REIM: LCA-based ranking of environmental investments model

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PART A

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SUMMARY & INTRODUCTION

A.1 SUMMARY

This report describes a method for the ranking of environmental investments on the basis of their environmental cost-effectiveness. The environmental yield is estimated on a cradle-to-grave basis, using life cycle assessment (LCA). The traditional economic cost-benefit analysis is restructured according to the method for LCA. This clarifies the analogue way of thinking.

The method is devised as a protocol with a number of elementary steps, all of which are described in operational terms. A collection of related steps is called a component, and a collection of related components a block. There are four blocks:

- *overall goal definition;*
- environmental assessment;
- economic assessment;
- overall evaluation.

In the overall goal definition, the environmental projects to be ranked are clearly defined.

The environmental assessment consists of four components, of which in particular the inventory analysis (which concentrates on the gathering and aggregation of data on emissions of substances and extractions of resources), the classification (in which an assessment of the harmfulness of those emissions and extractions is made in terms of contribution to the greenhouse effect, acidification, etc.) and the evaluation (in which the different effect categories are weighted) need to be mentioned.

The economic assessment is in principle an ordinary private type cost-benefit analysis, but restructured so as to resemble the step-wise procedure for LCA.

In the overall assessment, the resulting environmental improvement ΔE and the additional costs ΔC are combined to form the environmental cost-effectiveness $I = \Delta C/\Delta E$. This figure forms the basis of a ranking of the different investment projects. A special issue is that investment projects can last for a long time, and that the environmental impacts may differ per year. The question whether environmental discounting should take place is, along with e.g. the question of the magnitude of the weighting factors, addressed in the sensitivity analysis, which concludes the overall evaluation.

Finally the question how to use the results of the ranking raises. This leads to a discussion of boundary conditions, such as financial constraints and technical constraints. Obviously, one function of the model is to select environmental investments on the basis of the obtained ranking. Another function of the model may be to convince policy makers of the importance of a higher environmental cost-effectiveness instead of meeting all ordinary policy goals.

Next, some remarks concerning the applicability are made. This part discusses the limitations arising from some of the shortcomings of the current model, and the way towards improvement. One major issue here is the absence of a detailed inventory analysis. The current model is based on the premise that a technical department of a company provides the aggregated environmental data. Though this may be satisfactory for internal decision making, including a full inventory analysis enhances the transparency of the calculations, and may thereby both improve data and be more

convincing for external use. Moreover it gives the opportunity to readily change process data, and to add a next component to the model: the improvement analysis.

A.2 INTRODUCTION

A.2.1 Aim of the study

The aim of this study is to contribute to the development of software for the combined environmental and economic analysis of investment projects of the main Dutch natural gas producer, NAM. That contribution concerns several levels. The first level is that of the overall model, as a theoretical concept, to make the analysis. The second level is the specification of this conceptual model in operational terms. A third level is the indication of how this more operational model might be implemented in software, taking the current REIM model of NAM as a reference. The first two levels, main structure and operationalization cover Part B of this report, with some data and examples in appendices, Part D. Parallel to the execution of this study, NAM developed the related software as the REIM, the Ranking of Environmental Investments Model. It incorporates some main elements of the conceptual model described here, but not all of them. In Part C, an assessment is made of the possibilities and priorities for further development of REIM software.

As a general background for the environmental part of the analysis, the method for environmental life cycle assessment of products has been chosen. It is the LCA method as has been developed for NOH by CML, TNO and B&G, the Guide LCA*. The reason for the choice of LCA as the analytic tool is twofold. First, LCA brings in view a number of indirect effects of decisions. Using an installation here implies a number of activities at other locations, ranging from the primary production of materials that it is made of and consumes, to the processing of process wastes and the processing of the discarded installation. Secondly, in LCA the environmental effects are expressed in terms of the contributions to specific environmental problems like greenhouse effect, ozone layer depletion, and acidification.

More specifically, one aim of the REIM model is to contribute to the discussions on how environmental policies and implementation thereof might be set up if prevention is to count. Nearly all economic activities have interactions with the environment. These interactions may result in environmental effects, which will be defined at the level of environmental problems, such as resource depletion, greenhouse effect, and acidification. Authorities on the local or national level may wish to regulate environmental impacts by posing regulatory limits for individual plants, partly related to the specific locations of these installations. Next to these location specific measures, objectives may be defined in a more general way. An example of this are target emission reductions of, say, 25% for SO_2.

* R. Heijungs, J.B. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede: *Environmental life cycle assessment of products. I: Guide – October 1992. II: Backgrounds – October 1992.* CML, Leiden 1992.

What do these statements mean? One interpretation is that any individual plant must strive for a 25% reduction of its SO_2 emissions. This may lead to strange implications. A plant may wish to achieve this goal by not any longer generating its own electricity by fossil combustion, but instead buying externally produced electricity. Obviously, the plant's SO_2 emissions are reduced, but the problem is in fact shifted to another sector of industry: the electricity companies. When many plants behave in this way, nearly all branches of industry achieve the national objective, but this is entirely compensated by an enormous increase in SO_2 emissions by one single branch. The overall result may even be negative.

One way out of this dilemma is that such a policy objective be defined at the level of the life cycle of the product delivered to the consumer. Not the manufacturer, but the entire chain of raw materials acquisition, production, transportation, consumption, waste handling, etc. should strive for a defined reduction. This may imply that changes in certain parts of the life cycle do not satisfy the objectives or even are confronted with an increased emission. An example of this is the purchase of cleaner virgin materials, but for which longer transport is required, with higher emissions resulting.

Even this improved definition of reduction targets is not fully satisfying. For some branches of industry, certain emission reductions may be very difficult to reach whereas other emission reductions may be easily exceeded.

Life cycle assessment (LCA) may give other conclusions, leading to more flexibility in reaching environmental aims. Firstly, emissions of different substances may be brought under a number of common denominators. Examples are the emissions of substances which contribute to the problems of acidification. These emissions can be expressed as a quantified contribution to this environmental problem, allowing a choice between reducing e.g. acid emissions of SO_2 and NO_x. Next, by stating the relative importance of each of the different problems (acidification, greenhouse effect, etc.), a further generalization in policy objectives might become possible by stating environmental objectives in terms of the life cycle based reduction in "general problem contribution". The aim of the model as developed by NAM is to make development in this direction possible, thus preventing several forms of problem shifting on the one hand and allowing flexible, cost-effective problem reduction on the other. The model cannot help in deciding on the attractiveness, economically and environmentally, of different locations.

Producers may wish to invest in environmental measures. Some will do this to reduce their own emissions, but it is to be expected that the life cycle idea will be a winning approach, both for the environment and for their corporate image.

A.2.2 Environmental ranking of projects: the procedure

This report discusses a life cycle based method for the ranking of alternatives for environmental investments according to their environmental cost-effectiveness. In the environmental analysis site-specific environmental effects are not specified. These are taken account of, at least partly, in the design procedure of the investment projects to be assessed. A transparent procedure will be developed for this assessment of investment projects. To achieve a maximum transparency the procedure is structured hierarchically. It consists of four blocks, each containing a number of components, and each component containing a number of operational steps. Steps are merely technical operations, such as data collection and netting. Components are a collection of steps of an identical nature for which a similar type of knowledge is required. Components and steps are discussed in detail in the next chapters. In this introductory chapter only the blocks will be discussed. The blocks distinguished are:

- overall goal definition;
- environmental assessment;
- economic assessment;
- overall evaluation.

They may be arranged in a coherent framework as in Figure A.1.

Block 1: Overall goal definition
including definition of functional unit

↓ ↓

Block 2: Environmental assessment
COMPONENT 1: GOAL DEFINITION
↓
COMPONENT 2: INVENTORY ANALYSIS
↓ (environmental inventory table)
COMPONENT 3: CLASSIFICATION
↓ (environmental profile)
COMPONENT 4: EVALUATION
↓ (environmental improvement: ΔE)

Block 3: Economic assessment
COMPONENT 1: GOAL DEFINITION
↓
COMPONENT 2: INVENTORY ANALYSIS
↓ (economic inventory table)
COMPONENT 3: NETTING
↓ (nett costs per year)
COMPONENT 4: EVALUATION
↓ (additional costs: ΔC)

↓ ↓

Block 4: Overall evaluation
ranking according to environmental cost-effectiveness $I = \Delta E/\Delta C$ and sensitivity analysis

FIGURE A.1. Procedural structure for the model of environmental investment assessment.

The overall goal definition is concerned with a clear description of the investment projects to be assessed. This serves as a starting point for a parallel route of analysis: the environmental analysis and the economic analysis. In this report, a much more detailed description of the environmental analysis is given than of the economic one. The environmental analysis is described prior to the economic one because the existing procedure for environmental life cycle assessment has been imposed to restructure the normal practice for economic assessment. Both environmental and economic assessment consist of four components. Although some subjectivity is involved in choices in inventory analysis and classification, explicit normative choices have been reduced in one component, the evaluation. This final component of environmental and economic analysis together result in two numbers: the environmental improvement ΔE and the additional costs ΔC. How this environmental improvement is arrived at will be explained in detail in Part B of this report. Finally, these two outputs are combined into the environmental improvement per unit of cost, i.e. their cost-effectiveness of environmental improvement, expressed as the $\Delta E/\Delta C$ ratio. The overall evaluation also comprises sensitivity analyses. These are implemented as a means to assess the reliability and validity of the resulting ranking order of the projects investigated. The cost-effectiveness of environmental improvements is the sole basis for the combined environmental-economic ranking of investment projects.

A.2.3 Environmental life cycle assessment: the framework

The framework of Figure A.1 is based on the procedure for environmental life cycle assessment of products as described in the Guide LCA. This section will give a short overview of the protocol.

An environmental life cycle assessment is made up of five components which together form a comprehensive structure. These components are:

- goal definition;
- inventory analysis;

* classification;
* evaluation;
* improvement analysis.

The general concepts behind these components will be explained here.

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.

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

* Notice from the word and the definition that the unit pertains to a *function*. Often, two different products fulfil the same function, e.g. a pen and a typewriter may be compared for writing a letter. In other cases, the product is the same, but the production differs in some respects, e.g. wood from sustainable forests and non-sustainably harvested wood may be compared as a building material. In that case, it is often possible to restrict one's scope to the production. The functional unit may in that case be defined as the production of a certain product, assuming other stages of the life cycle to be unaffected. In the case of investment projects, the product is indeed unaltered, and the production stage is extended with a certain investment.

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

In 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 unweighed 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 the relative importance of different environmental effects depend on the situation and consensus (based on personal opinions) contrary to the 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 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 the methodology for LCA. 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.

A.2.4 Structure of the document & and how to read it

The report consists of four parts:

- Part A: Summary & Introduction;
- Part B: Implementation;
- Part C: Applications;
- Part D: Appendices.

Part A gives – apart form an executive summary – an introduction to and an overview of the model for environmental investment analysis and its place in the environmental-economic model. Its non-technical nature allows it to be read by managers, decision makers and government officials. The implementation Part B is a rather technical one. It is purely intended to be used by specialists who wish to provide decision support to the less specialized audience mentioned above. It contains four chapters: one on the overall goal definition, one on the environmental assessment, one on the economic assessment, and one on the overall evaluation. Part C is a discussion on the possibilities for application of general model and of the currently available NAM model, and on ways to overcome some of its limitations. The appendices, in Part D, contain the sets of data required for the classification and normalization, and a preliminary and limited set of data for the weighing procedure in the evaluation. It also contains a fully elaborated numerical example of the procedure and a glossary.

PART B

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IMPLEMENTATION

BLOCK 1

OVERALL GOAL DEFINITION

In dealing with the environmental risks of their production processes, most companies reserve a budget for environmental investment projects that are deemed necessary or that are required because of public policies. Usually, a choice between different investment projects must then be made. The LCA environmental investment model described here is primarily meant to be used by managers of companies which have such a freedom of choice on investment projects, either independent from specific policies, or under policies that leave that freedom of choice, or in the phase of public policy formation where choices on specific technologies have not yet been made. In the following we assume *the* company to be of the type where choices between environmental investment projects still are to be made. When deciding on projects the environmentally most attractive options should be chosen, within constraints. A central constraint is the economic one, here included in the analysis in the form of private costs of investments. Some other constraints limit the possibilities of installation design, like those on workers health and safety, and are left out of the analysis here. Finally, there are constraints that have to be considered in the decision procedure independently, as those on some specialized kinds of manpower. In the procedure of LCA the start of any analysis is the precise definition of this or similar aims and limitations. In that procedure, the overall goal definition is the first component, with two steps distinguished:

- determining the application;
- defining the subject of the study.

At this starting point of the model a clear description of the investment projects to be assessed should be given. Above all, technical relations and interactions of the assessed project with the current process of the company are necessary to be made transparent. The aim of this is to be able to determine how substantial the influences of implementing project *X* are on the other processes.

Step: Determining the application

A broad description of the group using the outcomes of REIM could be: business managers and other decision makers of the company, other industrial partners, governmental officials and social organisations. From the company's point of view in general one can distinguish internal and external users. Starting the implementation of the model, one has to describe the user group and their kind of use of the model precisely.

In the following we first assume the users to be internal users and we describe the model as an internal decision support system for management. The model enables them to determine the most effective way in which the company's financial resources for environmental projects can be allocated. Therefore the overall goal definition of the model is defined as to rank the relevant projects as to their potency to relieve the company's environmental pressure per guilder of the company related costs.

For this aim we define the cost effectiveness: $I_X = \Delta E_X/\Delta C_X$ of an environmental investment project X. The numerator ΔE_X stands for the lightening of the environmental pressure or the relative environmental improvement achieved by project X. Clearly there is no absolute environmental improvement, because the company's current process causes environmental pressure anyway. The very aim of the investment is to diminish this pressure. Therefore it could be called an environmental project. The denominator ΔC_X stands for the extra costs added by project X to the company's total costs of the current process.

Where ratio I_X is defined as the relative environmental improvement per unit of cost, it can be considered as the cost-effectiveness of the environmental improvement of the project. For two reasons factor I_X is extremely useful for decision making. First, the goal of the decision support system is to select those projects in which the environmental gains are maximized. Secondly: multiplying the cost effectiveness I_X with the costs of all intended projects separately and then summing up these products, represents the total relative environmental improvement ΔE_X of the company, within the limitations of the predefined budget.

Factor I_X can be derived by running the combined environmental and economic assessment. Both assessments are structured according to the Guide LCA developed by CML, TNO and B&G.

Step: Defining the subject of the study

After determining the application of the model, the subject of study has to be defined. Normally this is a product. More precisely, this is a certain amount of function fulfilled by this product.

In LCA terminology the subject of study is described by means of the *functional unit*. By this is meant: the specification of the function of a product or product system which is used as the basis for the selection and comparison of the product(s) which provide that function. For example: packaging 1 litre of milk for comparing glass bottles with (laminated) cartons with plastic materials.

When defining the functional unit of a company completely in line with LCA, the best choice would be: the year production of the company, specified by the product package differentiated in the amounts of the different products. One then could define the environmental index E_X of project X as: the parameter which represents the harmfulness to the environment of producing this year production by implementing the environmental project X. As the LCA comparison takes place through a difference analysis, situation X could be compared with situation 0 which stands for the company producing this yearly product package in the current way; which means without implementing any environmental investment project. The difference between environmental index E_X and environmental index E_0 will be denoted by ΔE_X and is a quantitative indication for the relative environmental improvement of the current production process by implementing project X.

The environmental index ΔE_X could also be compared with the environmental index E_Y of producing the same yearly product package implementing project Y. Project X and Y could then be ranked in order to their value of the environmental index*.

For the time being in most companies the subject of study are mostly projects which will be added to the production process in order to diminish the company's contribution to environmental problems. Therefore the project itself can be considered as the functional unit. While the difference ΔE reflects the relative environmental improvement of the company's process achieved by the project, one then could determine this improvement directly. Because of using the LCA method the environmental effects are assessed from the cradle to the grave of the project. However, this is only possible when adding this project to the company's current process has no effect on the functioning of the process itself. If implementing the project has substantial effects on the process, all parts of the process that are affected should be included, which could mean that the company's entire production process

* One disadvantage of using an environmental index for this ranking is that one single parameter might suggest scientific accuracy. The classification and normalization factors are more or less objectively determined, but the evaluation factors are subjective. To avoid too rapid decisions, a sensitivity analysis has been included in Chapter B.4.

should be described in the environmental inventory table to make transparent how these effects spread through the process*.

Therefore, before applying this model it is important to define the project to be assessed and especially the effects on the company's current process clearly and in advance. Three types of projects can be distinguished:

- *add-on projects*, in most cases end-of-pipe projects. For these it can be shown that they have no effect on the company's current process in the technical sense: their process tree being independent of the company's current process tree (e.g. filters on chimneys).
- *pseudo add-on projects*, which are strictly speaking (at least partly) process integrated projects. For these, the company's technical department now has to deliver the data of nett effects of incorporation of the project in the company's current process. If these indicate that the project only slightly influences minor parts of the company's processes, the project can be dealt with as add-on project. If these data are not available, the possibilities for ranking the projects are as follows:
  - if with other arguments it can be shown that incorporation of the project only slightly influences minor parts of the company's processes, again the project can be dealt with as add-on project and the effects as pro memoria data†.
  - if this is not the case, the project is considered to be a process integrated project.
- *process integrated projects*. These are built-in projects which have substantial and mutually different effects on other parts of the company's process. They therefore (indirectly) change the company's emissions beyond the project's boundaries. With this model as it is presented here it is not possible to assess this kind of projects‡.

Because the comparative character of the LCA omits identical parts of the analysis, process integrated projects can also be dealt with as pseudo add-on projects, if they have substantial influences on the company's process, but all the same for the projects to be compared.

In practice, at this point the model user should define the assessed project as add-on (AO), pseudo add-on (PAO) or process integrated (PI), based on a clear description of the influences its implementation has on the company's current process. This will be mentioned in the environmental inventory table as project type, in combination with the quality of the data.

For the time being it is impossible to use the model to assess ranking PI-projects, except for sufficiently simple ones. In the future this can be made possible by making all the effects transparent in the model by including all relevant parts of a company's process tree in the environmental inventory. On the long term the model can be updated to the potential assessment of more process integrated projects and eventually of a whole new plant; see Section C.2.

In the following we assume the functional unit to represent an add-on project or a pseudo add-on project with demonstrable minor influence on the company's current process.

* The company's process is defined as: all company's economic activities, such as: exploration, exploitation, production, waste handling, marketing, distribution/transportation, etc. All these activities have a direct or indirect impact on the environment.

† A pro memoria datum is a datum from which the numeric value is impossible to be assessed for the time being. To reserve an empty parameter for it in the calculation, the datum is filled in with the alpha-numeric value: p.m. Later on when the numeric value of the datum is known accurate enough, p.m. will be exchanged by this numeric value.

‡ In case the company has many almost independently operating locations, a whole location could be considered in the analysis, provided the complexity of such a location is low enough to allow the use of the current REIM.

BLOCK 2

ENVIRONMENTAL ASSESSMENT

A project *X* may consist of an integrated group of technical measures. The environmental assessment of a project should be conform the Guide LCA. In this model all procedures will be considered apart. This is to arrive at a transparent procedure.

In the environmental assessment 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 the next four sections. Each step is discussed in a separate subsection.

An environmental life cycle assessment is made up of five components which together form a comprehensive structure. These components are:

- goal definition;
- inventory analysis;
- classification;
- evaluation;
- improvement analysis.

On the short term this model can not contain a full inventory analysis nor an improvement analysis. This is due to the choice of the types of the projects (see the overall goal definition) which makes poses restrictions to the inventory table: it is limited to the project involved. Further explanation about this limitation will be given below. For ranking a portfolio of projects, except from process integrated ones, the model is adequate.

Component 1: Environmental goal definition

The aim in the environmental life cycle assessment is to consider all potential effects on the environment caused by the project. This means in this context considering the total contribution of a project in reducing emissions and waste streams in the entire life cycle. Although the intention of implementing a project is reducing emissions and waste streams, the project could also have negative environmental effects. Certain problems may for instance have been shifted to other environmental media or economic sectors (e.g. power plants).

The goal definition of the environmental assessment is based on the overall goal definition of this model. This might be to provide an indication of the relative environmental improvement per guilder investment of a project. For defining this indication first an environmental assessment is necessary to calculate the relative environmental improvement of a project. The goal of the environmental improvement is to derive ΔE_X, the environmental improvement of adding project X to the total operations of a company.

Attention must be paid to the fact that this model differs at this point from the more usual LCA in which the quantitative part results in a single parameter: the environmental index E_X. This environmental index E_X is defined as an absolute measure which indicates the total contribution of a functional unit to all selected environmental problems.

In this model however, the unit analyzed is project X, aimed at diminishing the company's total contribution to all environmental problems. This implies a reduction of the environmental index E_X of the whole of a company's operations. Mathematically this can be described as follows:

$$\Delta E_X = E_0 - E_X \tag{B.1}$$

where

ΔE_X = the environmental improvement of a company achieved by implementing project X;

E_0 = indication of the company's total contribution to selected environmental problems without project X;

E_X = indication of the company's total contribution to selected environmental problems after implementing project X.

Summarizing, the goal of the environmental assessment is to define the contribution of reducing total environmental effects of a company by implementing project X. This can also be defined as ΔE_X, the nett* environmental improvement due to a project.

Step: Determining the depth of the study

A life cycle assessment of investment projects requires a detailed study of the processes which are affected by these projects. However, because we are for the moment only interested in the environmental assessment of projects which can be characterized as add-on or pseudo add-on projects, a streamlined method could be used. This implies that only the processes which are affected by the project will be considered. This means for example that the inventory analysis only considers those inputs and outputs which are necessary for the project.

Another reason which limits the depth of this study and which is not due to the definition of this model is due to a more or less deliberate limitation of the quantitative analysis.

The life cycle of a project, which includes all processes required for the functioning of the project "from cradle to grave", affects the environment. This implies that all processes which concern the extraction of resources, production of materials and components, manufacturing the project, use of the product and waste processing, including the processes recycling and reuse should be considered. However due to the choice of the functional unit, it is not necessary to make a review of all processes of the company involved. Due to lack of time or money, it is also often not possible.

Other limitations are the impossibility to quantify all environmental interventions and their environmental effects. This could include environmental interventions such as the emission of radiation which at present cannot be translated into environmental effects. Because of the limitation to quantify all information, the user of this model should realize that the quantified result of this model rank the projects only on the basis of this quantified information and excluding qualitative information. The ranking is therefore in some cases a fairly good indication, but in other cases a very rough one. To help the user of the model to keep this in mind, the user has to describe the relevant qualitative information in each step of the model.

* ΔE expresses the nett environmental improvement due to a project which means: the improvement caused by the project minus its negative effects on the environment.

Component 2: Environmental inventory analysis

The inventory analysis is a survey of the interaction between the life cycle of the investigated project and the environment. Using the life cycle analysis implies that the inventory must include all upstream and downstream processes as well.

The first action in the inventory analysis is to draw up an overview of all processes in the entire life cycle that are influenced by the project, 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 project, this is the environmental inventory table. Four steps can be distinguished:

- drawing up the process tree;
- entering the process data;
- application of the allocation rules;
- creating the environmental inventory table.

The four steps will be discussed separately.

Step: Drawing up the process tree
In this step the life cycle of a project selected in the overall 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 B.1. Similarly each process output flows either to another process or to the environment.

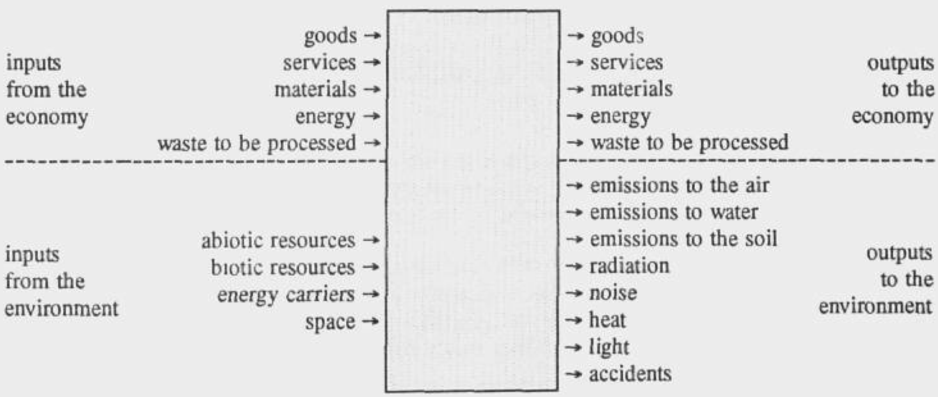

FIGURE B.1. An economic process is defined by the magnitude and composition of the flows to and from the economy and the environment. (Taken from the Guide LCA.)

The processes concern the extraction of resources, production of materials, waste processing, etc. There are also many processes which support other processes, such as transport and electricity generation.

The complete process tree has to provide the links between all economic inputs and outputs and all 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. All processes associated with a project have to be traced back to their origin and followed through their completion.

Drawing up a process tree for a project differs from the proposed process tree as described in the Guide LCA because of the chosen definition of the functional unit.

Referring to the functional unit as described in the definition of the subject of the study, we only concentrate in this model on the relevant processes to a project. Hence, only the use and production of goods, materials, energy, services and waste to be processed which is directly linked to the project will be considered in the process tree. As stated before the main reason for this partial study is the add-on character of the project*.

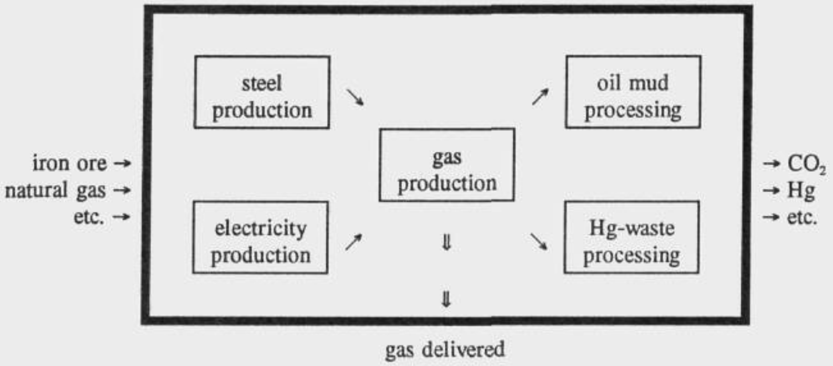

FIGURE B.2. The processes which are linked to a project include both the input from and the output into other economic processes: the use and production of goods, materials, energy, services and waste to be processed.

Step: Entering the process data

In this step the process data for all processes in the life cycle of the project must be collected. The data should not be aggregated but refer to individual processes whenever possible. There are two important aspects per process when presenting the process data:

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

A special format has been developed for the specification and storage of process data as shown in Table B.1. The form consists of a main structure and rules for entering the process data. Some processes have non-quantifiable aspects. These should also be included; the format makes a special provision for them.

The nature and the quality of the process data have to be specified for each process. Data whose quality or representativeness does not match the general standard may have to be identified separately.

The table describes the conceptual format for the storage of process data. This table will be the basic structure for describing all processes in the entire life cycle of a project added to a company; processes within the boundaries of the company as well as processes concerning input and output flows of the company.

* The implication of this approach is that when a process tree of a pseudo add-on or a process integrated project will be drawn up, it is in case of substantial and mutual different effects on other parts of the process of a company not possible to consider the project isolated from the company's total process any more. When pseudo add-on and process integrated projects will be assessed anyway, the user of the model should assess whether the result of the environmental assessment leads to an underestimation of certain environmental interventions.

TABLE B.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
	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

Using this conceptual format all processes involved can be specified in a separate table. One of the processes is of a special nature: the usage of the project installed. As it may happen that the project requires inputs or outputs which differ per year (i.e. a larger energy consumption in the first two years of operation) information on the operation in various years may be required. The implementation of project *X* is shown as an example in the following table. Note that the amount of waste is included as an economic output ("sludge"), as it is delivered to other economic processes.

TABLE B.2. Example of entering process data: central process of project *X*.

item	year 1	year 2	etc.
1 format			
1.1 name or institute	P.Jones; distribution division		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 process			
2.1 name or code	venture spiral		
2.2 representativeness			
2.2.1 scale	Dutch situation		
2.2.2 date	early nineties		
2.2.3 duration	capacity: 500 m^3/min		
2.2.4 status	data estimated by designers		
2.3 quality			
2.3.1 clarity	good description		
2.3.2 accuracy	unknown: no empirical material		
2.3.3 completeness	no maintenance included		
2.4 sources	calculations by internal technical division		
2.5 overall assessment	rough but best estimation		
2.6 comment	none		
3 economic input	... MJ elec. ... kg steel	... MJ elec.	...
4 environmental input			
4.1 resources	... m^3 natural gas	... m^3 natural gas	...
4.2 space			
5 economic output	... kg sludge leak prevention for one pump	... kg sludge leak prevention for one pump	...
6 environmental output			
6.1 emissions to air	... kg CH_4 ... kg SO_2	... kg CH_4 ... kg SO_2	... ...
6.2 emission to water	... mg phenol	... mg phenol	...
6.3 emissions to soil	... kg scrap	... kg scrap	...
6.4 radiation	none	none	...
6.5 sound	negligible	negligible	...
6.6 heat	... MJ to air	... MJ to air	...
6.7 accidents	... victims	... victims	...

item	year 1	year 2	etc.
7 balances	...	...	...
8 comments/other	none		

Apart from quantification (and if not possible qualification) of the processes within the boundaries of the company, also the data for the production of inputs (electrical energy production, steel production) and outputs to be processed (incineration of sludge) must be specified in the same way as the example in the table, unless these are neglected in the previous on the ground of being insignificant.

Step: Application of the allocation rules

Many processes produce several valuable outputs. In general, only one of these is part of the life cycle of a project. The emissions of such a multiple process are thus only partly due to the output needed in the life cycle. They therefore have to be in some way allocated among the various valuable outputs. The same arguments apply to economic inputs, such as electricity, and economic outputs to be processed as waste. Currently, there is no general accepted method for allocation. If required, it is still a cumbersome step in the procedure for LCA. The Guide LCA gives more details on this problem.

In case that a technical department of the company produces the integrated emission data of a project as one composite project, some form of allocation has already been made. The allocation problem has been replaced to that department, and this step in the model remains empty. It is not very probable that the few processes contained in the process tree contains processes that are essentially of a multiple nature. Only when a complete inventory component is added (see Chapter C.2), allocation will be a topic of concern.

Step: Creating the environmental inventory table

All environmental interventions of all processes for the functional unit, project *X*, should be as fully quantified as possible. This could 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 the contribution of that process to the functional unit. The section listing the environmental interventions of all processes required, together, is the inventory table of the life cycle of the project.

In this step all inputs and outputs of products, materials, energy, services and waste to be processed have been translated to inputs from and outputs to the environment. As stated before all non-quantifiable information could be lost during the quantification in this step. Therefore to include this aspects an item "qualitative aspects" will have to be included.

TABLE B.3. Example of the inventory table of a functional unit: project *X*.

item	year 1	year 2	etc.
1 format			
1.1 name or institute	P.Jones; distribution division		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 process			
2.1 name or code	life cycle of venture spiral for leak prevention		
2.2 representativeness			
2.2.1 scale	Dutch situation		

item	year 1	year 2	etc.
2.2.2 date	*early nineties*		
2.2.3 duration	capacity: 500 m^3/min		
2.2.4 status	pseudo add-on project: only electricity generation and treatment of mercury containing waste include in process tree		
2.3 quality			
2.3.1 clarity	good		
2.3.2 accuracy	reasonable		
2.3.3 completeness	very incomplete due to ignorance of pseudo add-on character		
2.4 sources	diverse, see separate process data for more detail		
2.5 overall assessment	rough but best estimation		
2.6 comment	none		
3 economic input	... kg steel p.m.		
4 environmental input			
4.1 resources	... m^3 natural gas ... kg coal	... m^3 natural gas ... kg coal	... ...
4.2 space			
5 economic output	... kg sludge p.m. leak prevention for one pump	... kg sludge p.m. leak prevention for one pump	...
6 environmental output			
6.1 emissions to air	... kg mercury ... kg SO_2 ... kg CO_2	... kg mercury ... kg SO_2 ... kg CO_2	... ...
6.2 emission to water	... kg phenol	... kg phenol	...
6.3 emissions to soil	... kg scrap	... kg scrap	...
6.4 radiation	some	some	...
6.5 sound	negligible	negligible	...
6.6 heat	... MJ to air	... MJ to air	...
6.7 accidents	... victims	... victims	...
7 balances	...	...	...
8 comment/other	none		

The economic inputs and outputs of the inventory table must be none, because all economic flows except the function of project *X* as the economic output have to be translated into environmental interventions. When not all process data of the economic inputs required for a project are available, it must be included in the inventory table as a p.m. item.

Component 3: Environmental classification

In the classification the environmental interventions of the functional unit as stated in the environmental inventory table are translated into relevant environmental effects by environmental models. This means that the different substances will be converted to one standard substance for one particular environmental problem (for example CO_2-equivalents for the greenhouse effect or SO_2-

equivalents for acidification). The effects reflect the contribution of the functional unit to environmental problems like greenhouse effect, acidification, biotic depletion, etc. The final result of the classification is the normalized environmental profile. During the classification the physical and other environmental interventions are projected onto the potential environmental effects in four steps:

- selection of the problem types;
- definition of the classification factors;
- creating the environmental profile;
- normalization of the effect scores.

Step: Selection of the problem types

The problems which the assessment will address are selected in this step. These will be exclusively environmental problems. The assessment could include other environmental problems than those used here. An example is the environmental effect of radiation, where no suitable environmental model that relates the amount of radiation to a specific contribution to an environmental effect is available yet.

Table B.4 lists the types of problems, which are environmental effects, not environmental interventions, such as emissions to air, energy consumption and waste production.

TABLE B.4. List of widely recognized problems which can be investigated with the standard classification model.

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

Step: Definition of the classification factors

This section describes how the effect scores of the environmental effects listed in the above table can be calculated. The Guide LCA explains the range of models available to describe the environmental processes. A classification factor is the result of the modelling of environmental effects which represents the effects as a result of one unit of an environmental intervention. In Appendix D.1, a list of classification factors is included. Here we give for illustrative purposes an excerpt.

TABLE B.5. Example of classification factors used for the for the classification.

environmental intervention	greenhouse effect (kg CO_2)	ozone depletion (kg CFC-11)	human toxicity (kg body weight)	etc.
m^3 natural gas	0	0	0	...
kg CH_4 to air	11	0	0	...
kg SO_2 to air	0	0	1.2	...
etc.	...	...	...	...

Step: Creating the environmental profile

An inventory table listing the environmental interventions associated with the functional unit project X is 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 and adding up all the interventions.

The data from the complete inventory table are used to multiply with the classification factors of the Guide LCA (see Appendix D.1). The resulting table of effect scores is known as the environmental profile of project X for each year until the end of the project. This table consists of problem oriented effect scores.

Calculating the effect scores and thereby creating the environmental profile is relatively easy. Mathematically this can be defined as follows:

$$Z_{k,j} = \sum_s F_{k,s} \times I_{s,j} \tag{B.2}$$

where

$Z_{k,j}$ = effect score k in year j;

$F_{k,s}$ = classification factor for substance s and environmental effect k;

$I_{s,j}$ = intervention of substance s in year j.

It is obvious that one effect score will not be caused by just one intervention or vice versa. Therefore 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 fully included more than once.

Besides the quantified effects there are also unquantifiable effects. This is initially due to the unquantified environmental interventions in the inventory table. Another reason is that it is not possible to model all quantified interventions. For example, some substances are known to be toxic but there is no further information available about their toxicity. All qualitative aspects have to be stated clearly.

TABLE B.6. Example of an environmental profile of a functional unit: project X.

effect score	year 1	year 2	etc.
abiotic depletion	...	...	...
biotic depletion	... yr^{-1}	... yr^{-1}	...
greenhouse effect	... kg	... kg	...
ozone depletion	... kg	... kg	...
human toxicity	... kg	... kg	...
aquatic ecotoxicity	... m^3	... m^3	...
terrestrial ecotoxicity	... kg	... kg	...
oxidant formation	... kg	... kg	...
acidification	... kg	... kg	...
nutrification	... kg	... kg	...
malodorous air	... m^3	... m^3	...
noise	... $Pa^2 \cdot s$	... $Pa^2 \cdot s$	...
damage	... $m^2 \cdot s$	... $m^2 \cdot s$	...
victims	...	...	...
comments/other	...		
qualitative aspects	...		

Step: Normalization of the effect scores
After the classification the normalization procedure will be applied. This means the effect scores are normalized in this step. The contribution made by a project to an environmental effect is linked to the total 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 of a period is calculated using the same classification model.

However, when a company is located in a bounded area (for example within a country) and several of the selected environmental problems are not of a global type, such as acidification and water pollution, the user of this model can consider to normalize some of the environmental effect scores at a lower level. If the user of this model decides to normalize some of the environmental effect scores at for example a Dutch or European level, one way of doing this is by multiplying the global normalization scores with the fractions referring to the share of the gross national product (GNP) of the Netherlands or Europe to the GNP of the world, as an approximation. Alternatively, one can define the environmental effect of interest and determine the total of all emissions contributing to this defined problem. When applying normalization not at world level the user of this model must realize that the evaluation factors referring to those environmental effect scores, which are used in the next section must correspond with the level of normalization.

The ratio between each effect score and the relevant contribution to that effect score over a certain year at world level provides the *normalized environmental profile* consisting of normalized effect scores, all which are expressed in a fraction of the world's effect score in a certain year. They all thus have the dimension of a time: the product is responsible for a certain number of seconds contribution to the environmental problem under consideration. Although these normalized effect scores have the same dimension, the plain addition or comparison of normalized effect scores belonging to different problems makes no sense*.

For an effect score for a global environmental problem this results in:

$$\zeta_{kj} = \frac{Z_{kj}}{W_k} \qquad \text{(B.3)}$$

where

ζ_{kj} = normalized effect score k in year j;
Z_{kj} = effect score k in year j;
W_k = world's effect score k in one year.

For a regional and local normalization, a similar procedure applies. It is important in this model to note at which scale the normalization will be applied for the different environmental problems.

In Appendix D.2, a list of annual world effect scores is given. Here we give an example.

TABLE B.7. Example of world effect scores.

effect score	world's contribution
greenhouse effect	$6{,}01 \cdot 10^{13}$ kg·yr^{-1}
ozone depletion	$1{,}00 \cdot 10^{9}$ kg·yr^{-1}
etc.	...

The following table gives an example of a normalized environmental profile.

* An analogy may elucidate this. One may specify the height of a triangle along with the size of its base. They can both be expressed in m. The addition of these two numbers makes in general no sense, as one needs a rule of combination, associated with the quantity desired. If one desires e.g. a measure for the surface, the rule is to multiply the base with the height and divide by 2.

TABLE B.8. Example of a normalized environmental profile of a functional unit: project *X*.

normalized effect score	year 1	year 2	etc.
abiotic depletion	... yr	... yr	...
biotic depletion	... yr	... yr	...
greenhouse effect	... yr	... yr	...
ozone depletion	... yr	... yr	...
human toxicity	... yr	... yr	...
aquatic ecotoxicity	... yr	... yr	...
terrestrial ecotoxicity	... yr	... yr	...
oxidant formation	... yr	... yr	...
acidification	... yr	... yr	...
nutrification	... yr	... yr	...
malodorous air	... yr	... yr	...
noise	... yr	... yr	...
damage	... yr	... yr	...
victims	... yr	... yr	...
comments/other	...		
qualitative aspects	...		

Component 4: Environmental evaluation

After the classification one is left with a list of numbers, which should enable one to make a reasonable assessment of the investment project. However, to compare projects with different profiles in different years, a way has to be developed to compare different effects and effects in different years. This is done in the environmental evaluation, which intends to aggregate the information to one number. It consist of two steps:

- discounting the effect scores;
- weighting the effect scores.

The first step is about the aggregation of effect scores of the same kind but of different years. It thus enables a comparison between different years. In the second step, the so-called discounted effect scores are weighted and combined into one overall score. This provides a comparison between different environmental effects.

The result of the two-step procedure reflects the improvement of the environmental index ΔE_X for project *X*.

Step: Discounting the effect scores
In this step all normalized effect scores related to the 15 environmental problems which are collected for each year of the life time of the project must be discounted to a reference year if discounting is considered appropriate. This means at this moment adding up all effect scores of a particular environmental problem, because we propose a discount rate zero to start with*. We still give a formula which enables discounting, for usage in the sensitivity analysis; see Section B.4.

Mathematically discounting of the normalized effect scores can be done by:

* In the literature several reasons comes up for not discounting environmental effects. See for example D. Pearce & R.K. Turner: *Economics of natural resources in the environment*. Harvester Whithsheaf, New York 1992.

$$\zeta_k = \sum_j \frac{1}{(1+r_{env})^{j-1}} \zeta_{k,j} \rightarrow \sum_j \zeta_{k,j} \quad \text{(B.4)}$$

where

ζ_k = discounted normalized effect score k;

$\zeta_{k,j}$ = normalized effect score k in year j;

r_{env} = environmental discount rate (= 0).

TABLE B.9. Example of a discounted environmental profile of a functional unit: project *X*.

effect score	discounted normalized score
abiotic depletion	... yr
biotic depletion	... yr
greenhouse effect	... yr
ozone depletion	... yr
human toxicity	... yr
aquatic ecotoxicity	... yr
terrestrial ecotoxicity	... yr
oxidant formation	... yr
acidification	... yr
nutrification	... yr
malodorous air	... yr
noise	... yr
damage	... yr
victims	... yr
comments/other	...
qualitative aspects	...

Step: Weighting the effect scores

The result of discounting the normalized effect scores in the previous step is the environmental profile of project *X* in a preference year. It consists of 15 effect scores for selected problem types such as acidification, ozone layer depletion, ecotoxicity, etc. However, for unambiguously comparing the contribution to environmental improvement by different projects it is impossible to use the environmental profile of the assessed projects. Therefore to make comparison possible the 15 effect scores must be aggregated into one environmental index ΔE. For this a set of evaluation factors is required.

A set of evaluation factors which is broadly accepted is not available yet. Different manners for defining evaluation factors can be distinguished:

- on the basis of expert judgement;
- on the basis of social opinion;
- on the basis of political decisions;
- on the basis of sustainability indicators;
- on the basis of monetarizing.

For the time being it is possible to use a set of evaluation factors which are derived from the Dutch environmental policy plan (NEPP/NEPP+)*. In many cases project differences are large and the

* Anonymous: *National environmental policy plan. To choose or to lose.* SDU, The Hague 1989 respectively Anonymous:

TABLE B.8. Example of a normalized environmental profile of a functional unit: project X.

normalized effect score	year 1	year 2	etc.
abiotic depletion	... yr	... yr	...
biotic depletion	... yr	... yr	...
greenhouse effect	... yr	... yr	...
ozone depletion	... yr	... yr	...
human toxicity	... yr	... yr	...
aquatic ecotoxicity	... yr	... yr	...
terrestrial ecotoxicity	... yr	... yr	...
oxidant formation	... yr	... yr	...
acidification	... yr	... yr	...
nutrification	... yr	... yr	...
malodorous air	... yr	... yr	...
noise	... yr	... yr	...
damage	... yr	... yr	...
victims	... yr	... yr	...
comments/other	...		
qualitative aspects	...		

Component 4: Environmental evaluation

After the classification one is left with a list of numbers, which should enable one to make a reasonable assessment of the investment project. However, to compare projects with different profiles in different years, a way has to be developed to compare different effects and effects in different years. This is done in the environmental evaluation, which intends to aggregate the information to one number. It consist of two steps:

- discounting the effect scores;
- weighting the effect scores.

The first step is about the aggregation of effect scores of the same kind but of different years. It thus enables a comparison between different years. In the second step, the so-called discounted effect scores are weighted and combined into one overall score. This provides a comparison between different environmental effects.

The result of the two-step procedure reflects the improvement of the environmental index ΔE_X for project X.

Step: Discounting the effect scores

In this step all normalized effect scores related to the 15 environmental problems which are collected for each year of the life time of the project must be discounted to a reference year if discounting is considered appropriate. This means at this moment adding up all effect scores of a particular environmental problem, because we propose a discount rate zero to start with*. We still give a formula which enables discounting, for usage in the sensitivity analysis; see Section B.4.

Mathematically discounting of the normalized effect scores can be done by:

* In the literature several reasons comes up for not discounting environmental effects. See for example D. Pearce & R.K. Turner: *Economics of natural resources in the environment*. Harvester Whithsheaf, New York 1992.

$$\zeta_k = \sum_j \frac{1}{(1+r_{env})^{j-1}} \zeta_{k,j} \rightarrow \sum_j \zeta_{k,j} \qquad (B.4)$$

where

ζ_k = discounted normalized effect score k;
$\zeta_{k,j}$ = normalized effect score k in year j;
r_{env} = environmental discount rate (= 0).

TABLE B.9. Example of a discounted environmental profile of a functional unit: project X.

effect score	discounted normalized score
abiotic depletion	... yr
biotic depletion	... yr
greenhouse effect	... yr
ozone depletion	... yr
human toxicity	... yr
aquatic ecotoxicity	... yr
terrestrial ecotoxicity	... yr
oxidant formation	... yr
acidification	... yr
nutrification	... yr
malodorous air	... yr
noise	... yr
damage	... yr
victims	... yr
comments/other	...
qualitative aspects	...

Step: Weighting the effect scores

The result of discounting the normalized effect scores in the previous step is the environmental profile of project X in a preference year. It consists of 15 effect scores for selected problem types such as acidification, ozone layer depletion, ecotoxicity, etc. However, for unambiguously comparing the contribution to environmental improvement by different projects it is impossible to use the environmental profile of the assessed projects. Therefore to make comparison possible the 15 effect scores must be aggregated into one environmental index ΔE. For this a set of evaluation factors is required.

A set of evaluation factors which is broadly accepted is not available yet. Different manners for defining evaluation factors can be distinguished:

- on the basis of expert judgement;
- on the basis of social opinion;
- on the basis of political decisions;
- on the basis of sustainability indicators;
- on the basis of monetarizing.

For the time being it is possible to use a set of evaluation factors which are derived from the Dutch environmental policy plan (NEPP/NEPP+)*. In many cases project differences are large and the

* Anonymous: *National environmental policy plan. To choose or to lose.* SDU, The Hague 1989 respectively Anonymous:

ranking is not very sensitive upon changes in the evaluation factors. In that case, indicative evaluation factors may already be adequate for decision making. Because there is no set of widely agreed weighting factors yet, in this model we use an imaginary set of evaluation factors to show the functioning of this model. In the future when a set of evaluation factors based on a broad consensus comes up, it is easy to change the numbers in Appendix D.3.

TABLE B.10. Example of a set of imaginary evaluation factors.

environmental problem	evaluation factor
greenhouse effect	21.0
ozone depletion	19.7
etc.	...

In this step the various environmental effects are added after multiplication with the evaluation factors assigned to each environmental problem. As a result of the weighting and addition, the quantitative part of the discounted environmental profile (which consists of a set of effect scores) is reduced to a single parameter: the relative environmental improvement ΔE.

The environmental improvement of a project can be derived now by the summation of all discounted effect scores after multiplication by the relevant evaluation factors*:

$$\Delta E = \frac{\sum_k \omega_k \zeta_k}{\sum_k \omega_k} \qquad (B.5)$$

where

ΔE = relative environmental improvement of the project;

ω_k = evaluation factor for environmental problem k;

ζ_k = discounted normalized effect score for environmental problem k.

Thus the final result of the environmental assessment is the relative environmental improvement of project X, expressed as ΔE_X. This result will be used in the overall evaluation B.4 after the economic assessment, described in the next chapter.

TABLE B.11. Example of a relative environmental improvement of a functional unit: project X.

item	value
relative environmental improvement	... yr
comments/other	...
qualitative aspects	...

National environmental policy plan plus. SDU, The Hague 1990.

* Notice that this equation is somewhat different from the formulation in the Backgrounds LCA. There, in fact, the denominator was absent. It has been introduced here to account for the fact that the absolute values of ω_k are irrelevant, and that only the relative differences are important. E.g. a weighting factor for ozone depletion of 3 and for greenhouse effect of 2 should amount to the same as weighting factors of 30 respectively 20.

BLOCK 3

ECONOMIC ASSESSMENT

In this part of the model, again the functional unit represents project *X* which is add-on or pseudo add-on to the company's current process. The aim of the investment is to diminish the environmental pressure of the company's production process by ΔE_X. As this project is added to the company's current process, so are the costs ΔC_X of the project added to the total costs of the current process. The economic assessment determines the total additional costs ΔC_X of the project *X* for which the environmental assessment is described above.

To determine the total additional costs one has to decide on the kind of investment analysis one chooses to use. In this model the nett present value method is used. In principle any ordinary investment analysis can be followed. However, for the sake of transparency we propose to break down such an all-in-one economic procedure into the differing steps. Here we build up the economic analysis along the structure of the environmental assessment of Section B.2*.

Component 1: Economic goal definition

The aim of the economic life cycle assessment is to produce a number which denotes the financial consequences of a particular investment project. In principle, the consequences for the economy as a whole could be addressed. In that case, an extensive analysis should be made of the financial consequences for the company which undertakes the investment, as well as the consequences for the other parts of the economy. These other parts are:

- other companies involved, e.g. those producing the equipment to be invested;
- competing companies, which might see their market share rise, but on the other hand their image as good for the environment decrease;
- consumers, who will have to pay for the more expensive production method;
- their government, receiving additional taxes for the investments, or may be supplying money to promote environmental investments;
- the country, which could experience a shift in its balance of payments;
- the country's people, who might experience shifts in employment;
- etc.

It is clear that this kind of analysis is too complex a matter to be dealt with when considering

* In fact the economic assessment is a true economic life cycle assessment, because through the functioning of markets all economic costs of the project from cradle to grave are taken into consideration in an investment analysis.

ordinary investment analyses. This report describes a way to extend the investment analysis with only one aspect: the environmental aspect*. Block C deals with the ordinary investment analysis which concentrates on the financial consequences for the company wishing to undertake an investment.

Step: Determining the depth of the study
In the first step of the economic assessment the desired depth of this part of the study has to be described, such as which kind of costs and benefits it deals with.

For the same reason as in the environmental part of the model (trying to achieve as much transparency as possible) as much detail as possible is preferred in this economic part. Therefore, for assessing the total additional costs of project *X*, all economic costs linked to the project should be taken into account. This means: not only operating costs, depreciation, dividend, etc., but also the monetary environmental costs, including those for which the company can be made responsible on the long term†.

For the benefits realized by the project the same detail of the data is preferred, such as: avoided license costs, saved waste handling costs, saved inputs or extra sales.

As in normal investment analyses, indirect taxes which have inevitably to be paid by the company without the possibility of bringing them into account by the customer, are brought into the table of costs. There are reasons for bringing in also corporate tax into the inventory table. But for ranking different projects often it will not be very relevant so one could leave it out if this is the case.

Component 2: Economic inventory analysis

Due to the limited scope, the economic inventory analysis is much simpler than the environmental inventory analysis. In the costs of an equipment, the costs of its constituents are reflected. There is no need to trace these in a process tree. One can directly draw up an economic inventory table.

Step: Creating the table of costs and benefits
This table consists of a description of all economic costs and benefits. Referring to the depth of the analysis, the inventory should not only describe all economic benefits, but also all additional economic costs.

TABLE B.12: The economic inventory of project *X*.

	year 1	year 2	etc.
1 format			
1.1 name or institute	P.Jones; distribution unit		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 project			
2.1 name or code	venture spiral		
2.2 representativeness			
2.2.1 scale	Dutch situation		

* It is a remarkable observation that there is large amount of agreement that environmental problems should not be shifted to other companies or countries, whereas the bankruptcy of other companies or an increased unemployment in other countries is "part of the game" of economics.

† Because this model makes a clear distinction between an environmental and economic assessment, *non-monetary* environmental costs, that is environmental damage, is only described in the environmental assessment (Section B.2).

	year 1	year 2	etc.
2.2.2 date	early nineties		
2.2.3 duration	capacity: 500 m^3/min		
2.2.4 status	clear		
2.3 quality			
2.3.1 clarity	good		
2.3.2 accuracy	good		
2.3.3 completeness	no maintenance included		
2.4 sources	calculations by internal financial division		
2.5 overall assessment	quite good		
2.6 comment	none		
3 costs			
3.1 investments	*f*... capital *f*... labour		...
3.2 operating costs	*f*... operation *f*... labour *f*... indirect taxes *f*... waste treatment *f*... environmental insurance	*f*... operation *f*... labour *f*... indirect taxes *f*... waste treatment *f*... environmental insurance	...
3.3 miscellaneous costs			
4 benefits			
4.1 operating cost savings	*f*... gas *f*... maintenance	*f*... gas *f*... maintenance	...
4.2 extra product sales	*f*... gas *f*... electricity	*f*... gas *f*... electricity	...
4.3 miscellaneous benefits	*f*... grants *f*... avoided licences	*f*... grants *f*... avoided licences	...
5 comment/other	...		

Component 3: Economic classification

In analogy with the environmental classification, this step is done separately from the economic inventory analysis. Although it could be done in the same spreadsheet as the inventory table, transparency requires conformity with the environmental assessment*. Besides, the economic balancing procedure is separated from the economic discounting procedure. Balancing is performed first, discounting afterwards, as a less objective step in the economic evaluation.

Step: Netting costs and benefits
The algebra of the balancing procedure is therefore quite easy: subtracting all economic benefits in one year from all economic costs in the same year. This gives the following formula for the nett

* One could also consider the netting procedure as a classification procedure with classification factors +1 for the economic benefits and −1 for the economic costs.

economic costs in year j:

$$N_j = \sum_i C_{i,j} - \sum_i B_{i,j} \tag{B.6}$$

where

N_j = nett economic costs of the functional unit in year j;

$C_{j,i}$ = cost category i of the functional unit in year j;

$B_{j,i}$ = benefit category i of the functional unit in year j.

The results of the calculation are as an example represented in the following table.

TABLE B.13. Nett yearly economic costs of project X.

item	year 1	year 2	etc.
nett costs	f...	f...	...
comments/other	...		
qualitative aspects	...		

For the purpose of convenience to the model users, the yearly aggregated costs C_j and the yearly aggregated benefits B_j linked to the project may be specified separately:

$$C_j = \sum_i C_{i,j} \tag{B.7}$$

for the costs and

$$B_j = \sum_i B_{i,j} \tag{B.8}$$

for the benefits. The ranking on the basis of cost-effectiveness however needs solely the nett costs specified per year C_j.

Component 4: Economic evaluation

In the economic part of the model the evaluation only consists of a discounted addition procedure.

Step: discounting nett costs

In analogy with the environmental part discounting takes place separately from and following to the classification procedure. Therefore, in one step the total discounted nett economic costs is calculated as the accumulated nett present value of the nett yearly costs N_j after discounting. Thus:

$$N_{dis} = \sum_j \frac{1}{(1 + r_{com})^{j-1}} N_j \tag{B.9}$$

where

N_{dis} = total discounted nett economic costs;

N_j = nett costs of the functional unit in year j;

r_{com} = the company's commercial discount rate.

In the above formula year 1 functions as the base year with discounting factor 1*. The calculation is done with a commercial discount rate $r_{com} = p$, p being the economic discount rate. According to usual investment analyses p is set equal to the internal interest rate, which the company uses for assessing investments projects in general.

For the purpose of convenience to the model users, the total discounted costs C_{dis} and the total

* If the discount rate is specified as a percentage, it has to be divided by 100 before completing the equation.

discounted benefits B_{dis} linked to the project may be specified separately:

$$C_{dis} = \sum_j \frac{1}{(1+r_{com})^{j-1}} C_j \tag{B.10}$$

for the discounted costs and

$$B_{dis} = \sum_j \frac{1}{(1+r_{com})^{j-1}} B_j \tag{B.11}$$

for the discounted benefits.

Back to the example: the resulting total discounted nett costs N_{dis} is represented in the following table.

TABLE B.14. Discounted costs, benefits and nett economic costs of project *X*.

item	value
discounted nett costs	*f*...
comments/other	...
qualitative aspects	...

In the previous formula N_{dis} reflects the total present value of the additional costs ΔC the company has to add to the costs of the current process by implementing project *X*. Therefore one can define total additional costs ΔC_X as

$$\Delta C_X = N_{dis} \tag{B.12}$$

This number is the result of the economic assessment of project *X*. In the overall evaluation it will be combined with the result of the environmental assessment ΔE_X.

BLOCK 4

OVERALL EVALUATION

This part of the model puts together the results of the environmental and the economic assessment: ΔE_X and ΔC_X of project X (Section B.2 and B.3). It consists of two parts:
- ranking the projects;
- analyzing the sensitivity.

Step: Ranking the projects
As described in the overall goal definition (Section B.1) the aim of an LCA-oriented decision support model is to make it possible to select under some predefined budget a set of investment projects which achieves the maximum of relative environmental improvement. The model enables the business manager to determine the most effective way in which the company's financial resources for environmental projects can be allocated.

The model therefore ranks the projects X, Y, Z, etc., to the potency to relieve the company's environmental pressure per guilder invested. In order to maximize the cost-effectiveness of the environmental improvement, we define a factor $I = \Delta E/\Delta C$ as target variable in the optimization procedure. After determining this factor for project X, the same can be done for the other assessed environmental projects Y, Z, etc. With the factors I_X, I_Y, I_Z, etc., a ranking of the projects to environmental improvement per guilder investment can be made. The result of this is a sequence of projects X, Y, Z, etc. ranked to their cost effectiveness of environmental improvement e.g.: $I_Y < I_X < I_Z$. This can be made visible in a simple figure as beneath.

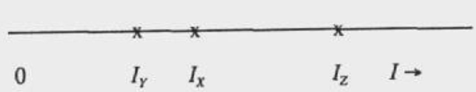

FIGURE B.3. Three projects (X, Y and Z) are ranked according their environmental cost-effectiveness I. In this example project Z is to be preferred.

With only a limited budget to spend, this ranking order can be used to implement (part of) the projects using the company's resources in the most effective way.

Step: Sensitivity analysis

In this last step of the model a sensitivity analysis of the reliability and the validity of the results of the life cycle assessment will be assessed. The reliability is defined by the influence of uncertainties in the data. Validity is about the effects of choices and assumptions. These two subjects will be discussed separately.

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

Assumptions are made in all components of a life cycle or economic assessment. These uncertainties affect the end results and in some cases they may result in drastic changes in the conclusions. Hence it is advisable to make an early estimate of uncertainties and to determine the stability of the results through a sensitivity 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. A mathematical method to calculate the effects of the uncertainties can be found in the Background document of the Guide LCA.

A marginal analysis (see Background document) can identify the process data whose magnitude has major effects on the results. It is advisable to employ a marginal analysis to determine the crucial (process) data and then to ensure that those data are as accurate as possible. With this same analysis the data which have minor effects on the results can be identified. Those data need no further attention.

A validity analysis is used to estimate the validity of the results in view of the assumptions and choices made during the course of the project. This includes choices and assumptions associated with the method as well as choices and assumptions associated with the study itself. Examples of these are: the life time of an investment project or the data left out of the study because the effects on the results are assumed to be negligible.

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 an other alternative suddenly gets a higher cost effectiveness I, for example by varying the life span of a product. The likelihood of this life span can then be discussed.

In the sensitivity analysis there are two special choices to be mentioned:

- environmental and economic discounting rates;
- evaluation factors.

The relevance of the value chosen for the discount rates $r_{env} = 0$ and $r_{com} = p$ now can be tested separately, by varying the discounting rates r_{env} and r_{com} and considering the effects on the model results. If the differences in the resulting ranking are substantial, one may discuss and find out, what is the right value to use. If the differences in the ranking are insignificant, there is no need to spend much effort to this item.

Because of a lack of consensus on the values of the evaluation factors, in the example we used hypothetical values. In practice the user of REIM still has to make choices about the values to be used. For every choice a validity analysis can bring transparency to the importance of the accuracy of the choioe of the values.

BLOCK 5

APPLICATION

In part B of this report, a procedural and technical framework has been developed with the aim to obtain a ranking of environmental investment projects. The assessment has been made to support decisions on investment programmes. The applications of the model - the decisions themselves - are outside the scope of the analytical tool as discussed so far. The most straightforward application of the model is therefore directly using the overall evaluation: select the projects which yields the highest environmental reduction per unit of cost. Obviously, other aspects than environmental performance and costs play a role. Also, not all environmental aspects are taken into account, e.g. it may happen that governments may interfere with regulations that have been defined otherwise. One of the topics discussed here is how to deal with two types of constraints:

- dealing with financial and technical constraints;
- dealing with emission reduction constraints.

These constraints will be dealt with in the following two sections. Next the nature of the current REIM model will be surveyed.

Step: Dealing with financial and technical constraints
In the overall evaluation a ranking of projects is achieved on the basis of the cost-effectiveness I of each of the projects. Assuming a linear dependency of the marginal nett costs ΔC and the marginal environmental improvement ΔE on the number of identical projects installed, an unambiguous preference for one of the projects arises. Usually there are financial constraints. Ideally, the total environmental improvement ΔE_{tot} may be found by selecting the best alternative and multiplying its environmental cost-effectiveness I_1 with the amount of money available R_0:

$$\Delta E_{tot} = R_0 \times I_1 \tag{B.13}$$

This is however not satisfactory, as there will in general be two types of constraints:

- financial constraints;
- technical constraints.

The two will be elaborated subsequently.

Let the number of times the best project can be installed be denoted by N_1. It then follows that in the above formula

$$N_1 = \frac{R_0}{\Delta C_1} \tag{B.14}$$

This of course is too simplified: in general this ratio will be non-integral, whereas one can only install an integral number of functional units of the best project. A more realistic definition of N_1 is therefore

$$N_1 = \text{int}\left[\frac{R_0}{\Delta C_1}\right] \tag{B.15}$$

where int(a) is the integer part of a.

Another constraint can be imposed by technical considerations. There are many projects of which only a limited number can be installed for technical reasons. One cannot for instance install a billion of venture seals. The definition of N_1 can again be redefined to account for that effect. Denote the physical maximum number of times the best project can be installed by P_1.

Combining the financial and technical constraints, N_1 is determined by the first constraint met:

$$N_1 = \min\left[\text{int}\left[\frac{R_0}{\Delta C_1}\right],\ P_1\right] \tag{B.16}$$

It now follows that the best project can be installed N_1 times. This yields a total environmental improvement of

$$\Delta E_{tot} = N_1 \times I_1 \tag{B.17}$$

After it has been decided to install this project, there may be financial resources left. This amount will be denoted by R_1 and is given by

$$R_1 = R_0 - (N_1 \times \Delta C_1) \tag{B.18}$$

This amount of money can be spent in the best way by installing the second best project. Similar reasoning leads to an expression for the number of times it can be installed:

$$N_2 = \min\left[\text{int}\left[\frac{R_1}{\Delta C_2}\right],\ P_2\right] \tag{B.19}$$

yielding a total environmental improvement of

$$\Delta E_{tot} = N_1 \times I_1 + N_2 \times I_2 \tag{B.20}$$

and leaving an amount of money to invest of

$$R_2 = R_0 - (N_1 \times \Delta C_1 + N_2 \times \Delta C_2) \tag{B.21}$$

This procedure may be repeated until the available budget is allocated, or until there are no more attractive project alternatives.

Step: Dealing with emission reduction constraints

As indicated in the introduction, environmental policy objectives are often formulated on the level of substances. The model described in this report is based on the ranking of environmental projects according to their reduction of the overall environmental effects. This may give rise to conflicts. This will be illustrated hereafter.

Suppose that two projects, X and Y, have been ranked, and that project Y yields a larger environmental improvement than project X. Suppose the governmental policy objective for CO_2 is a reduction of 10%, that project X amounts to a reduction of 10% and project Y to 30%. Next suppose that the objective for SO_2 aims at a reduction of 30%, that project X amounts to 30% and project Y to 20%. The objectives can only be met by selecting project X. But this alternative had a lower overall improvement than project Y. Figure B.4 illustrates the situation

Meeting governmental policy objectives on the substance level (or on the level of environmental effects) may yield a poorer overall result than is possible if the objectives had been defined at the level of an environmental index. Clearly, this is due to an assumed interchangeability of environmental effects.

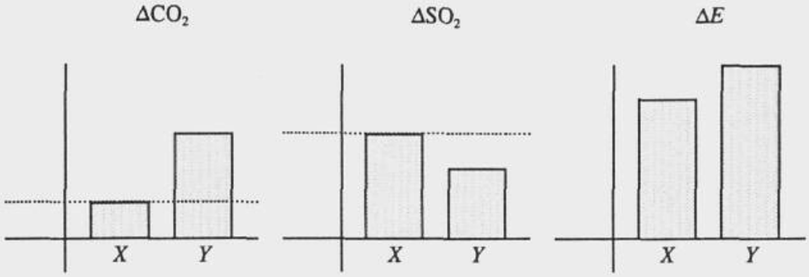

FIGURE B.4. Illustration of the conflict between meeting all separate policy goals (project *X*) and selecting the overall best project (project *Y*).

PART C

☆

APPLICABILITY

C.1 CURRENT APPLICABILITY

In this chapter, first, the applicability and the limitations of the current REIM are discussed, in terms of the general model as has been described in Part B. In the next chapter, C.2, some indications are given on how REIM might be extended and improved.

C.1.1 Possibilities

The current REIM software of NAM, in its environmental part, covers two main components of the life cycle assessment: the classification and the evaluation. Both these steps have been implemented in a transparent manner, allowing those involved in decision making to test the results against the assumptions as are relevant to them. These may concern the spatial level of the normalization and the weights used in the evaluation.

The one and main application of the current software is in the ranking of investment projects, mainly of the add-on type, as a decision support tool in both private and public decisions related to these projects.

C.1.2 Limitations

The goal definition is different from the usual procedure for LCA. Also, the inventory component is lacking as is, relatedly, the improvement analysis*. This means that the current software is limited in its applicability and, within one application, is not yet optimal. The analysis to investigate options for improvement requires a detailed inventory analysis. Thus, the current model can support design decisions in the development of the projects to be assessed only to a limited extent, and only if the project design does not change.

Also related to the lack of an explicit inventory analysis is the domain of investment types the model may be applied to. It may be doubted if those involved in installation design can produce the relevant inventory data for process integrated investments. Even if they were able to do so, this could not necessarily be made clear to those confronted with results. Transparency in this respect could be still lacking.

As most investment projects are not purely add-on, some caution is required in the interpretation of results. If pure add-on projects, like better flaring, are compared to not fully pure ones, like leaked

* The improvement analysis - see Chapter 5 of the Guide LCA - is an analytical method to find dominant aspects (processes, emissions, etc.) and to find options to efficiently reduce the contribution to environmental problems.

methane recompression, there could be a structural bias against the latter type of projects. This is due to the fact that the diminished environmental effects because of lower gross gas production (if that is the case) are not taken into account (assuming constant nett gas production).

The applicability is mainly limited to add-on projects and well-defined pseudo add-on projects. In an LCA sense, this is due to the limited definition of the functional unit, as "a project". The more relevant functional unit, which could be "x m^3 of gas supplied to the mains"*, requires the incorporation of most of NAM's processes in an inventory analysis.

* In the practice of NAM's activities, supplying a certain amount of natural gas to the means is a political determined requirement.

C.2 FUTURE APPLICABILITY

Further developments of REIM software relate to the further implementation of the environmental-economic model as developed and in tools at the user interface to facilitate an efficient use of the model. As regards the options for the further development of REIM software by NAM, a distinction may be made between options in the short term and options in the long term.

C.2.1 Project ranking

In the short term, there is one main LCA element lacking now that could be included quite easily, that is the inventory analysis. Incorporating available software for this main LCA component has several advantages. It structures the gathering of relevant data and allows a control on the shortcomings in the data set that will always remain. For reasons of transparency this addition is a must. If an inventory analysis is available, it allows technical departments to bring in their knowledge on many details of the functioning of NAM in the database that will be built up. The processes involved relate to information on the components required for the project, which requirements are for the operation of the project, and which for the initiation of it, what capital goods are involved, and so on. Also, the relation of these investment projects to the broader functioning of NAM is made explicitly, a feature that may be interesting for other reasons as well.

The advantages of having the detailed non-aggregated information within the model is twofold. There is:

- an enhanced transparency;
- a number of options for further LCA analysis.

The first point is important in the context of the discussions with the government and with other companies and organizations. One can only convince others with clear-cut arguments based on a sound scientific theory. A theorem must always be proven, ideally, but the arguments at least need to cover the field and be convincing. The second point has to do with the power of LCA as an analyzing tool. This will be elaborated below.

C.2.2 Improvement analysis

Including a complete quantified process tree yields possibilities to implement an improvement analysis. This may reveal hitherto unknown options for cleaner process management. A detailed inventory analysis allows a sensitivity analysis and an improvement analysis, thus enhancing an assessment of the reliability of results, and also allowing for a more goal directed design of environmental improvements. Other elements that might be improved upon regard the user interface, especially in combining the results of several potential projects into an overall picture. Such improvements could be installed well within a year of project time. One main advantage is that all types of investments, not just (pseudo) add-on projects, may be analyzed with the thus extended REIM tool.

C.2.3 New developments

In the longer term, developments as take place in LCA itself could be incorporated in the model, regarding, e.g., new methods for allocation in the inventory analysis, new items in the classification, new models for classification, and maybe other operational methods for evaluation.

In the current state of development of LCA, as an analytical tool, it might also be sensible to incorporate other methods available globally, to be able to assess the method-dependent parts of the outcomes. Setting up such a quite complicated analysis might be too large an activity for one company to support. Contributing to such a study project and incorporating its results in REIM might be a better option.

PART D

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APPENDICES

D.1 CLASSIFICATION FACTORS

The following tables contain the numbers needed for the environmental classification. They are taken from the *Guide* LCA. Classification factors are given for only a selected number of for NAM relevant chemicals. For a full list the reader is referred to the original source. For a number of substances, the classification factor is unknown. This may be due to several causes:

- The substances is known to contribute to the problem, but quantitative information on this is missing. This is indicated as n.a. (not available). This is clearly a classification problem. One should at least indicate these unclassified emissions as a p.m. post in the environmental profile.
- The substance is in fact a group of substances; there are classification factors for the individual substances, but not for the group. This is indicated as spec. (specification required). This is in fact an inventory problem, as a further specification of emissions is required. If this is not possible, a p.m. post should be used.

TABLE D.1. Classification factors for emissions to air.

substance	greenhouse effect ($kg \cdot kg^{-1}$)	ozone depletion ($kg \cdot kg^{-1}$)	acidification ($kg \cdot kg^{-1}$)	oxidant formation ($kg \cdot kg^{-1}$)	nutrification ($kg \cdot kg^{-1}$)	human toxicity ($kg \cdot kg^{-1}$)	malodorous air ($m^3 \cdot kg^{-1}$)
CO_2	1	0	0	0	0	0	0
CO	ind.	0	0	0	0	0.012	0
NO_x	n.a.	0	0.70	n.a.	0.13	0.78	0
H_2S	0	0	0	0	0	0.78	0.000,43
SO_2	0	0	1.00	0	0	1.2	0
HCFC-22	1,600	0.055	0	0	0	0	0
HALON-1301	4,900	16.0	0	0	0	0	0
HALON-1211	n.a.	4.0	0	0	0	0	0
CH_4	11 + ind.	0	0	0.007	0	0	0
hydrocarbons excl. BTEX	0	0	0	spec.	0	spec.	spec.
benzene	0	0	0	0.189	0	3.9	n.a.
toluene	0	0	0	0.563	0	0.039	n.a.
CS_2	0	0	0	0	0	1.2	0.18
PAH	0	0	0	spec.	0	spec.	0
As	0	0	0	0	0	4,700	0

substance	greenhouse effect (kg·kg⁻¹)	ozone depletion (kg·kg⁻¹)	acidification (kg·kg⁻¹)	oxidant formation (kg·kg⁻¹)	nutrification (kg·kg⁻¹)	human toxicity (kg·kg⁻¹)	malodorous air (m³·kg⁻¹)
Cd	0	0	0	0	0	580	0
Cu	0	0	0	0	0	0.24	0
Cr^{3+}	0	0	0	0	0	6.7	0
Pb	0	0	0	0	0	160	0
Ni	0	0	0	0	0	470	0
Hg	0	0	0	0	0	120	0
Zn	0	0	0	0	0	0.033	0
CFC-11	3,400	1.0	0	0	0	0	0
CFC-12	7,100	1.0	0	0	0	0	0
other CFCs	spec.	spec.	0	0	0	0	0
phenols	0	0	0	n.a.	0	0.56	0.039
formaldehyde	0	0	0	0.421	0	n.a.	0.49
ammonia	0	0	1.88	0	0.33	0.02	1.0
phosphate	0	0	0	0	1.00	0.000,48	0
nitrate	0	0		0	0.10	0.009,1	0
fluorides	0	0	0	0	0	0.48	0

n.a. = not available;
spec. = specification of substances required;
ind. = indirect contribution.

TABLE D.2. Classification factors for emissions to water.

substance	nutrification (kg·kg⁻¹)	human toxicity (kg·kg⁻¹)	aquatic ecotoxicity (m³·mg⁻¹)
H_2S	0	n.a.	n.a.
SO_2	0	n.a.	n.a.
hydrocarbons excl. BTEX	0	spec.	spec.
benzene	0	0.66	0.029
toluene	0	0.006,6	n.a.
PAH	0	spec.	spec.
As	0	1.4	0.20
Cd	0	2.9	200
Cu	0	0.020	2.0
Cr^{3+}	0	0.57	1.0
Pb	0	0.79	2.0
Ni	0	0.057	0.33
Hg	0	4.7	500
Zn	0	0.002,9	0.38
phenols	0	0.048	5.9
formaldehyde	0	n.a.	n.a.

substance	nutrification ($kg \cdot kg^{-1}$)	human toxicity ($kg \cdot kg^{-1}$)	aquatic ecotoxicity ($m^3 \cdot mg^{-1}$)
ammonia	0.33	0.001,7	n.a.
phosphate	1.00	0.000,041	n.a.
nitrate	0.10	0.009,1	n.a.
fluorides	0	0.041	n.a.

n.a. = not available;
spec. = specification of substances required.

D.2 NORMALIZATION FACTORS

To implement the normalization step, knowledge of the contribution of a certain area in a certain to the relevant environmental problems is require. The following table gives the world's annual contributions to the different environmental problems.

TABLE D.3. The annual contribution of the world to a number of effect scores*.

effect score	world's annual contribution
abiotic depletion	$1.13 \cdot 10^{1}$ yr^{-1}
biotic depletion	$2,16 \cdot 10^{-3}$ yr^{-2}
greenhouse effect	$6.01 \cdot 10^{13}$ $kg \cdot yr^{-1}$
ozone depletion	$1.00 \cdot 10^{9}$ $kg \cdot yr^{-1}$
human toxicity	$5.76 \cdot 10^{11}$ $kg \cdot yr^{-1}$
aquatic ecotoxicity	$1.11 \cdot 10^{14}$ $m^{3} \cdot yr^{-1}$
terrestrial ecotoxicity	$1.16 \cdot 10^{15}$ $kg \cdot yr^{-1}$
oxidant formation	$3.74 \cdot 10^{9}$ $kg \cdot yr^{-1}$
acidification	$4.08 \cdot 10^{11}$ $kg \cdot yr^{-1}$
nutrification	$1.55 \cdot 10^{10}$ $kg \cdot yr^{-1}$
malodorous air	$6.93 \cdot 10^{17}$ $m^{3} \cdot yr^{-1}$
noise	n.a.
damage	n.a.
victims	n.a.

n.a. = not available.

If one prefers to use for some or for all effect score the European or Dutch extent, these data would have to be gathered. If these data are not known, one may convert the world's numbers, using a factor which denotes the ratio in the gross national product (GNP). Thus one uses

$$W_k' = W_k \times \frac{GNP'}{GNP} \tag{D.1}$$

* Taken from J.B. Guinée: *Data for the normalization step within life cycle assessment of products.* CML, Leiden 1993.

where

W_k = world's effect score k in one year;
W'_k = effect score k of selected area in one year;
GNP = world's gross national product in one year;
GNP' = gross national product of selected area in one year;

TABLE D.4. Conversion factors, based on GNP ratios, used to convert world effect scores to European or Dutch effect scores.

Area	GNP'/GNP
world	1
Europe	0.34
The Netherlands	0.01

D.3 EVALUATION FACTORS

In the environmental evaluation, the effect scores are combined into one single environmental index ΔE. For this, a number of evaluation factors is needed. Unfortunately, there is no generally agreed set of evaluation factors. Quite recently, a preliminary research for the environmental experts' opinion regarding the relative importance of different emission-related problems was undertaken. The project's conclusions will appear soon*. We acknowledge the authors to allow us to quote material from their report before publication.

The numbers in the following table are taken from this report. As it was the project's aim to find evaluation factors for a limited number of emission-related problems, no factors are available for the majority of effect scores. Moreover, the authors emphasize the experimental nature of their set-up and findings, which show relatively large variations between experts' opinions, and stress extreme prudence in using these numbers. One of their main conclusions is the necessity of a more transparent procedure for obtaining evaluation factors.

When applying these weights, one should be aware of the fact that the weights have been specified for an undefined spatial level and that they are averages of quite widely diverging opinions.

TABLE D.5. Preliminary evaluation factors for a number of environmental problems. See main text for remarks concerning their limited applicability.

effect score	evaluation factor
abiotic depletion	n.a.
biotic depletion	n.a.
greenhouse effect	21.0
ozone depletion	19.7
human toxicity	11.0
ecotoxicity	14.6†
oxidant formation	n.a.
acidification	15.5
nutrification	18.7
malodorous air	n.a.

* E.W. Lindeijer, M. Sprengers, A.L.W. van Roekel, J.G.M. Kortman, H.J.W. Sas, A.L. Viergever & G.J. Teesink: In preparation. IDES & CE 1993.

† In the report cited here, no distinction was made between aquatic and terrestrial ecotoxicity.

effect score	evaluation factor
noise	n.a.
damage	n.a.
victims	n.a.

n.a. = not available

D.4 ELABORATED EXAMPLE

For a better understanding of the working of the model, an example using imaginary data has been fully elaborated.

Block 1: Overall goal definition

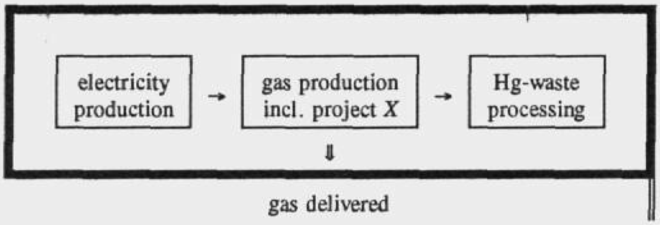
Step: Determining the application
The overall goal is to rank projects which could be added to operations of a company. For this aim the cost-effectiveness of the relative environmental improvement I of the different projects have to be defined. Here however, the computation of I is elaborated for just one project.

Step: Defining the subject of the study
The assessed investment project consists of placing several venturi spiral seals in a gas distribution system of a company to diminish gas leakages. Implementation of the seals has no technical influence on the current distribution process of the company. The project is of the "add-on" type. It will for convenience be called project X.

Block 2: Environmental assessment

Component 1: Environmental goal definition
Step: Determining the depth of the study
The aim in the environmental life cycle assessment is to consider all potential effects on the environment caused by project X. This means in this case considering the total contribution of project X in reducing emissions and waste streams in the entire life cycle of the functional unit. The goal of the environmental assessment is to determine ΔE, the environmental improvement of adding project X to the company's total operations.

Component 2: Environmental inventory analysis
Step: Drawing up the process tree
In this step the life cycle of a project selected in the overall goal definition is determined. This implies that all the economic and environmental processes linked with the project must be defined. The process tree is limited to the central gas production process, the generation of electricity and the incineration of mercury containing waste.



Step: Entering the process data
In this step the data for all processes influenced by a venturi spiral during its entire life cycle must be collected.

Example of entering process data: the functioning of a venturi spiral for one pump.

item	year 1	year 2	year 3
1 format			
1.1 name or institute	P.Jones; distribution division		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 process			
2.1 name or code	venture spiral		
2.2 representativeness			
2.2.1 scale	Dutch situation		
2.2.2 date	early nineties		
2.2.3 duration	capacity: 500 m^3/min		
2.2.4 status	data estimated by designers		
2.3 quality			
2.3.1 clarity	good description		
2.3.2 accuracy	unknown: no empirical material		
2.3.3 completeness	no maintenance included		
2.4 sources	calculations by internal technical division		
2.5 overall assessment	rough but best estimation		
2.6 comment	none		
3 economic input	500 MJ elec. 100 kg steel	200 MJ elec.	200 MJ elec.
4 environmental input			
4.1 resources	5 m^3 natural gas	5 m^3 natural gas	5 m^3 natural gas
4.2 space			
5 economic output	3 kg sludge leak prevention for one pump	3 kg sludge leak prevention for one pump	3 kg sludge leak prevention for one pump
6 environmental output			
6.1 emissions to air	10 kg CH_4 120 kg SO_2	10 kg CH_4 50 kg SO_2	10 kg CH_4 50 kg SO_2

item	year 1	year 2	year 3
6.2 emission to water	60 mg phenol	60 mg phenol	60 mg phenol
6.3 emissions to soil	2 kg scrap	2 kg scrap	2 kg scrap
6.4 radiation	none	none	none
6.5 sound	negligible	negligible	negligible
6.6 heat	10 MJ to air	10 MJ to air	10 MJ to air
6.7 accidents	$1 \cdot 10^{-11}$ victims	$1 \cdot 10^{-11}$ victims	$1 \cdot 10^{-11}$ victims
7 balances			
8 comment/other	none		

Example of entering process data: production of electricity.

item	every year
1 format	
1.1 name or institute	P.Jones; distribution division
1.2 date	May 25, 1993
1.3 comment	this is only an example: fictitious data
2 process	
2.1 name or code	electricity production
2.2 representativeness	
2.2.1 scale	average Dutch situation
2.2.2 date	late eighties
2.2.3 duration	(does not apply)
2.2.4 status	based on empirical data
2.3 quality	
2.3.1 clarity	clear definition
2.3.2 accuracy	checked data
2.3.3 completeness	fairly good
2.4 sources	Ministry of Energy, 1992
2.5 overall assessment	good
2.6 comment	none
3 economic input	
4 environmental input	
4.1 resources	0.1 m^3 natural gas
4.2 space	unknown
5 economic output	1 MJ electrical energy
6 environmental output	
6.1 emissions to air	2 kg CO_2 1 kg SO_2
6.2 emission to water	none
6.3 emissions to soil	none
6.4 radiation	not specified
6.5 sound	not specified

item	every year
6.6 heat	0.2 MJ to water 0.1 MJ to air
6.7 accidents	negligible
7 balances	missing energy assumed to be emitted as waste heat to air
8 comment/other	none

Example of entering process data: incineration of mercury containing sludge

item	every year
1 format	
1.1 name or institute	P.Jones; distribution division
1.2 date	May 25, 1993
1.3 comment	this is only an example: fictitious data
2 process	
2.1 name or code	sludge incineration
2.2 representativeness	
2.2.1 scale	company specific
2.2.2 date	1992
2.2.3 duration	capacity: 10 ton/day
2.2.4 status	estimations based on extrapolations
2.3 quality	
2.3.1 clarity	clear definition
2.3.2 accuracy	unknown
2.3.4 completeness	incomplete data due to uncertainties in composition of sludge to be incinerated
2.4 sources	technical description of producer of installation
2.5 overall assessment	insufficient
2.6 comment	none
3 economic input	1 kg sludge
4 environmental input	
4.1 resources	1 m^3 natural gas
4.2 space	unknown
5 economic output	0.5 kg ash
6 environmental output	
6.1 emissions to air	1 kg CO_2 10 mg Hg
6.2 emission to water	none
6.3 emissions to soil	none
6.4 radiation	none
6.5 sound	not specified

item	every year
6.6 heat	not specified
6.7 accidents	negligible
7 balances	?
8 comment/other	none

Step: Creating the environmental inventory table

All positive and negative environmental interventions of all processes of the life cycle of a venturi spiral are now quantified as fully as possible per unit of process output. In the next step, all economic processes like electricity production and the incineration of mercury containing waste are "translated" into environmental interventions. From the process data, we find the following factors.

Example of "translation factors", used to create the inventory table.

process	year 1	year 2	year 3
electricity production	500	200	200
venture spiral	1	1	1
sludge incineration	3	3	3

Example of an inventory table: the life cycle of a venturi spiral for one pump.

item	year 1	year 2	year 3
1 format			
1.1 name or institute	P.Jones; distribution division		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 process			
2.1 name or code	life cycle of venture spiral for leak prevention		
2.2 representativeness			
2.2.1 scale	Dutch situation		
2.2.2 date	early nineties		
2.2.3 duration	capacity: 500 m³/min		
2.2.4 status	pseudo add-on project: only electricity generation and treatment of mercury containing waste include in process tree		
2.3 quality			
2.3.1 clarity	good		
2.3.2 accuracy	reasonable		
2.3.3 completeness	very incomplete due to ignorance of pseudo add-on character		
2.4 sources	diverse, see separate process data for more detail		
2.5 overall assessment	rough but best estimation		
2.6 comment	none		
3 economic input	p.m. 100 kg steel		
4 environmental input			
4.1 resources	58 m^3 natural gas	28 m^3 natural gas	28 m^3 natural gas

item	year 1	year 2	year 3
4.2 space			
5 economic output	leak prevention for one pump	leak prevention for one pump	leak prevention for one pump
6 environmental output			
6.1 emissions to air	10 kg CH_4 620 kg SO_2 1003 kg CO_2 30 mg Hg	10 kg CH_4 250 kg SO_2 403 kg CO_2 30 mg Hg	10 kg CH_4 250 kg SO_2 403 kg CO_2 30 mg Hg
6.2 emission to water	60 mg phenol	60 mg phenol	60 mg phenol
6.3 emissions to soil	2 kg scrap	2 kg scrap	2 kg scrap
6.4 radiation	not specified	not specified	not specified
6.5 sound	not specified	not specified	not specified
6.6 heat	110 MJ to water 50 MJ to air	50 MJ to water 20 MJ to air	50 MJ to water 20 MJ to air
6.7 accidents	$1 \cdot 10^{-11}$ victims	$1 \cdot 10^{-11}$ victims	$1 \cdot 10^{-11}$ victims
7 balances	?	?	?
8 comment/other	none		

Component 3: Environmental classification

Step: Selection of the problem types

The data of the inventory table will be converted to contributions to environmental problems. In this step, the problem types which will be considered are selected. In this case we have chosen to select:

- greenhouse effect;
- ozone depletion;
- acidification;
- human toxicity.

Step: Definition of the classification factors

In the classification the environmental interventions of the functional unit as stated in the environmental inventory table are translated into relevant environmental effects by using classification factors. This means that the different substances will be converted to one standard substance (for example CO_2 for the greenhouse effect) per particular environmental problem. The result of this step is the environmental profile of the functional unit. The following table lists the classification factors for the substances that are in the inventory table.

environmental intervention	greenhouse effect (kg CO_2)	ozone depletion (kg CFC-11)	human toxicity (kg body weight)	acidification (kg SO_2)
m^3 natural gas	0	0	0	0
kg CH_4 to air	11	0	0	0
kg SO_2 to air	0	0	1.2	10
kg CO_2 to air	1	0	0	0
kg Hg to air	0	0	120	0
kg phenol to water	0	0	0.048	0

environmental intervention	greenhouse effect (kg CO_2)	ozone depletion (kg CFC-11)	human toxicity (kg body weight)	acidification (kg SO_2)
kg scrap to soil	0	0	0	0

Step: Creating the environmental profile

Calculating the effect scores and thus creating the environmental profile are relatively easy. The following environmental profile results:

effect score	year 1	year 2	year 3
greenhouse effect	1113 kg	513 kg	513 kg
ozone depletion	0 kg	0 kg	0 kg
human toxicity	3.603 kg	3.603 kg	3.603 kg
acidification	744 kg	300 kg	300 kg
comments/other	scrap could not be classified		
qualitative aspects	p.m. 100 kg steel		

Step: Normalization of the effect scores

After the classification the normalization procedure will be applied. In the normalization procedure the contribution made by a project 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 world's contribution to the problems that are relevant here are given below.

effect score	world's contribution
greenhouse effect	$6.01 \cdot 10^{13}$ kg
ozone depletion	$1.00 \cdot 10^{9}$ kg
human toxicity	$5.76 \cdot 10^{11}$ kg
acidification	$4.08 \cdot 10^{11}$ kg

Application of these data to the environmental profile gives the normalized environmental profile:

normalized effect score	year 1	year 2	etc.
greenhouse effect	$1.9 \cdot 10^{-11}$ yr	$8.6 \cdot 10^{-12}$ yr	$8.6 \cdot 10^{-12}$ yr
ozone depletion	0 yr	0 yr	0 yr
human toxicity	$6.3 \cdot 10^{-12}$ yr	$6.3 \cdot 10^{-12}$ yr	$6.3 \cdot 10^{-12}$ yr
acidification	$1.8 \cdot 10^{-9}$ yr	$7.4 \cdot 10^{-10}$ yr	$7.4 \cdot 10^{-10}$ yr
comments/other	scrap could not be classified		
qualitative aspects	p.m. 100 kg steel		

D.3.2.4 Environmental evaluation

Step: Discounting the normalized effect scores

In this step the effect score of each year of the life time of a project of a particular environmental problem are discounted to the first year. The environmental discount rate r_{env} has been put to 0. The resulting discounted normalized environmental profile is shown below.

discounted normalized effect score	value
greenhouse effect	$3.6 \cdot 10^{-11}$ yr
ozone depletion	0 yr
human toxicity	$1.9 \cdot 10^{-11}$ yr
acidification	$3.3 \cdot 10^{-9}$ yr
comments/other	scrap could not be classified
qualitative aspects	p.m. 100 kg steel

Step: Weighting the discounted normalized effect scores
The environmental improvement ΔE of project X can be found by the summation of all discounted effect scores after multiplication by the relevant evaluation factors. The following evaluation factors were used:

environmental problems	evaluation factor
greenhouse effect	21.0
ozone depletion	19.7
human toxicity	11.0
acidification	15.5

These evaluation factors were applied to aggregate the discounted normalized effect scores to the environmental index of the project.

item	value
relative environmental improvement	$7.7 \cdot 10^{-10}$ yr
comments/other	scrap could not be classified
qualitative aspects	p.m. 100 kg steel

The resulting environmental index is thus $\Delta E = 7.7 \cdot 10^{-10}$ yr. This result will be used in the overall evaluation.

Block 3: Economic assessment

Component 1: Economic goal definition
Step: Determining the depth of the study
For assessing the total additional costs and benefits of project X, all of them linked to the project will be taken into account. Also the indirect taxes which have inevitably to be paid by the company without the possibility of bringing them into account by the customer and the environmental insurance costs, are brought into the table of costs. However, in this example, we leave corporate tax out of the procedure.

Component 2: Economic inventory analysis
Step: Drawing up a table of costs and benefits
We use a format similar to the environmental one.

item	year 1	year 2	year 3
1 format			

item	year 1	year 2	year 3
1.1 name or institute	P.Jones; distribution division		
1.2 date	May 25, 1993		
1.3 comment	this is only an example: fictitious data		
2 process			
2.1 name or code	venture spiral		
2.2 representativeness			
2.2.1 scale	Dutch situation		
2.2.2 date	early nineties		
2.2.3 duration	capacity: 500 m^3/min		
2.2.4 status	clear		
2.3 *quality*			
2.3.1 clarity	good		
2.3.2 accuracy	good		
2.3.3 completeness	no maintenance included		
2.4 sources	calculations by internal financial division		
2.5 overall assessment	quite good		
2.6 comment	none		
3 costs			
3.1 investments	*f* 1200 capital *f* 8200 labour		
3.2 operating costs	*f* 800 operation *f* 3200 labour *f* 240 indirect taxes *f* 960 waste treat-ment	*f* 800 operation *f* 3200 labour *f* 240 indirect taxes *f*960 waste treat-ment	*f* 800 operation *f* 3200 labour *f* 240 indirect taxes *f*960 waste treat-ment
3.3 miscellaneous costs			
4 benefits			
4.1 operating cost savings	*f* 2000 gas *f* 200 maintenance	*f* 2000 gas *f* 200 maintenance	*f* 2000 gas *f* 200 maintenance
4.2 extra product sales	*f* 600 gas	*f* 600 gas	*f* 600 gas
4.3 miscellaneous benefits	*f* 3000 grants *f* 650 avoided licences	*f* 650 avoided licences	*f* 650 avoided licences
5 comment/other	none		

Component 3: Economic balancing
Step: Netting of costs and benefits
Netting of costs and benefits yields the nett costs due to the project.
The results of the calculation are represented in the following table.

item	year 1	year 2	year 3
nett costs	*f* 3850	*f* 1750	*f* 1750

item	year 1	year 2	year 3
comments/other	no maintenance included		
qualitative aspects	none		

D.3.3.4. Economic evaluation

Step: Discounting nett costs

The nett present value of the yearly nett costs was determined. For this an economic discount rate of 15% was taken.

item	value
nett costs	*f* 6602
comments/other	no maintenance included
qualitative aspects	none

The resulting discounted nett costs of the project is thus ΔC = *f*6602. This number will be used in the next part of the model in a comparison with the relative environmental improvement ΔE achieved by the project.

Block 4: Overall evaluation

Step: Ranking the projects

The cost effectiveness *I* of the environmental improvement of the project is calculated by dividing the relative environmental improvement ΔE by the costs of the investments ΔC. This gives $1.2 \cdot 10^{-13}$ yr/gld.

The same procedure has been applied to two other projects. For convenience, they are titled *Y* and *Z*. The cost effectiveness of the three projects is shown in the table.

project	environmental cost-effectiveness
venture spiral	$1.2 \cdot 10^{-13}$ yr/gld
project *Y*	$4.5 \cdot 10^{-13}$ yr/gld
project *Z*	$1.8 \cdot 10^{-15}$ yr/gld

The concluding ranking is thus that project *Y* is the most cost-effective investment, followed by the venture spiral.

Step: Analyzing the sensitivity

In this step the reliability and the validity of the ranking is assessed. Unfortunately, very little is known about the uncertainties of the data. But of course, something is known about p.m. posts, etc. There is no suspicion that these uncertainties may lead to a different ranking.

An environmental discounting was also performed with r_{env} = 5%. This leads to the following discounted environmental profile.

discounted normalized effect score	value
greenhouse effect	$3.5 \cdot 10^{-11}$ yr
ozone depletion	0 yr
human toxicity	$1.8 \cdot 10^{-11}$ yr

discounted normalized effect score	value
acidification	$3.2 \cdot 10^{-9}$ yr
comments/other	scrap could not be classified
qualitative aspects	p.m. 100 kg steel

The discounted effect scores were again weighted with the same evaluation factors.

item	value
relative environmental improvement	$7.6 \cdot 10^{-10}$ yr
comments/other	scrap could not be classified
qualitative aspects	p.m. 100 kg steel

Thus the environmental improvement of the venture seal is only slightly affected: from $7.7 \cdot 10^{-10}$ yr to $7.6 \cdot 10^{-10}$ yr. A similar procedure for the projects *Y* and *Z* does not give a different ranking. As the difference between the best project (*Y*) and the second best project (venture seal) is fairly large (factor > 3.5) it can be assumed that the influence of the evaluation factors on the ranking is negligible in this case.

D.5 GLOSSARY

This glossary provides a list of the most common terms used in the method for environmental life cycle assessment of products. It is included to make the report self-contained. It is a slightly adapted excerpt from the Guide LCA.

abiotic resource (non-renewable resource)
Resources which are considered abiotic and therefore usually 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 over the various process functions. The need for allocation occurs in processes with more than one valued output, with combined waste processing, and with recycling occurs in Main methods are based on mass, on function and on value, and especially with combined waste processing.

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. It states the contribution of a product system to a number of problems like greenhouse effect, acidification and ecotoxicity.

classification factor
Result of the modelling of environmental effects which represents the effect as a result of one unit of the environmental intervention. It states the contribution to an environmental problem, e.g., of one unit of a given substance emitted.

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 problem. It usually is expressed as an equivalency factor, stating the amount of a reference substance on the problem with the same magnitude.

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 overall harmfulness of a product to the environment, obtained by quantitative weighting the results of the classification as to the seriousness of the problems involved.

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

Any physical interaction between a product system and the environmental system. Examples are the extraction of resources, the emissions of substances to the environment, to water, air and soil, the space occupied by installations and final waste, etc.

environmental life cycle assessment (LCA)
Life cycle assessment in which only the environmental consequences are considered, maybe as part of an overall life cycle analysis that may also include economic, social, and any other types of effects.

environmental medium
One of the usually three main environmental compartments or domains, i.e. air, water and soil.

environmental pressure
The overall contribution to environmental problems of some unit, expressed as the weighted addition of its environmental profile scores.

environmental process
The set of events in the environmental system transforming inputs into outputs, e.g., determining what happens to a pollutant (accumulation, chemical breakdown, immobilisation, etc.). Environmental processes determine the effects of environmental interventions.

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. It is the result of the classification component of LCA.

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.

evaluation factor (in LCA evaluation)
Number indicating the importance of one environmental problem relative to other environmental problems.

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. It is one possible type of emissions.

format of process data
Set of requirements as to content and presentation of quantitative and qualitative data on processes.

functional unit
Unit that forms the basis for the comparison of different (variants of) product systems, the respect in which the systems to compare are equal. It is the 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. Effect scores may be normalised by expressing the effect on one problem as a fraction of the total effect on the problem caused by all contributions to the it occurring, e.g. in one year, at a global level. I then has the dimension [year].

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 secondary application occurs in a different product system than the primary application.

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 on more arbitrary grounds. 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 the emission of substances to the environment due to their contribution to one or more environmental problems.

pressure see environmental pressure

process
Unit transforming inputs into outputs, occurring both in economy (→ economic process) and environment (→ environmental process).

process tree
Graphical representation of the economic processes involved in 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 focused 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).