid out as a diagram, often with a summary process tree and separate trees for individual parts of the summary process tree.
- The extraction of raw materials from the environment is considered as the start of the life cycle.
- Although waste processing is considered as the end of the life cycle it is treated as an economic process which affects the environment through the consumption of raw materials, emissions and in other ways. Similarly, waste treatment steps carried out before a substance is introduced into the environment are included as part of the product system.
- The process tree is made up of economic processes.
- Economic processes have at least one economic output - goods (materials, components, products, etc.) or services (transport, energy, waste processing, etc.) - which forms the goal of the process.
- Each economic output of a process is the economic input of another process, with the exception of the service provided by the overall product system which is related to the functional unit.
- There is no need to extend the process tree by following the processes related to associated products and their production or the useful application of residual and waste materials.
- If the life cycle includes open loop recycling extraction and production are fully allocated to the primary application. Collection and upgrading are fully allocated to the secondary application while waste processing is only allocated to the last application in the cascade.
- This allocation system for open loop recycling will result in some of the consequences being shifted elsewhere. In some situations this shift may well be undesirable. In this event the reuse will not be interpreted as recycling in the LCA. The initial proposal for those situations in which there is no open loop recycling but where the rest of the life cycle has to be followed is as follows:
  — reuse of incinerator flue gas scrubbing residue;
  — reuse of incinerator fly ash;
  — application of combustible waste obtained from different, highly varied combustible waste fractions as RDF;
  — reuse of sewage sludge.
- Reuse which is considered to be open loop recycling must be identified.
- All branches of the process tree must be extended to include processes whose inputs are auxiliary environmental sources or whose outputs are emissions, unless they end in processes which are not considered in detail (i.e. indicated as *p.m.* processes).
- When drawing up a process tree the processes which have been excluded should be clearly indicated, where possible with a semi-quantitative estimate of the significance of these processes.

EXAMPLE

Figure 2.2 shows the summary process tree for the use of beverage packaging.

It is apparent that the production of some capital goods is also included and that processes further removed from the product, such as advertising, have not been included. The reason for this is that it is assumed that these will be the same for the product alternatives.

BACKGROUNDS

§1.2 - streamlined methods
§2.1 - the system boundaries

2.2 Entering the process data

INTRODUCTION

The process data for all processes in the process tree are collected in step 2.2. As long as there are

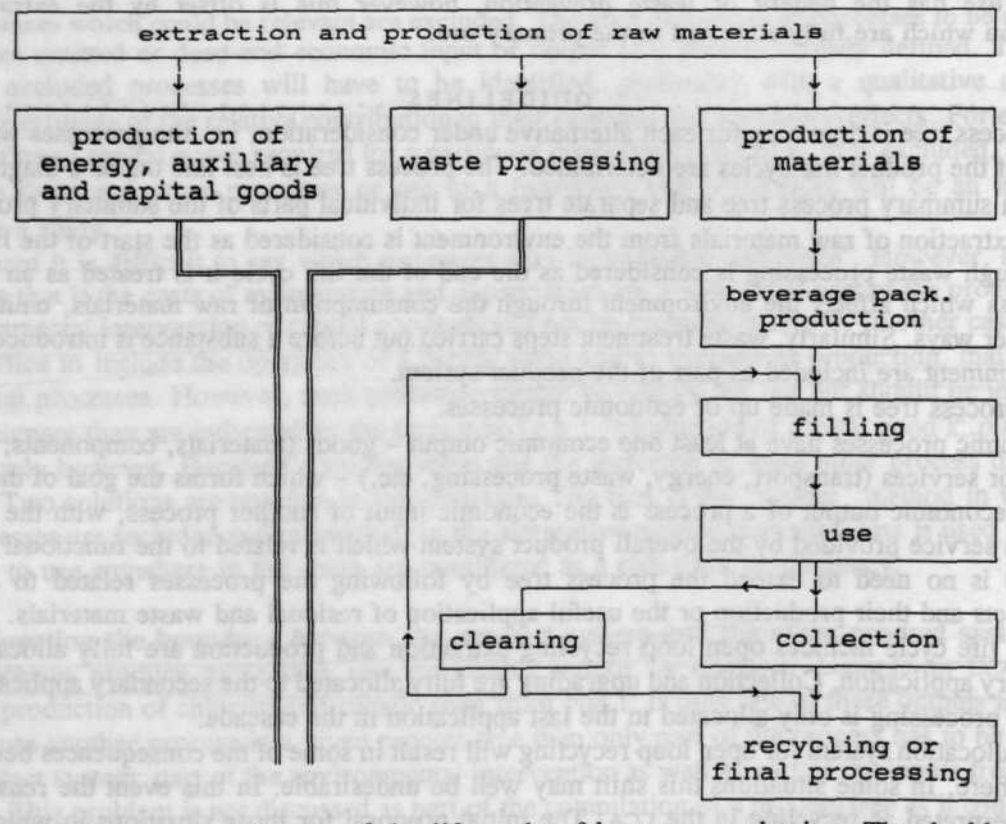

FIGURE 2.2. Summary process tree of the life cycle of beverage packaging. The double line (‖) represents the flow of energy, auxiliary and capital goods and waste processing services to all processes.

no references to a standard file for common processes the empirical data for the all processes concerned will have to be identified and included in the body of the document or in an appendix. The data should not be aggregated but refer to individual processes (i.e. at plant level) whenever possible.

There are two important aspects per process when presenting the process data:

- quantification of the inputs and outputs;
- the representativeness and quality of the data.

2.2.1 Quantification of the inputs and outputs

A special *format* has been developed for the specification and storage of process data. The format consists of a main structure (the *conceptual format*) and rules for entering the process data (the *technical format*). The main structure is based on the main characteristics of a process (see Figure 2.3): input from other economic processes and from the environment and output to other economic processes and to the environment. The conceptual format is illustrated in Table A.1 in Appendix A. The technical format falls beyond the scope of this study. This will also depend on the software used.

All economic processes in the process tree (see step 2.1) are connected by economic flows; when a flow leaves a process it is known as an *output*, when it enters a process it is an *input*. Hence the categories of economic inputs and outputs have to be fully symmetrical. These are: goods, services, materials, energy and waste to be processed. The distinction between these five types cannot always be clearly defined*, but these types of economic flows are largely intended to provide the user with a structure for the format. They also serve as a reminder: "remember to list the waste".

* The terms materials and goods cannot always be clearly delineated, energy can sometimes be considered as a service and it is not always clear whether or not a material is waste. It is not necessary to go to excessive lengths to assign everything to the right category. When a computer is used these categories would therefore have to be considered as a single category.

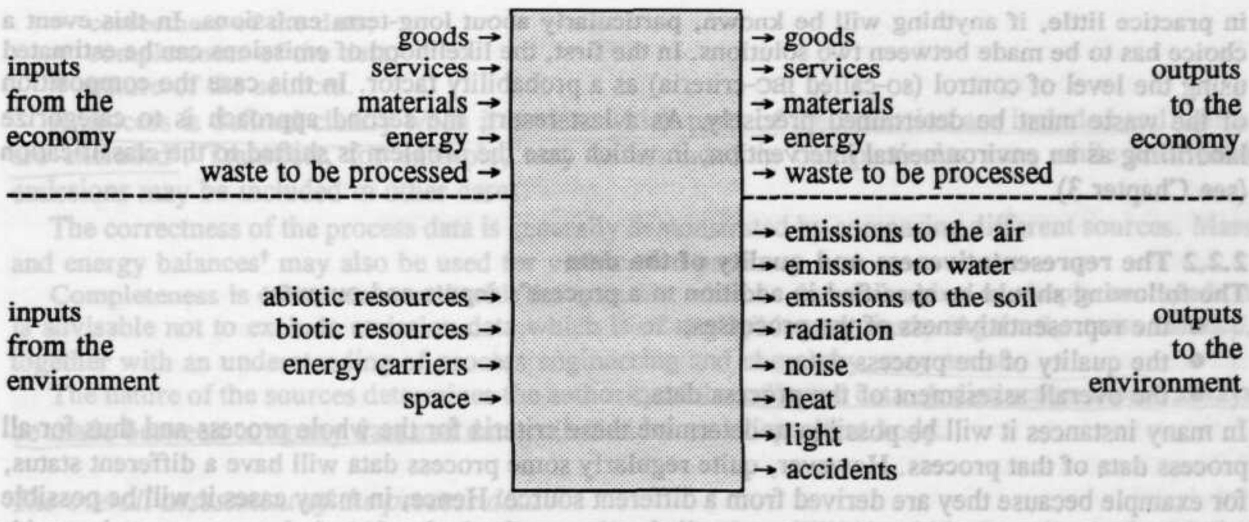

FIGURE 2.3. An economic proces is defined by the magnitude and composition of the flows to and from the economy and the environment.

The input from the environment consists of the extraction of resources (a distinction could be made between abiotic and biotic* resources and energy carriers) and space use. The output to the environment includes emissions of substances, radiation and noise. There are also environmental interventions of a more qualitative nature such as the fragmentation of ecosystems by road building programmes.

„Negative emissions" may occur, particularly in processes on the boundary between the economy and the environment. A production forest takes up CO_2 from the atmosphere. When the wood is burned in another process this CO_2 is released but it would be wrong to allocate the emissions from that process to a product system which includes forestry as well as the burning of wood. The reason for this is that there is an overall balance: the fixed CO_2 is released by the combustion. This can be achieved by including negative CO_2 in the forestry process. Processes such as soil clean-up also require special consideration. The removal of benzene from polluted soil is not described as the use of a resource but as a negative emission.

Many processes are non-linear in nature: the ratio between the production volume and the volume of emissions will depend on the production volume. As a life cycle assessment is based on a functional unit with an arbitrary magnitude for a given period the aim is not to consider short-term variations in a process but rather the overall changes in magnitude which may occur during a given period. It is best to use long-term marginal process data. In many cases these can be approximated by using the average process data during normal operations.

The type of presentation does not present any problems for most process data. Whenever possible SI units and notation should be used. For example mass should be expressed in kg, g, mg, µg, etc. Energy can be expressed in J, kJ, MJ, kWh, etc. (note the use of capitals). This document does not include guidelines on the use of decimal points or commas, exponential notation, and so on as this largely depends on the software used.

Some types of data will need conversion to take into account the time scale factor. For example, when noise is generated both the noise level, in dB and the time, in s, during which the noise is produced are relevant. The guidelines indicate how these two aspects can be combined. A similar approach applies to space use.

The inclusion of waste landfilling as an economic process in the process tree means that the process data must be known, i.e. it must be possible to predict emissions even over the long-term. However,

* Occasionally a distinction is made between renewable and non-renewable resources. However as this often leads to semantic confusion so the terms biotic and abiotic are used here. Again the exact categorization is irrelevant for the purposes of the inventory analysis. The categorization is important to the user as a reminder and to provide a structure.

in practice little, if anything will be known, particularly about long-term emissions. In this event a choice has to be made between two solutions. In the first, the likelihood of emissions can be estimated using the level of control (so-called IBC-criteria) as a probability factor. In this case the composition of the waste must be determined precisely. As a last resort, the second approach is to categorize landfilling as an environmental intervention, in which case the problem is shifted to the classification (see Chapter 3).

2.2.2 The representativeness and quality of the data

The following should be specified in addition to a process's inputs and outputs:

- the representativeness of the processes;
- the quality of the process data;
- the overall assessment of the process data.

In many instances it will be possible to determine these criteria for the whole process and thus for all process data of that process. However, quite regularly some process data will have a different status, for example because they are derived from a different source. Hence, in many cases it will be possible to make a single assessment which covers all the above criteria for the whole process, and provide specific information where the results of the assessment differ for some of the process data. The nature, quality and overall assessment of the process data can be included in the format together with the quantified process data (table A.1 on page 63).

The representativeness of the processes

The representativeness of each of the processes described should be indicated. This should include at least the following aspects:

- scale of the process;
- rough date of the process*;
- duration or capacity of the process;
- status of the process.

The scale indicates whether the selected processes represent a global, continental or national† average or whether the process is typical for the company concerned.

The date should provide an indication of the period for which the processes are representative‡, e.g. "1991" or "the '80s".

The capacity of a process or the time required to produce the volume described may be important as the characteristics of plants of different sizes may be markedly different. This applies not only to industrial processes but also, for example, to transport where there is no linear correlation between the emissions of a truck and its payload. The time required to produce a unit of material or a product is also relevant to some aspects of the inventory analysis (space, noise).

Finally the status indicates whether the process actually exists and has been measured or whether it is a design definition or a process for which an allocation has already been made to several commercial outputs§, or derived data (e.g. obtained through extrapolation). A combination of these terms could also apply.

The quality of the process data

The standards imposed on the process descriptions have to be specified. These aspects are:

- clarity of the process definition;

* The specification of the scale as well as the date of individual processes follows a similar approach as for the specification of the products investigated; see §1.3.2 and §1.3.3.

† These words should be interpreted flexibly, they serve only as an indication. For example many processes will be representative for the Western world or for the Northern part of the EC.

‡ Generally the time dimension should be excluded when drawing up a process tree. A hammer used to make a machine which makes a product in 1991 may have been made in 1970 but is also assumed to have been made in 1991.

§ See step 2.3 for the allocation of multiple processes. Generally it is not advisable (on the grounds of completeness and verifiability of the process data) to use allocated process data, but sometimes better data may not be available.

- correctness of the data;
- completeness of the data;
- nature of the sources.

A process is defined clearly when it is clear which parts of the operation are included and which are excluded*. Transport, for example, may be excluded in one particular case while accidental emissions may be included in other cases.

The correctness of the process data is generally demonstrated by comparing different sources. Mass and energy balances† may also be used for verification purposes.

Completeness is often concerned with the question whether data is lacking or simply excluded. It is advisable not to exclude emission data which is of negligible magnitude. Again the mass balance, together with an understanding of process engineering and chemistry, may assist.

The nature of the sources determines the authority of the collected data. A distinction should always be made between company data and data collected by an independent body.

The overall assessment of the process data

An overall assessment should be made of a set of process data. This should be based on a description of the representativeness and quality of the data described. When one of the above characteristics is unknown this will contribute most to a negative overall assessment. The assessment of the accuracy and completeness of the data in particular will determine the overall assessment.

GUIDELINES

- The data for all processes is collected and presented as shown in Table A.1. This includes both the input from and the output into other economic processes: the use and production of goods, materials, energy, services and waste to be processed. Other data includes flows to and from the environment in terms of raw materials, space use, and emissions of substances, noise, heat, etc.
- The nature and quality of the process data will be specified for each process. Data whose quality or representativeness does not match the general standard may have to be identified separately.
- Some processes have non-quantifiable aspects. These should also be included; the format makes special provision for them.
- Preferably, the long-term marginal process data should be collected. In many cases this data will be similar to the average process data during normal operations.
- Whenever possible numerical process data should be specified in SI units.
- Space use is a process parameter which requires a special conversion. It is expressed as a relationship between the area of the plant, its annual production and the consumption of a product or material. For a material whose quantity is expressed in kg this could be calculated as follows:

$$\textit{space use}\,(\mathrm{m^2 \cdot yr}) = \textit{material use}\,(\mathrm{kg}) \times \frac{\textit{area}\,(\mathrm{m^2})}{\textit{annual production}\,(\mathrm{kg \cdot yr^{-1}})} \tag{2.1}$$

  Thus space use is expressed in $m^2{\cdot}s$ or $m^2{\cdot}yr$.
- Noise is treated similarly:

$$\textit{noise}\,(\mathrm{Pa^2 \cdot yr}) = \textit{material use}\,(\mathrm{kg}) \times \frac{4 \cdot 10^{-10}\,(\mathrm{Pa^2}) \times 10^{\textit{sound pressure level}\,(\mathrm{dB})/10}}{\textit{annual production}\,(\mathrm{kg \cdot yr^{-1}})} \tag{2.2}$$

  The unit is $Pa^2{\cdot}s$ or $Pa^2{\cdot}yr$.

* A product system which has been calculated in full can be included in the process file, in which event the economic part will only consist of the functional unit and the environmental part will consist of the inventory table obtained. A considerable amount of detailed information will have been lost by the aggregation of the process tree in a single process. Hence, the major assumptions (where the process tree is cut off, allocation method, etc.) will have to be specified.

† In the event that process data has already been allocated the mass and energy balances of the single process may be incomplete, unless the allocation was made on the basis of mass; see also step 2.3. This provides yet another reason to try to obtain process data in step 2.2 which is obtained empirically and not by allocation. The mass and energy balances should be complete when the allocated single processes are combined to form the original multiple process.

. . . . EXAMPLE . . . .

The production of PVC is shown as an example in Table 2.1. Note that the volume of waste is included as an economic output.

TABLE 2.1. Example of entering process data: PVC production process.

1 format	
1.1 name or institute	Centre of Environmental Science
1.2 date	31-OCT-1992
1.3 comment	this is only an example!
2 process	
2.1 name or code	PVC production
2.2 representativeness	
2.2.1 scale	average situation in the Netherlands
2.2.2 dating	mid 80's
2.2.3 duration or capacity	large plant: approx. 10 Mton/year
2.2.4 status	
2.3 quality	
2.3.1 clarity	no information available
2.3.2 accuracy	very good data; externally checked
2.3.3 completeness	minor gaps, which have been reconstructed
2.4 sources	Registration of emissions (1989)
2.5 overall assessment	good
2.6 comment	emissions of thermal energy production included
3 economic input	9.28 MJ electrical energy (Netherlands electricity model)
4 environmental input	
4.1 resources	0.468 kg oil
	1.016 kg brine
4.2 space	2.3 $m^2 \cdot s$
5 economic output	1 kg PVC
	0.01 kg waste chlorine production
	0.015 kg mixed waste (hazardous composition)
6 environmental output	
6.1 emissions to the air	0.0014 kg vinylchloride
	0.0017 kg 1-2-dichloroethane
	0.0000003 kg Cl
	0.0014 kg hydrocarbons
6.2 emissions to water	0.0003 kg 2-chloroethanol
	0.0012 kg trichloroethanol
	0.000019 kg phenol
6.3 emissions to the soil	0.0004 kg scrap
6.4 radiation	none
6.5 sound	unspecified, assumed to be negligible
6.6 heat	approx. 9 MJ to air; none to water
6.7 light	none
6.8 accidents	approx. 10^{-15} victim
7 balances	
7.1 mass balancing item	0.2 kg more input than output; maybe emitted as steam?
7.2 energy balancing item	all missing energy assumed as emission of heat to air
8 comment/other	plant attracts a lot of traffic, including many trucks at night

BACKGROUNDS

§2.2 – the process data
§2.3 – the format

2.3 Application of the allocation rules

INTRODUCTION

Generally the process file will contain processes with more than one output with an economic value. In this event the processes may not have been defined at the most elementary level. If possible the data on the elementary processes should be collected during step 2.2. However, processes will remain for which this cannot be done, such as the combined production of fodder and pharmaceutics from abattoir waste. In such cases a calculation will have to be made, between entering the process data (step 2.2) and the aggregation to the inventory table (step 2.4) to distribute the environmental interventions of such a *multiple process* to the product system in question and the other product systems*. This step – step 2.3 – is known as *allocation*†. Using *allocation rules* the economic inputs and environmental interventions of such a process are divided among the co-products. Essentially allocation is used to split the actual multiple processes into a number of fictitious single processes. The sum of the single processes adds up to the multiple process.

There are three types of multiple processes:

- co-production (concurrent production of several materials, products, services, etc., including waste with a positive value);
- combined waste processing (concurrent processing of several waste flows with a negative value);
- open-loop recycling‡ (processing waste from one product system to material which can be reused in another product system).

These three types could also be considered as a single type, in which case the waste processing process should be considered a service, i.e. an output, and the status of services is similar to that of products§.

Two questions have to be answered for each multiple process to be allocated:

- what is allocated and to what?
- how is the allocation made?

In principle the aim is to make the allocation on a causal basis whenever possible. When this is impossible overall apportioned allocation has to be used, for which some basis will have to be found. For this purpose step 2.3 is divided into two sub-steps.

2.3.1 Causal allocation

An analysis of the causal relationships has to be made to answer the above two questions ("what and to what" and "how"). This analysis may be partly chemical-analytical and partly economic in nature as the causality may be either chemical or economic.

The causality is often of a physical nature. Zinc ore contains cadmium, hence zinc and cadmium are produced together and also emitted together. Hence the question arises whether cadmium emissions should be allocated to zinc or vice versa. Mercury emissions by waste incinerators can be allocated

* A process with more than one output with an economic value is sometimes referred to as a *multiple output process* (MO-process); in this case step 2.3 includes a transformation to a *single output process* (SO-process). The terms "outputs with an economic value", "commercial outputs" and "co-products" are equivalent.

† There is some confusion about the term allocation as it is commonly used in a wider context. According to some allocation is actually the issue at the heart of an LCA: which part of the environmental problems on Earth should be allocated to the functional unit under consideration?

‡ In practice a large part of the allocation problem associated with open-loop recycling will be covered in step 2.1 when the process tree is drawn up. In step 2.3 no more will be left than, for example, the distribution of an upgrading process among the two product systems, or the introduction of a degradation factor to quantify the deteriorating quality of the material.

§ In this way all types are reduced to the production of co-products. Hence the terms MO-process and SO-process are also used for the other two types. A more specific term is *multiple input process* (MI-process) or *input-output process* (IO-process), both of which are covered by the term *multiple process*.

to the mercury content of each mercury-containing product to be incinerated. However, NO_x from the same incinerator depends on the calorific value of the products.

In other cases the causality is of an economic nature. Due to market forces processes are "adjusted" in a certain way. The price determines whether something is a material or waste: when there is a demand for the substance its price will be positive as it is a useful output.

The social or physical causality has to be investigated in each case as it is impossible to provide a uniform guideline. In principle, causal allocation may be used for the comprehensive analysis of combined waste processing. At present however, many aspects are unclear and in practice many emissions will require overall apportioned allocation.

2.3.2 Overall apportioned allocation

In many cases it may be difficult or even impossible to allocate all interventions properly through an analysis of the causal relationships. Electricity consumption for the co-production of chlorine and caustic soda provides an example of this. There is no obvious reason for allocating this parameter to just one of the co-products. Hence, it can be allocated to the co-production in the same way as a town council divides up certain costs per capita of the local population.

The function should be central to determining the basis for overall apportioned allocation. In many industrial processes it can be claimed that mass provides a good reflection of the function. For other processes this may be area (e.g. for galvanizing), number of items or another physical parameter. In other cases the economic value provides the best indication of the function as it provides a measure of the social causality*. An economic allocation key is also an obvious choice when the SI unit in which the function is expressed is different for some of the co-products.

GUIDELINES

- Allocations are made to outputs with a positive economic value (or, where there is no external market, which have a useful application). The other flows (flows to and from the environment, economic inputs and economic outputs of zero or negative value) are the items which are allocated.
- Whenever possible the causal links should be determined first in an analysis. In this way part of the allocation problem may be neatly solved.
- The remaining allocation problems are solved by overall apportioned allocation.
- If the outputs to which the allocations are made have different units the allocation has to be made on the basis of economic value.
- For co-production allocation is generally made to the relevant physical unit. Normally this will be the unit in which the outputs, to which the allocation is made, are expressed. Generally, this will be mass, although area is not unusual.
- If the economic values of the outputs differ greatly for each physical unit, the allocation is made on the basis of economic value.
- If the allocation key could be open to dispute, it is advisable to use two or more variations of the allocation and consider the difference between the results as a measure of the reliability (see step 4.2).

EXAMPLE

The electricity production process is combined with that of steam for district heating. Table 2.2 lists both the original process as well as the two allocated processes. As some of the steam finds a useful application but is not the main reason for operating the processes, the secondary flows were largely allocated to electricity on the basis of an economic value ratio of $3 \div 1$. The pipes were only allocated to the steam as they are mainly used to transport this. This is one of the reasons why heat emissions were fully allocated to the steam.

* In the co-production of pharmaceutics and animal fodder the pharmaceutics amount to more than 90% of the revenue while their share of the mass is less than 10%.

TABLE 2.2. Example of the allocation of process data: the secondary flows of the coproduction (first column) of electricity and steam are divided between the single processes (second and third columns).

process parameter	multiple process	single process 1	single process 2
economic inputs			
km pipe	0.2	0	0.2
environmental inputs			
kg crude oil	1.0	0.9	0.1
economic outputs			
MJ electricity	3	3	0
MJ steam	1	0	1
environmental outputs			
kg NO_x to the atmosphere	1.0	0.9	0.1
MJ heat to water	0.2	0	0.2

. . . . BACKGROUNDS . . . .

§2.1 – the system boundaries

2.4 Creating the inventory table

. . . . INTRODUCTION . . . .

All environmental interventions of all processes for each functional unit of a product should be as fully quantified as possible. This will provide a large amount of data. For each process concerned there will be a list giving the magnitude of the direct environmental interventions of that process in proportion to that process's contribution to the functional unit. There will also be a list of all economic inputs and outputs required to make that contribution to the functional unit. These inputs and outputs define the relationships with the other processes. The section listing the environmental interventions is known as the *inventory table* of the process.

After step 2.1 the processes to be considered will be apparent. The data for each of these processes collected in step 2.2 is presented in its original state wherever possible. The decisions about allocation are made in step 2.3. All that is left in step 2.4 is to calculate the contribution of each process and present these processes in the correct ratios. By adding the inputs and outputs of all the processes concerned the environmental interventions of the complete product system can be determined. In this way the inventory table for the entire product system is defined. Any references made to *the* inventory table are to this table*.

By definition the product system will not have any inputs from or outputs to the economy after steps 2.1 to 2.4: all demand for and supply of products, materials, energy, services and waste to be processed has been translated to inputs from and outputs to the environment†. The only exception to this rule is the function performed by the product system itself, which is expressed in the functional unit. The product system itself can be described as a process, hence it can be fitted into the format (Table A.1). The natural choice is to use the same format, including the comments on the representativeness and quality of the data as determined in the goal definition.

* Another common term for this is eco-balance or environmental balance. It is advisable not to use these terms as they are sometimes used for the outcome of the classification (here: environmental profile). Furthermore, technically speaking, it is not actually a balance.

† Furthermore there are also the *p.m.* items which represent an interaction with the economy which is not zero but has been adjusted to zero.

It may be useful to divide the inventory table of the product or product system into sub-inventory tables relating to processes or substances. Providing further detail at the level of individual processes or groups of processes is particularly important when making recommendations for product improvement based on a dominance analysis (step 5.1). A distinction between the process groups in the summary process tree (step 2.1) is often required.

The following sub-steps can be distinguished:

- quantification of the environmental interventions;
- representation of the qualitative environmental interventions.

The overall outcome of the empirical inventory is a quantified overview, supplemented with non-quantifiable interventions, of all the environmental interventions which occur during the life cycle of a product.

2.4.1 Quantification of the environmental interventions

When the process tree is compiled the environmental interventions for each single process are calculated first by quantifying the process volume. For a good understanding of the backgrounds to the interventions it is recommended that the contribution of all specified processes is included as an appendix for each product alternative. This may produce a very large volume of data. An easy method has been developed in the backgrounds document to this guide by which the volume of the process, including that of networks and recursive processes can be calculated. It would be inappropriate to include this method (based on matrix algebra) in the guide.

2.4.2 Representation of the qualitative environmental interventions

All non-quantifiable information could be lost during the quantification step described above. This could include environmental interventions such as the fragmentation of areas by road construction which at present cannot be quantified. To include these aspects an item "qualitative aspects" will have to be included*. Often this item will not permit a clear distinction between the environmental intervention and the environmental impact. Strictly speaking the qualitative *interventions* should be included in step 2.4, while the resulting *impacts* should be included in step 3.3. In practice step 3.3 will involve a considerable repetition of step 2.4 or contain a reference to it.

GUIDELINES

- The quantitative occurrence of all processes in the process tree can be determined by drawing up mass and energy balances for each economic input: the sum of all occurrences in each process must be zero for each economic unit, with the exception of the process producing the functional unit.
- Thereafter the inventory table for the functional unit can be determined by calculating, for each environmental intervention, the sum of all the occurrences of these interventions.
- Additionally, all unquantified interventions for each process are combined and included in the inventory table of the functional unit.
- When a number of products are being compared and a conclusion can clearly be drawn by comparing the inventory tables, the classification and evaluation steps will not have to be carried out. However, the reliability and sensitivity of the result (step 4.2) will need to be determined.

EXAMPLE

This example provides an illustration of the matrix method discussed in the backgrounds document. This example is only relevant to readers interested in using the matrix method.

Table 2.3 includes the data for four processes and the kernel process representing the results of the complete product system.

When applied to the economic part of the process tree the matrix method results in

* Here qualitative is used as the opposite of quantitative, with the meaning "unquantifiable or only partly quantifiable".

TABLE 2.3. Four imaginary processes to illustrate the matrix method. Note that the processes are interconnected: electricity production requires aluminium and vice versa.

process / entity	electricity production	aluminium production	aluminium foil production	aluminium foil use	kernel process
MJ electricity	1	−50	−1	0	0
kg aluminium	−0.01	1	−1	0	0
kg aluminium foil	0	0	1	−1	0
100 sandwich bags	0	0	0	1	0.1
kg bauxite	0	−5	0	0	?
kg crude oil	−0.5	0	0	0	?
kg CO_2	3	0	0	0	?
kg solid waste	2	10	0	1	?

$$A = \begin{bmatrix} 1 & -50 & -1 & 0 \\ -0.01 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2.3)$$

with determinant det(A) = 0.5. Furthermore

$$A^1 = \begin{bmatrix} 0 & -50 & -1 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \\ 0.1 & 0 & 0 & 1 \end{bmatrix} \quad (2.4)$$

hence the determinant det(A^1) equals 5.1. The occurrence of the first process is now described by

$$p_1 = \frac{\det(A^1)}{\det(A)} \quad (2.5)$$

and is therefore equal to 5.1/0.5 = 10.2. In the same manner the other determinants are found to be 0.01, 0.05 and 0.05 respectively and the other occurrences 0.202, 0.1 and 0.1 respectively.

Aggregation over the complete process tree results in the following environmental interventions

$$\beta = \begin{bmatrix} -1.01 \\ -5.1 \\ 30.6 \\ 22.52 \end{bmatrix} \quad (2.6)$$

This refers to the extraction of 1.01 kg bauxite and 5.1 kg crude oil, the emission of 30.6 kg CO_2 and the production of 22.52 kg solid waste.

A fairly simple example was chosen. Hence a more complicated example now follows as an example of an inventory table (the inventory table for milk cartons; Table 2.4).

. . . . BACKGROUNDS . . . .

§2.4 – the inventory table

TABLE 2.4. Example of the inventory table of a functional unit; the life cycle of a milk carton, the functional unit is "packaging 1 litre of milk".

1 format	
1.1 name or institute	Centre of Environmental Science
1.2 date	31-OCT-1992
1.3 comment	this is only a hypothetical example!
2 process	
2.1 name or code	milk packaging in carton
2.2 representativeness	
2.2.1 scale	situation in the Netherlands, covering 30% of the market
2.2.2 dating	around 1988
2.2.3 duration or capacity	average consumption rate: 1.5 day/consumer
2.2.4 status	combination of estimated and empirical data
2.3 quality	
2.3.1 clarity	accidental emissions not included
2.3.2 accuracy	overall clarity: sufficient
2.3.3 completeness	most items present, emissions of CO2 have been deducted
2.4 sources	calculated with data from SimaPro 1.0
2.5 overall assessment	a little out of date, but still reliable
2.6 comment	this design does not refer to any actual product
3 economic input	none (this is a life cycle)
4 environmental inputs	
4.1 resources	$9.9302 \cdot 10^{-4}$ kg apatite
	$7.4564 \cdot 10^{-4}$ kg coal
	$4.5919 \cdot 10^{-3}$ kg coating materials (considered as p.m.)
	$5.0600 \cdot 10^{-2}$ kg wood (notice that wood is considered here as a resource, whereas it is actually grown in a production forest)
4.2 space	5 $m^2 \cdot s$ (no information concerning type of space consumption)
5 economic output	life cycle of 1 carton milk package
6 environmental output	
6.1 emissions to the air	$2.9080 \cdot 10^{-3}$ kg CO_2
	$7.4392 \cdot 10^{-5}$ kg NO_x
	$6.5580 \cdot 10^{-5}$ kg dust
	$1.4927 \cdot 10^{-5}$ kg hydrocarbons (unspecified)
6.2 emissions to water	$2.1733 \cdot 10^{-7}$ kg H_2S
	$2.0240 \cdot 10^{-6}$ kg aluminum
	$1.1056 \cdot 10^{-5}$ kg other pollutants (unspecified!)
	$8.8163 \cdot 10^{-6}$ kg total nitrogen
6.3 emissions to the soil	$3.0245 \cdot 10^{-5}$ kg aluminium
	$4.2098 \cdot 10^{-4}$ kg ash
6.4 radiation	no information available
6.5 sound	12 $Pa^2 \cdot s$
6.6 heat	15.2 MJ to air
6.7 light	no information available
6.8 accidents	no information available
7 balances	
7.1 mass balancing item	none
7.2 energy balancing item	none
8 comments/other	some drying occurs during wood growth

CHAPTER 3

CLASSIFICATION

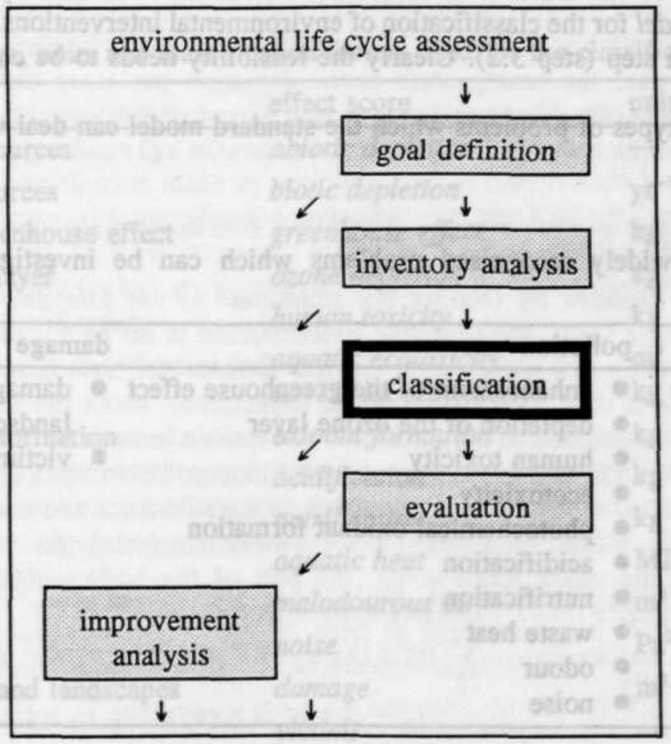

FIGURE 3.1. During the classification component of an LCA the potential environmental impact of interventions in the environment is determined.

Models are used to interpret the environmental interventions of a product (or rather a functional product unit). These models indicate how environmental interventions eventually lead to potential environmental effects. The environmental effects describe the contribution a functional unit of product makes to environmental problems. This includes environmental problems such as acidification, depletion of the ozone layer, etc. Eventually this results in the *environmental profile** of the product under consideration. During the classification the physical and other environmental interventions are projected onto the potential environmental effects in four steps:

- selection of the problem types (page 42);

* You are referred to footnote * on page 37 for other terms such as eco-balance.

- definition of the classification factors (page 43);
- creating the environmental profile (page 46);
- normalization of the effect scores (page 48).

Comprehensive guidelines have been drawn up for the first two steps. These provide a ***standard model*** for the classification. These steps provide the opportunity to deviate from the model provided the reasons for this are substantiated. The actual calculations are carried out during the third and fourth steps.

3.1 Selection of the problem types

INTRODUCTION

The problems which the assessment will address are selected in step 3.1. These will be exclusively *environmental* problems. The assessment could include other environmental problems than those used here. The *standard model* for the classification of environmental interventions as environmental effects is provided in the next step (step 3.2). Clearly the feasibility needs to be considered when selecting the type of problems.

Table 3.1 lists the types of problems which the standard model can deal with*.

TABLE 3.1. List of widely recognised problems which can be investigated with the standard classification model.

depletion	pollution	damage
• depletion of abiotic resources • depletion of biotic resources	• enhancement of the greenhouse effect • depletion of the ozone layer • human toxicity • ecotoxicity • photochemical oxidant formation • acidification • nutrification • waste heat • odour • noise	• damage to ecosystems and landscapes • victims

GUIDELINES

- ■ The provisional classification system is shown in Table 3.1. It indicates the environmental effects under consideration and which are to be used in step 3.2.
- ■ If necessary, a different set may be chosen provided the reasons for this are given.

EXAMPLE

The standard classification model was largely followed in this study. However, due to lack of data the damage to ecosystems and landscapes has not been considered.

BACKGROUNDS

§3.1 – general principles

* As explained above this table lists environmental effects, not environmental interventions, such as energy consumption and waste production.

3.2 Definition of the classification factors

INTRODUCTION

This section describes how the effect scores of the environmental effects listed in Table 3.1 can be calculated. The backgrounds document explains the range of models available to describe environmental processes. This section provides the standard model for the classification of environmental interventions as environmental effects. Classification models other than this standard model may be selected in step 3.2 of the life cycle assessment procedure. When another model is selected an explanation should be given in this step. The standard model specifies the environmental effects which should be considered in the assessment. The model is described in Table 3.2 and explained in the guidelines*. The calculations should be carried out as described in the guidelines unless good reasons have been given for departing from the standard model.

TABLE 3.2. Effect scores, units and classification factors used for the classification.

environmental effect	effect score	unit	classification factor
depletion of abiotic resources	*abiotic depletion*	—	1/reserves
depletion of biotic resources	*biotic depletion*	yr^{-1}	BDF
• enhancement of the greenhouse effect	*greenhouse effect*	kg	GWP
• depletion of the ozone layer	*ozone depletion*	kg	ODP
• human toxicity	*human toxicity*	kg	HCA, HCW, HCS
• ecotoxicity	*aquatic ecotoxicity*	m^3	ECA
	terrestrial ecotoxicity	kg	ECT
• photochemical oxidant formation	*oxidant formation*	kg	POCP
• acidification	*acidification*	kg	AP
nutrification	*nutrification*	kg	NP
waste heat	*aquatic heat*	MJ	1
odour	*malodourous air*	m^3	1/OTV
noise	*noise*	$Pa^2 \cdot s$	1
damage to ecosystems and landscapes	*damage*	$m^2 \cdot s$	1
victims	*victims*	—	1

GUIDELINES

- The depletion of abiotic raw materials is assessed by comparing the nett quantity used of each raw material with the reserves (Table B.1 on page 65) of that raw material. This produces a dimensionless expression:

$$abiotic\ depletion = \sum_i \frac{material\ use_i(\text{kg})}{reserves_i(\text{kg})} \tag{3.1}$$

- The depletion of biotic raw materials is assessed by comparing the nett quantity used of each raw material with its reserves and its reserves/production-ratio. These two together provide a *biotic depletion factor* (BDF; Table B.2 on page 65). The result is an expression in yr^{-1}:

* The calculation method for some aspects has not yet been fully developed, or essential data to make the calculations is lacking. A temporary solution to some of these aspects is provided. Other aspects will have to be disregarded for the time being. The backgrounds document discusses how all these aspects may be implemented eventually.

$$biotic\ depletion(yr^{-1}) = \sum_i BDF_i(kg^{-1}\cdot yr^{-1}) \times material\ use_i(kg) \quad (3.2)$$

- For some substances which contribute to the enhancement of the greenhouse effect parameters have been developed in the form of a *global warming potential* (GWP; see Table B.3 on page 66). These parameters can be used to express the potential direct* contribution to the greenhouse effect in a single effect score. The GWP is a relative parameter which uses CO_2 as a reference†: the extent to which a mass unit of a given substance can absorb infrared radiation compared with a mass unit of CO_2. In this way atmospheric emissions (in kg) can be converted to CO_2 emissions (in kg) with an equivalent greenhouse effect:

$$greenhouse\ effect(kg) = \sum_i GWP_i \times emission_i\ to\ the\ air(kg) \quad (3.3)$$

- For some substances which contribute to the depletion of the ozone layer parameters have been developed in the form of an *ozone depletion potential* (ODP; see Table B.4 on page 67). These parameters can be used to express the potential contribution which these substances make to the depletion of the ozone layer in a single effect score. The ODP is a relative parameter which uses CFC-11 as a reference: the *steady state* ozone depletion per mass unit of gas emitted to the atmosphere per year is calculated relative to that of a mass unit of CFC-11. In this way atmospheric emissions (in kg) can be converted to CFC-11 emissions (in kg) resulting in an equivalent depletion of the ozone layer:

$$ozone\ depletion(kg) = \sum_i ODP_i \times emission_i\ to\ the\ air(kg) \quad (3.4)$$

- Human toxicity is assessed by relating the emissions‡ to the *tolerable daily intake* (TDI), the *acceptable daily intake* (ADI), the *tolerable concentration in air* (TCL), the *air quality guidelines*, the *maximum tolerable risk level* (MTR) or the *C-value for soil based on human toxicology considerations*. This is data from toxicological experiments about the maximum daily intake or concentration which is considered acceptable. A conversion is made so that emissions to water, the atmosphere and soil can be combined in an acceptable way. This results in the definition of *human toxicological classification factors* which depend on the substance and the environmental medium concerned (see Table B.5 on page 68): for the atmosphere (HCA), for water (HCW) and for soil (HCS). The unit of the effect score is kg: the part of the body weight in kg exposed to the toxicologically acceptable limit. This is calculated as follows:

$$\begin{aligned} human\ toxicity(kg) = \sum_i & HCA_i(kg\cdot kg^{-1}) \times emission_i\ to\ the\ air(kg) + \\ & HCW_i(kg\cdot kg^{-1}) \times emission_i\ to\ water(kg) + \\ & HCS_i(kg\cdot kg^{-1}) \times emission_i\ to\ the\ soil(kg) \end{aligned} \quad (3.5)$$

- The assessment of substances with an ecotoxic effect on species in the ecosystem is based on *maximum tolerable concentrations* (MTCs) determined according to the EPA-method. This results in the definition of two groups of *ecotoxicological classification factors*: one for aquatic ecosystems (ECA) and one for terrestrial ecosystems (ECT); see Table B.6 on page 77. The unit of aquatic ecotoxicity is m^3 polluted water:

$$aquatic\ ecotoxicity(m3) = \sum_i ECA_i(m^3\cdot mg^{-1}) \times emission_i\ to\ water(mg) \quad (3.6)$$

and for terrestrial ecosystems, it is kg polluted soil:

* The indirect contribution is included as a qualitative aspect, see §3.3.1.

† In addition to CO_2 another reference gas which is commonly used is CFC-12. As CFC-11 is also used occasionally the term GWP should be used with some caution.

‡ In the context of this study it was proposed that the properties of toxic substances in the environment be included in the assessment. This has already been done with some other effect scores; for GWP for example, the degradation of the substance in the environment has also been considered. For human toxicity this results in the definition of a *human toxicity potential* (HTP) and a reference substance. However, HTP has not yet been implemented.

$$terrestrial\ ecotoxicity(\text{kg}) = \sum_i ECT_i(\text{kg}\cdot\text{mg}^{-1}) \times emission_i\ to\ the\ soil(\text{mg}) \quad (3.7)$$

- *Photochemical ozone creation potential* parameters (POCP; see Table B.7 on page 83) have been developed* for some substances† which contribute to the formation of photochemical oxidants. These values can be used to express the potential contribution made by these substances to this problem as a single effect score. The POCP is a relative measure which uses ethylene (C_2H_4) as a reference: the extent to which a mass unit of a substance forms oxidants compared with a mass unit of ethylene. In this way atmospheric emissions (in kg) can be converted to ethylene emissions (in kg) with equivalent oxidant formation:

$$oxidant\ formation(\text{kg}) = \sum_i POCP_i \times emission_i\ to\ the\ air(\text{kg}) \quad (3.8)$$

- The contribution to acidification made by various forms of intervention in the environment can be determined by weighting with *acidification potentials* (AP; see Table B.8 on page 86) which are a measure of the propensity to release H^+ compared with sulfur dioxide (SO_2). Atmospheric emissions (in kg) are converted, using the AP, to sulfur dioxide emissions (in kg) resulting in equivalent acidification:

$$acidification(\text{kg}) = \sum_i AP_i \times emission_i\ to\ the\ air(\text{kg}) \quad (3.9)$$

- The contribution to nutrification made by various forms of intervention in the environment can be determined by weighting with *nutrification potentials* (NP; see Table B.9 on page 87) which are a measure of the capacity to form biomass, compared with phosphate (PO_4^{3-}). Emissions to the atmosphere, water or soil (in kg) are converted, using the NP, to an equivalent phosphate emission (in kg) in terms of nutrification:

$$nutrification(\text{kg}) = \sum_i NP_i \times emission_i(\text{kg}) \quad (3.10)$$

- Until the consequences of waste heat have been sufficiently determined, the release of heat, as a form of environmental intervention, can only be taken directly from the inventory analysis and aggregated. Only waste heat emissions into water are included:

$$aquatic\ heat(\text{MJ}) = energy\text{-}emissions_{\text{water}}(\text{MJ}) \quad (3.11)$$

- The odour threshold values in air (OTV; see Table B.10 on page 87) which have been determined for the most important substances can be used to assess odours. Atmospheric emissions are converted to the volume of air polluted up to the odour threshold:

$$malodourous\ air(\text{m}^3) = \sum_i \frac{emission_i\ to\ the\ air(\text{kg})}{OTV_i(\text{kg}\cdot\text{m}^{-3})} \quad (3.12)$$

- To assess noise, sound production data from the inventory analysis are aggregated:

$$noise(\text{Pa}^2\cdot\text{s}) = sound(\text{Pa}^2\cdot\text{s}) \quad (3.13)$$

- As the exhaustive effects of space use are inextricably bound up with displacement effects, they are combined in a single effect score. A maximum of ten forms of intervention of this nature are collected during the inventory. At present categories I, II and III are considered "natural" and categories IV and V as "unnatural". Thus the ten forms of intervention are combined in a single effect score with the unit $m^2\cdot s$:

* As the use of the POCP for this purpose is disputed, a further indication could be obtained by adding the quantities of VOC and NO_x without further weighting; see step 4.2.

† No POCP has yet been defined for nitrogen oxides hence the quantity of NO_x emitted is included separately as a "flag", see §3.3.1.

$$damage\,(m^2 \cdot s) = space\ use_{I \rightarrow IV}(m^2 \cdot s) + space\ use_{I \rightarrow V}(m^2 \cdot s) + space\ use_{II \rightarrow IV}(m^2 \cdot s) + space\ use_{II \rightarrow V}(m^2 \cdot s) + space\ use_{III \rightarrow IV}(m^2 \cdot s) + space\ use_{III \rightarrow V}(m^2 \cdot s) \quad (3.14)$$

■ In the inventory analysis processes hazards were determined as the number of fatalities directly attributable to an accident. This parameter is included in the classification without further weighting:

$$victims = number\ of\ victims \quad (3.15)$$

EXAMPLE

The standard method was used for all problems listed in step 3.1. An effect score for radiation was also introduced by relating the data in the inventory analysis on radiation released to the ***annual limit of intake*** (ALI).

BACKGROUNDS

§3.1 – general principles
§3.2 – operationalisation
§3.3 – development of the classification factors

3.3 Creating the environmental profile

INTRODUCTION

An inventory table listing the environmental interventions associated with a functional unit of a product was drawn up during the inventory analysis. A table containing the potential environmental effects in the form of *effect scores* can now be drawn up by sorting, weighting and adding up all the interventions. The models in step 3.2 are used to sort and add up all the weighted data. The table of effect scores is known as the *environmental profile*. Besides the method described in the guide there are several other procedures for calculating effects on the basis of interventions, each based on different models and premises. The choice made in this guide may be debatable, therefore it has not been included in the inventory analysis, which should be as objective as possible*.

The environmental profile is created in two sub-steps:

- quantification of the environmental effects;
- representation of the qualitative environmental effects.

Often it is not only desirable to create an environmental profile for the product system but also to calculate it at the level of processes or groups of processes, or substances or groups of substances. Thus creating the environmental profile is very similar to drawing up the inventory table (step 2.4).

3.3.1 Quantification of the environmental effects

Once the modelling choices have been made (see step 3.2) calculating the effect scores and creating the environmental profile are relatively easy. The formulas described in step 3.2 or defined by the user are applied to all the environmental interventions in the inventory table, to calculate the potential contribution of each environmental effect in the environmental profile.

Often the quantified effect scores will be presented as a graph as well as in a table. The contribution of the various process groups to each effect score is easily visualized in a bar graph by

* However, the reason for separating the inventory analysis and classification is the fact that the subjects of the study, and therefore the disciplines concerned, are different. The inventory analysis is about economic processes while the classification is about environmental processes.

building each bar up with different colours or shading. The most widely used product or the highest effect score can be used as the 100% level in a bar graph. However, there are also some disadvantages. A graphical representation may assist in the comprehension of information but this will only be from a certain perspective. It is easy to create the wrong impression. For example the worst product alternative could be set at 100% as a result of which all other alternatives will appear to be about equally good. This can be improved by using a logarithmic scale but this often leads to problems of interpretation. It will have to be decided in each individual case whether some form of normalization or the use of a logarithmic scale provides an acceptable form of presentation.

A graph could also result in an implicit evaluation: "five longer bars and three shorter bars means that there is an increase", without a discussion of the relative significance of the different problems.

3.3.2 Representation of the qualitative environmental effects

Besides the quantified effects there are also unquantifiable effects. This is initially due to the unquantified environmental interventions (see step 2.4) in the inventory table. The second cause is that it is not possible to model all quantified interventions in step 3.2. For example, some substances are known to be toxic but there is no further information available about their toxicity. Thus, they cannot be quantified with the standard model. The GWP of some greenhouse gases is under discussion because their direct contribution has been excluded (see Table B.3). The use of the POCP is also being discussed. We recommend that the total (unweighted) quantities of VOC and NO_x are listed as additional information.

Such cases can be included in the qualitative part of the environmental profile. This information may put the bar graphs referred to above in a completely different light. However, this should be considered in the evaluation rather than in the classification.

GUIDELINES

- The standard classification model (possibly amended or extended) is applied to the quantitative part of the inventory table.
- Forms of intervention which may contribute to more than one effect (CFC emissions for example contribute to the greenhouse effect as well as to ozone depletion) are included more than once.
- The qualitative aspects of the inventory table appear as a qualitative part of the environmental profile, wherever possible in the form of effects.
- It is preferable not to use graphs at this stage as they may give the wrong impression or depend solely on the choice of scale used in the graphs.
- Caution is advised when discussing the environmental profile, otherwise the classification could include an implicit evaluation.
- When products are being compared it may happen that all effect scores and all qualitative aspects point in the same direction. In such an event there will be no need to take steps 3.4 and 4.1. However, the reliability and validity will have to be considered; see step 4.2.

EXAMPLE

Table 3.3 lists the fictitious environmental profiles for two types of desk chair.

Notes:

- the process data on wood production was very incomplete;
- VOC emissions are estimates, hence the effect score for oxidant formation is rather unreliable;
- the inventory analysis provided no data on noise, space use and victims.

BACKGROUNDS

§3.1 – general principles

TABLE 3.3. Example of an environmental profile: comparison of two desk chairs.

effect score	desk chair 1	desk chair 2
abiotic depletion	0.10	0.11
biotic depletion (yr^{-1})	0	0
greenhouse effect (kg)	12	17
ozone layer depletion (kg)	0	0.002
human toxicity (kg)	13.2	9.2
aquatic ecotoxicity (m^3)	0.03*	0.01
terrestrial ecotoxicity (kg)	0.02	0.03
oxidant formation (kg)	$1 \cdot 10^{-7}$	$3 \cdot 10^{-8}$
acidification (kg)	1.1	2.7
nutrification (kg)	2.3	3
malodourous air (m^3)	$3 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
noise ($Pa^2 \cdot s$)	?	?
damage ($m^2 \cdot s$)	?	?
victims	?	?

* Uncertain due to the lack of some classification factors.

3.4 Normalization of the effect scores

INTRODUCTION

It is difficult to interpret the effect scores which constitute the environmental profile. The reason for this is that the order of magnitude and units of the various effect scores differ. Strictly speaking, it is not necessary to interpret the effect scores in the classification, rather this task should be undertaken during the evaluation. Nevertheless, a step has still been included in which the effect scores, and thus the environmental profile, become more meaningful by adding purely empirical information.

The effect scores are normalized in this step. The contribution made by a given product to an environmental effect is linked to the contribution made by a given community to the same problem over a given period of time. The scale of the community considered here should match the model on which the classification is based. For the global standard model this means that the global contribution over a certain period is calculated using the same classification model. The period of time used to calculate the contribution is irrelevant as this is expressed in the resulting unit. Generally the contribution over a year can be obtained from annual statistical reports or other sources.

The ratio between each effect score and the global contribution to that effect score over a year provides the *normalized environmental profile* consisting of *normalized effect scores*, all of which are expressed in years.

The normalization of the effect scores has not been included in this guide as it was not possible to calculate all global contributions in accordance with the standard model. In principle this should not be too difficult: data is available for a range of effect scores (depletion of abiotic resources, enhanced greenhouse effect, depletion of the ozone layer). However, this is much more difficult for effects lower down on the scale (toxicity, noise). As a temporary solution the normalization could be based on the quantities for e.g. the Netherlands.

GUIDELINES

- To make the effect scores of the environmental profile more meaningful they can be normalized by relating them to the magnitude of the problem in a given period. For this purpose the same classification model should be used as that used to draw up the environmental profile; the difference being that the magnitude of the environmental intervention in one year, for example, is used as the input data rather than the magnitude of the environmental intervention of a single functional unit. This results in a normalized environmental profile, comprising a number of normalized effect scores all with the unit yr. For an effect score expressed in kg this results in:

$$\textit{normalized effect score}(\mathrm{yr}) = \frac{\textit{effect score}(\mathrm{kg})}{\textit{annual volume}(\mathrm{kg{\cdot}yr^{-1}})} \tag{3.16}$$

- Although these normalized effect scores have the same unit they should never be added to each other in the classification.
- While information about the global magnitude of the effect scores is not available, the magnitude in e.g. the Netherlands alone will have to be used.
- As it will continue for some time to be difficult to obtain all the required information for the normalization this step will often have to be dispensed with.

EXAMPLE

The environmental profile used in the preceding step was normalized. Table 3.4 lists the scale of the (purely fictitious) global contributions and the normalized effect scores.

TABLE 3.4. Example of a normalized environmental profile: the example used in the preceding step was normalized using fictitious data about global volumes in one year.

normalized effect score	desk chair 1	desk chair 2
abiotic depletion (yr)	$8.0 \cdot 10^{-7}$	$8.8 \cdot 10^{-7}$
biotic depletion (yr)	0	0
greenhouse effect (yr)	$3.6 \cdot 10^{-11}$	$5.1 \cdot 10^{-11}$
depletion of the ozone layer (yr)	0	$3.0 \cdot 10^{-15}$
human toxicity (yr)	$6.1 \cdot 10^{-9}$	$4.6 \cdot 10^{-9}$
aquatic ecotoxicity (yr)	$3.0 \cdot 10^{-7}$*	$2.0 \cdot 10^{-7}$
terrestrial ecotoxicity (yr)	$2.0 \cdot 10^{-12}$	$3.0 \cdot 10^{-12}$
oxidant formation (yr)	$1.0 \cdot 10^{-17}$	$3.0 \cdot 10^{-18}$
acidification (yr)	$5.5 \cdot 10^{-4}$	$1.35 \cdot 10^{-3}$
nutrification (yr)	$4.6 \cdot 10^{-8}$	$6.0 \cdot 10^{-8}$
malodourous air (yr)	$6.0 \cdot 10^{-14}$	$2.0 \cdot 10^{-14}$
noise (yr)	?	?
damage (yr)	?	?
victims (yr)	?	?

* Unclear due to the lack of some classification factors.

BACKGROUNDS

§3.1 – general principles

CHAPTER 4

EVALUATION

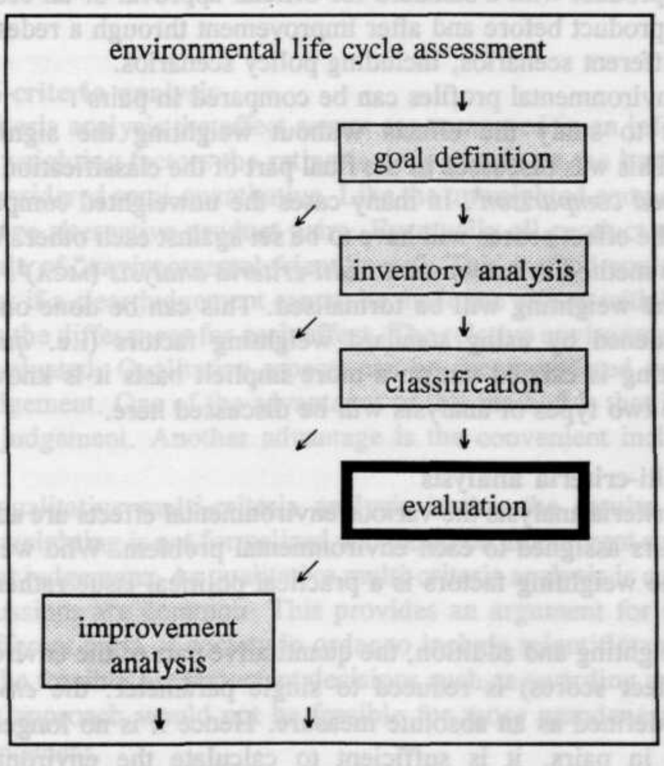

FIGURE 4.1. During the evaluation the results of the classification are evaluated in two respects: the effect scores are weighted or weighed, and the reliability is examined.

The potential environmental effects of the products can be evaluated on the basis of the environmental profiles drawn up during the classification. The relative magnitudes of the effect scores are an important element in this. The validity of the environmental profiles is also relevant to the evaluation. The environmental profile should always be evaluated, unless a product alternative has a higher or lower score for all effects (see step 3.3). However, even in this case the validity will still need to be considered.

Thus the evaluation consists of two steps:

- evaluation of the environmental profile (page 52);
- evaluation of the reliability and validity (page 54).

During the first step the effect scores in the environmental profiles of each product alternative are assessed. Two methods for this assessment will be discussed: quantitative multi-criteria analysis and qualitative multi-criteria analysis. Each of these methods has its own advantages and disadvantages. In step 4.2 the outcome of the evaluation will be examined in the context of the reliability and validity of all steps carried out during the life cycle assessment. This may result in a refinement of the conclusion. Therefore this step should not be omitted in the evaluation of an environmental profile, even when it is not necessary to weight or weigh the effect scores.

4.1 Evaluation of the environmental profile

INTRODUCTION

Evaluation of the different environmental profiles drawn up during the classification will generally involve a comparison*:

- comparison of a number of products;
- comparison of a product with a standard for official approval or an ecolabel;
- comparison of a product before and after improvement through a redesign;
- comparison of different scenarios, including policy scenarios.

In all these cases the environmental profiles can be compared in pairs†.

The first option is to study the effects without weighting the significance of the various environmental effects. This was discussed as the final part of the classification (step 3.3), where it was referred to as *unweighted comparison*‡. In many cases the unweighted comparison will not result in a clear conclusion and the effect scores will have to be set against each other. When the environmental effects are weighted the method is known as a *multi-criteria analysis* (MCA)§. If the weighting factors are explicitly defined the weighting will be formalised. This can be done on an *ad hoc* basis or the validity could be broadened by using standard weighting factors (i.e. *quantitative multi-criteria analysis*). If the weighting is carried out on a more implicit basis it is known as *qualitative multi-criteria analysis*. These two types of analysis will be discussed here.

4.1.1 Quantitative multi-criteria analysis

In a quantitative multi-criteria analysis the various environmental effects are added after multiplication with the weighting factors assigned to each environmental problem. Who weights the environmental effects or determines the weighting factors is a practical political issue rather than a methodological matter.

As a result of the weighting and addition, the quantitative part of the environmental profile (which consists of a set of effect scores) is reduced to single parameter: the *environmental index*. The environmental index is defined as an absolute measure. Hence it is no longer necessary to compare environmental profiles in pairs, it is sufficient to calculate the environmental index for each environmental profile and to arrange them on an interval scale¶.

One of the advantages of this method is that the result is reproducible and does not depend on experts' estimates. However this requires a consensus about the weighting factors used. Given a standard set of weighting factors the method is also quick and cheap.

A major disadvantage of quantitative multi-criteria analysis is that it is difficult to deal with the

* The most important application of LCA which is not included here is in innovation. During the improvement analysis (Chapter 5) recommendations for a redesign are made on the basis of an understanding of the process tree and the environmental effects. Improvements due to these recommendations can then be assessed in a comparative LCA (see Figure 5.2).

† The comparison of N products will require at most $\frac{1}{2}N(N-1)$ paired comparative assessments. This number will often be smaller due to the transitive properties of an ordinal scale: when it is known that product A is worse than product B and that product B has a poorer score than product C it is clear that product A will also be inferior to product C.

‡ This is often referred to as *dominance analysis*. However in this report this term is reserved for the analysis in step 5.1.

§ Alternative terms include multi-criteria method and multi-criteria evaluation.

¶ There is no ratio scale since there is no proper origin; this is because many choices have been made, about the inclusion of capital goods and the selection of relevant environmental effects, for example.

qualitative aspects. These qualitative aspects may be regarded as unquantified increases or decreases in the effect scores. As they are unquantified they can only be included as qualitative aspects in the environmental index as a comment on the number. One way of dealing with qualitative aspects is to provide a rough quantitative indication and evaluate the sensitivity of the result.

Another disadvantage, this time of a more psychological nature, is that the creation of an environmental index might suggest scientific accuracy. However, due to the methodological choices made in the goal definition, inventory analysis, classification and evaluation the outcome has gradually become less objective.

However, the main problem associated with quantitative multi-criteria analysis is the definition of the weighting factors. The backgrounds document gives the technical requirements which the weighting factors must meet and the solutions available. This report does not provide any weighting factors. However, it will be an interesting challenge to attempt to develop the basis provided in the background document and eventually to provide a set of weighting factors like the classification factors which reflect current scientific and social values. This set could be included as an appendix to the next version of this guide.

4.1.2 Qualitative multi-criteria analysis

In a qualitative multi-criteria analysis the effect scores are compared in an informal way. This means that instead of defining weighting factors the rating is done purely on the basis of expert judgement. This method could be considered semi-quantitative. Like the unweighted comparison, this method will generally be used to judge alternative product pairs. Eventually all product alternatives can then be plotted on an ordinal scale of "environmental-friendliness". This method could be used subsequent to unweighted comparisons: if a clear judgement cannot be made the effects with higher and lower scores are considered as well as the differences for each effect. The relative environmental-friendliness of two products can then be evaluated. Qualitative aspects can be accommodated without difficulty in this individual subjective judgement. One of the advantages of this method is that it will almost always be possible to arrive at a judgement. Another advantage is the convenient inclusion of all qualitative aspects.

A disadvantage of qualitative multi-criteria analysis is that the results will often be open to discussion. Because the weighting is not formalized and based on an inherent subjectivity someone else could arrive at a different judgement. As qualitative multi-criteria analysis is currently the most widely used method such discussions are common. This provides an argument for setting up a panel with representatives from different parts of society in order to include scientific and social opinions in the judgement. This would be feasible for important decisions such as awarding an official environmental approval. However this approach would not be feasible for more mundane applications such as in-company product improvement.

There are many different ways to judge effect scores. The simplest method is by crossing them off ("three higher effects and five lower effects works out as less"). A more thorough approach would be to use a semi-quantitative scale, for example by ranging the differences from − − − to + + +, and calculating the net result. The disadvantage of these methods is that there is no link with the seriousness of the problems. Extremely abstract parameters such as kg CFC-11 equivalent and moles H^+ are used in the calculations and an approach in which more of one is offset by less of another leads to very odd conclusions. An example of this is provided by a comparison of landfilling and incinerating waste. Incineration produces dioxins but landfilling results in less energy recovery. Besides using normalization* making a comparison on the basis of a scientifically or socially accepted level could be considered. This would demonstrate that waste incineration is responsible for a large part of the dioxin production while the recovered energy amounts to only a small proportion of the overall energy consumption. This does not result in a weighting of the problems but at least the abstract parameters in the environmental profile have been replaced by aspects of a problem whose consequences are known to some extent. In this way the evaluation can be made on a more responsible

* To be able to make a better estimate of the significance of these differences it was suggested that the effect scores be compared with the global magnitude of the problem in step 3.4.

basis.

The advantages and disadvantages of quantitative and qualitative MCA are listed in Table 4.1 and compared with the advantages and disadvantages of unweighted comparisons.

TABLE 4.1. Each method for the evaluation of environmental profiles has advantages and disadvantages in terms of its application and validity.

	unweighted comparison	qualitative MCA	quantitative MCA
convincing		+	+
includes qualitative aspects	+	+	−
reproducible	+	−	+
less open to discussion	+	−	□

Legend: +: yes; □: moderately; −: no.

. . . . GUIDELINES . . . .

- There are two methods for the evaluation of environmental profiles: quantitative and qualitative multi-criteria analyses. Quantitative multi-criteria analysis is preferable as it provides greater transparency but at present it is only used to a limited extent, if at all.
- As the evaluation will, for the time being, mostly be undertaken through qualitative multi-criteria analysis, the highest possible level of transparency should be aimed for. Hence, the reasons for preferring one product alternative over another will have to be specified in discussion.

. . . . EXAMPLE . . . .

As an unweighted comparison of the effect scores in the previous example (step 3.4) did not result in a conclusion and as weighting factors are not yet available, an informal weighting was provided by a panel including representatives of the client and those undertaking the assessment (see step 1.2 for a list of those involved). The panel's view was that alternative 1 is better for more effect scores but that the scores in which 2 does better are more important (toxicity!). However, the major contribution to acidification made by both alternatives means that the lesser of the two (1) is preferred.

. . . . BACKGROUNDS . . . .

§4.1 – quantitative multi-criteria analysis

4.2 Evaluation of the reliability and validity

. . . . INTRODUCTION . . . .

The reliability and validity of the results of the life cycle assessment will be assessed during this step. Reliability depends on the influence of uncertainty in the data. Validity is about the effects of choices and assumptions. These two subjects will be discussed separately in the sensitivity analysis:

- reliability analysis;
- validity analysis.

This step examines the value of the calculations and conclusions made in previous steps. This may affect all components (goal definition, inventory analysis, classification and evaluation). For example, it may be that the functional unit was not defined accurately enough in the goal definition, the quality of process data affects the inventory analysis, the classification depends on the choice of standards and the evaluation depends on the weighting factors. In many cases a sensitivity analysis can be used to convert uncertainties to variations and sub-variations of the product system. If this does not affect the results of the life cycle assessment this indicates that the reliability is high.

Uncertain assumptions are made in all components of a life cycle assessment. These uncertainties affect the end results and in some cases they may result in drastic changes in the conclusion. Hence it is advisable to make an early estimate of certain uncertainties and to determine the stability of the results through a sensitivity analysis. The guidelines below show how, and during which steps of an LCA, this can be done.

4.2.1 Reliability analysis

A reliability analysis is used to determine the effects of uncertainties in the data. It is worthwhile to attempt to obtain estimates of the uncertainty margins of some process data. Such information about some classification factors is listed in the tables in Appendix B. A mathematical method to calculate the effects of these uncertainties has been developed in the backgrounds document. If the basic information required (such as the uncertainty of the process data) is known this method can be used systematically to determine the reliability of the outcome.

Marginal analysis (see also backgrounds document and step 5.2) can identify the process data whose magnitude has a major effect on the results. It is advisable to employ marginal analysis to determine the crucial process data and then to ensure that this data is as accurate as possible.

4.2.2 Validity analysis

Validity analysis is used to estimate the validity of the result in view of the assumptions and choices made during the course of the project. This includes choices and assumptions associated with the method (e.g. the decision to allocate open-loop recycling to two product systems in a particular way) as well as choices and assumptions associated with the study itself (e.g. the number of times return packaging is actually returned). There are many assumptions and choices. It would be impossible to include a complete list of important topics here. The guidelines and backgrounds document contain some examples.

Another option is an analysis of the reversal points. During such an analysis a choice is changed until the conclusion is reversed. A reversal may be defined as the point where the other alternative suddenly becomes more environmentally friendly, for example by varying the life span of a product. The likelihood of this life span can then be discussed. Missing classification factors can also be determined artificially in this way in order to discuss the effects of the absence of these classification factors.

GUIDELINES

- The functional unit may be formulated differently in the goal definition. For example, in a comparison of plastic coffee cups and porcelain cups, the calculations could be performed for cups with and without saucers.
- During the inventory analysis the exact definition of the system boundary in step 2.1 should not be relevant, so the inclusion of capital goods, for example, should not change the conclusion.
- In step 2.2 – when the process data are collected – there are generally some uncertainties included in the data. The aim is to provide a clear presentation by using the format and by estimating the quality of the data. However, the data will often be obtained from indefinite sources. In this step the estimate of the quality of individual process data, which in step 2.2 was converted to an estimate of the reliability of the complete data set, is extended to provide an estimate of the reliability of the inventory table or the environmental profile.
- The allocation rules used will also affect the outcome. Wherever possible it may be useful to assess the influence of alternative allocation rules.
- Soundly-based scientific knowledge about the effects of emissions, etc. is used for the classification. In practice, there is often a problem in that substances are released for which there is no information available about their harmful effects. In such cases a value may be determined by analogy with related substances. Alternatively, the magnitude of the harmful effect may be determined at which the conclusion of the study changes, after which the acceptability of this value can be discussed.

- This method can also be used in the evaluation of the weighting factors. By determining the magnitude of the weighting factors at which the conclusion changes, the sensitivity of the results to these factors can be assessed.
- For some of the process data there are estimates of its uncertainty in the form of margins, e.g. 12 ± 2. The range of the data is also known for some classification factors. The backgrounds document discusses a method requiring extensive calculations to determine the effects of these uncertainties on the inventory table, the environmental profile and the environmental index.
- A method of determining the influence of marginal changes in the process data has been developed for the improvement analysis (step 5.2). This method provides information about changes in the inventory table, environmental profile or environmental index as a function of such changes in the process data. However, this method can also be used to investigate which process data must be most accurately defined because a marginal change could have such a major impact.
- In view of the reliability analysis, it is better to estimate an unknown data item than to omit it. The reliability analysis may well show that the item is of minor importance but the insignificance of the actual value of the item can then be demonstrated even more clearly.

EXAMPLE

The uncertainty of the process data is not known. A marginal analysis shows that there is only one process parameter where a minor inaccuracy has an amplified effect: a 1% uncertainty in the energy consumption of the production process of PE results in a 3.2% uncertainty of the effect score for acidification. Verification through other sources confirms the magnitude of the process parameter.

When an alternative which can be used repeatedly is returned 40 times instead of 30 times the conclusions do not alter significantly. Between 40 times and 121 times (unrealistic), only the effect score for the depletion of the ozone layer reverses. It is likely that the lack of a classification factor for some of the emitted substances has little effect on the toxicity effect scores.

You are referred to the appendix for a discussion of the numerical method. In general the evaluation of the environmental profile will be relatively insensitive to variations in the most obvious parameters.

BACKGROUNDS

§4.2 – sensitivity analysis
§5.2 – marginal analysis

CHAPTER 5

IMPROVEMENT ANALYSIS

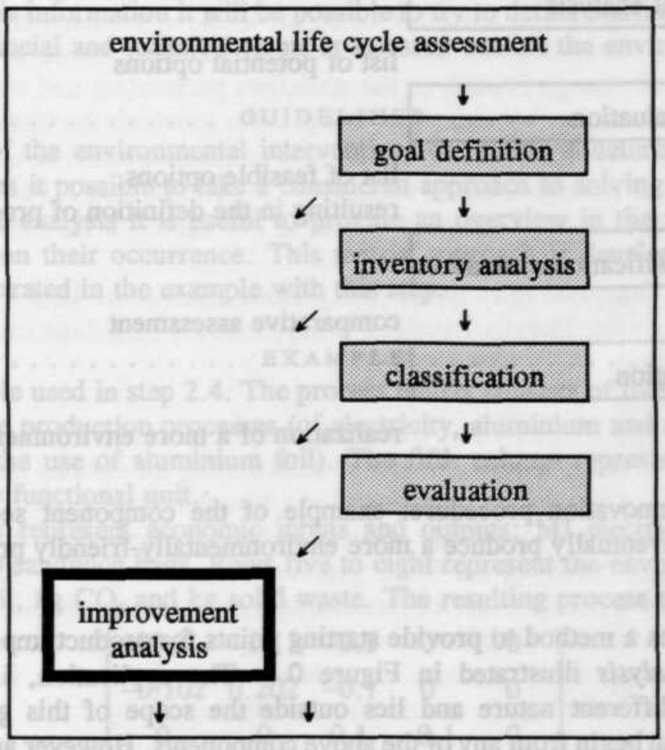

FIGURE 5.1. In the improvement analysis the information gathered during the inventory analysis, classification and evaluation is used to provide starting points for product improvement.

As discussed in the introduction a life cycle assessment may be used for a range of applications: product information, regulation, product innovation and the development of policy strategies. All these applications involve a *decision* which is not exclusively based on environmental considerations. This extends beyond the field of environmental life cycle assessment and requires the application of other disciplines such as consumer research, process engineering, cost-benefit analysis, etc. As shown in Figure 0.1 the guide does not include the analysis of other aspects and applications.

Product improvement is more complicated. An understanding of the process tree, of the processes concerned from the extraction of raw materials to all their emissions and the potential environmental effects to which the environmental interventions contribute provides *starting points* for product improvement. Once it is established which processes and substances make a significant contribution to the environmental profile an effective search can be made to find a more environmentally-friendly redesign or for process modifications. Other skills will then be needed to assess the feasibility of these recommendations. This will then lead to a decision which is taken partly on the basis of the environmental LCA. Process engineers, economists and market specialists will have to judge whether the suggestions are feasible in technical, financial and marketing terms. Product improvement is a cyclic process: any improvements suggested will have to be assessed in the light of their effectiveness. It is always possible to look for other options for product improvement. Figure 5.2 provides an example for a life cycle assessment procedure for product innovation.

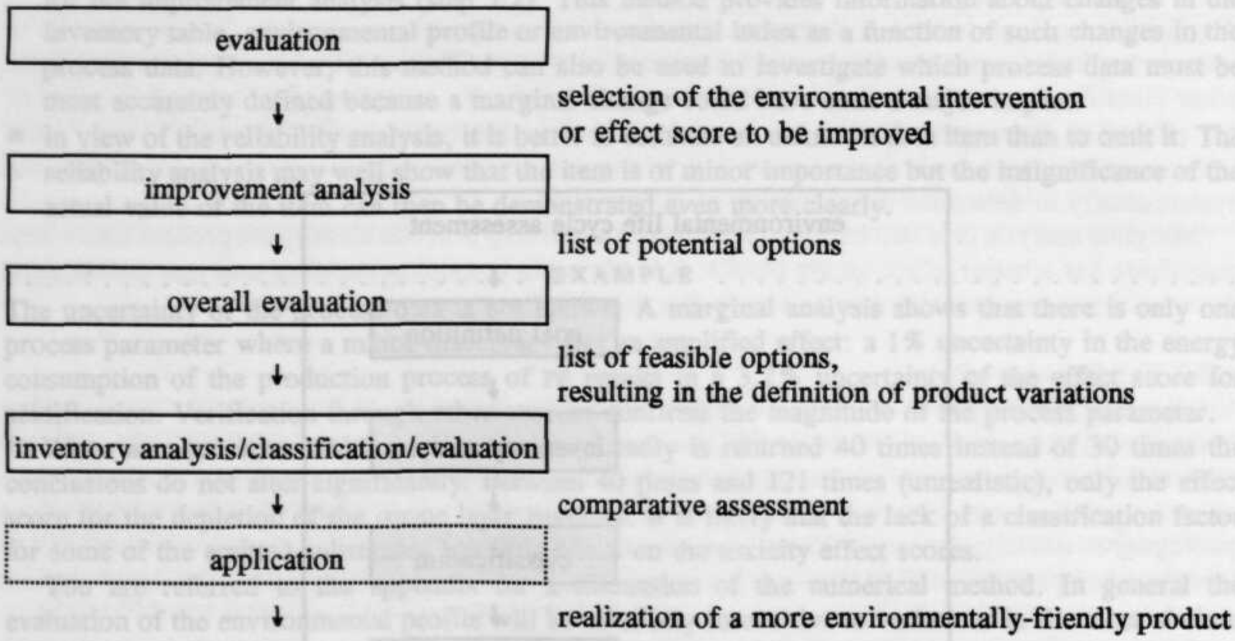

FIGURE 5.2. Product innovation procedure: example of the component sequence in a life cycle assessment which will eventually produce a more environmentally-friendly product.

This chapter describes a method to provide starting points for product improvement. This method is the *improvement analysis* illustrated in Figure 0.1. The application, i.e. the actual *product improvement*, is of a different nature and lies outside the scope of this guide. In principle, an improvement analysis can begin from any of the above components. However an improvement analysis is unlikely to start at the goal definition. The reason for this is that the product properties in the goal definition do not provide enough information about the interaction between the product system and the environmental system. The inventory table and the environmental profile however, provide excellent bases for an improvement analysis. The improvement analysis can be divided into two supplementary analysis techniques:

- dominance analysis (page 58);
- marginal analysis (page 60).

These methods will be discussed below.

5.1 Dominance analysis

INTRODUCTION

A dominance analysis is used to identify those substances and processes responsible for a substantial part of the environmental interventions, environmental effects or the environmental index. Knowledge of these dominant aspects provides a starting point for the redesign of more environmentally-friendly products. Examples include:

- the use of less material;
- the use of alternative materials;
- changing process engineering aspects;
- logistical changes;
- etc.

During the inventory analysis a process tree was drawn up in step 2.1. Normally this will be a summary process tree which includes sub-process trees. Comprehension may be aided by subdividing the inventory table, environmental profile or environmental index at the process level. This can be done using a *process matrix* which provides an overview of all the processes and all data and its occurrences. Dominant aspects of the inventory table may be revealed by studying the environmental part of this matrix. The volume of data could be reduced to a manageable level through aggregation by process groups as used in the summary process tree, i.e. by creating an inventory table or environmental profile for the production stage, the usage stage, maintenance, etc.

The parts of the life cycle where the major problems occur can be identified quickly with this method. Armed with this information it will be possible to try to define starting points. The feasibility of the indicators in financial and technical terms is assessed outside the environmental LCA.

GUIDELINES

- The "true origin" of the environmental interventions or effects is determined in the dominance analysis which makes it possible to take a considered approach to solving a problem.
- During a dominance analysis it is useful to provide an overview in the form of a matrix of all process data based on their occurrence. This matrix approach is developed in the backgrounds document. It is illustrated in the example with this step.

EXAMPLE

We return to the example used in step 2.4. The process matrix consists of five columns. The first four columns represent three production processes (of electricity, aluminium and aluminium foil) and one consumptive process (the use of aluminium foil). The fifth column represents the fully aggregated process resulting in the functional unit.

The first four rows represent economic inputs and outputs: MJ electricity, kg aluminium, kg aluminium foil and 100 sandwich bags. Rows five to eight represent the environmental interventions: kg bauxite, kg crude oil, kg CO_2 and kg solid waste. The resulting process matrix looks like this:

$$\begin{bmatrix} 10.2 & -10.1 & -0.1 & 0 & 0 \\ -0.102 & 0.202 & -0.1 & 0 & 0 \\ 0 & 0 & 0.1 & -0.1 & 0 \\ 0 & 0 & 0 & 0.1 & 0.1 \\ 0 & -1.01 & 0 & 0 & -1.01 \\ -5.1 & 0 & 0 & 0 & -5.1 \\ 30.6 & 0 & 0 & 0 & 30.6 \\ 20.4 & 2.02 & 0 & 0.1 & 22.52 \end{bmatrix} \tag{5.1}$$

Most of the waste (22.52 kg) is due to electricity production (20.4 kg, i.e. about 90%). The economic section also shows that the production of aluminium accounts for the largest share (10.1 MJ, i.e. 99%) of the electricity consumption (10.2 MJ).

Improvements in the subsequent design process may be found in a different choice of material for the functional unit, improving the efficiency of the aluminium production process, the use of a different energy source for aluminium production and waste reduction during electricity production.

BACKGROUNDS

§5.1 – dominance analysis

5.2 Marginal analysis

INTRODUCTION

A dominance analysis clearly shows the processes or emissions which are largely responsible for high effect scores. One of the problems associated with dominance analysis is that changes in the economic inputs and outputs of a process are not easily traced. When an economic process parameter is changed it implies that a number of processes in the process tree are used to a greater or lesser extent. As a result a minor change in an economic process parameter can have a major effect on the inventory table; a greater effect than would be expected from the dominance analysis. Obviously some economic process parameters could be changed and the complete inventory table recalculated. This would be time consuming and would be incompatible with the method of systematic process improvement described. However, the information provided by the quantified process tree can be used to undertake a *marginal analysis*, which provides information about the effects of marginal process changes on the inventory table.

The crux of the method is that marginal changes in an environmental intervention (inventory analysis), environmental effect (classification) or the environmental index (evaluation) are studied as a function of the marginal change in each of the economic parameters and environmental parameters of the processes. This illustrates the changes in the process to which the intervention, effect or index is most sensitive. In this way the inventory table, environmental profile or environmental index may be improved considerably through a small change in the process data*. The method shows where a small modification will have a major effect. Whether or not this small modification can be carried out easily is a different matter.

Marginal analysis is described fully in the backgrounds document. This form of analysis requires a large number of calculations. Marginal analysis is impractical unless these calculations can be carried out by a computer program.

GUIDELINES

- In theory marginal analysis is a powerful tool in determining the options for product improvement. The method has yet to prove itself in practice. It is a new development which has still to be applied and assessed. The approach is described in detail in the backgrounds document.
- An effective method of handling the large quantity of numbers is to make a list in which the calculated numbers are listed in order of decreasing magnitude (in absolute terms).
- There is a close link with the reliability analysis in step 4.2: process data in which small changes may have major consequences are also process data which have to be calculated extremely accurately. Hence marginal analysis should also be used carefully.

EXAMPLE

Marginal analysis was applied to the example in step 2.4 and step 5.1. Solid waste ($k = 4$) was selected as the environmental intervention. The elements calculated were included in a matrix:

$$\begin{bmatrix} -1.902 & 1.883 & 0.019 & 0 & 0 \\ 0.996 & -1.973 & 0.977 & 0 & 0 \\ 0 & 0 & -0.996 & 0.996 & 0 \\ 0 & 0 & 0 & -1.000 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0.906 & 0.090 & 0 & 0.004 & 1 \end{bmatrix} \tag{5.2}$$

The largest number, in absolute terms, is −1.973 which refers to the quantity of aluminium created

* The numbers obtained are approximations which are only valid if the marginal change is small.

by the aluminium production process. This means that if the efficiency of the process is increased by 1% the total volume of waste will be reduced by approximately 1.9%.

.... BACKGROUNDS ....

§5.2 – marginal analysis

APPENDIX A

FORMAT FOR STORING PROCESS DATA

This appendix describes the conceptual format for the storage of process data. Technical specifications concerning decimal points, record length, etc. are not included.

TABLE A.1. Main structure of the format. The shaded level gives an optional further subdivision of the preceding level. The decimal classification may be used for simple references.

level 1	level 2	level 3	code
format	name or institute		1.1
	date		1.2
	comment		1.3
process	name or code		2.1
	representativeness	scale	2.2.1
		date	2.2.2
		duration	2.2.3
		status	2.2.4
	quality	clarity	2.3.1
		accuracy	2.3.2
		completeness	2.3.3
	sources		2.4
	overall assessment		2.5
	comment		2.6
economic input			3
	goods		3.1
	services		3.2
	materials		3.3
	energy		3.4
	waste to be processed		3.5
environmental input	resources		4.1
		abiotic resources	4.1.1
		biotic resources	4.1.2
		energy carriers	4.1.3

level 1	level 2	level 3	code
	space		4.2
economic output			5
	goods		5.1
	services		5.2
	materials		5.3
	energy		5.4
	waste to be processed		5.5
environmental output	emissions to air		6.1
	emissions to water		6.2
	emissions to soil		6.3
	radiation		6.4
	sound		6.5
	heat		6.6
	light		6.7
	accidents		6.8
balances	mass balancing item		7.1
	energy balancing item		7.2
comments/other			8

APPENDIX B

CLASSIFICATION FACTORS

This appendix contains tables with classification factors to indicate how the classification is carried out according to the standard model. The formulas to be used are also repeated. You are referred to the guidelines in step 3.2 for an explanation of how to use the tables.

B.1 Depletion

B.1.1 Depletion of abiotic resources

TABLE B.1. Classification factors for the effect score abiotic depletion.

formula	substance	reserves	unit
energy carriers			
—	crude oil	123,559	Mton
—	natural gas	109,326	10^9 m^3
U	uranium	1,676,820	ton
metals			
Cd	cadmium	0.535	Mton
Cu	copper	350	Mton
Pb	lead	75	Mton
Hg	mercury	0.005,7	Mton
Ni	nickel	54	Mton
Sn	tin	4.260	long Mton
Zn	zinc	147	Mton

Recoverable reserves of abiotic resources whose reserves may become insufficient within 100 years. Source: *World Resources Institute* (1990-1991). The effect score for the depletion of abiotic resources is calculated as follows:

$$\textit{abiotic depletion} = \frac{\textit{material use}\,(\text{kg})}{\textit{reserves}\,(\text{kg})} \qquad (\text{B.1})$$

B.1.2 Depletion of biotic resources

TABLE B.2. Classification factors for the depletion of biotic resources.

species	BDF
black rhino	$4 \cdot 10^{-5}$
great indian elephant	?
northern white rhino	?
sumatran rhino	?
african elephant	$4 \cdot 10^{-8}$
Kemp's Ridley sea turtle	?
chinese alligator	?
cuban crocodile	?
estuarine crocodile	?
morelet's crocodile	?
siamese crocodile	?
sperm whale	$2 \cdot 10^{-6}$
humpback whale	$1 \cdot 10^{-7}$
fin whale	$2 \cdot 10^{-5}$
blue whale	?

Biotic depletion factor (BDF) in yr^{-1} for a number of animal species threatened with extinction. Sources: World Resources Institute, 1990: *World Resources 1990-1991. A report by the World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme.* Oxford University Press, New York/Oxford; World Wildlife Fund, 1990: *Atlas of the environment. The most up-to-date report on the state of the world.* Arrow Books Ltd., London. The effect score for biotic depletion is calculated with:

$$\textit{biotic depletion}(yr^{-1}) = \textit{BDF}(yr^{-1}) \times \textit{species use} \tag{B.2}$$

B.2 Pollution

B.2.1 Enhancement of the greenhouse effect

TABLE B.3. Classification factors for the effect score greenhouse effect.

formula	substance	GWP_{20}	GWP_{100}	GWP_{500}	indirect
CO_2	carbon dioxide	1	1	1	0
CH_4	methane	35	11	4	+
N_2O	dinitrogen oxide	260	270	170	0
$CFCl_3$	trichlorofluoromethane (CFC-11)	4,500	3,400	1,400	–
CF_2Cl_2	dichlorodifluoromethane (CFC-12)	7,100	7,100	4,100	–
CF_3Cl	chlorotrifluoromethane (CFC-13)	11,000	13,000	15,000	–
CF_4	tetrafluoromethane (CFC-14)	>3,500	>4,500	>5,300	0
CHF_2Cl	chlorodifluoromethane (HCFC-22)	4,200	1,600	540	–
$C_2F_3Cl_3$	1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)	4,600	4,500	2,500	–
$C_2F_4Cl_2$	1,2-dichlorotetrafluoroethane (CFC-114)	6,100	7,000	5,800	–
C_2F_5Cl	chloropentafluoroethane (CFC-115)	5,500	7,000	8,500	–
C_2F_6	hexafluoroethane (CFC-116)	>4,800	>6,200	>7,200	0
$CHCl_2CF_3$	1,1-dichloro-2,2,2-trifluoroethane (HCFC-123)	330	90	30	–

formula	substance	GWP_{20}	GWP_{100}	GWP_{500}	indirect
$CHFClCF_3$	1-chloro-1,2,2,2-tetrafluoroethane (HCFC-124)	1,500	440	150	–
CHF_2CF_3	pentafluoroethane (HFC-125)	5,200	3,400	1,200	0
CH_2FCF_3	1,1,1,2-tetrafluoroethane (HFC-134a)	3,100	1,200	400	0
CH_3CFCl_2	1,1-dichloro-1-fluoroethane (HCFC-141b)	1,800	580	200	–
CH_3CF_2Cl	1-chloro-1,1-difluoroethane (HCFC-142b)	4,000	1,800	620	–
CH_3CF_3	1,1,1-trifluoroethane (HFC-143a)	4,700	3,800	1,600	0
CH_3CHF_2	1,1-difluoroethane (HFC-152a)	530	150	49	0
CCl_4	tetrachloromethane (HC-10)	1,800	1,300	480	–
CH_3CCl_3	1,1,1-trichloroethane (HC-140a)	360	100	34	–
CF_3Br	bromotrifluoromethane (HALON-1301)	5,600	4,900	2,300	–
$CHCl_3$	trichloromethane (chloroform)	92	25	9	–
CH_2Cl_2	dichloromethane	54	15	5	–
CO	carbon monoxide	—	—	—	+
—	non-methane hydrocarbons (NMHC)	—	—	—	+
NO_x	nitrogen oxides	—	—	—	0

Global warming potential (GWP) relative to CO_2, with time horizons of 20, 100 and 500 years. The last column provides a qualitative indication of the indirect contribution to the greehouse effect: +: positive indirect contribution; –: negative indirect contribution; 0: no indirect contribution. Source: Houghton, J.T., B.A. Callander & S.K. Varney, 1992: *Climate change 1992. The supplementary report to the IPCC scientific assessment*. Cambridge University Press, Cambridge. The effect score of the greenhouse effect is calculated with:

$$\textit{greenhouse effect}(\text{kg}) = GWP \times \textit{emission to the air}(\text{kg}) \quad \text{(B.3)}$$

B.2.2 Depletion of the ozone layer

TABLE B.4. Classification factors for the effect score ozone depletion.

formula	substance	ODP	range
$CFCl_3$	trichlorofluoromethane (CFC-11)	1.0	1.0-1.0
CF_2Cl_2	dichlorodifluoromethane (CFC-12)	1.0	0.88-1.06
$C_2F_3Cl_3$	1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)	1.07	0.92-1.07
$C_2F_4Cl_2$	1,2-dichlorotetrafluoroethane (CFC-114)	0.8	0.57-0.82
C_2F_5Cl	chloropentafluoroethane (CFC-115)	0.5	0.29-0.5
CHF_2Cl	chlorodifluoromethane (HCFC-22)	0.055	0.032-0.08
$CHCl_2CF_3$	1,1-dichloro-2,2,2-trifluoroethane (HCFC-123)	0.02	0.013-0.020
$CHFClCF_3$	1-chloro-1,2,2,2-tetrafluoroethane (HCFC-124)	0.022	0.016-0.034
CH_3CFCl_2	1,1-dichloro-1-fluoroethane (HCFC-141b)	0.11	0.10-0.12
CH_3CF_2Cl	1-chloro-1,1-difluoroethane (HCFC-142b)	0.065	0.035-0.07
	HCFC-225ca	0.025	0.016-0.025
	HCFC-225cb	0.033	0.023-0.033
CCl_4	tetrachloromethane (HC-10)	1.08	1.03-1.15
CH_3CCl_3	1,1,1-trichloroethane (HC-140a)	0.12	0.11-0.13
CF_3Br	bromotrifluoromethane (HALON-1301)	16	10.0-17.2
CF_2BrCl	bromochlorodifluoromethane (HALON-1211)	4	1.8-5.0

formula	substance	ODP	range
	HALON-1202	1.25	1.25-1.7
$C_2F_4Br_2$	dibromotetrafluoroethane (HALON-2402)	7	5.9-10.2
	HALON-1201	1.4	1.4-1.4
	HALON-2401	0.25	0.25-0.4
	HALON-2311	0.14	0.14-0.3
CH_3Br		0.6	0.44-0.7

Ozone depletion potential (ODP) relative to CFC-11, with an indication of the range. Source: World Meteorological Organization, 1991: *Scientific assessment of ozone depletion: 1991.* Global Ozone Research and Monitoring Project – Report no. 25. The ozone depletion effect score is calculated with:

$$ozone\ depletion(\text{kg}) = ODP \times emission\ to\ the\ air(\text{kg}) \qquad (B.4)$$

B.2.3 Human toxicity

TABLE B.5. Classification factors for the effect score human toxicity.

formula	substance	HCA	HCW	HCS
metals				
As	arsenic	4,700	1.4	0.043
Ba	barium	1.7	0.14	0.019
Cd	cadmium*	580	2.9	7.0
Cr^{3+}	chromium(III)	6.7	0.57	0.018
Cr^{6+}	chromium(VI)	47,000	4,100	130
Co	cobalt	24	2.0	0.065
Cu	copper	0.24	0.020	0.005,2
Fe	iron (excluding iron oxides)	0.042	0.003,6	
	iron oxides	0.067	0.005,7	
Pb	lead	160	0.79	0.025
Mn	manganese	120		
Hg	mercury	120	4.7	0.15
	methylmercury (as Hg)	120	7.1	0.15
Mo	molybdenum	3.3	0.29	0.70
Ni	nickel	470	0.057	0.014
Sn	tin	0.017	0.001,4	0.000,045
V	vanadium	120		
Zn	zinc	0.033	0.002,9	0.007,0
inorganic compounds				
NH_4^+	ammonium	0.020	0.001,7	
	asbestos	†		
Br^-	bromide	0.033	0.002,9	
	calcium disodium-EDTA	0.013	0.001,1	
CO	carbon monoxide	0.012		

formula	substance	HCA	HCW	HCS
CN^-	cyanide (free)	0.67	0.057	1.4
	cyanide (bound in complex; as CN)	2.6	0.22	5.4
	EDTA	→ calcium disodium-EDTA		
F^-	fluoride	0.48	0.041	
H_2S	hydrogen sulfide	0.78		
NO_3^-	nitrate	0.009,1	0.000,78	
NO_2^-	nitrite	0.26	0.022	
NO_x	nitrogen oxides‡	0.78		
	phosphates (excluding sodium aluminium-phosphate; as P)	0.000,48	0.000,041	
	sodium aluminium phosphate	0.005,6	0.000,48	
SO_3^{2-}	sulfite	0.038	0.003,3	
	sulfur dioxide (combined with black (coal) smoke)	2.3		
SO_2	sulfur dioxide§	1.2		
SCN^-	thiocyanate	3.0	0.26	6.4
unhalogenated aromatic hydrocarbons				
C_6H_6	benzene	3.9	0.66	
	catechol	→ 1,2-dihydroxybenzene		
	cresols	0.67	0.057	0.46
$C_6H_4(OH)_2$	dihydroxybenzenes (general)	1.3	0.11	
	1,2-dihydroxybenzene (catechol)	0.83	0.071	1.4
	1,3-dihydroxybenzene (resorcinol)	1.7	0.14	2.8
	1,4-dihydroxybenzene (hydroquinone)	1.3	0.11	2.4
$C_6H_5C_2H_5$	ethylbenzene	1.5	0.021	0.15
	hydroquinone	→ 1,4-dihydroxybenzenes		
	2-hydroxybiphenyl	→ 2-phenylphenol		
C_6H_5OH	phenol	0.56	0.048	0.62
$C_6H_4C_6H_5OH$	2-phenylphenol (2-hydroxybiphenyl)	1.7	0.14	
	phthalates (general)	1.3	0.11	
	di(2-ethyl)hexylphthalate	1.3	0.11	0.002,9
	butylbenzylphthalate	1.3	0.11	0.092
C_5H_5N	pyridine	33	2.9	31
	resorcinol	→ 1,3-dihydroxybenzenes		
$C_6H_5CHCH_2$	styrene (vinylbenzene)	0.15	0.037	0.17
$C_6H_5CH_3$	toluene	0.039	0.006,6	0.098
	vinylbenzene	→ styrene		

formula	substance	HCA	HCW	HCS
	xylenes	2.2	0.29	1,5
	halogenated aromatic hydrocarbons			
	chlorobenzenes (general)	0.19	5.7	
C_6H_5Cl	monochlorobenzene	0.11	0.009,5	0.073[¶]
$C_6H_4Cl_2$	1,2-dichlorobenzene	0.19	0.004,8	
$C_6H_4Cl_2$	1,4-dichlorobenzene	0.097	0.015	0.042[¶]
$C_6H_3Cl_3$	1,2,4-trichlorobenzene	0.19	5.7	6.8
$C_6H_2Cl_4$	1,2,3,4-tetrachlorobenzene	0.19	5.7	3.9
C_6HCl_5	pentachlorobenzene	0.19	5.7	2.9
C_6Cl_6	hexachlorobenzene	0.19	5.7	2.6
	chlorophenols (general; excluding pentachlorophenol)	11	0.95	0
C_6H_4ClOH	2-monochlorophenol	11	0.95	4.5
$C_6H_3Cl_2OH$	2,4-dichlorophenol	11	0.95	2.1
$C_6H_2Cl_3OH$	2,3,4-trichlorophenol	11	0.95	1.3[¶]
C_6HCl_4OH	2,3,4,5-tetrachlorophenol	11	0.95	2.9[¶]
C_6Cl_5OH	pentachlorophenol (PCP)	1.1	0.095	0.98[¶]
	dioxin	→ 2,3,7,8-TCDD		
	PCP	→ pentachlorophenol		
	polychlorobiphenyls (general)	370	32	
$C_6H_3Cl_2C_6H_4Cl$	2,5,2-trichlorobiphenyl	370	32	13
$C_{12}H_4Cl_6$	hexachlorobiphenyl	370	32	7.6
$(C_6H_2Cl_2)_2O_2$	2,3,7,8-TCDD (2,3,7,8-tetra-chlorodibenzo-p-dioxin; „dioxin")	3,300,000	290,000	
	TEQ (2,3,7,8-TCDD-toxicity equivalents)	3,300,000	290,000	
	polycyclic aromatic hydrocarbons (PAHS)			
	anthracene	0.67	0.057	0.000,45
	benzo(a)anthracene	1.7	0.14	0.001,3
	benzo(k)fluoroanthene	1.7	0.14	0.001,2
	benzo(ghi)perylene	1.7	0.14	0.001,1
	benzo(a)pyrene	17	1.4	0.013
	chloro-PAH (general)	67	5.7	
	chloronaphthalene	67	5.7	7.2[¶]
	chrysene	17	1.4	0.33
	fluoroanthene	1.7	0.14	0.066
	indeno(1,2,3,c,d)pyrene	1.7	0.14	0.001,1
	naphthalene	0.7	0.057	0.11[¶]
	phenanthrene	1.7	0.14	0.11
	pyrene	1.7	0.14	0.012

formula	substance	HCA	HCW	HCS
unhalogenated aliphatic hydrocarbons				
CH_2CHCN	acrylonitrile	23		
$C_4H_{10}(OH)_2$	1,3-butanediol (1,3-butyleneglycol)	0.0083	0.000,71	
	1,3-butyleneglycol	→ 1,3-butanediol		
CS_2	carbon disulfide	1.2		
$C_6H_{10}O$	cyclohexanone	0.86	0.000,62	0.005,7[¶]
$CH_3CO_2C_2H_5$	ethylacetate	0.001,3	0.000,11	
C_7H_{16}	heptane	1.6	0.000,92	0.055
	isopropanol	→ 2-propanol		
C_8H_{18}	octane	1.6	0.000,92	0.000,013
	petrol	1.7	0.000,92	
$CH_3CHOHCH_2OH$	1,2-propanediol (propyleneglycol)	0.0013	0.000,11	
$CH_3CHOHCH_3$	2-propanol (isopropanol)	0.022	0.001,9	
	propyleneglycol	→ 1,2-propanediol		
C_4H_8O	tetrahydrofuran	3.3	0.29	68
C_4H_8S	tetrahydrothiophene	3.3	0.29	5.8[¶]
$C_{12}H_{20}O_6$	triethylcitrate	0.003,3	0.000,29	
halogenated aliphatic hydrocarbons				
	chloroalkanes			
CH_2Cl_2	dichloromethane (methylenechloride)	0.069	0.048	1.6
$CHCl_3$	trichloromethane (chloroform)	1.2	0.095	3.3
CCl_4	tetrachloromethane	1.9	0.71	32
CH_2ClCH_2Cl	1,2-dichloroethane	2.4	0.20	7.1
	chloroalkenes			
CH_2CHCl	monochloroethene (vinylchloride)	1.2	0.82	320
$CHClCCl_2$	trichloroethene	0.061	0.005,3	0.10
C_2Cl_4	tetrachloroethene (perchloroethene)	0.047	0.18	7.6
	chloroform	→ trichloromethane		
CCl_2F_2	dichlorodifluoromethane	0.022	0.001,9	
	perchloroethene	→ tetrachloroethene		
	vinylchloride	→ monochloroethene		
pesticides				
	acephate	1.1	0.095	
	acrilonitrile	23		
	aldicarb	6.7	0.57	

formula	substance	HCA	HCW	HCS
	aldrin	330	29	4.5
	aminocarb	8.3	0.71	
	amitraz	11	0.95	
	amitrol	1,100	95	
	anilazin	0.33	0.029	
	atrazine	6.7	0.57	3.2[¶]
	azinphos-methyl	13	1.1	
	azocyclotin	11	0.95	
	benalaxyl	0.67	0.057	
	bendiocarb	8.3	0.71	
	benomyl	1.7	0.14	
	benzenehexachloride (BHC)	→ hexachlorocyclohexane		
	BHC	→ hexachlorocyclohexane		
	bitertanol	3.3	0.29	
	bromide	0.033	0.002,9	
	bromophos	0.83	0.071	
	bromophos-ethyl	11	0.95	
	bromomethane	→ methylbromide		
	bromopropylate	4.2	0.36	
	captan	0.33	0.029	
	carbamates (general)	33	2.9	
	carbaryl	3.3	0.29	0.10
	carbendazim	3.3	0.29	
	carbophenothion	67	5.7	
	carbofuran	3.3	0.29	0.10
	carbosulfan	3.3	0.29	
	cartap	0.3	0.029	
	chlorobenzide	3.3	0.29	
	chlorobenzilate	1.7	0.14	
	chlorocholinechloride	→ chloromequat		
	chlordane	67	5.7	
	chlorfenson	3.3	0.29	
	chlorfenvinphos	17	1.4	
	chlormequat	0.67	0.057	
	chlorthalonil	11	0.95	
	chlorpyrifos	3.3	0.29	
	chlorpyrifos-methyl	3.3	0.29	
	clofentezine	1.7	0.14	
	crufomate	0.33	0.029	
	cyanazine	17	1.4	
	cyfluthrin	1.7	0.14	
	cyhalothrin	1.7	0.14	
	cyhexatin	4.2	0.36	

formula	substance	HCA	HCW	HCS
	cypermethrin	0.67	0.058	
	2,4 D (2,4-dichlorophenoxy acetic acid)	0.11	0.009,5	
	daminozide	0.067	0.005,7	
	DDD	1.7	0.14	
	DDE	1.7	0.14	
	DDT	1.7	0.14	
	decamethrin	→ deltamethrin		
	deltamethrin	3.3	0.29	
	demeton-S-methyl	110	9.5	
	demeton-S-methylsulfon	→ demeton-S-methyl		
	demeton-S-methyl-sulfoxide	→ oxydemetonmethyl		
	diazinon	17	1.4	
	1,2-dibromoethane as Br^-)	0.033	0.002,9	
	dichlofluanide	0.11	0.009,5	
	2,4-dichlorophenoxy acetic acid	→ 2,4-D		
	dichlorovos	8.3	0.71	
	dichloran	1.1	0.095	
	dicofol	1.3	0.11	
	dieldrin	330	29	13
	diphenyl	0.27	0.023	
	diphenylamine	1.7	0.14	
	diflubenzuron	1.7	0.14	
	dimethipin	1.7	0.14	
	dimethoate	3.3	0.29	
	dimethyl-dithiocarbamates (DMDC; general)	6.7	0.57	
	dinocap	33	2.9	
	dioxathion	22	1.9	
	diquat	4.2	0.36	
	disulfoton	17	1.4	
	DMDC	→ dimethyl-dithiocarbamates		
	dodine	3.3	0.29	
	drins (general)	330	29	
	EBDC	→ ethylenebis-dithiocarbamates		
	edifenphos	11	0.95	
	endosulfan	5.6	0.48	
	endrin	330	29	16
	ethiofencarb	0.33	0.029	
	ethion	5.6	0.48	
	ethoprophos	110	9.5	
	ethoxyquin	0.56	0.048	
	ethylene-dibromide	→ 1,2-dibromomethane		

formula	substance	HCA	HCW	HCS
	ethylenebis-dithiocarbamates (EBDC; general)	0.67	0.057	
	ethylenethio-urea (ETU)	17	1.4	
	etrimfos	11	0.95	
	ETU	→ ethylenethio-urea		
	fenamiphos	67	5.7	
	fenbutatin oxide	1.1	0.095	
	fenchlorphos	3.3	0.29	
	fenitrothion	6.7	0.57	
	fensulfothion	110	9.5	
	fenthion	33	2.9	
	fenthoate	11	0.95	
	fentin acetate	67	5.7	
	fentin chloride	67	5.7	
	fentin hydroxide	67	5.7	
	fentin compounds (general)	67	5.7	
	fenvalerate	1.7	0.14	
	ferbam	1.7	0.14	
	flucythrinate	1.7	0.14	
	flusilazole	33	2.9	
	folpet	3.3	0.29	
	formothion	1.7	0.14	
	glyphosphate	0.11	0.009,5	
	guazatine	1.1	0.095	
	HCH	→ hexachlorocyclohexane		
	heptachloro/ heptachloro-epoxide	67	5.7	
	α-hexachlorocyclohexane (α-HCH)	470	2.9	3.4[¶]
	β-hexachlorocyclohexane (β-HCH)	1,700	140	113[¶]
	γ-hexachlorocyclohexane (γ-HCH; lindane)	470	2.9	3.4[¶]
	δ-hexachlorocyclohexane (δ-HCH)	470	2.9	2.9[¶]
	2-hydroxybiphenyl	→ 2-phenylphenol		
	imazalil	3.3	0.29	
	iprodione	0.11	0.009,5	
	isofenphos	33	2.9	
	lindane	→ γ-hexachlorocyclohexane		
	malathion	1.7	0.14	
	maleic hydrazide	0.0067	0.000,58	
	mancozeb	0.67	0.057	
	maneb	0.67	0.057	0.000,44

formula	substance	HCA	HCW	HCS
	mecarbam	17	1.4	
	metalaxyl	1.1	0.095	
	methacrifos	11	0.95	
	methamidophos	56	4.8	
	methidathion	6.7	0.57	
	methiocarb	33	2.9	
	methomyl	1.1	0.095	
	methoprene	0.33	0.029	
	methoxychloro	0.33	0.029	
	methyl bromide (bromomethane; as Br^-)	0.033	0.002,9	
	methyl parathion	→ parathion-methyl		
	mevinphos	22	1.9	
	monocrotophos	56	4.8	
	omethoate	110	9.5	
	OPP	→ 2-phenylphenol		
	oxamyl	1.1	0.095	
	oxydemeton-methyl	110	9.5	
	oxythioquinox	→ chinomethionaat		
	paclobutrazol	0.33	0.029	
	paraquat	8.3	0.71	
	parathion	6.7	0.57	
	parathion-methyl	1.7	0.14	
	permethrin	0.67	0.057	
	phenothrin	0.48	0.041	
	2-phenylphenol (2-hydroxybiphenyl; OPP. SOPP)	1.7	0.14	
	phorate	170	14	
	phosalone	5.6	0.48	
	phosamidon	67	5.7	
	phosmet	1.7	0.14	
	phoxim	33	2.9	
	piperonylbutoxide	1.1	0.095	
	pirimicarb	1.7	0.14	
	pirimiphos-methyl	3.3	0.29	
	prochloraz	3.3	0.29	
	procymidone	0.33	0.029	
	prometryn	8.3	0.71	
	propamocarb	0.33	0.029	
	propargite	0.22	0.019	
	propazine	13	1.1	
	propiconazole	0.83	0.071	
	propoxur	1.7	0.14	0.11

formula	substance	HCA	HCW	HCS
	pyrethrins	0.83	0.071	
	quinomethionate (oxythioquinox)	5.6	0.48	
	quintozene	4.8	0.41	
	simazine	17	1.4	
	SOPP	→ 2-phenylphenol		
	2,4,5-T	1.1	0.095	
	tecnazene	3.3	0.29	
	terbufos	170	14	
	terbutryn	33	2.9	
	terbutyl-azin	11	0.95	
	tetrachlorovinphos	1,700	140	
	thiabendazole	0.11	0.009,5	
	thiodicarb	1.1	0.095	
	thiophanate-methyl	0.42	0.038	
	thiometon	11	0.95	
	tin and organo-tin compounds	→ fentin compounds		
	tolylfluanide	0.33	0.029	
	triadimefon	1.1	0.095	
	triadimenol	0.67	0.057	
	triazines (general)	17	1.4	
	triazofos	170	14	
	trichlorfon	3.3	0.29	
	triforine	1.7	0.14	
	triphenyl tin compounds	→ fentin compounds		
	vamidothion	4.2	0.36	
	vinclozolin	0.48	0.041	
	hydrogen cyanide	0.67	0.057	
	zineb	0.67	0.057	
	ziram	1.7	0.14	

* Based on the basic data for the air quality guideline for cadmium which represents the *direct* toxicty.

† Value: $0.12{\cdot}10^{-9}{\times}F_s/m^3$ or $0.23{\cdot}10^{-9}{\times}F_o/m^3$, where F_s = number of critical fibres emitted as determined by scanning electron microscopy and F_o = number of critical fibres emitted determined by optical microscopy. Critical fibres are fibres that are ≥ $5\mu m$ long, ≤ $3\mu m$ in diamter and with aspect ratio ≥ 3÷1.

‡ The value for NO_2 was adopted for NO_x.

§ This value is based on the air quality guideline for the combined toxicity of SO_2 and black (coal) smoke in equal mass ratios. It was assumed that SO_2 and smoke particles are each responsible for half of the combined effect.

¶ Value deviates from Dutch original report.

Human toxicological classification factor for the air (HCA), human toxicological classification factor for water (HCW) and human toxicological classfication factor for the soil (HCS). Sources: see backgrounds document §3.3. The effect score for human toxicity is calculated as follows:

$$\begin{aligned} \textit{human toxicity}(\mathrm{kg}) = {} & HCA\,(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission to the air}(\mathrm{kg}) + \\ & HCW(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission to water}(\mathrm{kg}) + \\ & HCS\,(\mathrm{kg{\cdot}kg^{-1}}) \times \textit{emission to the soil}(\mathrm{kg}) \end{aligned} \qquad (B.5)$$

B.2.4 Ecotoxicity

TABLE B.6. Classification factors for the effect scores terrestrial and aquatic ecotoxicity.

formula	substance	ECA	ECT*
metals			
As	arsenic	0.20	3.6
Cd	cadmium	200	13
Cr	chromium	1.0	0.42
Co	cobalt		0.42
Cu	copper	2.0	0.77
Pb	lead	2.0	0.43
Hg	mercury	500	29
Ni	nickel	0.33	1.7
Zn	zinc	0.38	2.6
unhalogenated aromatic hydrocarbons			
$C_6H_5NOCCH_3$	acetanilide (N-phenylacetamide)		5.9
$C_6H_5NH_2$	aniline (phenylamine)	5.0	5.9
C_6H_5CHO	benzaldehyde		0.32
C_6H_6	benzene	0.029	
	1,2-benzenedicarboxylic acids	→ phthalates	
$(C_6H_5)_2$	biphenyl (phenylbenzene)		2.9
$C_6H_4OHCH_3$	*o*-cresol (2-hydroxytoluene)		2.0
$C_6H_4OHCH_3$	*m*-cresol (3-hydroxytoluene)		2.1
$C_6H_4(NH_2)_2$	1,2-diaminobenzene (*o*-phenylenediamine)		10
	2,5-diaminotoluenesulfate		0.20
$C_6H_3OH(NO_2)_2$	2,4-dinitrophenol		2.0
$C_6H_5C_2H_5$	ethylbenzene	0.023	
	hydroxynaphthalene	→ naphthol	
	hydroxytoluene	→ cresol	
	mercaptobenzene	→ thiophenol	
$C_{10}H_7OH$	α-naphthol (1-hydroxynaphthalene)		4.0
$C_{10}H_7OH$	β-naphthol (2-hydroxynaphthalene)		2.3
$C_6H_5NO_2$	nitrobenzene		4.3
$C_6H_4OHNO_2$	*m*-nitrophenol		2.0
$C_6H_4OHNO_2$	*p*-nitrophenol		26
$C_6H_4OHC_9H_{19}$	4-nonylphenol		0.32
C_6H_5OH	phenol	5.9	5.3
	N-phenylacetamide	→ acetanilide	
	phenylamine	→ aniline	
	phenylbenzene	→ biphenyl	
	o-phenylenediamine	→ 1,2-diaminobenzene	
	phthalates (1,2-benzenedicarboxylic acids)		

formula	substance	ECA	ECT*
$C_6H_4(CO_2CH_3)_2$	dimethylphthalate		200
$C_6H_4(CO_2C_2H_5)_2$	diethylphthalate		1.5
$C_6H_4(CO_2C_4H_9)_2$	dibutylphthalate		0.20
	di(2-ethyl)hexylphthalate		0.20
C_5H_5N	pyridine		1.0
C_6H_5SH	thiophenol (mercaptobenzene)		1.0
$C_6H_5CH_3$	toluene		0.63
halogenated aromatic hydrocarbons			
	chloroanilines (chlorophenylamines)		
$C_6H_4NH_2Cl$	monochloroanilines (general)	0.010	
	2-monochloroaniline		6.3
	3-monochloroaniline		13
	4-monochloroaniline		7.7
$C_6H_3NH_2Cl_2$	dichloroanilines		
	2,4-dichloroaniline		6.7
	3,4-dichloroaniline		20
	3,5-dichloroaniline		15
$C_6H_2NH_2Cl_3$	trichloroanilines		
	2,4,5-trichloroaniline		11.8
	2,4,6-trichloroaniline		8.3
$C_6HNH_2Cl_4$	tetrachloroanilines		
	2,3,4,5-tetrachloroaniline		8.3
	2,3,4,6-tetrachloroaniline		13
$C_6NH_2Cl_5$	pentachloroaniline		0.42
	chlorobenzenes		
C_6H_5Cl	monochlorobenzenes (general)		1.0
$C_6H_4Cl_2$	dichlorobenzenes (general)	0.16	
	1,4-dichlorobenzene		0.83
$C_6H_3Cl_3$	trichlorobenzenes (general)	0.83	
	1,2,3-trichlorobenzene		53
	1,2,4-trichlorobenzene		7.7
	1,3,5-trichlorobenzene		1.6
$C_6H_2Cl_4$	tetrachlorobenzenes (general)	2.3	
	1,2,3,4-tetrachlorobenzene		6.3
	1,2,3,5-tetrachlorobenzene		150
C_6HCl_5	pentachlorobenzene	18	3.6
C_6Cl_6	hexachlorobenzene	53	0.20
	chlorophenols		
C_6H_4ClOH	monochlorophenols		
	2-chlorophenol		4.5
	3-chlorophenol		29
$C_6H_3Cl_2OH$	dichlorophenols		

formula	substance	ECA	ECT*
	2,4-dichlorophenol		3.7
	3,4-dichlorophenol		3.2
	3,5-dichlorophenol		6.3
$C_6H_2Cl_3OH$	trichlorophenols		
	2,3,5-trichlorophenol		22
	2,4,5-trichlorophenol		9.1
	2,4,6-trichlorophenol		17
C_6HCl_4OH	tetrachlorophenols		
	2,3,4,5-tetrachlorophenol		3.4
C_6Cl_5OH	pentachlorophenol (PCP)	5.6	5.9
	chlorophenylamines	→ chloroanilines	
$C_6H_3ClCH_3OH$	chloromethylphenols		
	4-chloro-3-methylphenol		3.0
	4-chloro-2-methylphenol		3.0
$C_6H_4ClNO_2$	chloronitrobenzenes		
	1-chloro-2-nitrobenzene		37
	1-chloro-3-nitrobenzene		17
	polychlorobiphenyls (PCBs)		
	PCB-28	16	
	PCB-52	430	
	PCB-101	40	
	PCB-118	360	
	PCB-138	71	
	PCB-153	100	
	PCB-180	130	
	Aroclor 1254		40
	2,3,7,8-TCDD (dioxin)		1,400
polycyclic aromatic hydrocarbons (PAHs)			
	anthracene	2.0	
	benz(a)anthracene	18	
	benzo(b)fluoroanthene	160	
	benzo(k)fluoroanthene	40	
	benzo(ghi)perylene	140	
	benzo(a)pyrene	40	
	chrysene	18	
	dibenzo(a,h)anthracene	33	
	fluoroanthene	6.2	
	fluoroene		5.9
	indeno(1,2,3,c,d)pyrene	91	
	naphthalene		0.31
	phenanthrene	2.1	
	pyrene	7.5	

formula	substance	ECA	ECT*
unhalogenated aliphatic hydrocarbons			
$NH_2COCHCH2$	acrylamide		1.3
$CH_3CO_2C_4H_9$	n-butylacetate		0.14
	crude oil	0.050	
$NH_2CO(C_4H_9)_2$	dibutylamide		0.56
$NH_2CO(C_3H_7)_2$	dipropylamide		0.53
$(NH_2CO)_2C_2H_2$	ethenediamide		0.29
C_4H_4O	furan		0.32
	isobutylalcohol	→ methylpropanol	
$(CH_3)_2CH_2CH_2OH$	methylpropanol		0.56
$C_3H_3NOS_2$	rhodamine (4-thioxo-4-thiazolidone)		6.3
	trypan blue (dye)		0.67
halogenated aliphatic hydrocarbons			
NH_2COCH_2Cl	chloroacetamide		250
	chloroalkanes		
$CHCl_3$	trichloromethane (chloroform)	0.17	
CCl_4	tetrachloromethane	0.007,4	
$(CH_2Cl)_2$	1,2-dichloroethane	0.000,94	
CH_3CCl_3	1,1,1-trichloroethane	0.002,8	
C_2Cl_6	hexachloroethane	0.14	
$CH_3CHClCH_2Cl$	1,2-dichloropropane		0.24
	chloroalkenes		
C_2HCl_3	trichloroethene	0.046	
C_2Cl_4	tetrachloroethene (perchloroethene)	0.020	11
$CH_2ClCHCHCl$	1,3-dichloropropene	0.083	
$C_2H_5ClOCClCH_2$	2-chloroethylvinylether		1.4
	perchloroethene	→ tetrachloroethene	
pesticides			
	aldicarb	3.1	290
	aldrin	83	1,400
	arasan		3.7
	atrazin	5.0	150
	azinphos-ethyl	100	
	azinphos-methyl	100	200
	benomyl		1400
	bentazon		33
	benzenehexachloride (BHC)	→ hexachlorocyclohexane	
	BHC	→ hexachlorocyclohexane	

formula	substance	ECA	ECT*
	bifenthrin	910	
	bupirimate		11
	calcium cyanamide		9.1
	captafol	33	2.0
	captan	19	4.8
	carbendazim	5.0	5.0
	carbofuran		250
	chlorocholinechloride	→ chloromequat	
	chlorodane	100	230
	chlorodimeform		20
	chlorofenvinphos		0.77
	chloromequat		2.5
	chlorpyrifos		910
	copper-oxychloride		12
	cumafos	2,000	
	cypermethrin	250	
	2,4 D (2,4-dichlorophenoxy acetic acid)	0.25	370
	dasanit		400
	DDD	1.3	
	DDE	1.3	
	DDT	1.3	112
	decamethrin	→ deltamethrin	
	deltamethrin	1000	
	demeton	14	
	demeton-S-methyl-sulfoxyde	→ oxydemetonmethyl	
	dialifos		7.7
	diazinon	50	1,400
	3,3-dichlorobenzidine	10	
	1,4-dichlorophenoxy acetic acid	→ 2,4-D	
	dichlorovos	2,000	13
	dieldrin	83	900
	dimetilan		0.80
	dinoseb	200	
	disulfoton	3.8	910
	DNOC	15	48
	dymid		4.0
	endosulfan	100	150
	endrin	53	2,000
	ethiofencarb		3.8
	ethyl-parathion	→ parathion-ethyl	
	fenitrothion	100	200
	fenmidfan		5.9

formula	substance	ECA	ECT*
	fensulfothion		200
	fenthion	250	
	fentin compounds (general)	20	
	fentin-acetate	20	37
	folpet		2.9
	heptachloro	12	2,000
	heptachloro-epoxide	12	
	hexachlorobutadiene	11	
	γ-hexachlorocyclohexane (γ-HCH; lindane)	2.5	1,300
	isobenzan		5,000
	isodrin	170	
	leptophos		20
	lindane	→ γ-hexachlorocyclohexane	
	linuron	20	
	malathion	67	25
	mancozeb		2.9
	maneb	1.1	2.9
	MCPA (monochlorophenoxy acetic acid)	17	
	MCPP	→ mecoprop	
	mecoprop (MCPP)	25	
	mercaptodimethur		7.7
	methamidophos		59
	metham sodium	290	
	methaphenamifos		3.1
	methidathion		280
	methomyl		400
	methyl-parathion	→ parathion-methyl	
	mevinphos	1,000	7.7
	mexacarbate		34
	monochlorophenoxy acetic acid	→ MCPA	
	monochloronitrobenzene	0.10	
	monocrotophos		13
	NaDDC		0.080
	oxamyl	2.4	11
	oxydemeton-methyl	53	
	paraquat		5.9
	parathion-ethyl	250	1,400
	parathion-methyl	8.3	200
	pentachloronitrobenzene	3.2	
	permethrin	710	
	phorate		2,000

formula	substance	ECA	ECT*
	phoxim	50	
	potassium bromate		2.6
	potassium dichromate		2.4
	propachloro	59	
	propoxur		220
	pyrazophos	2,100	
	simazin	1.0	
	sodium chlorate		1.5
	2,4,5-T		20
	TBTO	63	
	terbufos		250
	tetrachlorovinphos		50
	thiophene		0.63
	thiram	63	2.9
	trematan		0.40
	triadimefon		3.7
	triazofos	200	8.3
	tributyl tin oxide and salts	250	
	trichloroacetate (TCA)		9.1
	trichlorfon	1,000	14
	triphenyl tin compounds	→ fentin compounds	
	trifluarin	5.0	
	zineb	0.63	1.5
	zinophos		2,900

* Values calculated for standard soil containing 10% organic matter and 25% argillaceous material (Parliamentary Documents II, 1987).

Ecotoxicolocial classification factor for terrestrial ecosystems (ECT) in kg soil·kg^{-1} substance and the ecotoxicological classification factor for aquatic ecosystems (ECA) in m^3 water·kg^{-1} substance. Sources: see backgrounds document §3.3. The effect score for aquatic toxicity is calculated with:

$$\textit{aquatic ecotoxicty}(\mathrm{m}^3) = ECA(\mathrm{m}^3\,\mathrm{mg}^{-1}) \times \textit{emission to water}(\mathrm{mg}) \quad \text{(B.6)}$$

The effect score for terrestrial ecotoxicity is calculated with:

$$\textit{terrestrial ecotoxicty}(\mathrm{kg}) = ECT(\mathrm{kg\,mg}^{-1}) \times \textit{emission to the soil}(\mathrm{mg}) \quad \text{(B.7)}$$

B.2.5 Photochemical oxidant formation

TABLE B.7. Classification factors for the effect score oxidant formation.

formula	substance	POCP	range
alkanes			
	methane	0.007	0.000-0.030
	ethane	0.082	0.020-0.300
	propane	0.42	0.160-1.240
	n-butane	0.41	0.150-1.150

formula	substance	POCP	range
	i-butane	0.315	0.190-0.590
	n-pentane	0.408	0.090-1.050
	i-pentane	0.296	0.120-0.680
	n-hexane	0.421	0.100-1.510
	2-methylpentane	0.524	0.190-1.400
	3-methylpentane	0.431	0.110-1.250
	2,2-dimethylbutane	0.251	0.120-0.490
	2,3-dimethylbutane	0.384	0.250-0.650
	n-heptane	0.529	0.130-1.650
	2-methylhexane	0.492	0.110-1.590
	3-methylhexane	0.492	0.110-1.570
	n-octane	0.493	0.120-1.510
	2-methylheptane	0.469	0.120-1.460
	n-nonane	0.469	0.100-1.480
	2-methyloctane	0.505	0.120-1.470
	n-decane	0.464	0.080-1.560
	2-methylnonane	0.448	0.080-1.530
	n-undecane	0.436	0.080-1.440
	n-duodecane	0.412	0.070-1.380
—	alkanes (average)	0.398	0.114-1.173
halogenated hydrocarbons			
	methylcyclohexane	—	—
	methylenechloride	0.010	0.000-0.030
	chloroform	—	—
	methylchloroform	0.001	0.000-0.010
	trichloroethylene	0.066	0.010-0.130
	tetrachloroethylene	0.005	0.000-0.020
	allylchloride	—	—
—	halogenated hydrocarbons (average)	0.021	0.003-0.048
alcohols			
	methanol	0.123	0.090-0.210
	ethanol	0.268	0.040-0.890
	i-propanol	—	—
	butanol	—	—
	i-butanol	—	—
	ethyleneglycol	—	—
	propyleneglycol	—	—
	but-2-diol	—	—
	dimethylether	—	—
	methyl-t-butylether	—	—
	ethyl-t-butylether	—	—

formula	substance	POCP	range
—	alcohols (average)	0.196	0.065-0.550
ketones			
	acetone	0.178	0.100-0.270
	methyl-ethylketone	0.473	0.170-0.800
	methyl-i-butylketone	—	—
—	ketones (average)	0.326	0.135-0.535
esters			
	methylacetate	0.025	0.000-0.070
	ethylacetate	0.218	0.110-0.560
	i-propylacetate	0.215	0.140-0.360
	n-butylacetate	0.323	0.140-0.910
	i-butylacetate	0.332	0.210-0.590
—	esters (average)	0.223	0.120-0.498
ethers			
	propyleneglycolmethyleneether	—	—
	propyleneglycolmethyletheracetate	—	—
—	ethers (average)	—	—
olefins			
	ethylene	1.000	1.000-1.000
	propylene	1.030	0.750-1.630
	1-butene	0.959	0.570-1.850
	2-butene	0.992	0.820-1.570
	1-pentene	1.059	0.400-2.880
	2-pentene	0.930	0.650-1.600
	2-methyl-1-butene	0.777	0.520-1.130
	2-methyl-2-butene	0.779	0.610-1.020
	3-methyl-1-butene	0.895	0.600-1.540
	isobutene	0.643	0.580-0.760
	isoprene	—	—
—	olefins (average)	0.906	0.650-1.498
acetylenes			
	acetylene	0.168	0.100-0.420
aromatics			
	benzene	0.189	0.110-0.450
	toluene	0.563	0.410-0.830
	o-xylene	0.666	0.410-0.970
	m-xylene	0.993	0.780-1.350

formula	substance	POCP	range
	p-xylene	0.888	0.630-1.800
	ethylbenzene	0.593	0.350-1.140
	1,2,3-trimethylbenzene	1.170	0.760-1.750
	1,2,4-trimethylbenzene	1.200	0.860-1.760
	1,3,5-trimethylbenzene	1.150	0.740-1.740
	o-ethyltoluene	0.668	0.310-1.300
	m-ethyltoluene	0.794	0.410-1.400
	p-ethyltoluene	0.725	0.360-1.350
	n-propylbenzene	0.492	0.250-1.100
	i-propylbenzene	0.565	0.350-1.050
—	aromatics (average)	0.761	0.481-1.285
aldehydes			
	formaldehyde	0.421	0.220-0.580
	acetaldehyde	0.527	0.330-1.220
	proprionaldehyde	0.603	0.280-1.600
	butyraldehyde	0.568	0.160-1.600
	i-butyraldehyde	0.631	0.380-1.280
	valeraldehyde	0.686	0.000-2.680
	acrolein	—	—
	benzaldehyde	−0.334	(−0.820)-(−0.120)
—	aldehydes (average)	0.443	0.079-1.263
—	hydrocarbons (average)	0.377	0.194-0.808
—	non-methane hydrocarbons (average)	0.416	0.195-0.799

Photochemical ozone creation potential (POCP) relative to ethylene, based on three scenarios and nine days: Germany-Ireland, France-Sweden and the UK. The range is based on three scenarios and 11 days. Source: United Nations – Economic Commission for Europe, 1991: *Protocol to the convention on longe-range transboundary air pollution concerning the control of emissions of volatile organic compounds or their transboundary fluxes.* Geneva. The effect score for the formation of photochemical oxidants is calculated with:

$$\textit{oxidant formation}(\text{kg}) = \textit{POCP} \times \textit{emission to the air}(\text{kg}) \quad \text{(B.8)}$$

B.2.6 Acidification

TABLE B.8. Classification factors for the effect score acidification.

formula	substance	AP
SO_2	sulfur dioxide	1.00
NO	nitrogen monoxide	1.07
NO_2	nitrogen dioxide	0.70
NO_x	nitrogen oxides	0.70
NH_3	ammonia	1.88
HCl	hydrochloric acid	0.88

formula	substance	AP
HF	hydrogen fluoride	1.60

Acidification potential (AP) relative to SO_2, based on the potential amount of H^+ per mass unit relative to the same parameter for SO_2. The effect score for acidification is calculated with:

$$acidification(\text{kg}) = AP \times emission\ to\ the\ air(\text{kg}) \quad (B.9)$$

B.2.7 Nutrification

TABEL B.9. Classification factors for the effect score nutrification.

formula	substance	NP
NO	nitrogen monoxide	0.20
NO_2	nitrogen dioxide	0.13
NO_x	nitrogen oxides	0.13
NH_4^+	ammonium	0.33
N	nitrogen	0.42
PO_4^{3-}	phosphate	1.00
P	phosphorus	3.06
COD	chemical oxygen demand (as O_2)	0.022

Nutrification potential (NP) relative to PO_4^{3-}, based on the average composition of biomass $C_{106}H_{263}O_{110}N_{16}P$, relative to phosphate. The nutrification effect score is calculated with:

$$nutrification(\text{kg}) = NP \times emission(\text{kg}) \quad (B.10)$$

B.2.8 Odour

TABEL B.10. Classification factors for the effect score malodourous air.

formula	substance	OTV
	acetic acid	0.061
	ammonia	1.0
	butanal (butyraldehyde)	0.000,84
	butanoic acid (butyric acid)	0.000,35
	1-butanol	0.077
	2-butanone	0.68
	n-butylacetate	0.031
	butylacrylate	0.001,5
	n-butylpropionate	0.086
CS_2	carbon disulfide	0.18
	chlorobenzene	1.0
	decaline	2.8
	dichloromethane	640
	diethylamine	0.09
	dimethylamine	0.001,4
	1,2-dimethylbenzene (o-xylene)	0.78
	1,3-dimethylbenzene (m-xylene)	0.54

formula	substance	OTV
	1,4-dimethylbenzene (p-xylene)	0.52
	ethanal (acetaldehyde)	0.000,27
	ethanethiol (ethylmercaptan)	0.000,044
	ethanol	0.64
	ethylacetate	2.1
	ethylacrylate	0.000,82
	2-ethyl-5,5-dimethyl-1,3-dioxane	0.000,005,6
	ethylbutyrate	0.000,03
	ethylthioethane (diethylsulfide)	0.001,4
H_2S	hydrogen sulfide	0.000,43
	isopentylacetate (iso-amylacetate)	0.075
	isopropylbenzene (cumene)	0.073
	isopropylpropionate	0.32
	methanal (formaldehyde)	0.49
	methanethiol (methylmercaptan)	0.000,24
	methanol	73
	methylacetate	22
	methylamine	0.001,2
	3-methylbutanoic acid (isovaleric acid)	0.000,22
	methyldithiomethane	0.001,5
	methylmethacrylate	0.63
	4-methylpentanon-2 (methylisobutylketone, MIKB)	0.69
	o-cresol (2-methylphenol)	0.001,8
	m-cresol (3-methylphenol)	0.000,57
	p-cresol (4-methylphenol)	0.000,18
	2-methylpropanoic acid (isobutyric acid)	0.005
	2-methylpropanol-1 (isobutanol)	0.035
	2-methylpropene (isobutene)	15
	methylacrylate	0.01
	methylpropionate	3.5
	methylthiomethane (dimethylsulfide)	0.000,3
	pentanal (valeraldehyde)	0.002,4
	phenol	0.039
	propanal (propionaldehyde)	0.003,5
	propanoic acid (propionic acid)	0.005,2
	2-propanon (acetone)	72
	2-propenal (acrolein)	0.069
	pyridine	0.12
	styrene (vinylbenzene)	0.068
	tetrachloroethene (per)	8.3
	terephthaloyldichloride	0.003,2
	toluene	3.8
	trichloroethene (tri)	3.9

formula	substance	OTV
	1,1,1-trichloroethane	5.3
	trimethylamine	0.000,26
	1,2,4-trimethylbenzene	0.14
	1,3,5-trimethylbenzene (mesitylene)	0.18

Odour threshold value in air (OTV) in mg·m^{-3}. Source: Roos, C., 1989: *Vooronderzoek financiële consequenties van een geurbelevingsnorm.* MT-TNO, report no. 88-230. The effect score for malodourous air is calculated with:

$$\textit{malodourous air}(\mathrm{m}^3) = \frac{\textit{emission to the air}(\mathrm{mg})}{\textit{OTV}(\mathrm{mg{\cdot}m^{-3}})} \qquad (B.11)$$

APPENDIX C

GLOSSARY AND LIST OF ABBREVIATIONS

This appendix provides definitions of the most important terms. It also includes a list of the abbreviations used.

C.1 Glossary

This glossary provides a list of the most common terms used in the method for environmental life cycle assessment of products. The glossary is limited to terms defined in this report or whose meaning is slightly different or narrower in this context than normal.

abiotic resource (non-renewable resource)
Resources which are considered abiotic and therefore not renewable. Zinc ore and crude oil are examples of abiotic resources.

allocation
Step (2.3) in an LCA in which it is determined how environmental interventions of a multiple process will be distributed to the various process functions. A distinction can be made between causal allocation and overall apportioned allocation.

biotic resource (renewable resource)
Resources which are considered biotic and therefore renewable. The rain forest and elephants are examples of biotic resources.

causal allocation
Form of allocation in which it is attempted to allocate subflows (such as emissions) to main flows on a causal basis, using the rules of chemistry.

classification
The third component of a life cycle assessment in which the contribution made by the environmental interventions to the potential environmental effects is determined through model-based calculations.

classification factor
Result of the modelling of environmental effects which represents the effect as a result of one unit of the environmental intervention.

closed loop recycling
Form of recycling in which the product system which produced the waste can reuse the waste, possibly after upgrading.

combined waste processing (MI process)
Method of waste processing in which more than one product or material is simultaneously processed.

component
One of the five main elements of an environmental life cycle assessment. Each component (goal definition, inventory analysis, classification, evaluation and improvement analysis) produces a result which can be used independently (→ environmental indicator) and requires specific expertise.

co-production (MO process)
Production process resulting in more than one marketable output.

damage
A deterioration in the quality of the environment not directly attributable to depletion or pollution.

depletion
Result of the extraction of non-renewable resources from the environment or the extraction of renewable resources faster than they can be renewed.

difference analysis
A life cycle assessment which concentrates on the differences between given product alternatives.

dominance analysis
One of the two techniques for improvement analysis. The aim of dominance analysis is to uncover the basic causes of a poor environmental profile.

economic flow
The flow from one economic process to another, consisting of goods, materials, services, energy, waste, etc. used in the other process, i.e. in the economy.

economic process
Deliberate transformation of or to goods with a financial value.

effect score
Number representing the potential contribution of a process, group of processes or product system to a given environmental effect.

emission
Discharge of chemical or physical entities (substances, heat, noise, etc.) from the product system to the environmental system.

environmental effect
The consequence of an environmental intervention in the environmental system.

environmental flow
Flow from the environment to a process or vice versa: resources, emissions, etc.

environmental index
Parameter representing the harmfulness of a product to the environment, obtained by quantitative weighting.

environmental indicator
One of the results of an environmental life cycle assessment. Environmental indicators are produced in all five components: the goal definition provides the product properties (e.g. life span), the inventory analysis results in the inventory table and a set of aggregated parameters (e.g. energy consumption), the classification results in the environmental profile comprising a number of the effect scores (e.g. acidification), the evaluation results in an environmental index or assessment and the improvement analysis provides starting points for the design or redesign. When product information is transferred all that information should be restricted to the level of a single component.

environmental intervention
Physical interaction between a product system and the environmental system, defined in terms of the extraction of resources, substance emissions to the environmental media, space occupied by waste and plant, etc.

environmental life cycle assessment (LCA)
Part of an overall life cycle assessment in which only the environmental consequences are considered.

environmental medium
One of the three environmental domains, i.e. air, water and soil.

environmental process
The set of events in the environmental system which determine what happens to a pollutant (accumulation, leaching, etc.) and what effect it will have.

environmental profile (environmental balance, eco-profile, eco-balance)
List of effect scores for all environmental effects associated with the life cycle of the product under consideration.

environmental system
The environment and all the processes which occur in it.

evaluation
The fourth component of a life cycle assessment in which different product systems are assessed in comparison with each other or in which potential environmental effects of different kinds are compared.

extraction
Use of materials obtained directly from the environment (→ resource) by a product system.

final waste
Landfilled solid waste which will not undergo further processing.

format
System for the representation and possibly processing of quantitative process data.

functional unit
Specification of the material or immaterial function of a product or product system used as a basis for the selection of one or more products which could provide that function.

goal definition
The first component of a life cycle assessment in which the functional unit is specified and the product group is delineated.

improvement analysis
Component of a life cycle assessment carried out only when the assessment is undertaken for product improvement. Improvement analysis provides starting points for the redesign of the product and processes concerned and the use of different materials.

inventory table (eco-balance, environmental balance)
List of entities added to and taken from the environment through economic actions which are directly related to a product system and which have a potential effect on the environment.

inventory analysis
The second component of a life cycle assessment in which an analysis is made of the environmental interventions associated with the processes required for that functional product unit. Such an analysis should be as much as possible objective and adequately substantiated.

life cycle
The combination of processes needed by a product to fulfil the function specified by the functional unit. Life cycle stages include production, use and processing after disposal, including the processing of the waste generated in these stages.

life cycle assessment (LCA)
See overall life cycle assessment and environmental life cycle assessment.

main flows
All flows to and from an economic process which are the goal of the process and to which allocations are made. These flows are economic flows with a positive value.

marginal analysis
One of the two techniques for improvement analysis. Marginal analysis is used to detect process data where a minor change will have a major effect on the environmental profile. This may provide an efficient way to improve the product.

multi-criteria analysis (MCA; multi-criteria evaluation)
Method by which a formal or informal structure can be applied to the weighting of the effect scores in a life cycle assessment.

multiple process
A process which produces more than one economically valuable good (product, material, service, energy, waste with a positive value). Co-production, combined waste processing and recycling are all multiple processes.

normalized effect score
Effect score related to the scale of the overall effect in a given area over a given period as predicted by the classification model

normalized environmental profile
Environmental profile consisting of the normalized effect scores.

normalizing
Relating all the effect scores of a functional unit in the environmental profile to the overall magnitude of the same effect scores in a given area over a certain period. This results in the normalized environmental profile which consists of normalized effect scores.

open loop recycling (IO process)
Form of recycling in which the primary and secondary applications occur in different product systems.

overall apportioned allocation
Form of allocation in which all subflows which cannot be allocated to main flows on a causal basis are distributed among the main flows. The allocation could be based on physical or economic grounds.

overall life cycle assessment
Study of one or more aspects of a product, process, etc. in which the complete life cycle of the study object is considered and which covers a range of aspects such as the environment, costs and safety.

pollution
Consequence of emissions to the environment of undegradable substances or emissions.

process
Event occurring in a product system (→ economic process) or in the environmental system (→ environmental process).

process tree
Graphical representation of the interconnected economic processes which make up the life cycle of a product.

product
A tradeable good or service produced by an economic process which is or may be used in a different economic process.

product system
Set of processes and flows of goods and services which contribute to the life cycle of a functional unit. The product system covers the complete life cycle.

recycling
Processor set of processes to collect and/or process waste from a product system to result in a useful application in the same (→ closed loop recycling) or in another product system (→ open loop recycling).

reliability analysis
One of the two analyses made during step 4.2. The uncertainty of the data on the processes, environmental models, etc. is used to judge the reliability of the results.

resource
Material found in the environment which can be extracted from the environment in an economic process. There are biotic and abiotic resources.

reversal point
In a validity analysis (step 4.2): value of the parameter under consideration at which a result, such as the difference in environmental indices of product A and product B is reversed. The parameter under consideration could be a missing classification factor.

sensitivity analysis
Analysis to determine the sensitivity of the outcome of a calculation to small changes in the assumptions or to variations in the range within which the assumptions are assumed to be valid. This includes changes in the process data.

standard model
Method used in this guide to model environmental effects.

step
Part of a component of an environmental life cycle assessment. Each step covers a complete action.

system boundary
Border between one system and another (product system, environmental system, etc.)

subflows
All flows to and from an economic process which do not form part of the process goal and which have to be allocated. This includes environmental flows and economic flows with a negative value.

subprocess tree
Process tree focussed on a given main process group. For example this could reveal the details of the electricity supply.

summary process tree
Process tree limited to the main groups of relevant processes, such as the extraction of resources, energy supply, assembly, transport, use, maintenance and disposal.

validity analysis
One of the two analyses included in step 4.2. The influence of choices and assumptions on the outcome is assessed by means of a validity analysis.

waste
Materials without any positive economic value created by an economic process. (Sometimes a byproduct with a low value or which makes only a small contribution to the total revenues is also considered as waste.) A distinction can be made between waste to be processed (which is processed in the economic system) and final waste (which is introduced into the environment).

C.2 List of abbreviations

ADI	acceptable daily intake
ALI	annual limit of intake
AP	acidification potential
AVI	waste incinerator
BDF	biotic depletion factor
B&G	Fuel and Raw Materials Bureau
CFC	chlorofluorocarbon
CML	Centre of Environmental Science (part of Leiden University)
DGM	Directorate-General of Environmental Management (part of VROM)
ECA	ecotoxicological classification factor for aquatic ecosystems
ECT	ecotoxicological classification factor for terrestrial ecosystems
EIA	environmental impact assessment
ETP	ecotoxicity potential
GWP	global warming potential
GFT	putrescible waste
HCA	human toxicological classification factor for the air
HCS	human toxicological classification factor for the soil
HCW	human toxicological classification factor for water
HTP	human toxicity potential
IBC	isolation, control, monitoring
IBPC	Industry, Construction Sector, Products, Consumers (part of DGM)
IMET	Institute of Environmental and Energy Technology (part of TNO)

LCA	life cycle assessment
MCA	multi-criteria analysis
NEPP	National Environmental Policy Plan (1990-1994)
NOEC	no observed effect concentration
NOH	National Reuse of Waste Research Programme
NOVEM	Netherlands Agency for Energy and the Environment
NP	nutrification potential
ODP	ozone depletion potential
OTV	odour threshold value
p.m.	*pro memoria* (as a reminder)
POCP	photochemical ozone creation potential
RDF	refuse derived fuel
RIVM	National Institute of Public Health and Environmental Protection
RMNO	Advisory Council for Research on Nature and the Environment
RUL	Leiden University
SI	*Système International des Unités*
SR	Substances and Risk Management (now IBPC)
TCL	tolerable concentration in air
TDI	tolerable daily intake
TMTC	terrestrial maximum tolerable concentration
TNO	Netherlands Organisation for Applied Scientific Research
VOC	volatile organic compound
VROM	Ministry of Housing, Planning and Environment