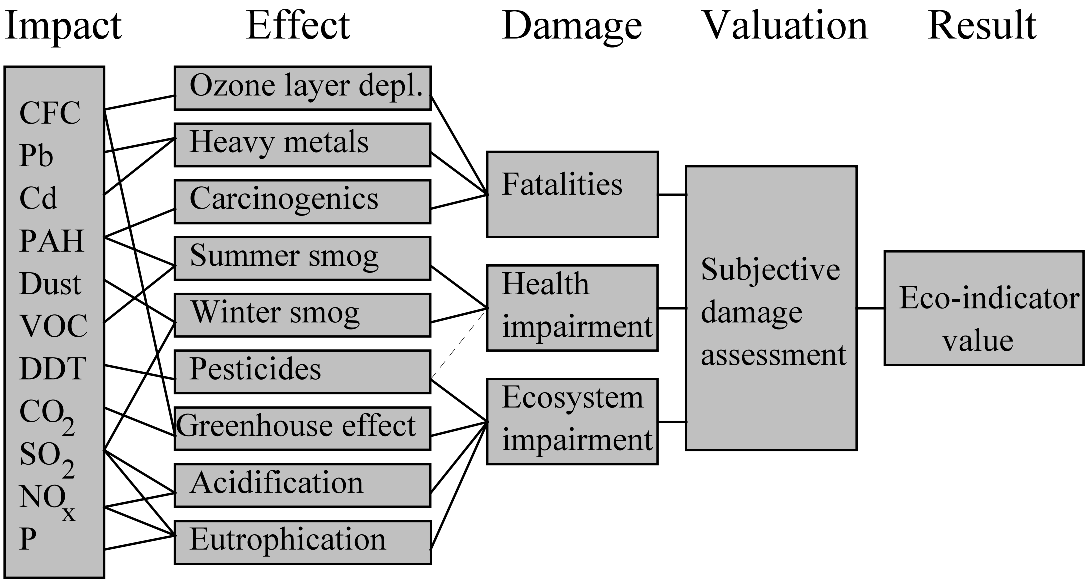
The Eco-indicator 95

Weighting method for environmental effects that damage ecosystems
or human health on a European scale.
Contains 100 indicators for important materials and processes.

Final Report



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With the cooperation of:

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- PRé Consultants
- DUIJF Consultancy BV[1]

In addition to this final report a manual for designers and an appendix are available. The manual describes the practical application of the Eco-indicators. The appendix, which is only available in Dutch, describes the full contribution of the cooperating institutes and the full impact tables. Additional copies of this report, the manual for designers and the appendix are available from:

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NOH report 9523	The Eco-indicator 95, Final Report	Dfl. 45.00
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The reports 9523 and 9524 are also available in Dutch at the same cost. For shipment abroad Fl 20,- postage and packaging costs will be charged extra. The NOH has made it possible to give a discount off the price of reports used for educational purposes.

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[1] At 25.1.1995 Duijf Consultancy BV went out of business.

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Preface

Environmental care behind the drawing board has been a familiar concept for some years in the attempt to achieve more environmentally-sound products. But what is the environment, and how do you bring it behind the drawing board? Until now there is no unambiguous measure for environmental impacts of products, which makes it difficult to develop environmentally sound products. For Philips, NedCar, Océ and Schuurink, this prompted the request to the NOH to start the Eco-indicator project.

Our work within the Eco-indicator project as a multidisciplinary team of representatives from industry, science and government was to give fundamental and in-depth consideration to the question of what the environment actually is and how we should evaluate the consequences of impairment of the environment. Do we evaluate this on the basis of measurable damage to ecosystems or on the basis of impairment of human health? Is raw materials depletion an environmental problem or is it a different problem? And what should be done with local and transient effects?

The outcome of our work is a carefully considered method. It is not a perfect method and it will certainly be possible to improve it. Within the limitations of our knowledge of environmental problems we have attempted to develop the best method feasible at this time. No more, no less.

In addition to the method, which is described in the current report, a list of 100 indicators for commonly used materials and processes has been produced. This list is included it this report and in the Manual for Designers, which is a separate publication from this project. This manual describes the application of the Eco-indicators in the design process, the limitations and the possibilities.

In its "Product and the Environment" paper the Dutch Government announced that it would be developing a method in conjunction with organisations from the community to enable the seriousness of environmental effects to be weighted for the purposes of product policy. In September 1994 *VROM*, the Dutch Ministry of Housing, Spatial Planning and the Environment submitted a proposal for such a weighting method to the *Raad voor het Milieubeheer* [Council for Environmental Management]. In November 1994 the Council responded positively to this proposal. It recommended though that experiments should be carried out initially before definitively specifying the method. Since the Eco-indicator contains all the important features of the *VROM* proposal this means that the Eco-indicator dovetails perfectly with government policy. It will be possible to specify a definitive proposal in 1995 on the basis, among other things, of experiments with the Eco-indicator.

Sincere thanks are extended to the NOH who had the courage and vision to instigate this project at the request of a number of companies. Many thanks are also due to Mr. Sondern. Without his enthusiastic chairmanship this project would probably never have got off the ground. The very constructive role of our scientific representatives, Messrs. Sas, Heijungs, Lindeijer and Remmerswaal also merits special mention.

Mark Goedkoop

Summary

Life cycle assessment (LCA) is the most suitable method for determining the environmental impacts resulting from a product. However, product developers have two complaints about the use of LCAs:

- LCAs are too time-consuming and complex.
- The result of an LCA is a number of discrete effect scores that are difficult to interpret.

This was what caused Philips, NedCar, Schuurink and Océ to request the NOH to instigate the Eco-indicator project. These problems were resolved as explained below in close co-operation with a number of independent scientific advisors.

- Life cycle assessment was expanded to include an extra weighting step, as a result of which it is now quite possible to obtain a clear result (an indicator value).
- About a hundred life cycle assessments were carried out with commonly used materials and processes, and the results (indicators) listed. The designer can use these indicators himself to analyse a product quickly.

In the Setac Code of Practice [34] and in the NOH manual for life cycle assessment [22] a weighting procedure is described but not fully developed. The Eco-indicator project has turned this procedure in to a fully operational evaluation method. The following choices were made:

- Only effects that damage human health and ecosystems on a European scale are assessed. This means that raw materials depletion, the space requirements for waste and local effects are not evaluated. Emissions from raw materials extraction and use and emissions from waste processing are included. The physical impairment of landscapes could not be included for practical reasons.
- The toxicity scores were redefined. Not all the effects defined in the NOH LCA manual [22] lend themselves to weighting. Winter smog, pesticides, carcinogens and heavy metals have replaced human toxicity and ecotoxicity. Chemicals that cause problems in the workplace but not outside were not included.
- The weighting is based on the distance-to-target principle, i.e. the distance between the current and target values for an effect. The greater the distance, the more serious the effect. The target value is based on an analysis of the damage caused by an effect on a European scale. The weighting principle was analysed and considerably improved during the project. The data for determining the weighting factors were largely based on data from the RIVM[33], OECD [28], WHO [2&38] and Eurostat[11]. The selection of the weighting method was preceded by an extensive analysis of existing weighting methods[18].

The table below summarises the weighting factors.

Effect	**Classification**	**Weighting factor**
1. Greenhouse effect	NOH LCA manual (IPCC)	2.5
2. Ozone layer depletion	NOH LCA manual (IPCC)	100
3. Acidification	NOH LCA manual	10
4. Eutrophication	NOH LCA manual	5
5. Summer smog	NOH LCA manual	2.5
6. Winter smog	WHO Air Quality Guidelines	5
7. Pesticides	Active ingredient	25
8. Heavy metals	WHO Air Quality Guidelines; Quality Guidelines for Drinking Water	5
9. Carcinogenic substances	WHO Air Quality Guidelines	10

Around one hundred LCAs were carried out in order to calculate the indicators, in accordance with quality criteria defined in advance. The choice of materials and processes

was partly based on the requirements of the companies, and partly on the basis of the availability of data. The data were largely taken from public-domain literature. LCA software was used for the calculations themselves.

A manual was written to enable designers to use the indicators. This manual, which is available as a separate publication[17], also indicates the possibilities and limitations offered by the Eco-indicators. The companies worked with the indicators for themselves during a workshop. This showed that designers were able to carry out reliable analyses of their own products. The Eco-indicator really brings the environment behind the drawing board.

1. Introduction

1.1. Life cycle assessment

In order to determine the interaction between a product and the environment it is necessary to understand the environmental aspects of products throughout the product life cycle. The method for environmentally-oriented life cycle assessment (LCA) of products was developed to provide this understanding.
An LCA starts with a systematic inventory of all emissions and all raw materials consumptions during a product's entire life cycle. The result of this inventory is a list of emissions and consumed raw materials that is termed the impact table. The impacts are sorted by the effect (classification), and the degree to which they contribute to the effect is expressed in a weighting factor (characterisation). How the effects should be weighted relative to each other, however, was not clear to date. It was frequently the case that the results of an LCA could not be unambiguously interpreted.
Conducting an LCA is generally a very time-consuming affair. This is not so much because of the method as because of the interaction between a product life cycle and the environment in all its aspects is, by definition, a complex matter.

1.2. Aim of the project

The aim of the project is to develop an easy-to-use instrument with which environment aspects can be integrated into the design process, particularly the idea, concept and detail design phases. The designer will use the instrument himself as part of the normal product development methodology.

The Eco-indicator is **not** intended for use in public comparisons of the environmental-friendliness of competing products and the conducting of environmental marketing, nor for making environmental labelling. Other instruments such as more extensive LCAs are preferred for such applications.
The Dutch Government has stated clearly in its "Product and the Environment" policy paper, that a single indicator is **not** to be used for public policy making, setting standards or developing regulations.
The sole application of the Eco-indicator should be the development of better and cleaner products. It is an instrument for internal use in companies.

1.3. Environmentally-aware design

Designer creativity enjoys a central role in product development. Creativity is part of a search process that is always carried out in a cyclical manner:

1. Get an idea..................
2. Analyse the possible consequences of the implementation of this idea.
3. Check how desirable these consequences are.
4. Take a decision on this idea.
5. Get a new idea...........

Selection of an idea is only possible if:

- the designer can analyse the consequences of an idea quickly and effectively.
- the designer has established clear selection criteria for an idea.

The environmental aspect is only one of the evaluation criteria in addition to cost, aspects of use, styling, ergonomics and standards/legislation.

The cyclical character of the design process makes it a difficult process to control. For this reason the design process is broken down into a number of phases. Each phase requires instruments to integrate the environmental aspects into the design process. Table 1.1 gives an overview of the design process and the instruments required.

Phase	Activity	Instrument
Product planning	The idea for a new product is born in this phase.	General rules, experience, policy parameters and legislation.
Orientation phase	The analytical phase. A large amount of information is collected on the design problem. The information is translated into a task definition and a large number of requirements and wishes, on the basis of which ideas can be selected.	Life cycle assessments of comparable products. These enable rules-of-thumb to be developed for this type of product and reveal what priorities have to be set. Any Eco-indicators that are unavailable, but might prove to be necessary, can be calculated now.
Idea development	This is the creative phase, in which the described cycle is run repeatedly.	Selection of materials and working principles based on the *Eco-indicator*
Concept development	In this phase the best ideas are developed into a number of concepts.	Rapid analyses of the concepts developed to date with the aid of the *Eco-indicator*.
Detail design	The best concept is developed in detail.	Detail choices with the *Eco-indicator*.

Table 1.1 Integration of environmental aspects into the design process

The LCA method must be adapted in two ways to make it usable by a designer:

- An LCA must produce a clear result rather than a number of, frequently contradictory, effect scores that cannot be interpreted by a designer (nor by many environmental experts).
- The speed with which LCA data can be generated must be dramatically increased. By definition, however, LCAs are extensive, and it seems unrealistic to assume that new methodologies will enable greater speeds to be achieved. For this reason a large number of LCAs were carried out in this project for commonly occurring materials and processes. The product developer can even make up combinations from these "pre-defined" LCAs.

These two developments form the core of this Eco-indicator project.

1.4. Project working method

Development of the method and tools was carried out in collaboration with Philips, NedCar, Océ and Machinefabriek Schuurink alongside current product development projects.
The approach outlined below was followed:

1. Several meetings were held with the companies to discuss the requirements that the Eco-indicator method must meet in order to be accepted as a decision support tool during the product development process.
2. A comparison was made of the methods currently available in Europe in order to achieve a quick evaluation of the environmental effects of a product based on an LCA. The result of this inventory and evaluation of methods was included in the report on phase 1 of this project [18]. A few important sections are repeated in this report.
3. In a number of rounds a provisional list of almost 80 materials[2] and processes was drawn up for which an Eco-indicator value was wanted by the relevant companies. Later this was expanded to 100 because the waste scenarios were specified in more detail.
4. Impact tables[3] were drawn up for these materials and processes which were then converted to a single score with the aid of the methodology developed.

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[2] A material can also be included as a process, i.e. the process that is necessary to make the material. 80 processes are therefore involved.

5. Parallel to this, Philips CFT carried out a very extensive inventory of the environmental effects of electronic components and printed circuit boards.
6. An evaluation method for LCA data was developed in close consultation with the advisors involved in this project.
7. An extensive search for data on the seriousness of emissions resulted in the drafting of weighting factors.
8. A manual for designers was written based on a number of discussions with various people involved.
9. The usefulness of the manual and the list of indicators was tested by a number of designers at the relevant companies.
10. A description of the methodology was drafted for this report.

1.5. Project team and supervisory group

For the purposes of the project a consultative and collaborative structure was established. A platform was created which included both industrial and scientific representatives. The platform convened ten times during the project to discuss the results and choices. In addition, a number of smaller-scale meetings were held to discuss certain specialised subjects. The platform was chaired by Mr. A. Sondern of Philips.

The scientific representatives had a completely independent role in this project. With such a project it goes without saying there was not unanimity on answers to all the methodological questions. There is, however, broad agreement with the results. It is felt that this method is the best possible for this application, given the limited state of our knowledge or, as R. Heijungs put it: "the restrictions have been used in a creative way".

Views relating to the project content were also exchanged during the project with representatives of organisations from other countries. Three joint workshops were organised with the Nordic NEP project (B. Steen, O. J. Hanssen *et al.*). Discussions also took place with H. Wenzel of the Danish EDIP project and with P. Hofstetter of the University of Zurich (ETH).

Collaboration among members of the platform was remarkably good. Very intensive talks were held, particularly between the industrial and scientific representatives who worked together to find a compromise between usability and the scientific integrity of the weighting methods. We are extremely grateful to the participants in this project for their critical but always constructive contributions to discussions.

Table 1.2 lists the contributors to this project and the most important contribution.

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[3] List of emissions and raw materials consumed.

Name[4]	**Employer**	**Contribution to this project**
Mr. (Ir.) A. Sondern	Philips Consumer Electronics (BGTV)	Chairman
Mrs. (Ir.) M. Meuffels	Philips CEEO	Secretary
Mr. (Ing.) A.A.P. Ram	Philips CFT	Process data electronics
Mr. (Ir.) M. Peters	Netherlands Car BV	Industrial representative
Mr. (Ir.) T. Geerken	Océ Nederland BV	Industrial representative
Mr. (Ing.) P. Bals	Machinefabriek Fred A. Schuurink BV	Industrial representative
Mr. (Ir.) T. van der Horst	TNO Product Centre	Ecodesign expert
Mrs. (Ing.) J. Hoekstra	NOH / Novem BV	Principal from phase 2
Mr. (Ing) J.v.d. Velde	NOH / Novem BV	Principal up to phase 2
Mr. (Mr.) G.L. Duvoort	NOH / RIVM	Principal
Mr. (Ir.) H. Wijnen	VROM / IBPC	Government representative
Mr. (Dr.Ir.) H. Remmerswaal	Technical University of Delft (Industrial Design Engineering)	Process data + methodological advisor
Mr. (Drs.) R. Heijungs	University of Leiden (CML)	Methodological advisor
Mr. (Drs.) E. Lindeyer	University of Amsterdam (IDES)	Methodological advisor
Mr. (Drs.) H. Sas	Centre for Energy Conservation and Environmental Technology, Delft	Methodological advisor
Implementation		
Mr. (Drs.) G.A.P. Duijf	DUIJF Consultancy BV	Project co-ordinator
Mrs. H. v. Nuenen	DUIJF Consultancy BV	Secretariat
Mr. (Drs.) T. v.d. Hurk	DUIJF Consultancy BV	Production process data
Mr. (Ir.) M. Wielemaker	DUIJF Consultancy BV	Manual for designers
Mr. (Ir.) M.J. Goedkoop	PRé Consultants	Methodology development, data collection, manual for designers
Mrs. (Ir.) I.V. de Keijser	PRé Consultants	Development up to phase 1
Mrs. (Ir.) M. Demmers	PRé Consultants	Manual for designers
Mr. (Drs). P. Cnubben	PRé Consultants	Normalisation and process data collection

Table 1.2 Overview of those involved in the project

1.6. Government policy during this project

In the "Product and the Environment" policy paper it was announced that the Dutch Government would develop a system of weighting factors (and methods) in 1994 in conjunction with organisations from the community which would enable the relative weighting of the environmental aspects of products to be indicated more objectively.

In September 1994 the Dutch Ministry of Housing, Spatial Planning and the Environment [7] published a proposal for such a weighting method for the purposes of product policy . This proposal contained the following elements:

- The seriousness of an environmental effect is derived from the exceeding of a reference level (distance-to-target principle).
- The reference levels chosen are the European sustainability levels.
- Only quantifiable environmental effects are included, such as an increase in the greenhouse effect, ozone layer depletion, diffusion of toxic substances, acidification, eutrophication and smog.
- If quantifiable, the following environmental effects should be included: drought, depletion of biotic raw materials, direct physical impairment of ecosystems and thermal pollution.
- The following environmental effects will not be included: odour, noise, working conditions, direct victims and depletion of abiotic raw materials.

This proposal was submitted to the *Raad voor het Milieubeheer* [Council for Environmental Management] for consultation. In its recommendation [32] dated 24 November 1994 the

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[4] The titels are abbreviated between brackets in Dutch.

Council responded positively to the weighting principle chosen. However, the Council foresaw some problems in its development and urgently recommended a trial period before definitively specifying the weighting method. It criticised the omission of abiotic raw materials. It finds the reduction in the degree of depletion an important element in achieving sustainability.

In 1995 the proposal for weighting of environmental effects will be further developed. Consultation with community organisations will take place, but sustainability levels will also have to be specified. Then experiments will be carried out. A definitive proposal will then be submitted before the end of 1995 or in early 1996 based on these and other experiments.

The Eco-indicator has been developed in the same period that the initial VROM proposal emerged. As a result of intensive contacts and mutual cross-over the main elements of the two methods are identical. It would be wrong, therefore, to talk of two methods; instead the two starting points should be referred to as one basic method which has already resulted in practical weighting factors in the Eco-indicator project. Practical interpretation of the sustainability levels has been made in the Eco-indicator project.

Working with Eco-indicators should be viewed as experimentation with the method. The results of these experiments will then also be used to definitively specify an updated weighting method.

2. Life cycle assessment method

Various methods are in use to assess the environmental effects of products. Almost all methods operate on the assumption that a product's entire life cycle should be analysed. The main differences between the methods are:

- the comprehensiveness of the analysis
- the type of effect that is included
- the degree of quantification of the result
- the interpretation (weighting) method of the environmental impacts identified

A brief overview of these methods is given below. This overview is an excerpt from the report on phase 1 of the Eco-indicator project [18].

2.1. Qualitative methods

Even without working systematically with weighting factors and classifications it is often possible to comment on the seriousness of the impacts on the basis of the impact table. The expertise and sometimes the intuition of the expert carrying out the evaluation often plays an important role. Designers and other non-experts in environmental matters cannot generally offer such comments.

Although a lot of variants on this subject are possible we will look at just two methods here.

2.1.1. Red flag methods

A number of companies, including Philips, work with "red flags". If an emission of CFCs or priority substances occurs in the impact table it is red-flagged. The product or process should then not actually be used.

A major problem is that red flags occur in this way in almost every impact table and that a very small emission is treated in just the same way as a large one. This approach is not very suitable for providing a qualified evaluation.

2.1.2. MET matrix

The Dutch Ecodesign programme uses the MET matrix. MET stands for Material, Energy and Toxicity. MET analysis is an experimental approach that is intended to identify the environmental problems of a particular product, and to enable designers to improve the environmental aspects of their products. This can be divided into five stages:

1. A discussion of the social relevance of the product's functions.
2. Determination of the life cycle of the product to be analysed.
3. Intuitive completion of the MET matrix, based on existing knowledge by inexperienced people who in this way will quickly familiarise themselves with the method. The various processes from the life cycle are entered in the matrix in order of harmfulness for the indicators material, energy and toxicity.
4. Careful completion of the MET matrix, with the aid of environmental experts.
5. Establishment of outline solutions for the environmental problems identified.

The method is intended to identify the environmental problems of one product and present them clearly. A feature of the Ecodesign approach is the presence of an environmental expert in the design team who analyses the design decisions. The Eco-indicator is being developed precisely to enable design decisions to be taken without external expertise. The MET matrix is not an indicator because it does not quantify and because it uses not one but three criteria. An MET indicator has now been developed at the Delft University of Technology that broadly follows the principles of the Eco-indicator.[31]

The disadvantage of these qualitative methods is their poor reproducibility (every expert can arrive at different judgements) and the lack of scientific basis.

2.2. Scientific basis of life cycle assessment

Much attention has been given in recent years to the standardisation and scientific basis of the life cycle assessment method. The most important stages of an LCA have been described, as part of the NOH programme, in a manual by the Centre for Environmental Science (CML) of the University of Leiden [22], referred to below as the *NOH manual*. This manual was used for reference in the development of the Eco-indicator. Internationally the most important developments in the LCA field have been brought together by the SETAC, the professional association for toxicologists. In its Code of Practice [34] this organisation describes a method that is closely related to and largely based on the work of the CML.
The environmentally-oriented life cycle assessment system (LCA) aims to produce a systematic analysis of all the environmental effects at every phase of a product's lifetime. As it is a method that describes a complex problem it can also as a rule be rather complex itself. Both a product life cycle and the term "environment" are difficult to define.
It is assumed that this methodology is broadly known, but it is outlined briefly below. In short, this method can be divided into the following stages:

1. **Goal definition** of the analysis. The application, depth and subject of the study are defined. The functional unit is specified in this stage.
2. **Inventory** of the environmental impacts throughout the life cycle. This is the stage when all emissions and all raw material consumption in every process of the entire life cycle are identified. The result is a (frequently long) list of emissions and raw materials, known as the *impact* table. These impacts generally result in very different types of environmental effect.
3. **Classification, Characterisation and Normalisation** of the impacts by environmental effect. Here the impacts are aggregated to a number of environmental effect scores. This occurs in two stages:
   - Sorting of the impacts by the effects they cause.
     Example: the substances CO_2 and methane are both placed in the greenhouse effect class. Mercury emissions are placed in the toxic substance class. This is the classification stage.
   - Characterisation of the impacts according to the degree to which they contribute to an effect. Example: the greenhouse effect of the emission of 1 kg methane is 11 times higher than that of carbon dioxide. For this reason the amount of methane is first multiplied by 11. The result in this case is a greenhouse effect score, expressed in carbon dioxide equivalents. The same is possible for other environmental effects. This is termed the characterisation stage in the SETAC Code of Practice[5].

   The effect scores can then be normalised. This can be done in various ways, but the essential feature is that the effects are compared with reference values (or normalised values). As a rule, the average effect in a particular area, for example Europe, is taken. By means of normalisation, therefore, the contribution of the effect to the total effect is determined.
   The result is an *environmental profile* with standardised (and dimensionless) effect scores.
4. **Evaluation**. During this stage the different environmental effects are weighted and totalled to form an *environmental index* in NOH terminology. An indication is thus given of how many times *more serious* the greenhouse effect is than the toxicity.

In principle, therefore, it ought to be possible to calculate a single Eco-indicator on the basis of the NOH manual. Unfortunately, the manual, nor the Code of Practice does describes how to carry out stage 4. The description of stage 3 is also not complete. Although the

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[5] The NOH manual includes the characterisation stage under classification. However, the Code of Practice distinguishes between classification and characterisation. We have used the latter terminology.

normalisation stage is described, it cannot be carried out because of a lack of the relevant data. In practice, therefore, it is not possible to calculate a single score with the manual.

2.3. Weighting principles

Various methods have been developed in the meantime to aggregate the results of an LCA to a single score. These involve weighting on the basis of the impact table based on effect scores. A normalisation stage does not always take place. An overview is given in this paragraph.

In addition to scientific influences, the weighting will also be determined by subjective and political views. The arguments used in the weighting will reflect social values and preferences. Six categories can be specified, with the weighting factor for a particular type of environmental pollution depending on the following:

1. The social evaluation (expressed in financial terms) of damage to the environment. The impairment of human health, for example, is based on the costs that a society is prepared to pay for healthcare. This principle is used in the EPS system (see below).
2. The prevention costs for preventing or combating the relevant environmental impact by technical means. The higher the prevention costs, the higher the rating given to the seriousness of the impact.
3. The energy consumption that is necessary to prevent or combat the environmental impact by technical means. The greater the energy consumption, the higher the rating given to the seriousness of this impact.
4. Avoiding the use of weighting factors by using only one environmental effect, in this case energy consumption, as a measure of the total environmental pollution.
5. The evaluation of experts (for example, a group of respondents in a panel) who express the relative seriousness of an effect by assigning a weight to the effect or impact.
6. The degree by which a target level is exceeded. The greater the gap between the current environmental impact and a target level, the higher the rating given to the seriousness of the impact. This method has become known as the Ecopoints method.

The Eco-indicator is mainly based on this last principle. Some elements from the so-called EPS system are also used in the Eco-indicator methodology.
The principles mentioned are outlined briefly below. The weighting principles are tested against a list of requirements, and the Eco-indicator weighting principle is defined.

2.3.1. EPS system

The IVL[6] in Sweden developed a method for Volvo that results in one score. This is a complex method known as EPS (Environmental Priority Strategy)[35] that is based on the premise that it is not the effect itself that has to be evaluated but the *consequences* of that effect. It is assumed that society places a certain value on a number of matters that are termed *safeguard subjects*:

1. **Resources**, or the depletion of resources;
2. **Human health**, or the loss of health and the number of extra deaths as a result of the environmental effects;
3. **Production**, or the economic damage of the environmental effects (particularly in agriculture);
4. **Biodiversity**, or the disappearance of plant or animal species;
5. **Aesthetic values**, the perception of natural beauty.

In this method the effects are first determined, in theory approximately as in the NOH manual. In practice a very limited number of impacts are currently being used, and so it is hardly possible to refer to any classification.

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[6] IVL: Swedish Environmental Research Institute, approximately comparable to the RIVM.

By contrast with the NOH manual, a number of correction factors are used, in addition to the potential effect (for example, toxicity), such as:

- exposure; for example, the number of people who actually come into contact with the substance or phenomenon (the populations of the Netherlands and Bangladesh are exposed to the danger of flooding in the event of a rise in the level of the sea).
- frequency; the number of times that an effect occurs or the probability that it will do so (for example, a flood caused by a rise in the level of the sea).
- period; the time for which an effect occurs, including the speed with which a substance degrades.

Although it is right scientifically to apply this correction it substantially increases the complexity.

Using the safeguard subjects mentioned, the damage is determined on the basis of these corrected effects. This damage is then expressed in financial terms. The valuation is based on three different principles:

- Raw materials depletion is valuated by looking at the future extraction costs for raw materials. These are the costs that must be expended in order to extract the "last" raw materials resources. For oil and coal the costs of alternative fuels is used. Oil is valuated using the price of rapeseed oil production, while the price of wood is used to valuate coal. Strangely, in the case of minerals, no attempt is made to use alternative minerals (many applications of copper could also use aluminium or glass fibre which are much less scarce).
- The production losses are measured directly from the estimated reduction in agricultural yields and industrial damage (for instance: corrosion).
- The other three safeguard subjects are valuated in terms of the willingness-to-pay principle. The sums that a society is prepared to pay for ill health or the death of its citizens, the extinction of plants and animals and impairment of natural beauty are examined.

It is implicitly assumed that these three value judgements are interchangeable. The result of the method is found by totalling up the financial sums calculated. The method's usability depends greatly on the availability and reliability of the large number of weighting factors. Unfortunately, the system is not very clearly described and documented.

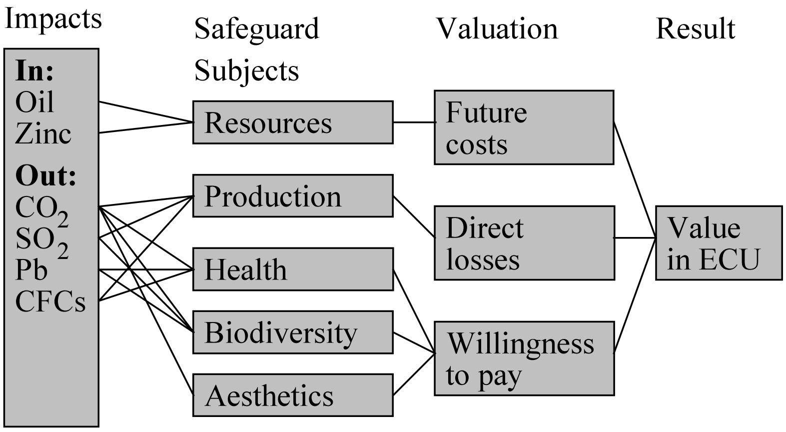

Fig. 2.1 Schematic representation of the EPS system. The result is also a measure of the possible social costs as a result of the environmental impacts.

In conjunction with Volvo Sweden a prototype of a software program was developed with the particular ability to carry out a sensitivity analysis of both the data and the weighting factors. The researchers specified a standard deviation for each weighting factor or correction factor. The data from the inventory phase also have a standard deviation. It is not always clear on what the standard deviation is based. This sensitivity analysis enables the user to examine how sure it is possible to be that product A is better than product B or vice versa and what the reason for this is.

Volvo's own designers use the EPS system themselves in practice, even though the software is rather complicated and time-consuming to use, particularly because of the sensitivity analyses. The system has been intensively used for a number of technology choice studies, for various automotive components and for the Environmental Concept Car. At the moment a Nordic project (Scandinavia) is beginning in which the EPS system is being further developed.

In the Eco-indicator project we have used a financial evaluation of effects to assess different types of damage caused by these effects (see para. 3.1.5).

2.3.2. Prevention costs of emissions

TME [7] and several other institutes are working on a system that assesses the emissions not on their effect nor on the threat to ecosystems, but on the basis of the costs that would have to be expended to prevent an emission, insofar that this is at least possible.
The costs to prevent an emission depend in practice on a large number of technological factors which can differ greatly from country to country and process to process. This makes the method well suited for the optimisation of a specific process, but less suited for general assessment of impacts.
Furthermore it is not clear to what extent an emission must be prevented, or which concentration or which absolute amount is still acceptable. To allow prevention costs to be calculated it is therefore necessary to know the required reduction. The question thus recurs of what is an acceptable (persistence) level for each emission. Before this method can be used, therefore, such levels first have to be defined.

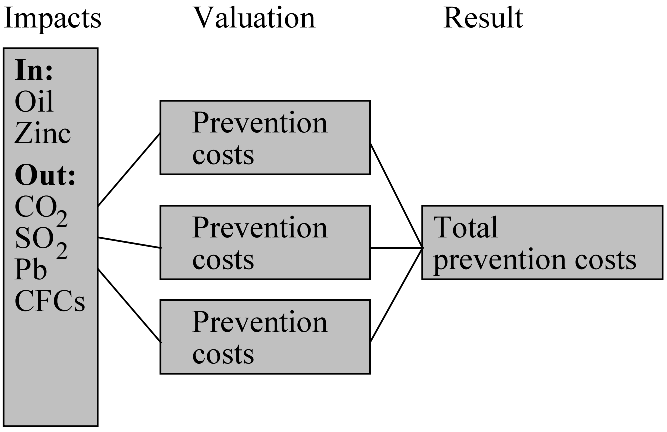

Fig. 2.2 Schematic representation of weighting based on prevention costs

This line of thought contains interesting elements because working with costs has its attractive sides, particularly with reference to the optimisation of production processes. For an Eco-indicator that is not location- or process-specific the method is less interesting.

2.3.3. Energy consumption needed to prevent emissions

In a study of the "Theory and practice of integral chain management" [8] a provisional method is developed in which three time-independent variables for environmental pollution are aggregated to one score. These variables are energy consumption, carbon dioxide emissions and water consumption. These three evaluation variables are converted to a single

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[7] Bureau voor Toegepaste Milieu Economie [Office for Applied Environmental Economics], The Hague.

score, energy. The total energy input is equal to the total input estimated to be needed to prevent the emissions.
Just as with the prevention costs the energy consumption to prevent emissions depends in practice on a large number of process engineering factors and on the question of the degree to which an impact has to be counteracted. In principle there is little difference from the method described above, except that calculations here are based not on money but on energy.

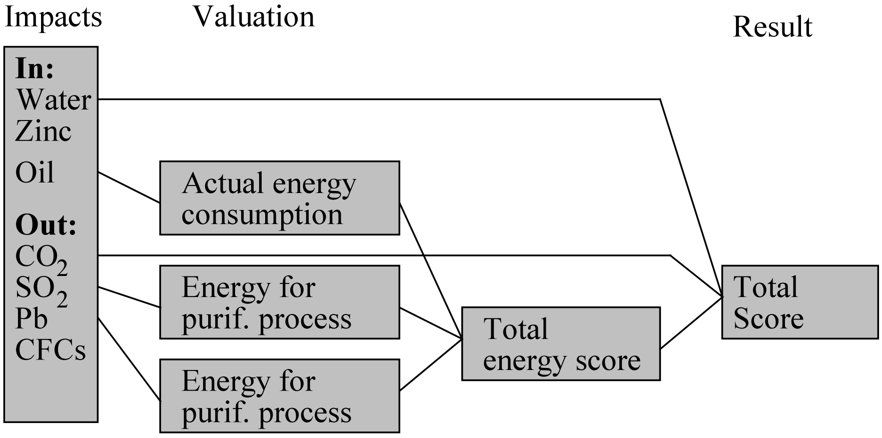

Fig. 2.3 Schematic representation based on prevention energy.

2.3.4. Energy consumption as a measure of total environmental pollution

Because many emissions are linked to the conversion of energy from fossil fuels, energy consumption is sometimes used as an evaluation criterion. The energy consumption can be viewed as an indicator for:

1. Combustion emissions from fossil fuels
2. The depletion of energy sources

No weighting is in fact applied with these methods because only one parameter is taken into account.

1. Energy consumption as an indicator for combustion emissions

Because of their dominance energy conversion processes are good predictors of the most important emissions from the impact table. If the energy conversion processes (type of fuel, combustion method) are known, it is possible to estimate reasonably well what the combustion emissions will be. The combustion energy is thus a measure of the combustion emissions. The impact table only has to have specific process emissions entered. It is not an ideal method, but it can be useful to estimate the most important emissions in this way. However, the problem of interpreting the specific process emissions (heavy metals, CFCs etc.) is not resolved with this method.

2. Energy consumption as an indicator for the depletion of energy resources

It is assumed for the sake of convenience that all conversion processes have the same emissions (a gross simplification) and aggregate all energy conversions. The product with the most energy conversions is the least environmentally friendly. All kinds of specific process emissions are difficult to include in this method.
The evaluation and the collation of the impact table overlap in this method. Very large distortions can occur, particularly because serious environmental problems such as ozone layer depletion, heavy metals and such like are completely ignored.

2.3.5. Evaluation by experts (panel method)

Attempts have been made in England (Bryan Jones)[8] and in the Netherlands (CE/IDES [25] and PRé [27]) to develop a weighting method with the assistance of experts.

In Bryan Jones' approach a list of emissions was forwarded to a number of experts. The emission of 1 kg mercury was set at 100. The experts were requested to scale the other emissions relative to mercury. The results were unsatisfactory. CO_2, for example, was given a scale value of 16. In practice, emissions of CO_2 are greater than those of mercury by a factor of 10,000 (in kg). Consequently CO_2 would dominate all other impacts in most LCAs. The introduction of a preceding normalisation stage would enable the results to be somewhat better.

In the CE/IDES panel method 20 respondents were asked to place six environmental effects in order and to assign weightings to them on a scale of 0 to 100. The experiment revealed that there were major variations in the results from the different respondents because there was a very large variation in the arguments used to define something as serious or not serious. In our view the disadvantage of a panel method is that the arguments are frequently based on a personal conviction or on a particular political trend which uses environmental arguments that are not scientifically underpinned. Such an intuitive approach is difficult to use for a generally applicable Eco-indicator.

With the P-method a weighting based on a single expert was used [27][9]. The effect scores of all processes and materials were determined (based on Buwal report 132 [20]). The effect scores were compared with those for the production of 1 kWh European electricity. This electricity was thus the normalisation basis and was assigned the value P=1. The effect scores were scaled as accurately as possible with reference to this normal. If the effect scores for steel production were approximately 6 times higher steel was assigned the value P=6. Because effect scores by no means always occur in the same mutual proportions an intuitive judgement was frequently necessary. Consequently, the P-values cannot be well underpinned. In the Milion project it turned out afterwards that the P-method led to the same results as the LCA method.

As will be seen, weightings that are subjective to a greater or lesser extent are also necessary in the Eco-indicator method. However, the subjectivity has greater restrictions placed on it than the completely subjective methods described here.

2.3.6. Ecopoints

The Ecopoints method was developed back in 1990 as a commission by BUWAL [1] (the Swiss Environment Ministry). This is the oldest system working on the Distance-to-Target principle, by which is meant that an effect's seriousness is evaluated in terms of the distance between the current level of this effect and a target level.
In the Swiss system it is not the effects but the individual emissions, as well as energy consumption and waste that are evaluated. The target value set is the national policy objectives. At present, as far as we are aware, Ecopoints systems based on Swiss, Norwegian and Dutch policy targets are available.
As a result of the use of policy targets the result of this method is rather distorted by political priorities. Thus the reduction target for CO_2 is 3% in the Netherlands. This is much less than could be expected if a judgement on the seriousness of CO_2 had to be made on purely scientific grounds.

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[8] Personal communication, September 1993, report is not available.

[9] This report describes the use of the P method; the P figures themselves have never been published.

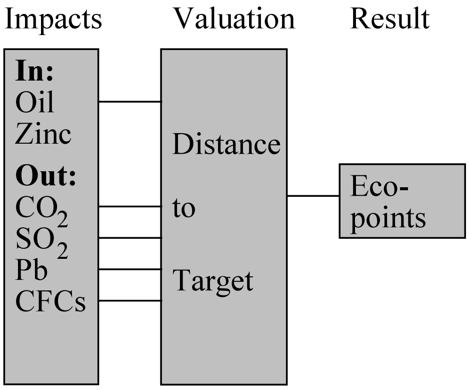

Fig. 2.4: Schematic representation of the Ecopoints method

2.4. Requirements for an Eco-indicator weighting method

Based on the information gained from the existing methods much attention was given in the project to defining the requirements that the indicator weighting method must meet. The goal definition together with a number of principal requirements and wishes are given below.

2.4.1. Goal

In product development there is a need for a figure that accurately represents the environmental pollution of a process or material. Within this project this need was limited to a list of 100 materials and processes.

The methods described above to produce such a figure have clear shortcomings. Thus a method will first have to be developed. Since there is no correct or reference method available, it is unclear how the correctness of this new method can be tested.

For the participating companies it is of great importance that a product that is developed with the aid of the Eco-indicator is well evaluated in a full life cycle assessment. It is therefore important that the Eco-indicator calculation method follows the LCA method closely.

From this principal requirement it follows that the results of an analysis with the aid of Eco-indicators must comply with the results that would be achieved with an extensive analysis in accordance with the Dutch LCA manual.

For this reason the Eco-indicator method is based on the presently applicable LCA method; it is an extension of the method, not a simplification!

2.4.2. Requirements and wishes

With this starting point a number of other requirements and wishes can be formulated:

- **Acceptance**: The environmental pollution expressed by the indicator must preferably fit in with public perceptions of environmental pollution. The weighting factors used and (subjective) choices must be communicable and justifiable. Acceptance will depend in part on the method's understandability and transparency.

- **Stability**: If an organisation is choosing a method on the basis of which design decisions will be taken in the future, a certain stability is desired. The chance that decisions taken today would be very different in the future, as a result of changing weighting factors, must be avoided as much as possible. The stability of the weighting factors depends among other things on changing scientific insights or shifts in political priorities. Methods that are very controversial amongst scientists, the public or politicians will be less stable.

- **Accuracy**: The result of an Eco-indicator calculation must offer a sufficient degree of accuracy. A distinction must be made between two types of inaccuracy:
  - Inaccuracy in the impact table (the table of emissions and raw materials consumed)
  - Inaccuracy in the weighting factors and the weighting procedure

  Inaccuracy in the impact table is a general problem in every environmental analysis. In the choice of an evaluation method only the second factor is of importance.

2.4.3. Selection of the weighting principle

Based on these requirements it was decided in phase 1 of this project to develop a method with the following features:

- The Eco-indicator method is not a simplification of the LCA method, but a further development of the framework outlined in the NOH manual. Phases 3 and 4 (see para. 2.2) will be made operational. Only in this way is it possible to ensure that the method complies well with current environmental analysis practice. This starting point seems to contradict the objective, i.e. a fast and easy to use instrument for designers. Time is gained, however, by the prior generation of standard Eco-indicator values.
- The distance-to-target principle seems the most suitable for expansion into a credible weighting method that is relatively simple to communicate.
- In line with the international character of the companies, the Eco-indicator must apply to the whole of Europe.
- Target values must be based on the scientific data and not on policy targets.

Based on the experiences of the EPS and Ecopoints systems it was decided to weight effects rather than impacts. This means that the impacts first have to be classified and characterised. The major advantage of this is that many more impacts can be included in the indicator method.

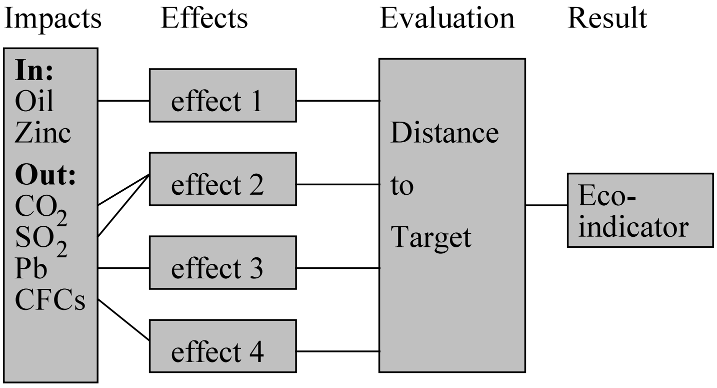

Fig. 2.5 Weighting principle of the Eco-indicator method, as seen at the end of phase 1 based on the choices outlined in this chapter.

3. Eco-indicator weighting method

In chapter 2 it was stated that the NOH manual in principle indicates how the results of an LCA can be weighted in two stages but that it does not define how this can take place. It is furthermore stated that the Eco-indicator method must fit in with current LCA practice. This means that the Eco-indicator method in fact amounts to completing the last stages, i.e. normalisation and weighting. The Eco-indicator method is therefore an extension of the current LCA method according to the NOH manual and thus also according to the SETAC Code of Practice.

This chapter develops these stages. The fundamental aspects of the weighting stage are first examined, after which the required weighting factors and normalisation data are gathered. It will be shown that some points of the classification stage also need adjustment.

3.1. Weighting according to Distance-to-Target

In phase 1 of this project it was decided to take the Distance-to-Target as the starting point for the weighting. This means that the seriousness of an effect is related to the difference between the current and target values.

An example will illustrate this principle.
Let us assume that current acidification levels in Europe are higher than desired by a factor of 10 and that the greenhouse effect is higher by a factor of 2.5. According to the distance-to-target principle this means that the weighting factor for acidification is equal to 10 and for the greenhouse effect 2.5. It will be clear that the choice of the target value is crucial. Much thought has also been given to the choice and development of the target values.

In this project advice was sought from the Centre for Environmental Science (CML) of the University of Leiden, IDES of the University of Amsterdam and the Centre for Energy Conservation and Environmental Technology. Furthermore, detailed consultation took place with representatives of the Nordic NEP project, the Danish EDIP project and with Patrick Hofstetter of the University of Zurich (ETH). The full text of these contributions is only available in Dutch in the annexe report [14].

It became apparent from this advice that the procedure outlined below has to be followed in order to achieve a weighting:

1. Determine the relevant effects that are caused by a process or product (which effects are involved is determined later).
2. Determine the extent of the effect in Europe. This is the normalisation value. Divide the effect that the product or process causes by the normalisation value. This step determines the contribution of the product to the total effect. This is done because the effect itself is not so relevant but rather the degree to which the effect contributes to the total problem. An important advantage of the normalisation stage is that all the contributions are dimensionless.[10]
3. Multiply the result by the ratio between the current effect and a target value for that effect. The ratio, also termed the reduction factor, may be seen as a measure of the seriousness of the effect.
4. Multiply the effect by a so-called subjective weighting factor. This factor is used because other factors in addition to the distance-to-target can also determine the seriousness of an effect.

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[10] In the Swiss Ecopoints method it is not the current value but the target value that is used as the normalisation value. The result is the contribution to an effect level that will (it is hoped) be achieved in the future. We find that less logical. The SETAC Code of Practice also recommends normalisation on the basis of the current value.

The procedure can be expressed in the following equation.

$$I = \sum_i W_i * \frac{E_i}{N_i} * \frac{N_i}{T_i} = \sum_i W_i * \frac{E_i}{T_i} \text{......(1)}$$

where:

I	indicator value
N_i	current extent of the European effect *i*, or the normalisation value
T_i	target value for effect *i*
E_i	contribution of a product life cycle to an effect *i*
W_i	subjective weighting factor which expresses the seriousness of effect *i*

The subjective weighting factor is entered in this phase to make corrections in the event that the distance-to-target principle does not sufficiently represent the seriousness of an effect. When this factor is introduced the distance-to-target principle seems to lose much of its value because there is an unlimited degree of subjectivity. The weighting begins to resemble a panel method. Closer analysis of this problem shows that it is not the effect that has to be subjectively evaluated but the damage caused by the effect. An effect should only be evaluated if the damage it causes is known. This subject is examined in greater detail in para. 3.2.

It will be noted that the normalisation value *N* is omitted from this equation. This is a more or less coincidental effect that is more to do with the formulation of the different terms. The term *N/T*, for example, can be written as a reduction factor *F*. The reduction factor is equal to the weighting factor, as can be seen from the above. In that case the equation becomes:

$$I = \sum_i W_i * \frac{E_i}{N_i} * \frac{N_i}{T_i} = \sum_i W_i * \frac{E_i}{N_i} * F_i \text{......... (2)}$$

This means either that the target value must be known (for equation 1) or the current level and the reduction factor (for equation 2). During the project it became apparent that it is much easier to determine the reduction factor plus the current value than the target level. The reduction factor can be directly seen as a weighting factor. The use of equation 2 makes the weighting much clearer because, in accordance with the SETAC method, the effect of the normalisation stage must first be apparent and then the effect of the weighting. This has resulted in a great deal of attention having to be paid to the retrieval of current values.

Before developing the method further it is important to answer the following questions:

- What is the basis for defining the target level?
- What effects are evaluated, and how are these defined?
- How can effects that cause different types of damage be assigned an equivalent target value?

3.1.1. Policy or science

It is apparent that there are different approaches to selecting target levels. In the Swiss Ecopoints system target levels are taken from Government policy objectives. An alternative is to use scientifically determined target levels.

3.1.1.1. Politically determined target values

Both the EU [12] and a number of European countries have formulated objectives for environmental pollution reductions. In general the objectives are a compromise between scientific, economic and social considerations. This can result in values being chosen that are very different from the scientifically defined value. An indicator that is based on politically determined target values refers not so much to environmental pollution as to conformity with policy decisions. That was not the aim of this method.

3.1.1.2. Scientifically determined target values

If the decision is taken to use a scientific approach, a number of alternatives are available:

- Zero as the target value for the effect. A problem then arises when using the equation derived above.
- No effect level. This is a low value in which no demonstrable damage to the environment occurs. The problem is that such a level cannot be clearly defined. Taken literally, it means that at that level no single organism suffers even the slightest damage. Ecosystems are so complex that it is impossible to check this in practice.
- A low damage level. This is a level where demonstrable but limited damage occurs. For example, impairment to the level of a few percent of a particular ecosystem or the death of a number of people per million inhabitants.

The third option was chosen for practical reasons. In itself the choice is not as important if the damage levels per effect are well comparable. If all target values are doubled all the reduction factors, thus all the weighting factors, will be halved. This has no relevance to the mutual correlations of the weighting factors.

3.1.2. Definition of the term "environment"

In formulating the project's outlines it is assumed that they should keep as close as possible to the NOH manual and the SETAC guidelines. The following effects are defined in the NOH manual.

1. Greenhouse effect
2. Ozone layer depletion
3. Human toxicity (air)
4. Human toxicity (water)
5. Human toxicity (soil)
6. Ecotoxicity (water)
7. Ecotoxicity (soil)
8. Smog
9. Acidification
10. Eutrophication
11. Odour
12. Depletion of biotic raw materials
13. Depletion of abiotic raw materials
14. Noise
15. Physical ecosystem degradation
16. Direct victims

These effects are not all defined with uniform clarity, and for some effects there is no characterisation. Furthermore, the question arises of whether it is so sensible to include all these effects in the weighting or whether other effects should perhaps also be included.

Up till now "Eco-indicator" has been used as if it is clear what the term "Eco" or "environment" means. It is apparent, however, that a very large number of problems have to be specified that can be included under the term "environmental problem".
It is clear that there is no point in developing an indicator without defining the term "environment" and restricting it to some extent. Two considerations are involved:

- It is desirable as far as possible to include all effects in the indicator in order to prevent the situation where the designer does not note important environmental effects when using the indicator.
- It is desirable to keep the weighting well-structured and sound by only including effects that result in a comparable type of environmental damage.

A compromise must therefore be achieved between these wishes.

Based on these considerations it was decided only to include environmental effects which:

- *result in damage to ecosystems on a European scale*

- *result in damage of human health on a European scale.*

This choice means that no account is taken of:
- local environmental problems such as odour, noise and light
- raw material depletion
- production of final waste
- a number of toxic effects

Furthermore, it unfortunately proved impossible to incorporate the direct physical ecosystem degradation caused by land use into the weighting. The score for direct victims is irrelevant for weighting because victims only occur in disasters. These are outside the scope of most LCAs.
These exclusions are discussed further below.

3.1.2.1. Physical ecosystem degradation

Physical ecosystem degradation is a major environmental problem to which only little attention has been given in LCA methodology development. The problem lies particularly in the unclear definition of the term "degradation". In a recently published extensive LCA of energy systems ecosystem degradation is quantified as follows [13][11]. Four quality classes for ecosystems were defined. The highest quality class is a richly varied and unimpaired system, while the lowest is a completely ravaged system such as a road or industrial area. Between these extremes lie two types of landscape with a particular ecological quality.

The LCAs record for each process what areas transfer from one quality class to another, over a certain period. This approach offers an initial impetus towards developing a quantification of the term "ecosystem degradation". Unfortunately this principle has not yet been developed further.
This approach is of great interest for the Eco-indicator project because here too the principle of ecosystem damage plays a decisive role in determining the target value. The Eco-indicator method would greatly benefit from a good definition of the term "degradation" because it would be possible to quantify the damage to ecosystems better. If that happens it will be easier in relative terms to include physical ecosystem degradation too; the effect can be directly translated into damage. There still then remains the problem that most life cycle assessments to date have taken no account of this aspect and that a lot of work still remains to be done to collate these data for the list of 100 indicators.

3.1.2.2. Raw materials depletion

The omission of depletions can be argued in two ways:
- Raw materials depletion does not result in damage to ecosystems or human health. It is true that towards the time when the raw material becomes more difficult to find more ecosystems will perhaps be impaired by exploration and extraction work. These effects can be incorporated into the indicator. The depletion of a raw material will cause economic and social problems in particular. As a rule environmental pollution will decrease if the raw material is actually exhausted. Copper extraction is associated with large quantities of emissions. Once the world's copper resources have been depleted it is expected that these emissions will be reduced and that greater emphasis will be given to recycling.
- Depletion is difficult to quantify because alternatives are available for most materials. For instance copper is already being replaced on a fairly large scale by glass-fibre (communications) and aluminium (electricity conduction). For energy too there are good prospects for substitution if the market is prepared to pay more for energy. In fact the problem with energy is not depletion of the fossil fuel but the environmental effects of combustion. These are explicitly incorporated in the indicator. In other words, it

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[11] Such a line of thought is also followed in the NOH manual [22].

would be a disaster for all currently known oil reserves to be actually used. The use of fossil fuels is not limited by stocks but by emissions from combustion.

The use of raw materials is evaluated on the basis of emissions during extraction and use. The fact that the raw materials can be depleted could be better expressed in a separate depletion indicator.

3.1.2.3. Space requirement for final waste

The same applies to waste as to raw materials, i.e. no-one is killed and only very small sections of ecosystems are threatened by the space taken up by waste (apart from fly-tipped waste). However, the emissions from incineration and the decomposition of waste, and the leaching of, for example, heavy metals do represent a significant problem. These emissions are specified in process data for the indicators. Waste is thus evaluated in terms of emissions.

If ecosystem degradation could be included in the weighting process it would be possible to include the space taken up by waste. Waste is also not an effect score in the NOH manual.

3.1.2.4. Toxicity

With regard to toxicity this definition of the environment also has a number of far-reaching consequences. A closer analysis of the environmental problems in Europe (see para. 3.5) reveals that there are only a limited number of toxic substances that cause problems in the outdoor environment. Many toxic substances cause a problem particularly in the workplace and its direct vicinity. This means that not all toxic substances can be weighted.

Substances that cause health problems in production processes do not necessarily create environmental problems outside the workplace. Most substances are regarded as not harmful provided their concentration remains below a certain level. This is also the background to the MACs (maximum acceptable concentrations) defined in occupational hygiene.

Any analysis of environmental problems must take account of the scale of the problem. On a very small scale, e.g. in the direct vicinity of a factory, the concentrations of many substances can be high and thus cause genuine problems. On a somewhat larger scale concentrations of many substances have been reduced to such an extent that they can no longer be regarded as harmful. This does not apply to a number of substances which, even on a larger scale, occur in concentrations that are harmful. This refers in particular to substances that:

- degrade only very slowly or not at all and thus gradually accumulate; good examples of this are the heavy metals and sulphur;
- are produced in very large quantities so that problems still occur, despite fairly high decomposition rates; examples of this are pesticides, dust (winter smog), hydrocarbons (summer smog) and most carcinogenic substances.

The consequence of these choices is that a large number of substances that are very important in occupational hygiene are not included in the Eco-indicator. That means that in addition to the use of the Eco-indicator separate account must also be taken of occupational hygiene. Examples of substances not included are: carbon monoxide, aldehydes, cyanides, chlorinated hydrocarbons and other solvents, though hydrocarbons are evaluated in the summer smog score.

In addition to these substances that are knowingly not evaluated there are a number of others that we would have liked to include, such as dioxin and PCBs. It proved not to be possible to obtain sufficient clear effect descriptions and reduction targets.

The toxicity scores were specified on the basis of the above-mentioned analysis in terms of a number of toxic effects that are a problem on a wide scale:

New effect definition	Current NOH definition
Carcinogenic substances	Human toxicity
Winter smog[12]	Human toxicity
Airborne heavy metals	Human toxicity
Waterborne heavy metals	Human and ecotoxicity
Pesticides in groundwater and surface water	Ecotoxicity

Table 3.1 Specification of the NOH effect definitions for toxicity

The choice for these definitions is closely linked to the description of the environmental problems in Europe, such as was used in drawing up the weighting factors. The classification must tie in with the weighting factor.

3.1.3. Definition of the effect scores

The following effect scores will be used in the weighting. The second column indicates which characterisation will be used. See also para 3.3

Effect	Characterisation
1. Greenhouse effect	NOH (IPCC)
2. Ozone layer depletion	NOH (IPCC)
3. Acidification	NOH
4. Eutrophication	NOH
5. Summer smog	NOH
6. Winter smog	Air Quality Guidelines (WHO)
7. Pesticides	Active ingredient
8. Airborne heavy metals	Air Quality Guidelines (WHO)
9. Waterborne heavy metals	Quality Guidelines for Drinking Water (WHO)
10. Carcinogenic substances	Air Quality Guidelines (WHO)

Table 3.2 The effects weighted in the Eco-indicator method

In total therefore there are 10 scores. Because the scores for heavy metals are later combined 9 scores ultimately remain.

3.1.4. Target level and damage

The choice of basing target values on a certain measurable damage makes it necessary to define this damage. A high damage level results in a higher target value. Only if all damage levels are equal is it possible to formulate mutually comparable target values and thus reduction objectives.

If all effects were to cause the same type of damage (e.g. a number of deaths each year) it would be relatively easy to define a target value. Unfortunately that is not the case. Based on the choice of effects we have to deal with two types of damage:

- Damage to health and human fatalities
- Damage to (disruption of) ecosystems

In the table below the defined effects are correlated with the type of damage that they cause. It should be borne in mind that an effect frequently causes several types of damage. We have only taken account of the most dominant damage.

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[12] In fact summer smog belongs to the toxicity score; it has already been specified as such in the NOH manual.

Type of damage	Effect contributing to this damage
Number of fatalities as a consequence of the effect	Ozone layer depletion Airborne heavy metals Pesticides Carcinogenic substances
Nuisance and number of non-fatal casualties as a result of the occurrence of smog periods	Winter smog Summer smog
Damage to parts of the ecosystem	Greenhouse effect Acidification Eutrophication Waterborne heavy metals Pesticides

Table 3.3 Relation between effects and damage types

3.1.5. Subjectivity in the weighting

For an Eco-indicator it is absolutely essential to compare the different types of damage well with one another. The use of unequal damage levels has direct consequences for the weighting. In the project we have decided to regard the following damage levels as equivalent:

- One extra death per million inhabitants per year,
- Health complaints as a result of smog periods,
- Five percent ecosystem impairment (in the longer term).

This choice is subjective and in a certain sense the method's Achilles heel. If a different level were to be chosen for one of the damage levels the weighting would give different results.[13] However, this weakness is also its strength because the subjectivity is explicitly formulated, unlike the completely subjective methods, such as the panel methods.

The choice is based in part on the way in which environmental problems are described in the literature consulted. Here too these criteria are often used.

In specifying this choice a number of examples were worked through for the purposes of discussions in the Eco-indicator platform. These examples help to clarify the rather abstractly formulated damage levels. However, they prove nothing.

Example 1: Dutch scale

5% impairment of the ecosystem represents in the Netherlands something like harm to the woods on the Veluwe, after which it is perhaps possible that only grass and bird-cherry will continue growing. This is seen by many ecologists as an impoverishment. It can also mean the poisoning of a piece of ground in the North-East Polder, which does not have a very interesting ecosystem. It is therefore not entirely clear how seriously such a level of impairment should be evaluated.

The norm for deaths means that 14 people will die each year. That is only 2% of the number of road deaths and is roughly equivalent to the risk of death from a rare disease. The number of people who suffer serious problems during periods of smog falls in the range of several tens to several hundreds in the Netherlands. In this comparison it must be borne in mind that impairment of the ecosystem occurs in the course of several years whereas there will be 14 deaths every year. The impairment of the ecosystem on the Veluwe must thus be set against a much larger number of deaths.

Example 2: European scale

With an average population density of 140 inhabitants per km^2 16 million people will end up living in an "impaired" ecosystem in the event of 5% impairment of the ecosystems. This would have to be weighed against 352 extra deaths per year.

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[13] If ten percent ecosystem impairment were to be taken as a damage level instead of five percent all the effects that lead to this type of damage would be rated only half as seriously.

Example 3: EPS approach
The question of to what extent the criteria match is very similar to the treatment of the "safeguard subjects" in the EPS system (see para. 2.3.1). We can use a number of the financial valuations developed in this system:

- The damage resulting from deaths is estimated at 1 million ECU per person. According to this criterion 352 deaths per year would occur in the EU. Using this approach the resulting social costs would have to be set at 352 million ECU per year.
- The damage as a result of production losses (agriculture) are directly accounted for. If the 5% ecosystem impairment relates entirely to agricultural land it could be estimated that EU agricultural yields would be 5% or 8,900 million ECU lower. Here too, however, it is unclear what damage to ecosystems means in precise terms for agricultural systems. Acidification can be fairly easily compensated for by using lime, and this measure is relatively inexpensive.
- The damage resulting from nuisance is set at 100 ECU per person using a not entirely transparent system. Consequently, damage resulting from ecosystem impairment is valued at approx. 1,600 million ECU.

It seems therefore that the "costs of human fatalities" are somewhat on the low side compared with the other items for damage. When, however, it is borne in mind that ecosystem impairment occurs in the course of a number of years, the damage per year can be estimated at a substantially lower rate. In that case the damage caused by ecosystem impairment and human fatalities do not show any major difference.

The three examples have only been presented to give a little more feeling for the correlations. They do not prove anything; at best they demonstrate that the damage could be comparable.
These examples show that the criterion of ecosystem impairment must be given a time scale (such as is also indicated in the NOH manual). If the amount of ecosystem lost per year were known it would be easier to compare this with the number of deaths per year; unfortunately this is not the case.

The assumption that the three damage levels are comparable is the most important subjective factor in the method. The method has the advantage that the subjectivity can be clearly specified. This is in contrast to very subjective methods such as panel methods.
The assumption must always be explicitly stated because the choice of target levels and thus the whole weighting factor is directly determined by this.

The whole weighting method is shown schematically in the figure below:

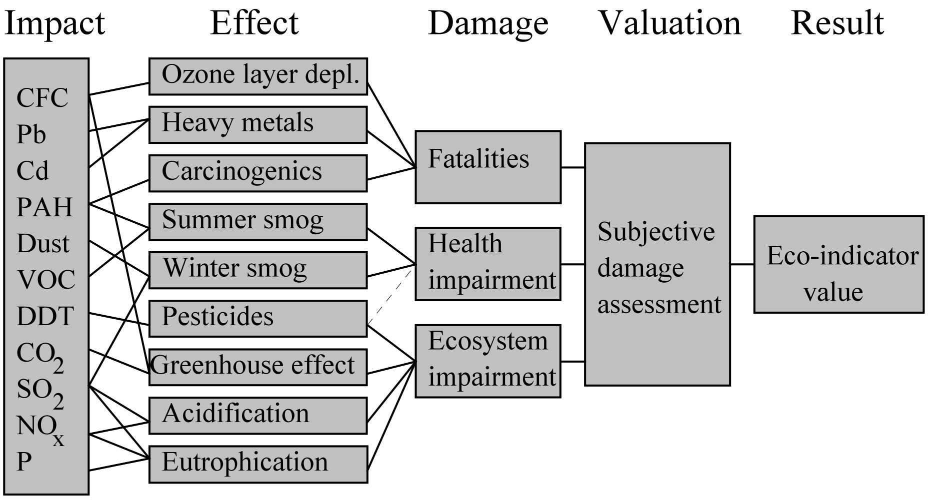


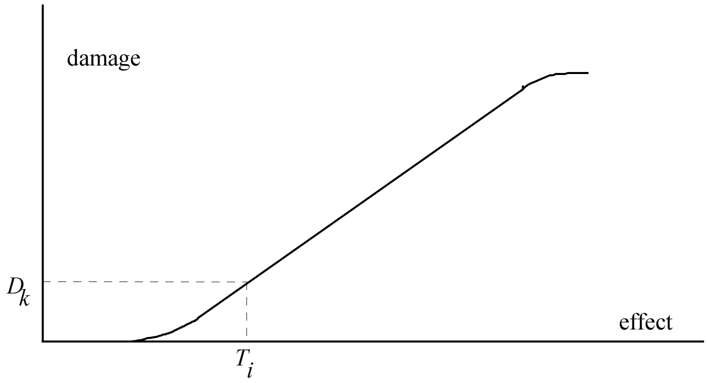
Fig. 3.1 Schematic representation of the Eco-indicator weighting method

3.2. Development of the weighting principle

In the following paragraphs the perceptions developed here are formalised and generalised. The result is an adapted weighting equation and a substantial reinforcement of the working of the weighting procedure.

3.2.1. Damage-effect correlation

The graph below shows a possible correlation between the size of the environmental effect and the extent of the damage. This correlation is a sigmoid curve that is often used as a model in toxicology. No damage is expected with a low effect. There then follows a more or less linear increase, after which a damage level is reached that cannot rise. Little is known, however, about the exact shape of this curve.



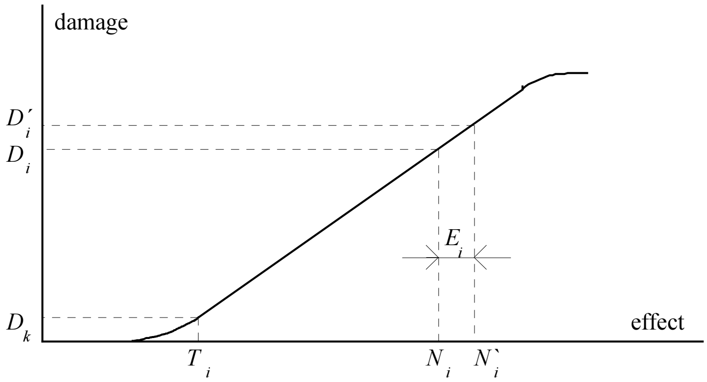
Graph 3.1 Simple correlation between damage and effect. There is no damage at a very low effect. If the extent of the effect increases, the damage also increases. Above a certain effect the damage does not increase further because everything is already damaged.

where:

T_i	target level of effect *i*
D_k	critical damage at target level T_i

The target level *T* is directly linked to the choice of the damage level D_k. If a different damage level is chosen a different target level must also be defined.

In addition to the target value, the following graph also gives the current value *N* of the effect and the damage *D* at the current value. It also shows what will happen if the current value is increased by a value *E*. *E* can represent the result of an LCA of a new product. In practice *E* will be very small in relative terms compared with *N*.



Graph 3.2 Damage-effect function

where:

N_i	current extent of an effect *i*
T_i	target value for this effect *i*
E_i	contribution of a product life cycle to an effect *i*
D_k	critical damage at target level T_i
D_i	damage at current extent N_i

If the current level rises from *N* to *N'*, the damage will increase from *D* to *D'*. The correlation between the increase in an effect and the damage is thus equal to the direction coefficient of the function at *N*. This direction coefficient is thus the weighting factor that we need in order to translate an effect into damage.

The direction coefficient of a line can be determined if two points on a line can be defined.

$$dc_i = \frac{D_i - D_k}{N_i - T_i} \quad ......(3)$$

where dc_i= direction coefficient

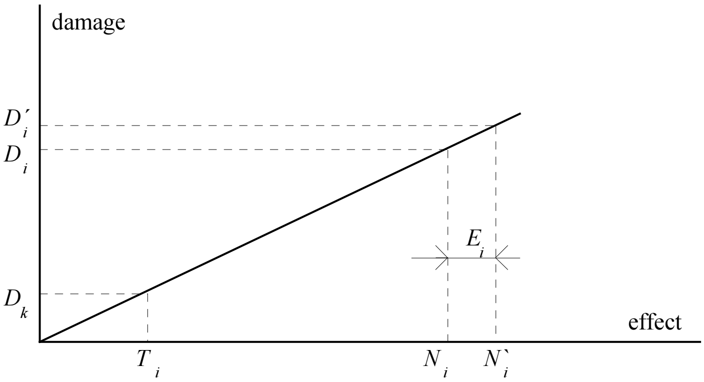
The contribution of effect score E_i to the indicator value *I* is thus:

$$I_i = D_i' - D_i = dc_i * E_i = \frac{D_i - D_k}{N_i - T_i} * E_i ....(4)$$

This equation has a different shape from that of the distance-to-target equations (1) derived above. It shows agreement with the equation proposed by Heijungs in his contribution to this project. It enables us to establish a direct correlation between effect and damage, if two points on the damage-effect line are known and if it is assumed that this line between the two points can be regarded as a straight line.

In the distance-to-target equation only one point, rather than two, is defined on the curve, namely the damage at the target level. The height (damage) of the other point on the curve at the current effect level is not determined. No direction coefficient can be defined on the basis of a single point; for this reason this equation cannot be used as it currently stands to indicate a correlation between effect and damage.

It proves possible to use the distance-to-target equation if we make an additional assumption, namely that the effect curves pass through the origin. Such a simplified version of the damage-effect function is shown below.



Graph 3.3 Simplified damage-effect function that passes through the origin

In this case the direction coefficient is equal to *D/T*. The contribution of effect *i* to the indicator can thus be written as:

$$I_i = \frac{D_k}{T_i} * E_i = D_k * \frac{E_i}{T_i} \quad ....(5)$$

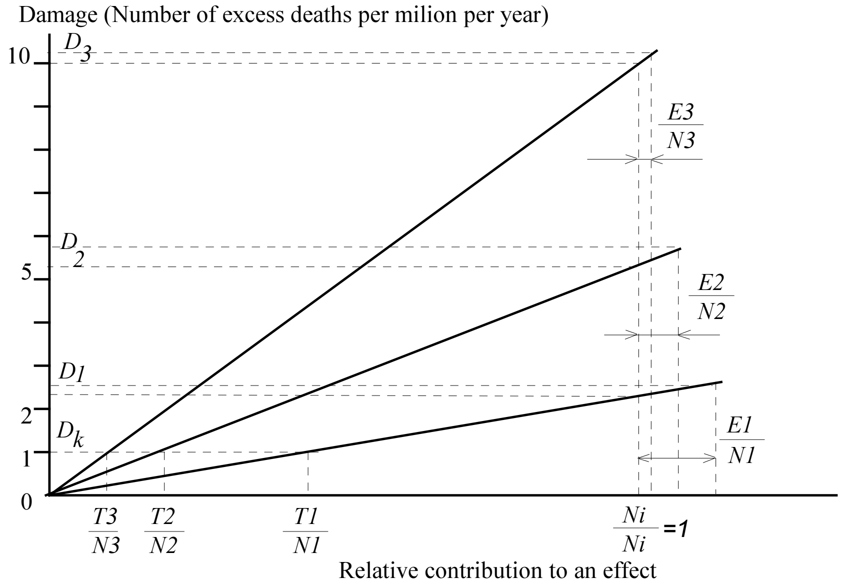
This equation is very similar to the Eco-indicator equation derived above (see 1), except that the subjective weighting factor *W* is now substituted by *D*. The indicator is thus directly proportional to the damage at the target level. The indicator also has the same dimension as the type of "damage". This is also the correct dimension.

During the project we discovered that the distance-to-target method according to the chosen equation meant that we were working in accordance with the simplified model shown in graph 3.3. None of those involved had realised this.
Relatively little is known to date on the position of the curve, and it has therefore been difficult to identify the error that occurs as a result of the assumption that the lines pass through the origin.

3.2.2. Damage-effect correlation for multiple effects

To date we have always used one curve for one effect *i* in a graph. It would be desirable, in order to gain an overview, to plot all the effects in a single graph. Two measures must be implemented for this:

- It is not possible to plot the different effects along a single horizontal axis. However, it is possible to plot the normalised effects along the same axis. The axis then comes to signify a relative contribution.
- A single type of damage is entered on the vertical axis, in this example the number of deaths per million per year. This means that only effects relating to human fatalities can be plotted on the graph.



Graph 3.4 Three damage-effect functions in a single graph. The horizontal axis plots the normalised effects. The vertical axis contains in this case the damage expressed in numbers of deaths. A graph of this type could also be plotted for other types of damage, such as the percentage impairment of an ecosystem.

Thanks to normalisation it is possible to plot all the effects on a single axis. All the current values are then superimposed on each other with a value of 1. The target values lie on the point T_i/N_i [14]. The target values have all been chosen such that the effect under study results in one death per million per year.

If, as a result of a product, an extra effect E_1, E_2 and E_3 arises, the values N_1, N_2 and N_3 are increased, just as in the graph above. This means that the values D_1, D_2 and D_3 will also increase. The total damage is the sum of the D values. In more general terms, the effect of a number of impacts can be written as:

$$I = {}_{i}\; dc_i * \frac{E_i}{N_i} = {}_{i}\; \frac{D_k}{\frac{T_i}{N_i}} * \frac{E_i}{N_i} = {}_{i}\; D_k * \frac{N_i}{T_i} * \frac{E_i}{N_i} = D_k * {}_{i}\; \frac{E_i}{T_i} \text{.... (6)}$$

This is a generalisation of formula 5[15]. The indicator value is determined by the product of D_k and the sum of the proportions E/T. This means the critical damage D_k is the scale factor for the combined effects. This factor also determines the dimension of I since E/T is dimensionless.

This reasoning applies to the effects that all cause the same type of damage. The other effects can also be plotted on this graph, however, if the damage levels are weighted relative to each other. The damage weighting factor developed above is therefore an integral part of the weighting equation.

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[14] It is also possible, however, to plot this graph by normalising the target value. All the damage-effect curves then coincide. The position of the factor N/T then also determines the damage.

[15] If it is assumed that the lines do not pass through the origin the formula is:

$$I = {}_{i}\; \frac{D_i - D_k}{1 - \frac{T_i}{N_i}} * \frac{E_i}{N_i} = {}_{i}\; (D_i - D_k) * \frac{E_i}{N_i - T_i}$$

3.2.3. Damage weighting

In order to process the differences in damage level in the equation for weighting a damage weighting factor must be introduced. This factor expresses the relative seriousness of the damage. In equation form:

$$w_1 * D_{1\_death\_per\_million\_per\_year} = w_2 * D_{5\%\_\mathrm{ecosystem\_impairment}} = w_3 * D_{\mathrm{smog\_periods}} \quad .... (7)$$

The *w* here represents a weighting factor for the seriousness of the damage.

If the indicator now has to be calculated for effects causing different types of damage the following equation results:

$$I = \sum_j w_j * D_k * \left(\sum_i \frac{E_i}{T_i} \right)_j \quad ......(8)$$

This equation can be read as follows:

- Aggregate the ratio *E/T* for the effects *i* resulting in damage type *j*
- Multiply this sum by the product of D_k and the damage weighting factor
- Repeat this for all types of damage and aggregate the values found

3.2.4. Choice of the subjective damage weighting factor *w*

Because we have considered all damage levels to be equal (see para 3.1.5) all damage weighting factors can be set at 1. The equation can thus be written simply as:

$$I = D_k * \sum_i \frac{E_i}{T_i} \quad ....(9)$$

In this D_k can mean both 1 death per million inhabitants per year and the impairment of 5% of the ecosystem.

3.2.5. Conclusion on the weighting method

This analysis has demonstrated that the formula used in the distance-to-target is more than an abstract principle. It offers a means of establishing a direct correlation between effect and damage. This is a fundamental breakthrough in our thinking on the weighting of effects. The ability to translate the effects into damage means that a rather abstract and very subjective intereffect factor does not have to be used. The subjectivity is replaced by evaluation of the damage itself.

Seen retrospectively we have perhaps not made the optimum choice in the equation for distance-to-target used; this is because our equation can only be used if it is assumed that the damage-effect curve passes through zero as we only define *one* point on the line. In a refinement of the Eco-indicator better use can perhaps be made of a method in which two points are chosen on the damage-effect line. Determination of the direction coefficient then becomes somewhat more accurate.

3.3. Classification and characterisation

A characterisation stage has to be developed to obtain new effect scores for the different types of toxicity. This requires weighting factors that can convert the relative harm of an impact into an effect score. To determine the other scores you are referred to the NOH manual.

We have used the Air Quality Guidelines (AQG) and the Quality Guidelines for Drinking Water (QGDW) of the WHO as a starting point. These guidelines describe the effect of substances based on long-term, low-level exposure.

3.3.1. Effect score for airborne heavy metals

This effect score relates particularly to heavy metals because they represent significant health risks in the event of long-term, low-level exposure. The risks that are related mainly

to the nervous system and liver can be evaluated in terms of toxicity to humans and toxicity to ecosystems. It is generally assumed (Globe, AQG) that human toxicity is the most important limiting factor.
The AQG defines the following acceptable airborne concentrations for exposure to man in the course of a year:

	Maximum concentration µg/m3	**Weighting factor m3/µg**	**Dominant health effect**
Cadmium	0.02	50	Kidneys
Lead	1	1	Blood biosynthesis, nervous system and blood pressure
Manganese	1	1	Lungs and nervous system (deficiency causes dermatological conditions)
Mercury	1	1	Brain: sensory and co-ordination functions

Table 3.4 Characterisation values for airborne heavy metals

Chromium and nickel are included with the carcinogenic substances because the risk of cancer is greater than other toxicological effects.

Based on this concentration a weighting factor can be determined that is equal to the inverse of the acceptable concentration. This fits with the critical volume approach such as was previously used with the MAC value. We have expressed the effect score as a lead-equivalent.

3.3.2. Effect score for waterborne heavy metals

The WHO 'Quality Guidelines for Drinking Water' specify a number of values for persistent substances based on long-term, low-level exposure. These criteria were established to evaluate drinking water, based on identified health effects. The table below contains a selection of substances that are persistent to a greater or lesser extent and thus accumulate in the environment.

Substance	**Norm (mg/litre)**	**Weighting factor (litre/mg)**	**Effect**
Antimony	0.005	2	Glucose and cholesterol in blood
Arsenic	0.01	1	$6*10^{-4}$ chance of skin cancer
Barium	0.07	0.14	Blood pressure and blood vessels
Boron	0.3	0.03	Fertility
Cadmium	0.003	3	Kidneys
Chromium (all)	0.05	0.2	Mutagenic (carcinogenic only if inhaled)
Copper	2	0.005	No problem as a rule, sometimes liver disorders
Lead	0.01	1	Blood biosynthesis, nervous system and blood pressure
Manganese	0.5	0.02	Nervous system
Mercury	0.001	10	Kidneys, nervous system (methylmercury)
Molybdenum	0.07	0.14	No clear description
Nickel	0.02	0.5	Weight loss, great uncertainty

Table 3.5 Characterisation values for waterborne heavy metals

With this effect score too the weighting factor was determined in order to be able to calculate a lead-equivalent. It was later decided to combine the scores for waterborne and airborne heavy metals. A lead-equivalent for water was then made the same as a lead-equivalent for air.

3.3.3. Carcinogenic substances

The 'AQG' does not provide any acceptable levels but calculates the probability of cancer at a level of 1 µg/m^3. In the table below this probability is expressed as the number of people from a group of 1 million who will contract cancer at this exposure level.

	Probability of cancer at 1 µg/m^3	**Weighting factor for PAH equivalent**	**Type of cancer**
Arsenic	0.004	0.044	General, also mutagenic effects
Benzene	0.000001	$1.1 * 10^{-5}$	Leukaemia
Nickel	0.04	0.44	Lung and larynx
Chromium 6	0.04	0.44	Various incl. lung, also mutagenic effects
PAH (Benzo[a]pyrene)	0.09	1	Lung cancer, but also other forms

Table 3.6 Characterisation values for carcinogenic substances

The PAH group contains a large number of substances. Benzo[a]pyrene has been chosen as a representative. An improvement in this score would be possible if account could be taken of a substance's persistence. This applies in particular to the group of PAHs.

The inclusion of asbestos can also be considered. The difficulty here is that asbestos emissions cannot be expressed sensibly in a unit of weight. The number and type of fibres is of decisive importance.

3.3.4. Winter smog

Only dust and SO2 play a role with this effect. The 'Air Quality Guidelines' specify a level of 50 µg/m^3 for both substances. The weighting factors are equal; we have chosen 1. An improvement is possible by taking account of the average persistence time of the components. There was a lack of data on this. The definition of the term could also be improved.

3.3.5. Pesticides

Pesticides cause a number of problems, including:

- Groundwater becomes too toxic for human consumption.
- Biological activity in the soil is impaired, resulting in damage to vegetation.

This means that account must be taken of both ecotoxicity and human toxicity in the effect score weighting. A distinction must be drawn between: disinfectants, fungicides, herbicides and insecticides.

The NOH classification provides an extensive list of weighting factors for pesticides based on their ecotoxic effect. We considered using these, but it proved not to be possible because no adequate normalisation data were available for these substances. The normalisation data are based on an aggregate of the amount of active ingredient without further weighting of the toxicity itself.

A further improvement in this effect score is possible by weighting the substances for their persistence. Some pesticides remain active for years, while others have almost disappeared after one day.

3.3.6. Uncertainty

In the WHO publications estimates of the uncertainties are made in a number of places. As a rule the greatest uncertainty arises from extrapolation of animal experiments to humans (generally one order of magnitude). Other uncertainties arise because the exposure and the resulting consequences are only measured in a small number of test subjects and always retrospectively. Here too the error can easily be one order of magnitude.

3.3.7. Conclusion

The NOH classification remains the basis for the Eco-indicator; only the term "toxicity" is defined in greater detail. These new classifications fit much better with the description of the environmental problems in Europe. This makes it possible to carry out a weighting for each type of toxicity.

3.4. Normalisation

Strictly speaking, normalisation values are unnecessary in a distance-to-target evaluation because they are omitted from the weighting equation (1). However, it is seen to be important for two reasons to continue to include these values.

- Normalisation greatly increases our understanding of the weighting. Normalisation is a more or less objective step that illustrates what effects are relatively strongly represented in the effect scores.
- In much of the literature objectives are specified as reduction factors. In other words, the factor by which an effect must be reduced is specified, without stating which absolute value must be achieved.

It was intended at the outset of the project to use the normalisation values from the recent CML publication by Guinée [19]. The report is specially intended to calculate normalisation values that fit the NOH effect definition. The figures are based on recordings of emissions (fourth round) based on 1988. This list contains the total emissions in the Netherlands in 1988. A conversion factor was applied to translate these values into world effect values. To do this, all the figures were multiplied by 100 because the Dutch economy represents approximately 1% of world-wide GNP. An exception was made for greenhouse gases and ozone-layer-depleting substances, for which actual international figures were used (derived from the IPPC[16]). This raised a number of difficulties:

- The Dutch economy is certainly not a reflection of the world economy. In the Netherlands there is a relatively large amount of base chemical processes and transportation, but relatively little consumer goods production. The emissions pattern is specific to our economy, and it is dangerous to scale this pattern up to a world level.
- The publication of emissions recordings indicates itself that it is incomplete. Sectors such as agriculture are insufficiently covered.
- The Eco-indicator is based on a European scale.

We also investigated to what extent the characterisation of effects agrees with the descriptions of the most important environmental problems. It might be expected that a substance that makes a major contribution to a world effect score would also have to be described in other literature sources as an importance cause of this effect.[17]

The result of this analysis cannot always be explained. It turns out that substances that make a major contribution to the NOH effect score actually scarcely appear in the specialist environmental literature on impairment of health and ecosystems.

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[16] IPCC: Intergovernmental Panel on Climate Change

[17] It is therefore seen that when applying the NOH classification to the overall total of European emissions phenol emissions must be regarded as the most significant European human toxicity problem. Cobalt remains very dominant in terms of ecotoxicity. This result does not fit with the description of environmental problems in Europe. In most of the literature carcinogenesis, heavy metals such as cadmium, mercury, lead etc. are noted as major problems. Phenol almost cannot become a major problem because it has a half life of 6 weeks and therefore can hardly accumulate in the environment.

3.4.1. European normalisation values

When defining target values use was made of data that refer to the whole of Europe, apart from the former USSR. We searched for data for this area in various publications. The countries studied can be divided into two groups:
Western Europe: Austria, Belgium, Denmark, Finland, France, Germany[18], Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK.
Eastern Europe: Bulgaria, Czechoslovakia[19], Hungary, Poland, Romania and Yugoslavia[20]

3.4.2. Data sources

The data were taken from various sources. They refer to anthropogenic emissions. This implies that emissions from natural sources are not included. The table below lists the sources used in determining the normalisation values.

Source	Title and publisher
1	*The Environment in Europe and North-America*, *Annotated Statistics 1992*, Economic Commission for Europe, United Nations Publication [37]
2	*Corinair 1990* , provisional results [6]
3	*Environmental Statistics 1991*, Eurostat, [11]
4	*The Environment in Europe: a Global Perspective*, RIVM. [33]
5	*General Environmental Statistics 1992],* CBS (NL), [5]
6	*Industrial emissions in the Netherlands* No. 14, September 1993, [23]
7	*CFC commission, a collaborative project by Government and industry* Annual report 1993, [4]

Table 3.7 Data sources for normalisation values

Sources 1, 2, 3 and 4 provide information relating to a large area, mostly on a regional basis. Sources 5, 6 and 7 on the other hand are specific to the Dutch situation.
With regard to source 2 it may be noted that the data are not yet complete. The final version will be published in spring 1995.

3.4.3. Extrapolation of missing impacts

Where data were missing for one or several countries a total emission was extrapolated. This extrapolation is based on a country's energy consumption. It is anticipated that a country's energy consumption will best reflect the country's industrial structure and thus the emissions pattern. Because Eastern and Western Europe have a completely different infrastructure these areas have been calculated separately and later re-combined. A spreadsheet that is included as Appendix 2 was used for the calculations.

The table below lists the normalisation values. The data per European head of population (497 million inhabitants) are given in the penultimate column.

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[18] Data for West and East Germany combined.

[19] Data refer to the former Czechoslovakia as a whole; no division into the Czech Republic and Slovakia.

[20] Data specified for the area of the former Yugoslavia; no sub-division by separate republics.

	Unit	**Western Europe**	**Eastern Europe**	**Total**	**Per head of the population**	**Uncer-tainty**
Greenhouse effect	GWP kg	4.8E+12	1.7E+12	6.5E+12	**1.31E+04**	small
Ozone layer depletion	ODP kg	3.7E+08	9.4E+07	4.6E+08	**9.26E-01**	large
Acidification	AP kg	3.5E+10	2.1E+10	5.6E+10	**1.13E+02**	small
Eutrophication	NP kg	1.4E+10	5.1E+09	1.9E+10	**3.82E+01**	mod.
Heavy metals	Pb equiv. kg	2.1E+07	5.9E+06	2.7E+07	**5.43E-02**	large
Carcinogens	PAH equiv. kg	4.3E+06	1.1E+06	5.4E+06	**1.09E-02**	large
Winter smog	SO2 equiv. kg	2.3E+10	2.3E+10	4.7E+10	**9.46E+01**	small
Summer smog	POCP kg	7.0E+09	1.9E+09	8.9E+09	**1.79E+01**	large
Pesticides	active ingr. kg	3.8E+08	9.8E+07	4.8E+08	**9.66E-01**	large

Table 3.8 Normalisation values.

3.4.4. Uncertainty

A number of figures are based on only small data sets. The uncertainty relating to these effects is therefore fairly large. Determining the degree of uncertainty is not a simple matter. There are various error sources:

- Errors in the statistics. It seems not improbable that errors of 10% have occurred in the reported figures. This is sometimes apparent from differences between sources relating to the same country and year.
- Errors arising from extrapolation. Some figures are computed mainly from Dutch figures. Distortions to the order of several tens of percents can occur.
- Incomplete emissions list per effect. The statistics do not contain all the substances that contribute to an effect. We have ensured that all important substances are included, insofar that it is clear which are the relevant substances. The error resulting from this is estimated to be 10-20% in some cases.

It is difficult to underpin the percentage estimations given above. There is therefore uncertainty about the uncertainty.

The subjects to which this relates are:

- Ozone layer depletion. The score is based to an extent of 43% on Dutch data. These data are in themselves already unreliable because the use of CFCs is falling rapidly. The reference date thus plays an important role. We chose 1990. We estimate that the margin of uncertainty may be of the order of 100%.
- Heavy metals and carcinogens. Dutch figures have been used almost entirely for this. It is anticipated that it is precisely these emissions that will be relatively high in Eastern Europe because of the use of leaded petrol and coal. With reference to carcinogens the PAH group represents an important problem. Many sources do not indicate which substances should be included. The margin of uncertainty may be ±100%.
- Pesticides. These data are based on average Western European values and then scaled up to Eastern Europe. The uncertainty could be of the order of 50%.

The other effects are based on a relatively large number of data. We expect the uncertainty here to be of the order of ±10%. However, these uncertainties cannot be backed up in any way at all. They are based solely on estimates.

3.5. Target values

The target values were mainly taken from an extensive scenario study carried out by the RIVM for the GLOBE Europe organisation. We will refer to this as the Globe report [33]. The report describes the damage caused by each effect, using a large number of maps. Furthermore, it describes what the effects would be of a couple of scenarios. We have not used these scenarios themselves, but the underlying data. Although extensive reference lists are provided it is unfortunately not always clear on what statements in the report are

founded and what the uncertainties are. A request for clarification of a number of points was made during discussions with the editor of the report, Mr. J.P. Hetteling.
To aid comprehension of the following survey it is urgently recommended that this paper be consulted. We will only deal here with the conclusions that we have drawn from the report. In addition to the Globe report we also used the Air Quality Guidelines [2] and the Quality Guidelines for Drinking Water [38] that have been developed by a large team of experts under commission from the WHO. We used this to supplement the Globe report in a few areas.

3.5.1. Greenhouse effect

At the moment temperatures are rising by 0.2°C per decade. Under current policies this increase will rise to 0.3°C per decade. The consequence is a significant temperature change by 2050. In Northern and Eastern Europe the winters will be more than 5°C warmer, and in Southern Europe the summers will be 4°C warmer. Those areas in particular that have no other systems in their vicinity that can exist in such a climate will suffer serious damage. This will affect approx. 20% of Europe.
The Globe report provides sufficient information to estimate that less than 5% of the ecosystems will be impaired if the greenhouse effect is reduced by a factor of 2.5.

3.5.2. Ozone layer depletion

In accordance with the Montreal Protocol and its London amendment all CFC emissions must be reduced to zero by the year 2000. For the less persistent HCFCs it has been agreed that the contribution may not exceed 2.6% of the total adverse effect of CFCs in 1989. The use of these substances too is to be phased out by 2015.
If this happens, the annual total of fatalities per million inhabitants in Europe will first rise from approximately 1 to 2 and then fall to 1 death per year per million. It does not yet seem directly necessary to reduce all HCFC emissions to zero because the norm (2 ppbv) will be achieved, even if after 2100. For these gases the target reduction is linked to the greenhouse effect[21].
Based on this reduction for greenhouse gases, we therefore provisionally assume that a reduction target of 60% applies to HCFCs. On the premise that HCFCs are currently responsible for 2.6% of ozone layer depletion it can be estimated that this reduction will cause ozone layer depletion to fall to 1% of its present level. The reduction factor is therefore 100. There is a great deal of uncertainty about this figure.

3.5.3. Acidification

There is a great variety in Europe in the ability of ecosystems to withstand acid loads. In Scandinavia, for example, problems can occur with deposits of as little as 100 eq/ha.yr, while in some places in the Netherlands and Germany the soil can be subjected to deposits of more than 2000 eq/ha.yr. The actual deposit reaches its highest level, however, in Central Europe, particularly as a result of the use of lignite. If the deposit and capacity are compared with each other there prove to be major problems particularly in England, the Benelux countries, Germany, Poland, the Czech Republic and Slovakia [9].
A provisional estimate based on the information available reveals that the reduction must be of the order of a factor of 10 to keep ecosystem impairment below 5%. A value of 10 was ultimately chosen.

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[21] Conversely, a marked reduction in the greenhouse effect will also be achieved by the elimination of CFCs since CFCs are responsible for 24% of this effect. Elimination of CFCs will therefore yield a 24% reduction in the greenhouse effect.

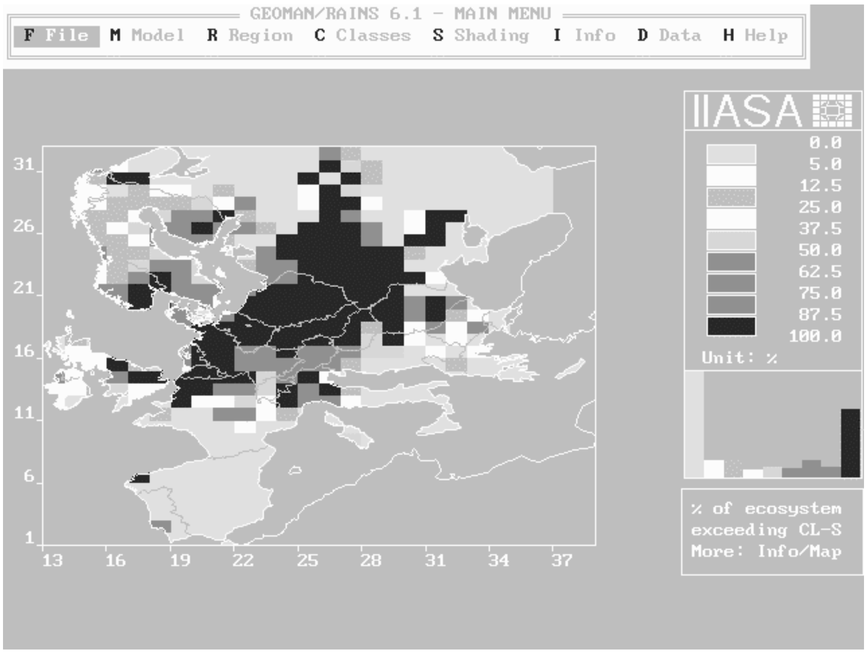

Fig. 3.2 Example of an acidification map from the RAINS program [30]

3.5.4. Eutrophication

Eutrophication is seen in the Globe report primarily as the problem of excessive use of fertilisers by agriculture as a result of which nitrates leach out and poison groundwater supplies. The problem is at its greatest in the Benelux countries, North-Rhine Westphalia and the Po valley region (approx. 200 kg P-eq/ha.yr).

The NOH manual refers mainly to eutrophication via air and water emissions. These rarely contribute more than 10% of the amount of fertiliser applied by farmers. In uncultivated biotopes, however, this eutrophication can have a serious adverse effect on biodiversity.

In describing the level of eutrophication in rivers and lakes it is assumed that the critical value for phosphates is 0.15 mg/l and for nitrates 2.2 mg/l. At these values no problems of eutrophication occur. In the rivers Rhine, Schelde, Elbe, Mersey and Ebro, however, these values are exceeded more than 5 times. This means that the emissions must be reduced by a factor of 5.

3.5.5. Summer smog

A hundred years ago the ozone concentration, averaged over the whole year, was approx. 10 ppb. At present it is 25 ppb. This is approximately the maximum acceptable level. Above 30 ppb, for example, crop damage can occur.

The major problem is not determined by the average figures but by the summer peaks which can reach more than 300 ppb. To reduce the occurrence of this type of dangerous peaks by 90% it is necessary to reduce VOCs and NO_X by 60-70%. A reduction factor of 2.5 is appropriate.

3.5.6. Heavy metals

Lead concentrations in Central Europe are very high, particularly in the soil and water. In towns and cities the airborne concentration is also high, particularly because of the use of leaded petrol. For adults the Air Quality Guidelines specify a limit of 0.5-1 µg/m^3 in the air. According to Globe this value is frequently exceeded several times over. Globe notes in passing (without reference) that average lead concentrations in Poland are 20 µg/m^3.

Eating locally grown vegetables would result in a blood lead level that is ten times too high. Lead levels in blood of 150-400 µg/l have been found in children. Such readings also occurred 30 years ago in the West, but not any more. Now the values are 5 to 10 times lower. There is thought not to be a no-effect-level for exposure for children. Above 100 µg/l clear reductions in learning ability can be measured.

Thus although it is plausible that this pollution has a clearly measurable effect on human health it is not easy to calculate a general reduction percentage for lead. The best estimate is a reduction by a factor of 5-10. We have taken a figure of 5 for heavy metal emissions to air.

Agriculture (fertiliser) is the major source of cadmium deposition. The average deposition rate is 0.6-0.67 g/ha.yr on grassland and 3.4-6.8 g/ha.yr on arable land. The Southern Netherlands holds the record with a deposit of 7.5-8.5 g/ha.yr. Furthermore, approx. 14% is distributed via the air (see "3.5.7 Winter smog" below).
This leaching is calculated in the Globe report for the Rhine. A detailed calculation makes a convincing case for the necessity to reduce cadmium emissions by 80-85%. In some other rivers such as the Elbe, cadmium contamination is substantially greater, and the required target will perhaps have to be set even higher. For the moment we are continuing with a target reduction by a factor of 5 for heavy metals in water and air.

3.5.7. Winter smog

The most important sources of this problem which occurs mainly in Eastern Europe are SO_2 and SPM (suspended particle matter, or fine dust and soot particles). NO_x, organic substances and CO are also involved to a lesser extent. The dust particles can also contain heavy metals.
This form of smog achieved notoriety in 1952 when it caused an estimated 4000 deaths in London. The SO_2 and SPM concentrations reached values of 5000 $\mu g/m^3$. In Southern Poland and Eastern Germany average readings of 200 $\mu g/m^3$ still occur. The Air Quality Guidelines specify a limit of 50 $\mu g/m^3$ for long-term exposure to both SPM and SO_2. Based on this, a reduction of 75% would be necessary.
Globe estimates that a reduction in SO_2 emissions of more than 80% is necessary to eliminate by and large the occurrence of occasional smog periods. No target is proposed for SPM because it is not well defined or well measured[22]. A factor of 5 is taken as a reduction target.

3.5.8. Carcinogenic substances

Globe also provides some data on the distribution of carcinogenic substances. The main substances involved are polyaromatic hydrocarbons (PAHs), of which benzo[a]pyrene in particular is an important example. This occurs, among other places, in coke furnaces and in (diesel) engines. In fact the problem is only relevant in urban areas.
Globe specifies a value of 0.8-5 ng/m^3 voor Northern European towns and cities. The Air Quality Guidelines specify a value of 1 ng/m^3 in American cities without coke furnaces in the vicinity and 1-5 ng/m^3 in cities with coke furnaces. In European towns and cities in the 60s when open coal fires were still very widely used, the average concentrations were in excess of 100 ng/m^3. In Eastern Europe the values are still high because of the use of coal-fired heating systems. As a point of comparison, a room in which a lot of people are smoking can contain 20 ng/m^3.
The Air Quality Guidelines specify a threshold concentration van 0.01 ng/m^3 at which 1 cancer case per million inhabitants per year will still occur. This criterion cannot be compared straightforwardly with the criterion for ozone layer depletion because not all the cancer cases are terminal. In addition, only about 1/3 of the population of Europe lives in towns or cities[23]. If we assume that one in every three cancer cases is terminal and if we take only the urban population the risk of death is about ten times lower. Based on these considerations there would be one death per year per million inhabitants at a concentration of 0.1 ng/m^3.

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[22] In the NOH manual there is no weighting factor for SPM in characterising human toxicity.

[23] Eurostat [11], estimate based on data for 6 EU member states

Assuming a background concentration of 1 ng/m^3 in towns and cities without coke furnaces (Western European towns and cities in particular) a reduction by a factor of 10 could be estimated.

3.5.9. Pesticides

Leaching of pesticides threatens groundwater sources throughout the EU. In 65% of the EU the groundwater is contaminated above the EU norm (0.5 µg/litre). The norm is exceeded tenfold in 25% of the EU. This occurs in 20% of the land area of Eastern Europe. A reduction by a factor of 25 is necessary to ensure that the norm is exceeded in less than 10% of Europe.

3.5.10. Uncertainty

There is uncertainty about every single value cited. A number of factors have an important role to play in this:

- The degree to which the criterion fits with the effect definition. This problem is reduced, but not entirely resolved, by redefining the effects. The uncertainty associated with this point cannot be quantified.
- The uncertainty over the occurrence of the effect[24]. These uncertainties are difficult to quantify.
- Uncertainty in the exposure of ecosystems and people. All kinds of local circumstances and human behaviour can result in substantial variations in the actual exposure to a substance .
- Intereffect combinations. It is known that some substances when in combination reinforce each other or work against each other[25].
- The derivation of the target values themselves. In various places in the above description it has been stated that there are uncertainties.

It is difficult to determine the magnitude of the uncertainty. In toxicological studies it is quite normal to work with uncertainties of several orders of magnitude. Nevertheless data with such uncertainties are used in order to establish standards and regulations.
In general we believe that the uncertainties in the reduction factors are of the order of several tens in percentage terms, but we are unable to back this estimate up.

3.5.11. Summary of the weighting factors

The table below summarises the figures and the values used in determining them.

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[24] Example: with the greenhouse effect a marked rise in temperature is expected. Recent calculations, however, predict a temperature reduction in Europe as a result of the disappearance of the warm Gulf Stream because of higher temperatures at the North Pole.

[25] Examples: nickel in combination with cigarette smoke is much more dangerous than nickel in isolation. Because of SO2 clouds become whiter and their reflecting capacity is increased; the outcome is that it gets colder on Earth.

	Character-isation	**Reduction factor**	**Criterion**
Greenhouse effect	NOH (IPCC)	2.5	0.1° per decade, 5% ecosystem impairment
Ozone layer depletion	NOH (IPCC)	100	Probability of 1 death per year per million people
Acidification	NOH	10	5% ecosystem impairment
Eutrophication	NOH	5	Rivers and lakes, impairment of an unknown number of aquatic ecosystems? (5% ecosystem impairment?)
Summer smog	NOH	2.5	Occurrence of smog periods, health complaints, particularly among asthma patients and old people. Occurrence of agricultural damage
Winter smog	Air Quality Guidelines	5	Occurrence of smog periods, health complaints, particularly among asthma patients and old people
Pesticides	Active ingredient	25	5% ecosystem impairment
Heavy metals in air	Air Quality Guidelines	5	Lead level in children's blood, limited life expectancy and learning ability in an unknown number of people
Heavy metals in water	Quality Guidelines for Water	5	Cadmium content in rivers, ultimately also effect on people (see air)
Carcinogenic substances	Air Quality Guidelines	10	Probability of 1 death per year per million people.

Table 3.9 Summary of the weighting factors

The last column indicates the criterion on which the target value is based. The damage types defined previously are recognisable here.

Conclusion

The Eco-indicator weighting method is a refinement of the LCA method using published guidelines, the NOH manual and the SETAC Code of Practice. The evaluation stage is based on the distance-to-target principle, and the normalisation stage is based on European data (excluding the former Soviet Union). The decision in favour of this principle was made in phase 1 after a detailed evaluation of other principles. During the project is became clear that this principle leaves a lot of room for interpretation and that improvements in the principle are possible in the event of future developments.

A number of conclusions can be drawn with regard to the methodology:

- An Eco-indicator cannot be developed without clearly defining and demarcating the term "environment" or "eco". Such a definition and demarcation were developed during this project. The Eco-indicator applies only to *environmental affects that damage ecosystems or human health on a European scale*. Other effects are not covered.
- In evaluating environmental effects the damage caused by the effect is a determining factor for the seriousness of an effect. It is inevitable that the damage-effect relation will be used when developing a weighting method. The direction coefficient of the damage effect function is in principle the weighting factor.
- Distance-to-target as a weighting principle does establish a link between damage and effect, but this effect is not ideal in its present form because it only defines one point on the damage-effect function. This means it is not possible to determine the slope of this function directly. In the future it seems that it will be possible to improve the weighting principle by defining two points on the damage-effect function. Such a method requires double the quantity of data.

- There are various types of environmental damage. For this reason it is necessary to weight different types of damage. Subjectivity is inevitable with such a weighting. In relative terms, however, it is much easier to weight damage subjectively than effects.
- The Eco-indicator is based on the subjective assumption that the 5% ecosystem impairment is equivalent to the death of one person per million per year. Different assumptions would result directly in different weighting factors.
- The difference of view that seemed so important in the first phase of this project as to whether the current or the target value should be normalised has proved to be much less relevant than first thought.
- Raw materials depletion and the space required for final waste cannot be correlated with a form of environmental damage. After all, no ecosystems are impaired and no-one dies as a result of such depletions. This means that it is not easy to weight the seriousness of raw materials depletion. The extraction of raw materials and the generation of waste are evaluated, however, in that the impacts as a result of the extraction of raw materials and the processing of waste are completely evaluated. It ought to be possible to develop a separate indicator for evaluating raw materials depletion.
- The uncertainties in the results of the weighting method are still large. This applies both to normalisation and to weighting. It could even be that the normalisation values contain even more uncertainties than the weighting factors. It seems to be very sensible to draw up a new inventory of the available normalisation data after some time.

4. Calculation of the Eco-indicators

The development of 100 Eco-indicators for materials and processes ultimately required 100 LCAs to be carried out. This means that the inventory phase was run 100 times.
The NOH manual and the SETAC Code of Practice state in general terms the requirements with which an inventory phase has to comply. The most important requirement is that the choices, the system boundaries and the allocation principles must all be clearly stated. There is no straightforward receipt for the inventory stage. The researcher has to make a large number of choices when searching for and interpreting data. These choices can greatly influence the result.
Both manuals rightly assume that the way in which the inventory phase is carried out depends among other things on the objective. Before the inventory phase can be carried out the objective must be carefully defined. Based on this objective certain methodological choices can be formulated. Explicitly stating these choices in advance will prevent the researcher from making different assumptions ad hoc for various processes or will prevent him, even worse, from working towards a result.

4.1. Definition of the objective

The Eco-indicators (the 100 figures) are intended for use within companies, particularly as a decision-making support tool for product design or management decisions. It is primarily a means of taking account of environmental aspects in a decision if there is little time to carry out detailed analyses.
The Eco-indicator is intended to take generic decisions on materials, working principles and life cycles. The indicators are not intended for use in controlling the purchase of materials (selection between two aluminium suppliers) or in taking important investment decisions. This means that the user does not know where the impacts will occur.
The users in this project are companies operating on the international market. This means that the indicator must also be relevant outside the Netherlands. Europe is an acceptable scale for the companies involved.
This objective has a number of other important consequences:

- The data must be generally applicable. The figure for aluminium, for example, must be based on the average emissions in the production of aluminium.
- The data must be gathered such that it is possible to compare the indicators well with each other. Mutual comparability of the figures is more important than the absolute value. All data must therefore be gathered in the same way.
- The inventory method must fit as well as possible with the current working method used by LCA researchers.

The consequences of these statements are explained in greater detail below.

4.1.1. Functional unit

For an LCA it is of great importance to define precisely which product is actually being studied. Particularly when comparing two products it is important to ensure that the products are actually equivalent and perform the same task.
In the Eco-indicator project the functional unit is somewhat less visible because no products are analysed over their entire life cycle. The aim is only to produce the building blocks for analysing product life cycles. The designer can establish his own functional unit and carry out an LCA with the indicators. What is required, therefore, is to develop an LCA kit of compatible LCA modules, each with its own indicator value. The are five types of LCA modules:

1. Material production
2. Material processing
3. Energy conversion or generation
4. Transport
5. Waste processing

Most product life cycles can be accurately described with these blocks.
Fig. 4.1 shows an example of a coffee machine. The blocks always represent an LCA module for which an indicator has to be developed. The designer himself determines what the entire life cycle will look like, what the functional unit is and which material and process quantities are required.

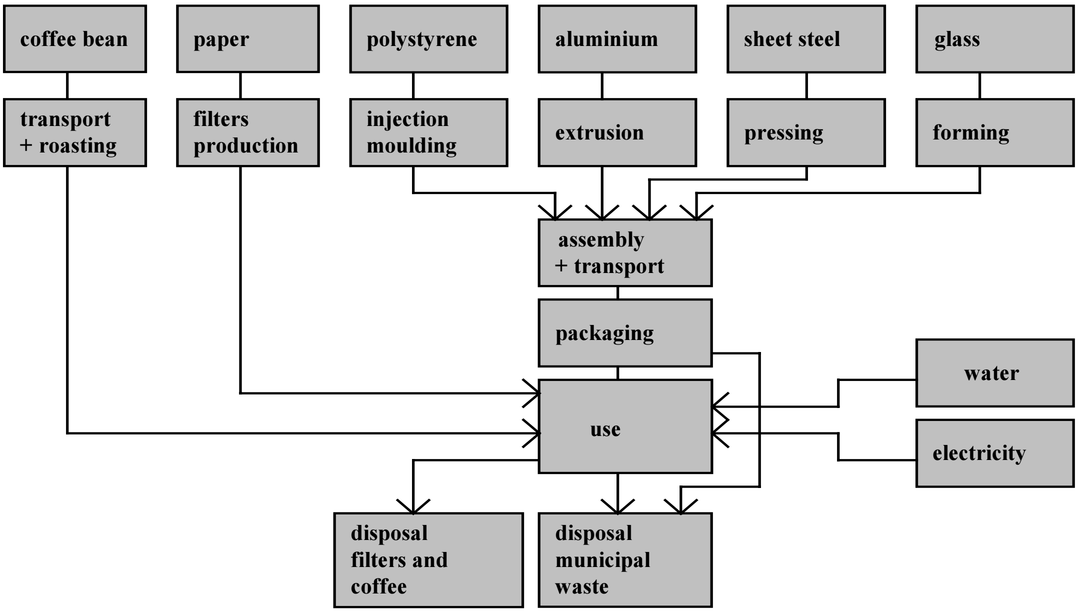

Fig. 4.1. Example of a life cycle for a coffee machine. The use phase, determines the overall functional unit of the product.

It will be obvious that the blocks must fit together well and that it is clear to the designer what is included in a block and what is not. The Manual for Designers [17] describes the process inputs and outputs.

4.1.2. Working with average figures

Working with average figures gives rise to two problems[26]:

1. The impact table in an LCA is strongly influenced by the location of a process. A factory in Sweden uses much "cleaner" electricity than the equivalent factory in Germany. A truck in Northern Europe produces much lower sulphur emissions than one in Southern Europe because the regulations for fuels are different.
2. The evaluation of the seriousness of an impact depends on the degree to which an ecosystem is contaminated. Eutrophication impacts are of concern for the Netherlands while for Central Spain they represent a blessing.

The user (the designer) of the Eco-indicator is not generally able to influence the choice of the region in which the process is taking place. This is sometimes the case to a certain extent for purchasing staff, but the Eco-indicator has not been developed for this purpose.

4.2. Description of the inventory phase

During the so-called inventory phase the emissions and raw materials consumption of processes are identified. The inventory phase is the most complex and labour-intensive phase in an LCA. During this phase estimates and allocations have to be made in a large number of cases. To prevent the Eco-indicators becoming impossible to compare with each other it is important to define in advance how these allocations are to be carried out. We

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[26] It is explicitly not the intention of the project to resolve in passing all the methodological problems that occur during the inventory phase. We will have to live with the same problems faced by all other LCA experts too.

have made a description of the way in which the inventory phase must be conducted in advance.
The description below of the working method during the inventory phase represents the ideal. The picture is determined by the objectives described above. In practice we had to deviate from this ideal, because there were simply no reliable data available. In some cases we dispensed with the calculation of an indicator. This description can also serve as a guide if new indicators have to be determined.

A large number of problems in the inventory phase are described in the LCA literature. However, almost all the problems can be grouped under a number of headings:

System boundaries problems	No single product forms a completely isolated product system, independent of other products. Capital goods and auxiliary products are almost always required to manufacture, transport, use and dispose of a product. Because it is impossible in practice to take account of all these interactions, boundaries must be set for the product system.
Allocation problems	Many processes result in by-products in addition to a main product. Furthermore, in the case of recycling, the same material is used in several product cycles. In these cases the environmental impacts of a process or cycle must be allocated to these products.
Choice of Technology	Particularly with an Eco-indicator it is important to assume the same state of the technology for all the processes.
Time and space	The location where a process takes place has a marked influence not only on the impact table but also on the evaluation of the seriousness of the effects. With durable products there is also the problem that use and disposal processes will not take place now but over an extended period. It is not known what the state of the art will then be.

Table 4.1 Summary of complications in the inventory phase.

4.2.1. System boundaries

A number of rules apply for all types of data, while others apply specifically to material production, transport etc.
In principle all processes are included from raw material extraction to the final process, which results in the outcome described in the material and process definition. However, the following are exceptions to this:

- Production, maintenance and disposal of capital goods. Capital goods are defined to include fixed installations, transport systems and such like that are seen as investment goods in an economic sense. Dies are also included. Maintenance primarily covers major inspections and repairs. Emissions of consumed auxiliary materials such as fuels, lubricants, quick-wearing parts and such like are included in the system.
- Human labour, transport of people etc. Heating and lighting of the production processes, however, are not included because they can often not be distinguished from the other processes in a factory.
- Risks and emissions resulting from accidents and major malfunctions.

In addition to these general rules, a number of specific rules apply.

4.2.1.1. Material production

The starting point is the extraction of raw materials. The finishing point is the process that produces the material in the quality and form for supply as described in the material and process definition.
The process tree incorporates all transport for the material and auxiliary items, including the industrial packaging. Mining processes are fully included, even if they take place outside Europe.

4.2.1.2. Energy generation

All raw material extraction, distribution and manufacturing processes must be included up to the moment that the fuel is ready for sale in Europe.

4.2.1.3. Transport

An important problem is the question of to what extent the transport means are used to their full load- or volume-carrying capacity, and also the question of to what extent transport means return empty. In the list of indicators transport is given both per kilo and per volume, for an average degree of loading; this takes account of transporters returning empty.

4.2.1.4. Production processes

The description of the production processes specifies the input and output of the process. The system boundaries must be based on this.

4.2.1.5. Waste processes

The materials and processes list also contains a number of waste processing and recycling processes. By this we mean the processes that are necessary to collect and process waste materials or to separate and purify the materials until they are more or less pure raw materials. Almost no experience is available with regard to carrying out LCAs for waste processing. This will change though when the *Afval Overleg Orgaan* [AOO - Waste Disposal Authority] publishes its environmental effect report on waste processing in the Netherlands. Based on personal communications and certain draft outlines we have already included some of these data and methodological choices in this project.
Within the Eco-indicator project there has been a great deal of information exchanged on the allocation of useful waste processing by-products, such as heat (electricity) and reclaimed materials (paper, scrap metal, glass etc.)[27].

An important fact is that recycling may only be used in the analysis if a material is actually going to be recycled. The fact that a product is recyclable is irrelevant. Only if the material is actually recycled does it produce an environmental benefit. This benefit can be specified as follows.

- If heat from incineration is collected and used for electricity production, less electricity has to be generated elsewhere. For this reason the impacts that would arise if electricity were generated in a different way are often deducted in an LCA. This only applies, of course, to electricity that is actually supplied to the grid. The impacts arising from the incineration process are taken into account.
- If scrap metal is collected and used for steel production less pig iron has to be manufactured. The impacts that would have been necessary to manufacture this pig iron can be deducted from the impacts arising from the collection and separation of the steel. The same applies to aluminium.
- If waste paper is collected and used for paper production there are savings in pulp production.
- If plastics that are sufficiently pure are collected they can be melted down and turned into pellets that can be used for products that would otherwise be manufactured out of new material.
- Waste glass can be used to replace new glass. Only the inputs for collection and energy for the melting process are taken into account.

As a result of this deduction of avoided emissions some indicators for recycling and combustion processes are negative, meaning that the emissions from the recycling process are lower than the emissions avoided. This would mean that the environment is cleaner in net terms as a result of a process. In fact this is not so because every process causes

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[27] The critical contributions and major input by Hein Sas of the CE in this field have been very valuable, although his view has not been completely adopted.

contamination. The negative score for the recycling process represents the fact that the losses from a recycling process are smaller than the benefits.
In extreme cases the indicator for the material's entire life cycle (apart from production, transport and use processes) can be negative. Taken literally, this would mean that the environment would become cleaner, the more products were manufactured. This seems nonsensical. Nevertheless it was decided to accept this "error" provisionally because the indicator's absolute value for its entire life cycle is less relevant. The main requirement is for the designer to be able to compare various options well with each other. For this it is more important that the differences between the indicators are determined consistently than that the absolute value tallies. If the designer sees a negative indicator for a particular waste processing method in the list he will be able to see that in this case the benefits of the process are greater than the losses.
This all proves still to be a theoretical problem at present. With the current indicator values such situations cannot occur[28].

In addition to the allocation of useful by-products a number of other allocation problems have a role to play in the analysis of waste processing systems.

- A number of emissions are material-specific (heavy metals, CO_2, SO_x and NO_x)
- A number of emissions are process-specific (e.g. CO and dioxin)
- The emissions are filtered with varying efficiencies

The material-specific emissions are relatively easy to assign. The amount of carbon determines the CO_2 production. The proportion of heavy metals is based on average figures for each waste fraction.
Process-specific emissions are assigned to materials on the basis of the amount of combustion gases produced. A substance that produces a lot of flue gas on incineration is also assigned a lot of process-specific emissions. Examples with incineration are: dioxin, carbon monoxide and trichloroethane.

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[28] This problem can be illustrated by means of a greatly simplified example. Let's assume that a designer can only choose between the following extremes.

1. A product can be made of primary or secondary materials. Let's assume that the indicator for primary material is 20 and for secondary material 2.
2. A product can be recycled or dumped. Let's assume that the indicator for disposal is 3 and for collection and reprocessing 2.

The choice of secondary material as the basic material is immediately rewarded with a difference of 18 points. If the material is dumped a further 3 points are added to this. So far the problem is straightforward.
If the material is recycled 2 points are added. However, material is also released. Because new material is released that is actually used, less primary material needs to be manufactured elsewhere. The saving is therefore 20 points.
If the product is made from primary material the net score is:

Primary production	20
Collection and reprocessing	2
Material avoided	-20

The total score is therefore 2. This result seems logical because after use the material is returned. Only the emissions from collecting and reprocessing are taken into account.

If the material was already secondary material a total negative score of -16 points can arise. This is because relatively clean material is used (only 2 points) which, after recycling, avoids the production of new material. After all, if secondary material is also recycled the demand for primary material falls in principle. The environment would thus apparently be cleaner if this material were used. This rather unfortunate distortion is difficult to avoid if we wish to reward the designer both for his sensible material choice and his choice of waste process.

An alternative arises if we agree only to reward the recycling of secondary material by deducting secondary material. (As a rule this is the same as the recycling process itselfzelf, as a result of which the total score for recycling plus benefit is, by definition, zero). In that case a designer who recycles previously new material receives as many points as a designer who recycles what was already secondary material. The use of secondary material as an input is therefore not rewarded.

As far as filtration is concerned we have assumed that modern installations are used. Landfill sites are assumed to be equipped with a reliable waste water purification system (90% efficient). These landfill sites are covered after several tens of years in operation as a result of which no further contaminated percolation water is released. The collection of landfill gas is not assumed. A distinction is drawn between short and long carbon cycles[29]. Waste incineration plants are assumed to be equipped with a modern incineration furnace and modern flue-gas treatment system. The slag is assumed to be used as road-surfacing materials. The leaching of heavy metals from this was derived from trials.
It is assumed that the filter residues and fly ash are treated as chemical waste. No allowance is made for leaching.
The end of the life cycle is a certain quantity of final waste. This is inert waste that does not need further digestion; leaching from this can be ignored.

The waste processing figures for these parameters are on the optimistic side. They are particularly intended for application to future situations, i.e. for products with a long lifetime. Considerably less favourable values can apply to landfill sites that are not covered and for less modern waste incineration furnaces.

4.2.2. Geographical distribution and type of technology

When defining the objective the necessity of using general figures was emphasised. By "general" we mean particularly European. This means that as far as possible the average European electricity figures are used and the other production processes are averaged out for Europe as much as possible. In practice this will not be easy because little is known about processes in Southern Europe.

The other problem, namely regional differences in evaluation for an impact, is simpler as a result. If it is not known, by definition, where an impact takes place there is also no point in continuing with weightings on a regional basis. When defining target values and normalisation values we will have to work with Europe as one homogeneous region.
For processes that mainly occur outside Europe, such as mining and shipping, this means that the evaluation of the emissions is carried out on the basis of European problems; this is not correct, but it is practical.

We have assumed technology such as has been used on average in the last 10 years in Western Europe. This specification leaves much room for interpretation, but there seems to be no better definition available. With regard to waste processing we have taken very up-to-date and, in some cases, future figures. This is logical because many products will only be disposed of in many years. Unfortunately, only Dutch figures where available in sufficient detail and quality.

4.2.3. Allocation of multiple output processes

In the case of processes that result in more than one product the impacts must be allocated to these different products. There are various ways of doing this. Attempts must be made to achieve the following:

1 Allocation on the basis of the products' economic value. This means that a product that provides 60% of the revenue is also assigned 60% of the impacts. The thought behind this is that economic considerations determine whether a process takes place. One advantage of this approach is that a distinction is automatically made between waste and by-products

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[29] In the case of products made of organic material that have extracted CO_2 from the air in the course of the preceding decennia the CO_2 and CH_4 emissions are not included (CH_4 arises from the natural decomposition of organic material). With regard to the incineration of plastics for which the CO_2 extraction took place millions of years ago the CO_2 emissions resulting from incineration are assigned as appropriate.

2 Subtraction of avoided emissions. This is particularly applicable in allocation useful energy. This approach is also used with the waste processes.

Only if these processes are not adequate or if the data found cannot be changed can allocation take place in accordance with the mass ratio.

4.2.4. Data quality and completeness

A number of general rules apply for the evaluation of data quality:

- The mass balance must be checked for material processing systems.
- The results must be compared with at least one other more or less comparable processes. Any large variations must be explained.

Account was taken, of the effect definitions from the Eco-indicator method. Where data were clearly missing estimates were made.

4.2.5. Documentation of the data

The following data at least must be recorded for each material and process.

1. Definition of the material or process
2. Sources used
3. Type of technology, region and period, where known
4. Graphic representation of the process tree, with the system boundaries clearly shown
5. Complete impact table, with impacts divided by:
    - use of raw materials (in connection with mass balance checks)
    - emissions to the air
    - emissions to water and soil
    - final waste (in connection with mass balance checks)
6. List of variations from the ideal model described above. In every case the results of the quality tests described above must be given:
    - mass balance
    - origin of the data
    - comparison with other data
7. Brief discussion of the consequences of these variations for the result
8. Calculated indicator and the three most important contributors to the indicator score.

Appendix 4 in the current report gives a specification of the data sources used. The full description of the data, according to this definition is available in the Annexe report [14]. The titles, sources and comments are in Dutch; the inventory tables are in English

4.2.6. Uncertainty

Despite all the precautionary measures taken there is a fairly large degree of uncertainty in the impact tables. These uncertainties are very difficult to quantify. Nothing is in fact known about the distribution, but it is probably not stochastic. This makes it almost impossible to use an uncertainty analysis. It does not seem impossible for the Eco-indicator to be erroneous by a factor of 2 in some cases because of uncertainties in the impact table. This estimate cannot, however, be backed up.

5. Use of Eco-indicators

The Eco-indicators can be used in two ways:
1. The analysis of products or ideas, with the aim of finding the most important causes of the environmental pollution and finding opportunities for improvement.
2. The comparison of products, semi-finished products or design concepts, after which the least environmentally polluting components can then be chosen.

The analysis of products is of particular importance at the beginning of the design process when comparable products (reference products) are analysed. In general this analysis provides good insight into the dominant environmental aspects for this particular type of product. This can direct the problem definition and the list of requirements at the start of the design process.
Specific rules-of-thumb can sometimes be developed for a type of product. In the concept phase too, once the contours of the new design have begun to take shape, it is useful to carry out an analysis to examine which factors are dominant and in which direction to look for possible optimisations.

The comparison of products is of particular importance during the creative phase and in the selection of concepts. During the creative phase there is sometimes a need for very simple comparisons, for example between two materials. As the design progresses, so the comparisons, become more complex.

During the project we looked at how these two functions could be supported with an operating manual and a number of special assessment forms. Various designers at the companies involved were interviewed regarding a number of proposals for forms and supporting texts. It was found that the designers saw little use in extensive support or intricate forms. There was a clear preference for a simple list of factors and a simple assessment-form. Based on these conclusions a specifications list was formulated and a first version of the form was drawn up.

5.1. Test workshop

The first version of the form and the list of Eco-indicators was tested during a workshop at Philips CFT on 14 December 1994. During the workshop designers from the four companies involved carried out a number of analyses themselves, without further instruction in advance. During the morning session an overhead projector was analysed by four subgroups, based on previously distributed data on the material composition and consumption of energy and sheets. In the afternoon each of the companies involved worked on a product of its own. At the end the results were evaluated.

The following conclusions emerged from the workshop:
- When four different groups analyse the same product they reach the same conclusions, independently from each other. There proved to be differences on a few points:
  - The missing indicator for zinc was estimated differently by the various groups.
  - Very different processes (injection moulding, foil blowing and extrusion blowing) were chosen for the production of overhead sheets. This had a fairly large effect on the outcome, although there was agreement on the main conclusion, namely that sheets play a dominant role. It is obviously very important for the processes to be clearly defined. The designers' lack of familiarity with the product plays an important role here. A designer who designs overhead projectors will know which process is used. In the afternoon session this problem did not occur.
  - Not all designers are equally good in adding numbers. In some cases the decimal point was wrongly positioned in the result.

- Despite the prior warning it was easy to slip into concentrating on details of the production phase. In the example of the overhead projector this plays only a minor role. Once the morning session had been completed, however, most realised that the principal need was to analyse the main features.
- Some found the manual too long, others too short. We concluded from this that we should separate a short introduction on using the list and the form from a somewhat more extensive description of the backgrounds and applications. Quite a number of comments were made about the manual's style. For this reason it has now been re-written.

The most noticeable fact was the ease with which the design teams analysed their own products in the afternoon session. Each group was able to name the dominant factors causing their own product to pollute the environment. These conclusions proved to fit well with the earlier product assessments.

5.2. List of Eco-indicators

The list of indicators is reproduced on the following pages. The figures have been computed with the computer program SimaPro 3.0. The figures are in fact milli-indicators. In other words, the result of the weighting has been divided by 1000 to give figures that are easier to handle. The unit in the following tables is thus mPt (milli Eco-indicator point). Appendix 1 shows how the indicators are composed, using a number of graphs.

A few materials that were included in the original list have since been deleted because the inventory stage was unsatisfactory and did not meet the minimum requirements. These include:

- A number of non-ferrous metals; no reliable data proved to be available.
- Magnetic material; data on non-ferrous metals are needed for this.
- Waste processing for aluminium. Only data on the non-ferrous fraction are known. This fraction also contains large quantities of harmful materials such as lead. The impacts resulting from the processing of this fraction are therefore very high; this cannot, however, be assigned to aluminium.
- Processing of chemical waste. The impacts from this were determined too much by the specific composition and physical form of the material to allow a general figure to be derived.

5.3. Assessment form

Two forms have been designed to carry out the calculations by the designer. Form 1 is primarily intended for comparing products or analysing simple products; Form 2 is intended for analysing more complex products.

Production of metals (in millipoints per kg)

	Indicator	Description
Secondary aluminium	**1,8**	made completely of secondary material
Aluminium	**18**	containing average 20% secondary material
Copper, primary	**85**	primary electrolytic copper from relatively modern American factories
Copper, 60% primary	**60**	normal proportion secondary and primary copper
Secondary copper	**23**	100% secondary copper, relatively high score through heavy metal emissions
Other non-ferrous metals	**50-200**	estimate for zinc, brass, chromium, nickel etc.; lack of data
Stainless steel	**17**	sheet material, grade 18-8
Secondary steel	**1,3**	block material made of 100% scrap
Steel	**4,1**	block material with average 20 % scrap
Sheet steel	**4,3**	cold-rolled sheet with average 20% scrap

Processing of steel (in millipoints)

	Indicator	Description
Bending steel	**0,0021**	one sheet of 1 mm over width of 1 metre; straight angle
Bending stainless steel	**0,0029**	one sheet of 1 mm over width of 1 metre; straight angle
Cutting steel	**0,0015**	one sheet of 1 mm over width of 1 metre
Cutting stainless steel	**0,0022**	one sheet of 1 mm over width of 1 metre
Pressing and deep-drawing	**0,58**	per kilo deformed steel, do not include non-deformed parts!
Rolling (cold)	**0,46**	per pass, per m^2
Spot-welding	**0,0074**	per weld of 7 mm diameter, sheet thickness 2 mm
Machining	**0,42**	per kilo machined material ! (turning, milling, boring)
Machining	**0,0033**	per cm^3 machined material ! (turning, milling, boring)
Hot-galvanising	**17**	per m^2, 10 micrometres, double-sided; data fairly unreliable
Electrolytic galvanising	**22**	per m^2, 2.5 micrometres, double-sided; data fairly unreliable
Electroplating (chrome)	**70**	per m^2, 1 micrometre thick; double-sided; data fairly unreliable

Processing of aluminium (in millipoints)

	Indicator	Description
Blanking and cutting	**0,00092**	one sheet of 1 mm over width of 1 metre
Bending	**0,0012**	one sheet of 1 mm over width of 1 metre
Rolling (cold)	**0,28**	per pass, per m^2
Spot-welding	**0,068**	per weld of 7 mm diameter, sheet thickness 2 mm.
Machining	**0,12**	per kilo machined material ! (turning, milling, boring)
Machining	**0,00033**	per cm^3 machined material ! (turning, milling, boring)
Extrusion	**2,0**	per kilogram

Production of plastic granulate (in millipoints per kg)

	Indicator	Description and explanation of score
ABS	**9,3**	high energy input for production, therefore high emission output
HDPE	**2,9**	relatively simple production process
LDPE	**3,8**	score possibly flattered by lack of CFC emission
Natural rubber	**15**	ozone-layer-depleting solvents used during production
PA	**13**	high energy input for production, therefore high emission output
PC	**13**	high energy input for production, therefore high emission output
PET	**7,1**	high energy input for production, therefore high emission output
PP	**3,3**	relatively simple production process
PPE/PS	**5,8**	A commonly used blend, identical to PPO/PS
PS rigid foam	**13**	block of foam with pentane as blowing agent (causes smog)
PS high impact (HIPS)	**8,3**	high-impact polystyrene
PUR	**14**	ozone-layer-depleting solvents used during production
PVC	**4,2**	calculated as pure PVC, without addition of stabilisers

Processing of plastics (in millipoints)

	Indicator	Description
Injection mould. in general	**0,53**	per kilo material, this figure may also be used as estimate for extrusion
Inject. mould. PVC & PC	**1,1**	per kilo material, this figure may also be used as estimate for extrusion
RIM, PUR	**0,30**	per kilo material
Extrusion blowing PE	**0,72**	per kilo, for bottles and such like
Vacuum forming	**0,23**	per kilo
Vacuum pressure forming	**0,16**	per kilo
Calandering of PVC	**0,43**	per kilo
Foil blowing PE	**0,030**	per m^2, thin foil (for bags)
Ultrasonic welding	**0,0025**	per metre weld length
Machining	**0,00016**	per cm^3 machined material

Production of other materials (in millipoints per kg)

	Indicator	Description
Glass	**2,1**	57% secondary glass
Glass wool and glass fibre	**2,1**	for isolation and reinforcement
Rockwool	**4,3**	score is largely determined by carcinogenic substances
Ceramics	**0,47**	simple applications, e.g. sanitary fittings etc.
Cellulose board	**3,4**	this material is particularly used in dashboards
Paper	**3,3**	chlorine-free bleaching, normal quality
Recycled paper	**1,5**	unbleached, 100% waste paper
Wood	**0,74**	wood from Europe, sawn into planks, without preservatives
Cardboard	**1,4**	corrugated cardboard made of 75% waste paper.

Production of energy (in millipoints)

	Indicator	Description
Electricity high voltage	**0,57**	per kWh, for industrial use
Electricity low voltage	**0,67**	per kWh, for consumer use (230V)
Heat from gas (MJ)	**0,063**	per MJ heat
Heat from oil (MJ)	**0,15**	per MJ heat
Mechanical (diesel, MJ)	**0,17**	per MJ mechanical energy from a diesel engine

Transport (in millipoints)

	Indicator	Description
Truck (28 ton)	**0,34**	per ton kilometre, 60% loading, European average
Truck (75m^3)	**0,13**	per m^3 km, 60% loading, European average
Train	**0,043**	per ton kilometre, European average for diesel and electric traction
Container ship	**0,056**	per ton kilometre, fast ship, with relatively high fuel consumption
Aircraft	**10**	*per kg !*, with continental flights the distance is not relevant

Self-made indicators for components (in millipoints)

	Indicator	Description

Waste processing and recycling (in millipoints per kg)

Fraction	Indicator	Notes
Incineration (in modern waste incinerator with heat recovery and flue-gas treatment)		
Glass	**0,89**	almost inert material on incineration
Ceramics	**0,020**	almost inert material on incineration
Plastics (excluding PVC)	**1,8**	plastics contain heavy metals, but also have a high energy yield
PVC	**6,9**	PVC contains heavy metals and it has a relatively low energy yield
Paper and cardboard	**0,56**	heavy metals (ink) are dominant, energy yield is relatively high
Steel and iron	**1,8**	70% is recovered from slag, particularly larger pieces
Landfill (in modern landfill site with percolation water treatment and dense base)		
Glass	**0**	almost inert material on a landfill
Ceramics	**0,027**	almost inert material on a landfill
Plastics (excluding PVC)	**0,035**	0.1 % of all heavy metals released
PVC	**0,077**	0.1 % of all heavy metals released
Paper and cardboard	**0,16**	10% of all heavy metals (mainly in ink) released
Steel and iron	**0,80**	small proportion (ca. 1%) of heavy metals released
Recycling (note: these values cannot be used for recycling of secondary material)		
Glass	**-1,5**	less glass has to be manufactured because of glass recycling
Ceramics	**n.a.**	cannot be sensibly recycled
Plastics (PP en PE)	**-0,46**	less plastic has to be manufactured because of plastic recycling
Engineering plastics	**-0,5 - -5,0**	the higher the indicator for production, the higher the "profit"
PVC	**-1,6**	less PVC has to be manufactured because of PVC recycling
Paper and cardboard	**-1,8**	less paper has to be manufactured because of paper recycling
Steel and iron	**-2,9**	less pig iron has to be manufactured because of steel recycling
Municipal waste (Processing of waste by average Dutch municipality)		
Glass	**0,35**	37% incinerated, 63% landfilled
Ceramics	**0,041**	37% incinerated, 63% landfilled
Plastics (excluding PVC)	**0,69**	37% incinerated, 63% landfilled
PVC	**2,6**	37% incinerated, 63% landfilled
Paper and cardboard	**0,33**	37% incinerated, 63% landfilled
Steel and iron	**1,2**	37% incinerated, from which 70% is recovered, 63% landfilled,
Household waste (Same, but with average separation by consumer (e.g. glass and paper containers))		
Glass	**-0,80**	61% separated and recycled, rest is municipal waste (see above)
Ceramics	**0,041**	almost all processed as municipal waste
Plastics (excluding PVC)	**0,66**	2% separated and recycled, rest is municipal waste (see above)
PVC	**2,5**	2% separated and recycled, rest is municipal waste (see above)
Paper and cardboard	**-0,43**	35% separated and recycled, rest is municipal waste (see above)
Steel and iron	**-0,28**	36% separated and recycled, rest is municipal waste (see above)

Product or component	Project
Date:	Author
Notes and conclusions	

Production

Materials, processing, transport and extra energy

material or process	amount	indicator	result
Total			

Use

Transport, energy and any auxiliary materials

process	amount	indicator	result
Total			

Disposal

Disposal processes per type of material

material and type of processing	amount	indicator	result
Total			
TOTAL (all phases)			

Product or component:	Project
Date:	Author
Notes and conclusions	

Production

Materials, processing, transport and extra energy

material or process	amount	indicator	result
Total			

Use

Transport, energy and any auxiliary materials

process	amount	indicator	result
Total			

Disposal

Disposal processes per type of material

material and type of processing	amount	indicator	result
Total			
TOTAL (all phases)			

Product or component	Project
Date:	Author
Notes and conclusions	

Production

Materials, processing, transport and extra energy

material or process	amount	indicator	result
Total			

Use

Transport, energy and any auxiliary materials

process	amount	indicator	result
Total			

Disposal

Disposal processes per type of material

material and type of processing	amount	indicator	result
Total			
TOTAL (all phases)			

6. Conclusions

Two sub-projects have been running in parallel within the Eco-indicator project:
- The development of the weighting method
- The calculation of 100 indicators

The conclusions for each sub-project are presented below.

6.1. Weighting method

At the end of chapter 3 a large number of conclusions were drawn about the weighting itself. The following general conclusion is central to these.

An Eco-indicator cannot be developed without clearly defining and demarcating the term "environment" or "eco". Such a definition and demarcation were developed during the project. The Eco-indicator only applies to *environmental effects that damage ecosystems or human health on a European scale.* Other effects have not been covered.

6.2. The 100 Eco-indicators

The 100 Eco-indicator values have been the most noticeable result of this project. The reliability of these figures is determined, except for by the weighting method, by the inventory phase of the underlying LCAs.
A reliable indicator can only be achieved if the other stages in the life cycle assessment are also good. The methodologically weak sides of the inventory phase proved to be well highlighted during the development of an indicator.

The weakness in the methodological description of the inventory phase is a general LCA problem and must be viewed in isolation from the development of a weighting method. However, these problems have made themselves felt in the 100 Eco-indicator values. It is clear that much attention still needs to be given to the further development and standardisation of the inventory phase of the LCA, in addition to the weighting method.

6.3. General

The Eco-indicator method that has now been developed is a first step in the development of a well underpinned method of weighting environmental effects based on the damage that they cause. Many methodological issues have been resolved during development, and a large amount of data has been collected. It is to be expected that our understanding in terms of the methodology and the available amount of data will increase. It therefore seems not unlikely that there will be revisions of the method and the data used.

The open working method with a platform on which both industry and science were represented was very fruitful. Views were exchanged intensively and openly, and a large degree of consensus quickly emerged on the possibilities and limitations of the weighting method. The foreign contacts also had an important stimulating effect.

Initial tests with designers confirm the appeal of the concept of the indicators. The Eco-indicator will bring life cycle assessment within the reach of the designer.

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Abbreviations

ABS	Acrilonitrile-butadiene-styrene
AOO	Afval Overleg Orgaan, Waste Coordination Body
AP	Acidification potential
AQG	Air Quality Guidelines
BUWAL	Bundesamt für Umwelt, Wald und Landschaft [Swiss Federal Ministry for Environment, Forestry and Agriculture]
CE	Centrum voor energiebesparing [Centre for Energy Conservation and Environmental Technology]
CFC	Chlorine- Fluor Hydrocarbons
CML	Centrum voor Milieukunde [Centre of Environmental Science]
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CH_4	Methane
ECU	European Currency Unit
EDIP	Environmental Design of Industrial Products
ELU	Environmental Load Unit
EPS	Environmental Priority Strategy
eq.	Equivalent
ETH	Eidgenössische Technische Hochschule (Zürich)
HCFC	Hydro Chlorine- Fluor Carbons
IBPC	Directie Industrie, Bouw, Produkten en Consumenten [Directorate for Industry, Building, Products and Consumers]
IDES	Interdisciplinary Department of Environmental Science
IVL	Swedish Environmental Research Institute, approximately comparable with the RIVM.
LCA	Life cycle assessment
MAC	Maximum acceptable concentration in the workplace. Established by the Labour Inspectorate
MET matrix	Materials Energy Toxicity matrix
VROM	(Ministerie van) Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer [(Ministry of) Housing, Spacial Planning and the Environment]
NOH	Nationaal Onderzoeksprogramma Hergebruik van Afvalstoffen [National Reuse of Waste Research Programme]
Novem	Nederlandse Onderneming voor Energie en Milieu bv. [Netherlands Agency for Energy and the Environment Ltd.]
NO_x	Nitrogen oxide
NP	Nutriphication Potential
ODP	Ozone depletion Potential
OECD	Organisation for Economic Co-operation and Development
PAH	Polycyclical Aromatic Hydrocarbons
PC	Polycarbonate
PCB	Polychlorobifenyl
POCP	Photochemical Ozone Creation Potential
POM	Polyoxymethylene
PP	Polypropylene
ppb	Parts per billion
ppbv	Parts per bilion by volume
PPO	Polyphenylene oxide
PS	Polystyrene
PUR	Polyurethane
PWMI	Plastic Waste Management Institute
QGDW	Quality Guidelines for Drinking Water
RIM	Reaction Injection Moulding
RIVM	Rijks Instituut voor Volksgezondheid en Milieuhygiëne [National Institute for Public Health and Environmental Protection]
SANEL	Scientifically Available No Effect Levels
SETAC	Society of Environmental Toxicology and Chemistry
SO_2	Sulphor dioxide
SPM	Small Particle Matter

TME	Bureau voor Toegepaste Milieu Economie [Office for Applied Environmental Economics]
TNO	Dutch organisation for applied research
VOS	Volatile Organic Substances
WHO	World Health Organisation

Annexe 1: Calculation of 100 Eco-indicators

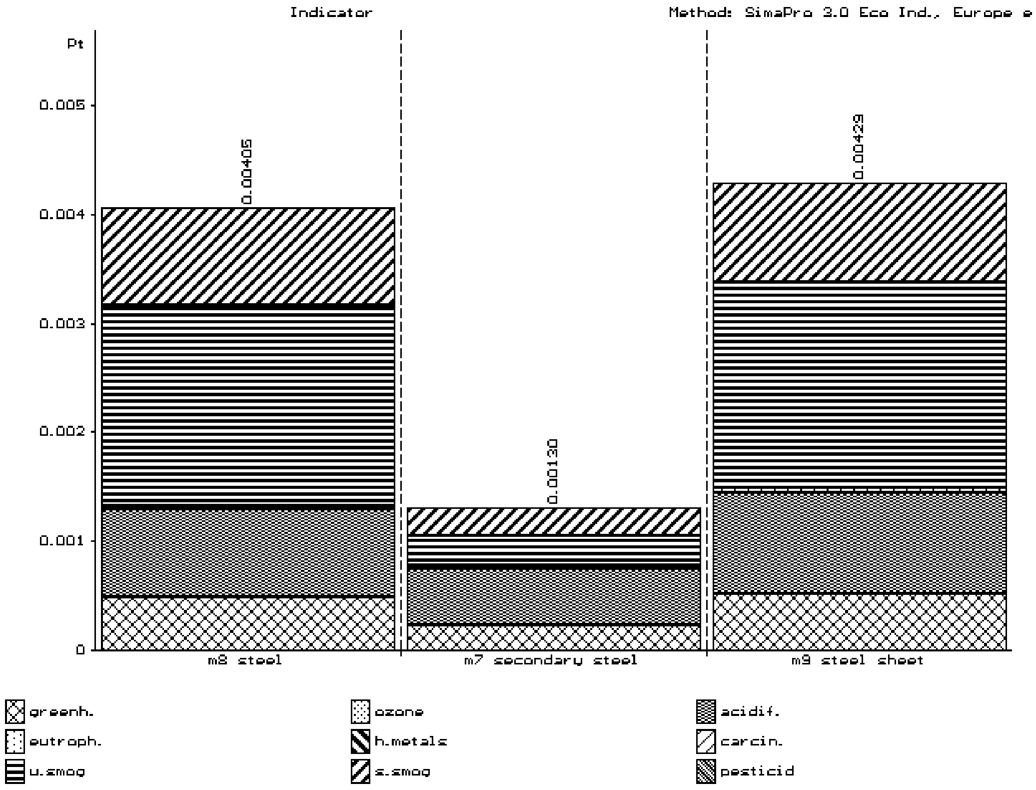
This annexe contains a set of graphs that specifies which effects contribute to an Eco-indicator. The graphs are generated in the LCA computer program SimaPro 3.0. The names of the materials and processes sometimes differ from the names in the report.

The graphs show some important trends. In general it seems the contribution of the acidification and to some extend the Winter smog is quite important. This means the SO_2 emissions, which contribute to both effects is significant.
Heavy metals and ozone depletion are sometimes responsible for quite high indicator values. From this it is clear that much attention should be given to emissions that contribute to these effects. We have the impression this is not always done in a proper manner, especially in older LCA literature. Such omissions can cause rather significant deviations.

Materials

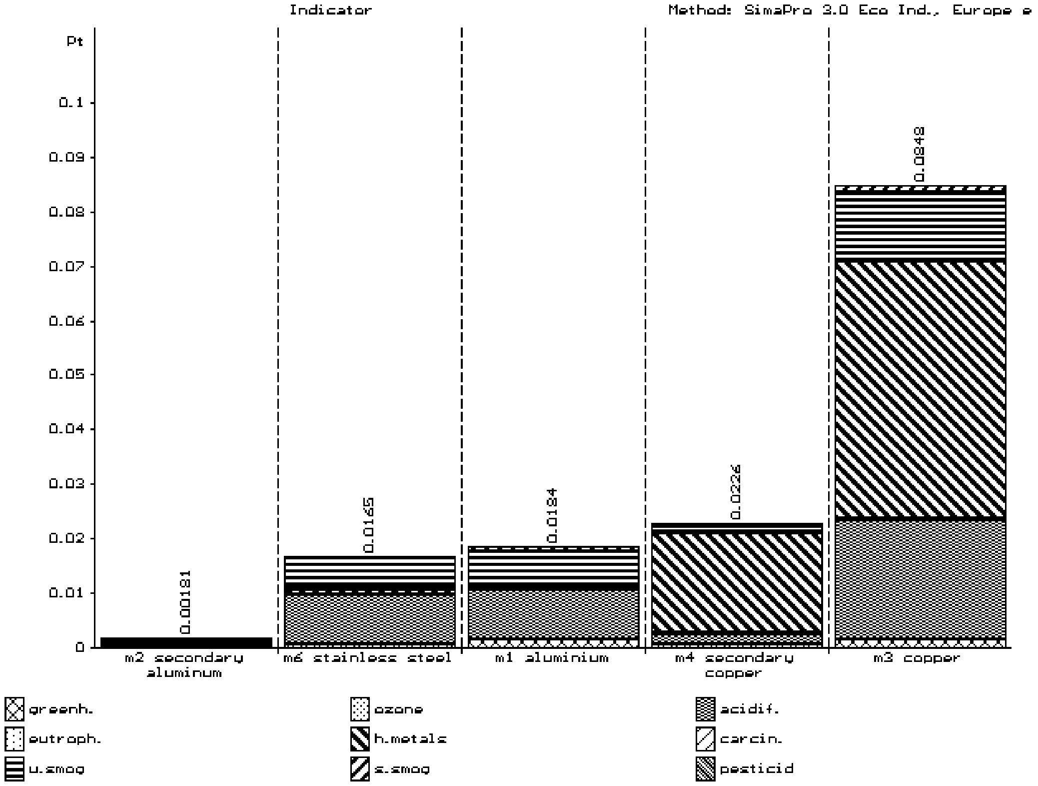
The first group of indicators specify the production of 1 kg material.

Ferro metals



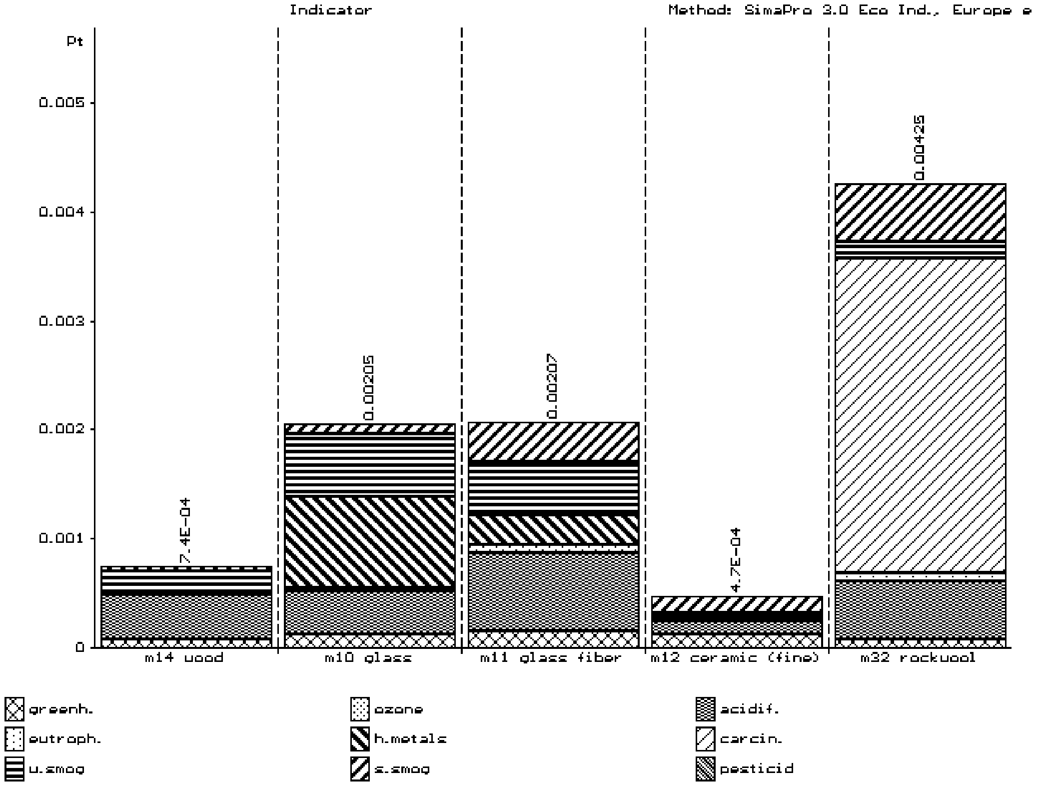
Non-Ferro metals

Heavy metal emissions are dominating the copper and zinc figures. Also the SO_2 emission is important for copper production. Copper ore (and most other non ferro metal ores) is usually a sulphite. The sulphur is partly released as SO_2.

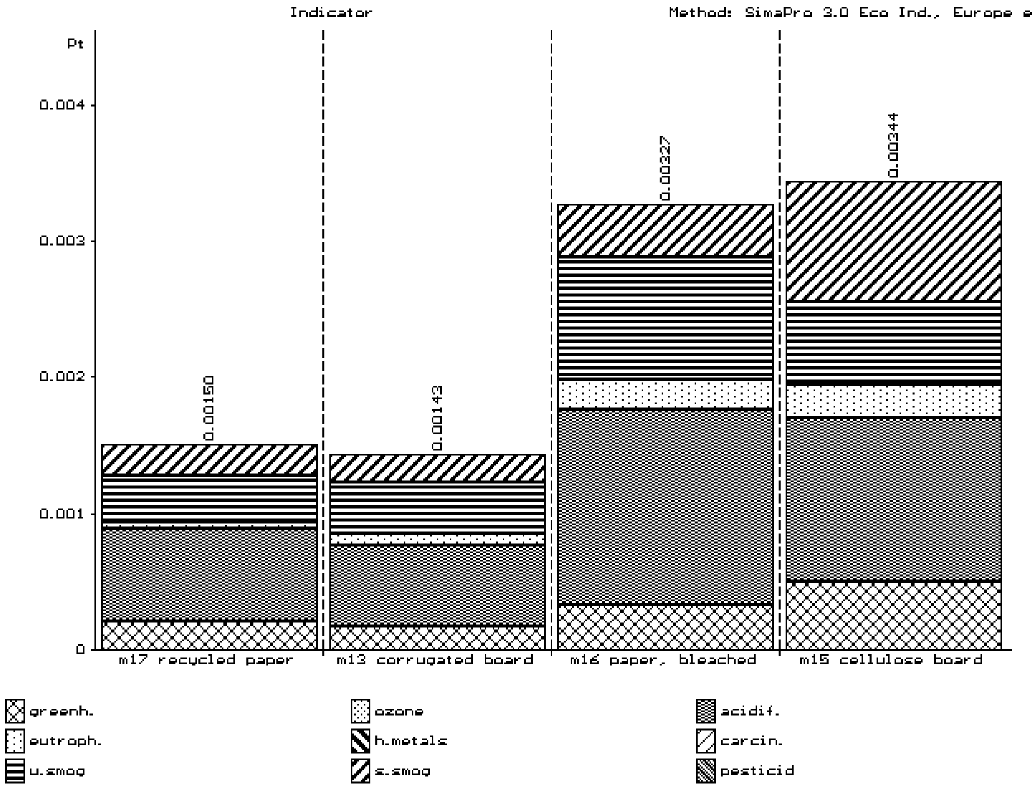


Building materials

The high figure for carcinogenisis is remarkable for rockwool.

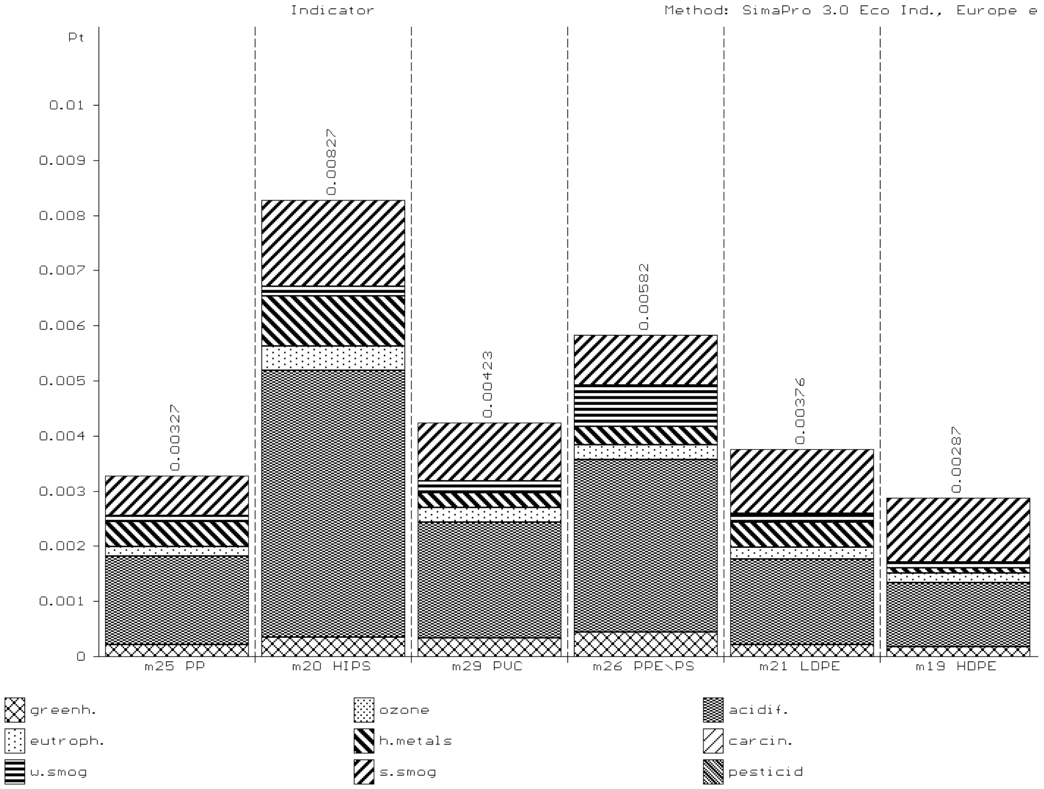


Paper and Board



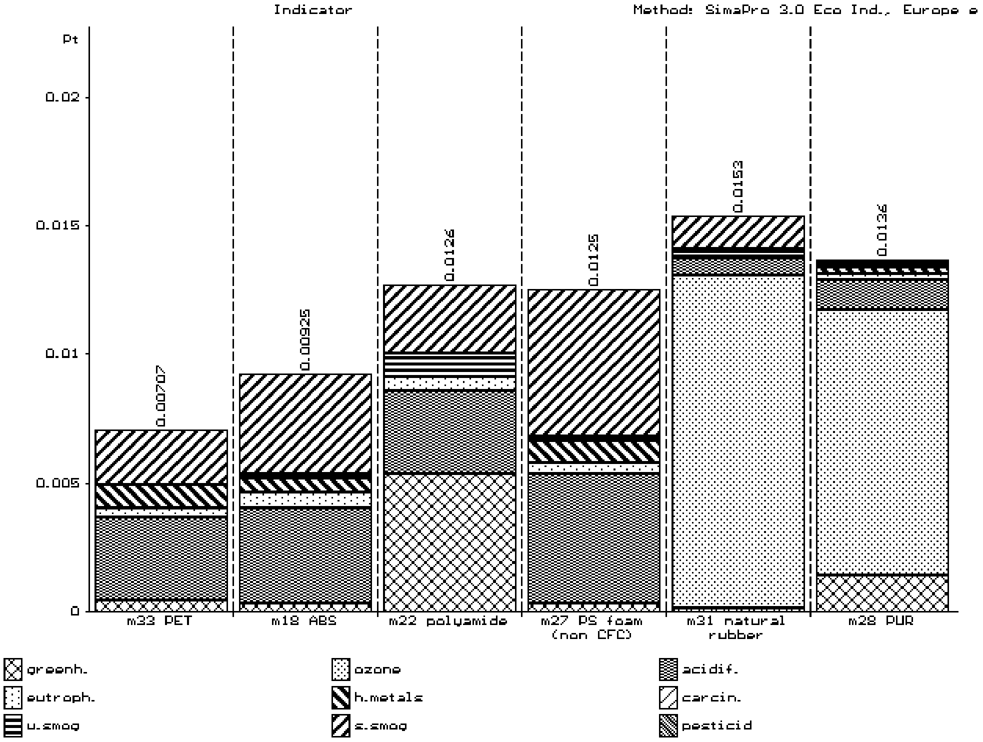
Plastics 1

In polymer production most emissions are directly related to the energy requirements. Especially the SO_2 emissions, from burning oil are significant. The high SO_2 figure for polystyrene is difficult to explain, but is taken directly from the PWMI.



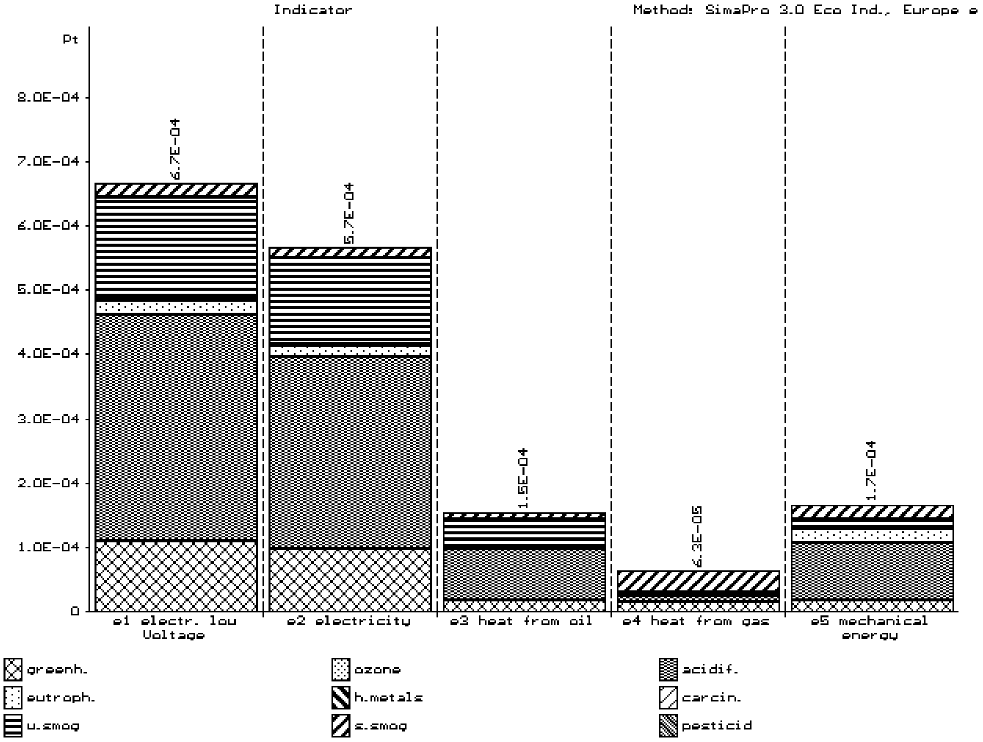
Plastics 2

The high ozone depletion in natural rubber production is due to a tri-chloroethane emission in the moulding process. In the PUR production the ozone depletion is to be ascribed to a cooling system. In polyamide production the greenhouse effect is large, due to the high energy requirements.



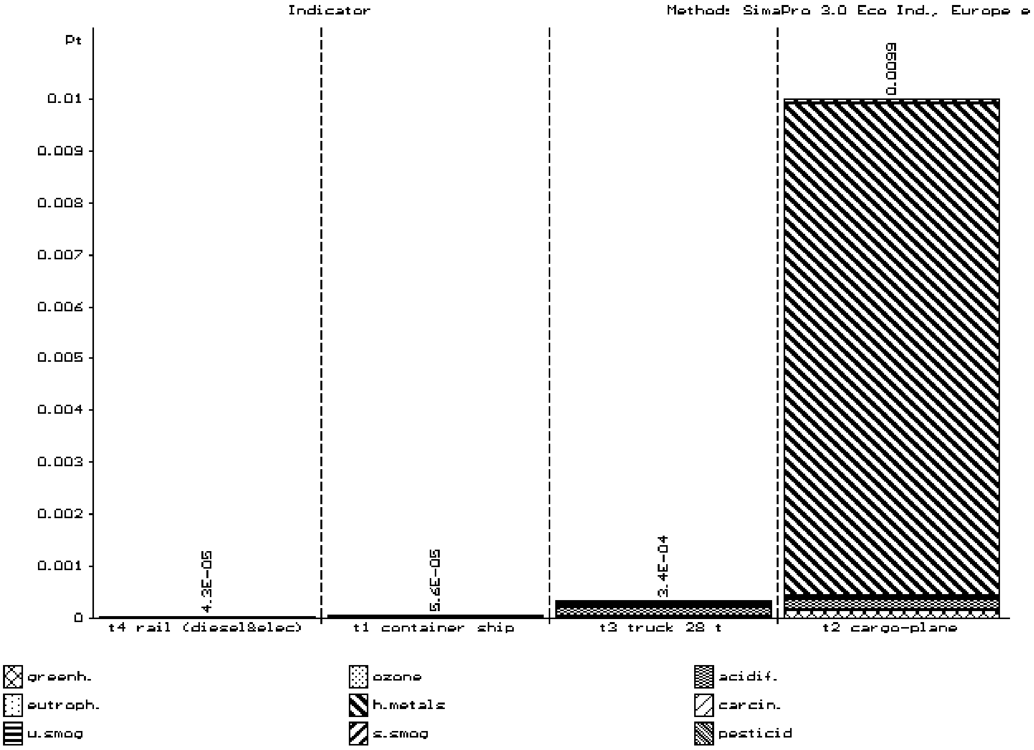
Energy

In energy conversion the SO_2 emissions are dominant.



Transport

The emission of heavy metals for air transport is due to a lead emission.

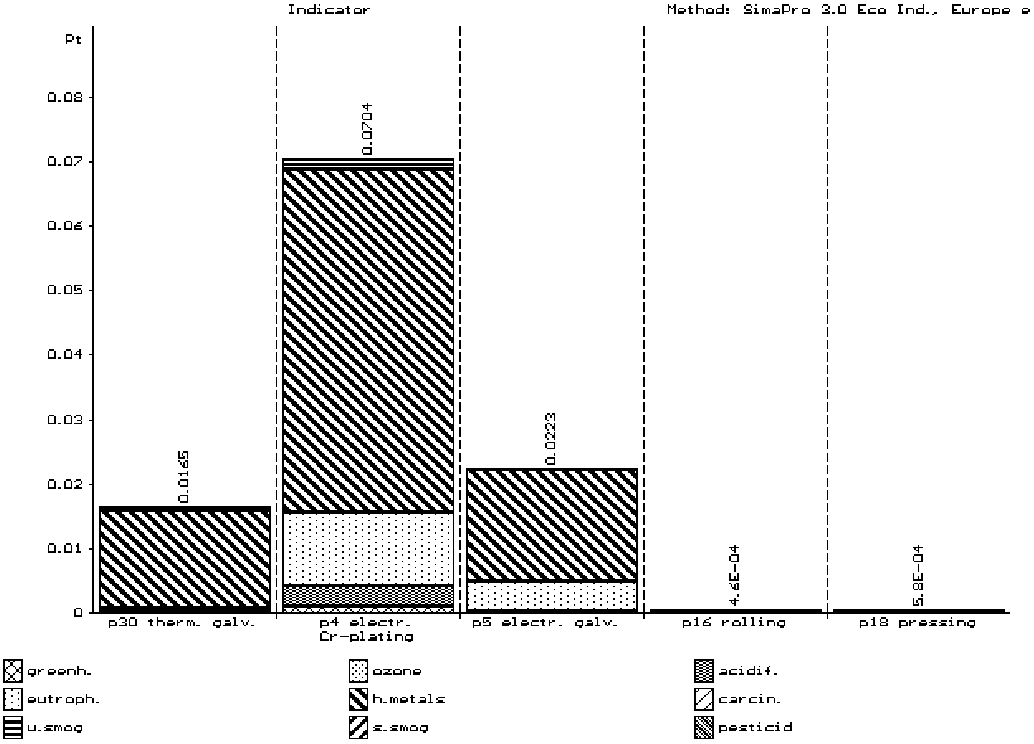


Production processes

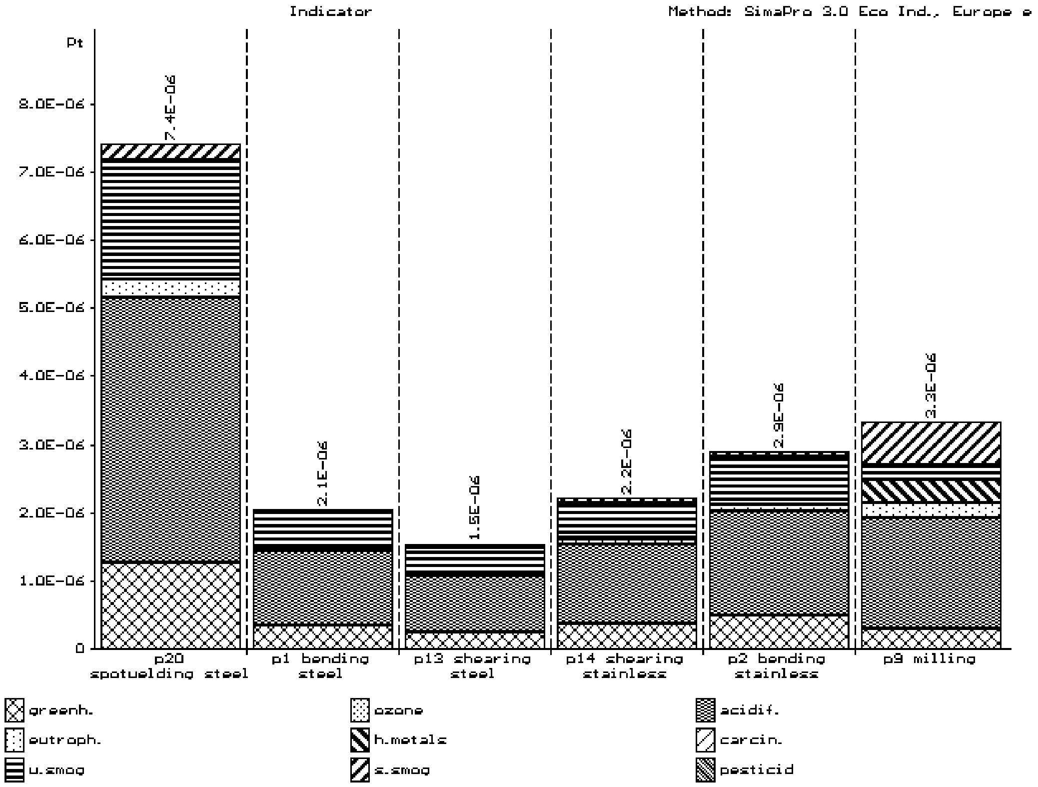
The following graphs show the calculation of the production processes. In most cases the electricity use is dominant. The graphs should not be compared among each other, since the functional units differ.

Processing of steel 1

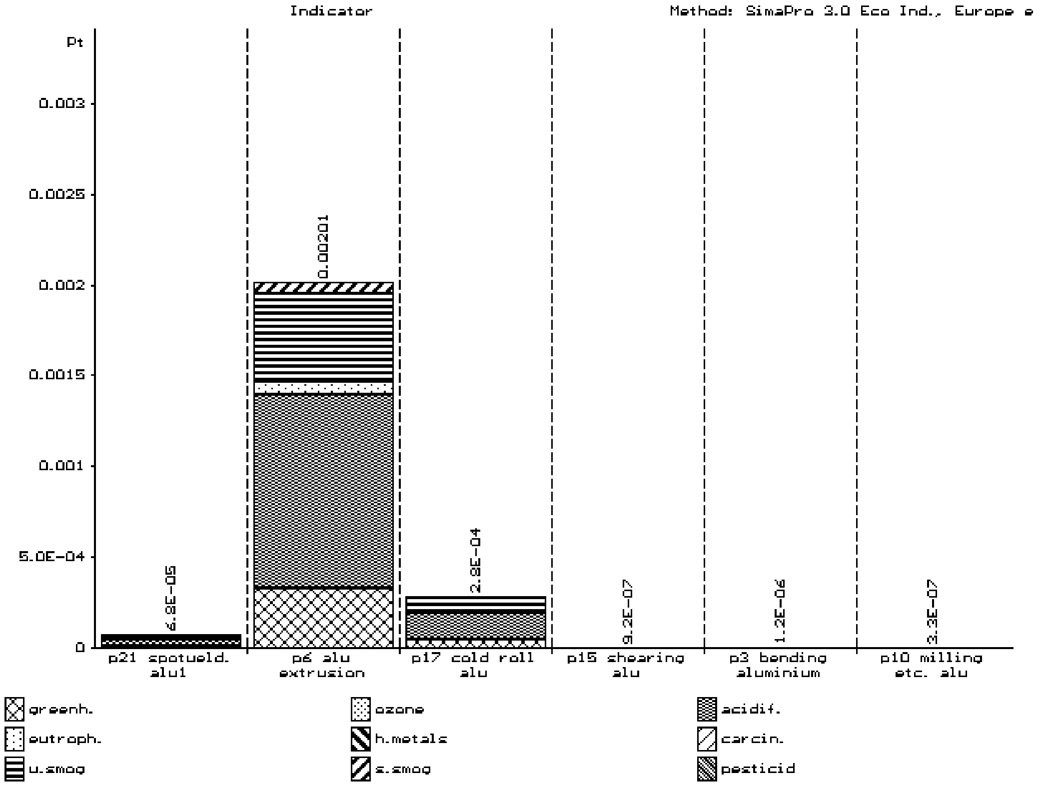
The surface treatment processes are characterised by a relatively high heavy metal emission.



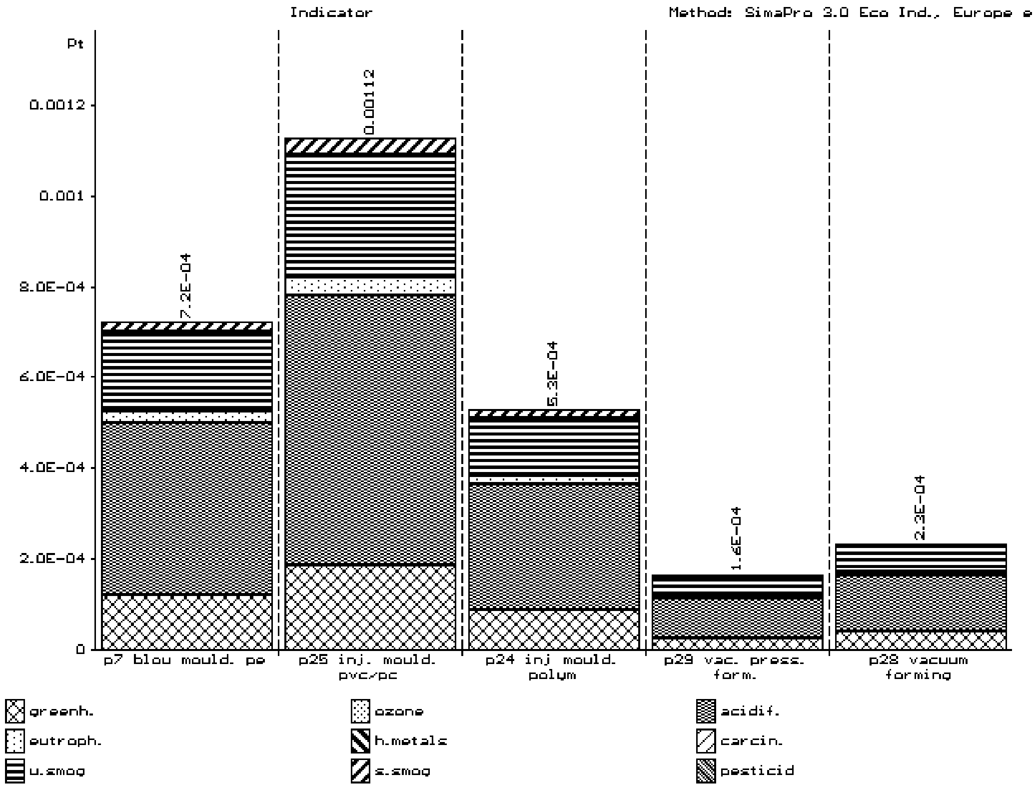
Processing of steel 2



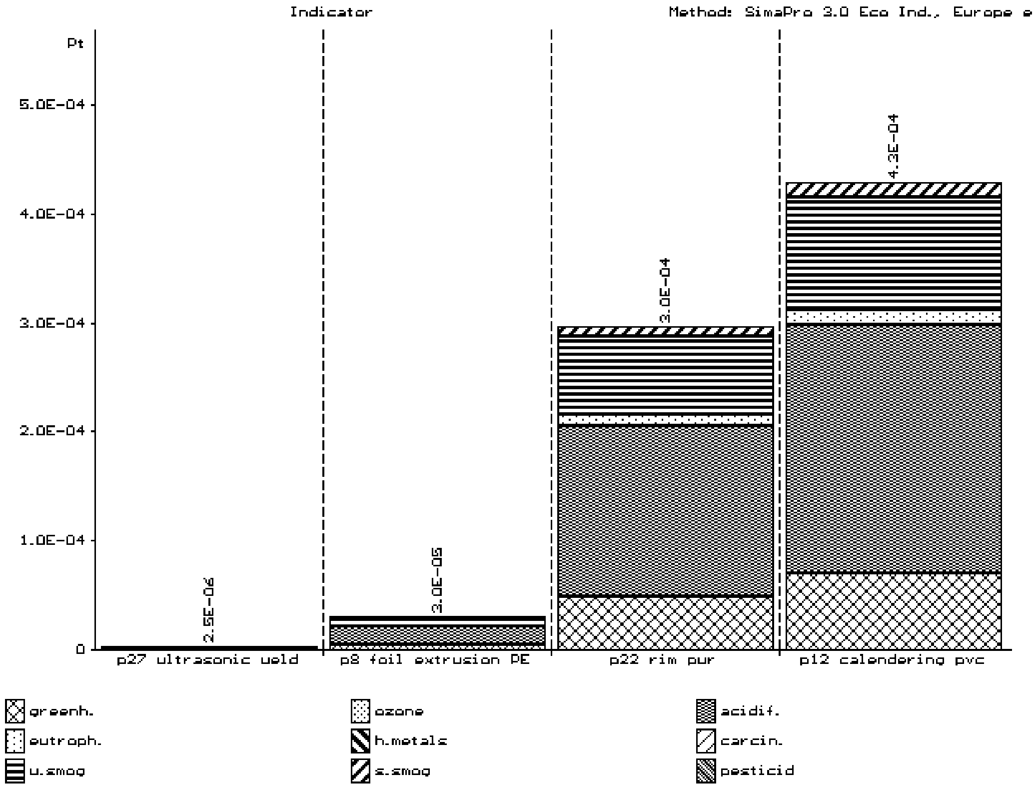
Processing of aluminium



Processing of plastics 1



Processing of plastics 2

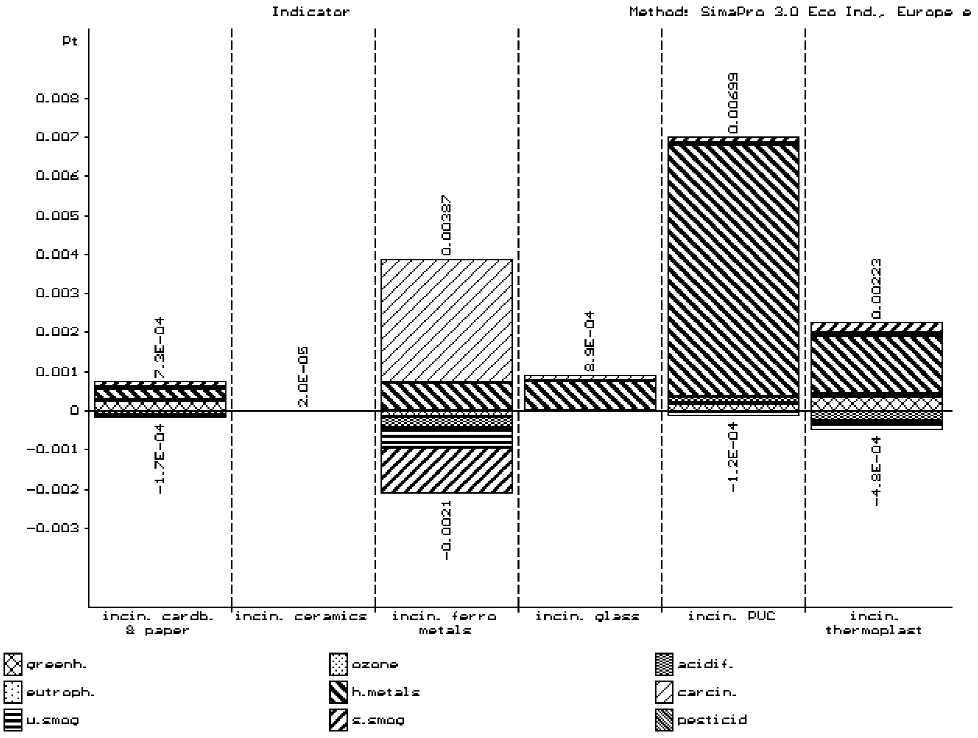


Waste treatment

The graphs show the combined positive and negative effects from waste treatment. The negative values are subtracted for each effect; the resulting values are plotted in the graph.

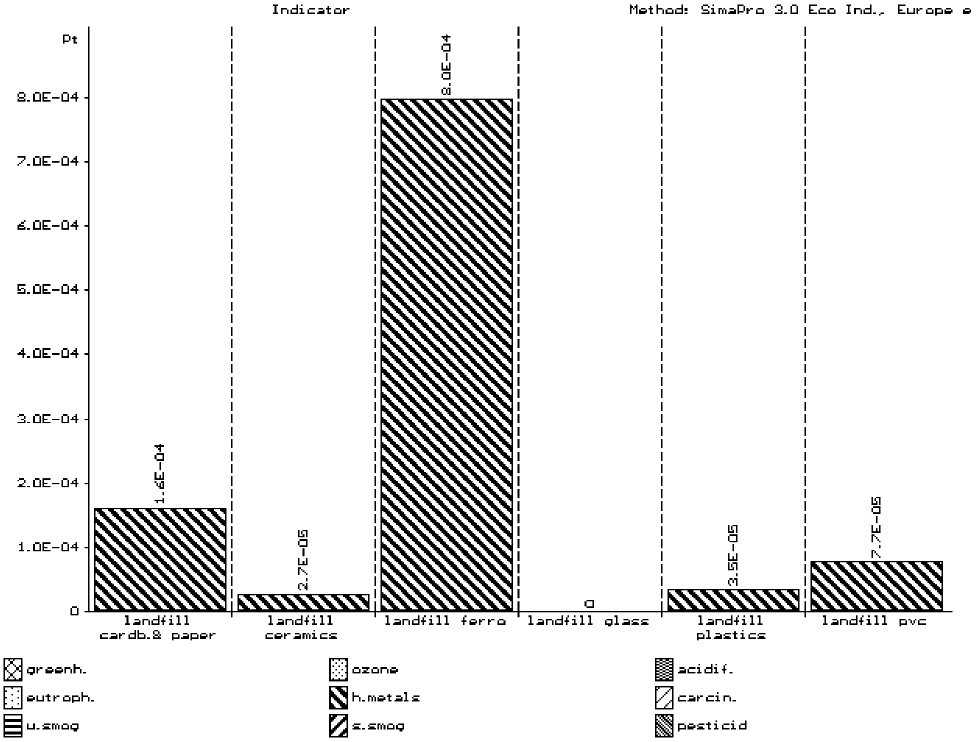
Incineration

The negative value for incineration of steel can be explained from the high efficiency of magnetic separation of scrap in modern incinerators.



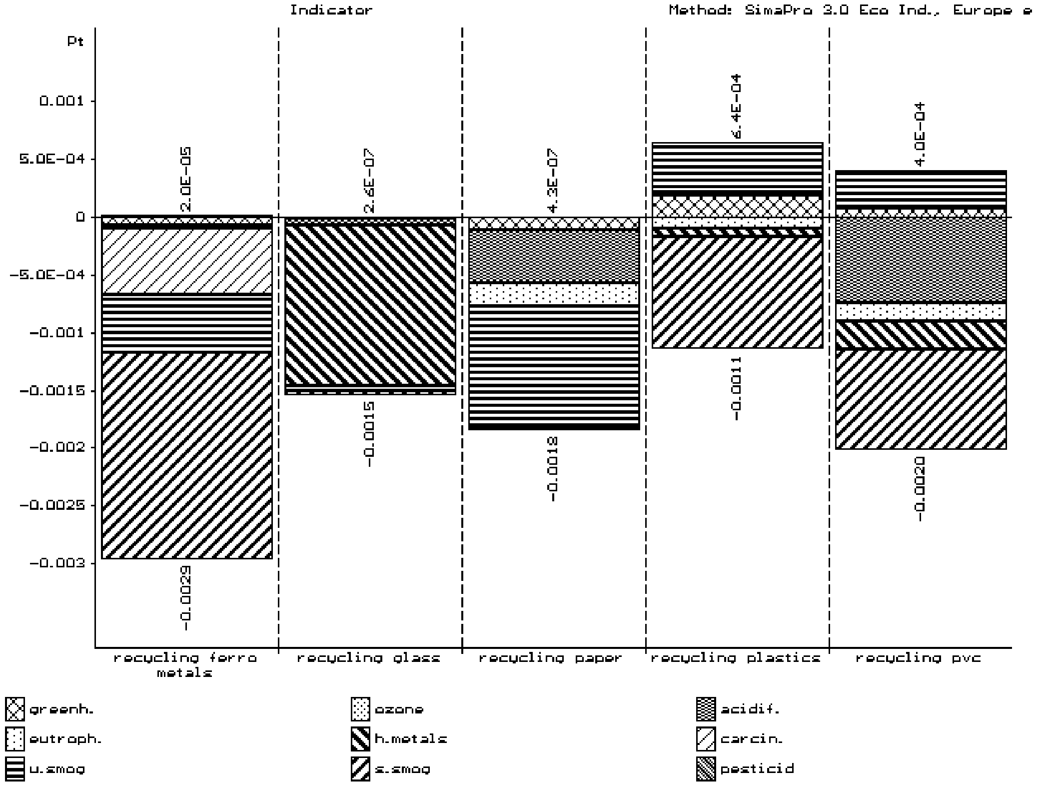
Landfill

The values are completely defined by the leaching of heavy metals (modern landfill site)

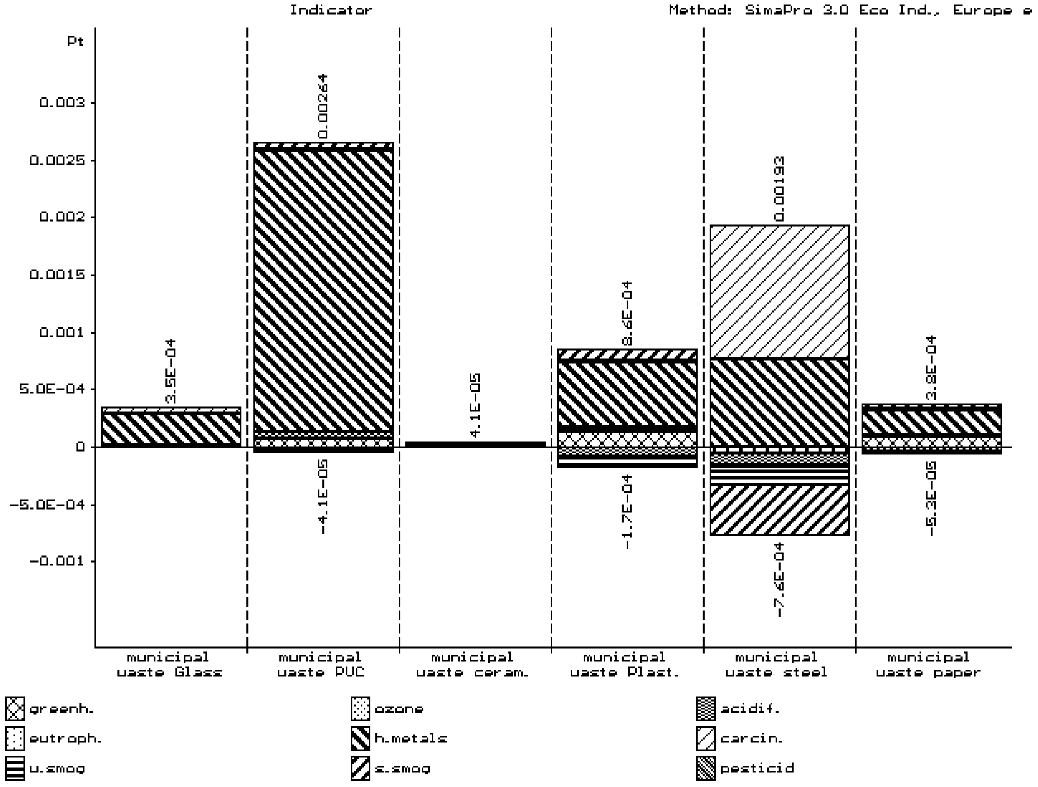


Recycling

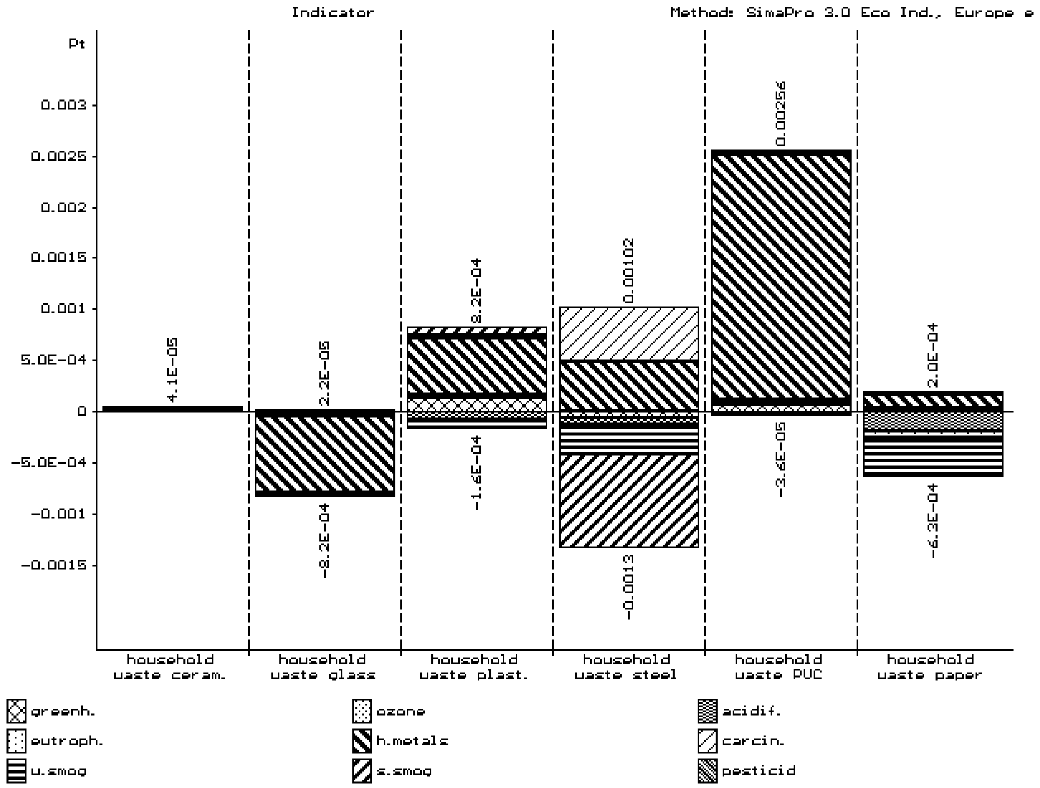
In most cases the avoided emissions are higher than the emissions from the recycling process. The plastic recycling process is here shown for polyethylene.



Municipal waste



Household waste



Annexe 2: Calculation of normalisation values

The normalisation values are calculated in the large spreadsheet on the following pages. The structure of the spreadsheet is described below.
The emissions are listed in the top row. Row 2 indicates whether this emission is to air or to water. Row 3, contains the year of measurement and row 4 and 5 contain information about the source. The sources are listed below.

Source	Title publisher
1	*The Environment in Europe and North-America, Annotated Statistics 1992*, Economic Commission for Europe, United Nations Publication [37]
2	*Corinair 1990* , provisional results [6]
3	*Environmental Statistics 1991*, Eurostat, [11]
4	*The Environment in Europe: a Global Perspective*, RIVM. [33]
5	*General Environmental Statistics 1992],* CBS (NL), [5]
6	*Industrial emissions in the Netherlands* No. 14, September 1993, [23]
7	*CFC commission, a collaborative project by Government and industry* Annual report 1993, [4]

The countries of Europe are listed twice in column A. In the upper part (row 7 to 33), the emissions are listed per county, as far as data was available. The sums of the known emissions are listed in row 26 for Western Europe and in row 34 for Eastern Europe.
In order to calculate the values for the countries with no data, an extrapolation was made based on the energy consumption per country. The energy consumption was chosen, since it seems to reflect the infrastructure and industry of a country. Since there are big differences in industrial structure in Eastern and Western Europe, we have made the extrapolation for both areas separately.

In cell B38 to B63, the energy use per country is listed. The spreadsheet is programmed in such a way that, if an emission is known for a certain country, the energy use is copied to the appropriate column. For instance, The CO_2 emission for Germany is known (cell D13), but the CO_2 emission for Greece is not known (cell D14). This means that cell D43 does contain the German energy consumption, whereas cell D44 remains empty.
Row 56 contains the total energy consumption in counties with known emissions for Western Europe (Row 64 for Eastern Europe). These figures allow for the calculation of the average emission per MJ energy use. Multiplication of this figure with the total energy use provides the extrapolated total emission.

$$\text{emission} = \text{total energy use} \times \frac{\text{known emission}}{\text{energy use in countries with known emissions}}$$

The result can be found in row 67 and 68 for Western and Eastern Europe. For a number emissions there was no data from eastern Europe available at all. In these cases the Eastern European data was directly extrapolated form Western European data. The result of this extrapolation can be found in row 69. The final result is listed in row 70, together with the unit in row 71.
The normalisation values for individual emissions are converted into normalisation values for effects, using the characterisation values is annexe 3.

	A	B	C	D	E
1				**CO2**	**CH4**
2		**COMPARTMENT**		AIR	AIR
3		**YEAR**		1990	1990
4		**SOURCE**		1	2
5					table I-2.1.6
6	**COUNTRY**	**UNIT -->**		Kilo-Tonnes	Kilo-Tonnes
7	EC				
8	AUSTRIA			56500	
9	BELGIUM				355
10	DENMARK			57900	
11	FINLAND			52000	
12	FRANCE			279200	3882
13	GERMANY			1070000	
14	GREECE				
15	ICELAND				
16	IRELAND				850
17	ITALY				
18	LUXEMBURG				
19	THE NETHERLANDS			148000	1040
20	NORWAY			34500	282
21	PORTUGAL			37800	330
22	SPAIN				
23	SWEDEN			63000	2106
24	SWITSERLAND			43400	
25	UNITED KINGDOM			584800	4288
26	**Total known emissions in Western Europe**			**2427100**	**13133**
27					
28	CSSR				
29	HUNGARY			87800	
30	POLAND			440000	6066
31	ROMANIA			127100	
32	BULGARIA				
33	EX-YUGOSLAVIA				
34	**Total known emissions in Eastern Europe**			**654900**	**6066**
35					
36	**EXTRAPOLATION**	**ENERGY-USE**			
37		1988, source 1, table I 1.5.4			
38	AUSTRIA	1209.6	PJ	1209.6	
39	BELGIUM	1927.8	PJ		1927.8
40	DENMARK	798	PJ	798	
41	FINLAND	1239	PJ	1239	
42	FRANCE	8773.8	PJ	8773.8	8773.8
43	GERMANY	15573.6	PJ	15573.6	
44	GREECE	861	PJ		
45	ICELAND	71.4	PJ		
46	IRELAND	407.4	PJ		407.4
47	ITALY	6371.4	PJ		
48	LUXEMBURG	142.8	PJ		
49	THE NETHERLANDS	2709	PJ	2709	2709
50	NORWAY	1176	PJ	1176	1176
51	PORTUGAL	5359.2	PJ	5359.2	5359.2
52	SPAIN	3553.2	PJ		
53	SWEDEN	2360.4	PJ	2360.4	2360.4
54	SWITSERLAND	1180.2	PJ	1180.2	
55	UNITED KINGDOM	8757	PJ	8757	8757
56	Total energy use of countries with known emissions in Western Europe	**62470.8**		**49135.8**	**31470.6**
57			PJ		
58	CSSR	3183.6	PJ		
59	HUNGARY	1260	PJ	1260	
60	POLAND	5359.2	PJ	5359.2	5359.2
61	ROMANIA	3007.2	PJ	3007.2	
62	BULGARIA	1310.4	PJ		
63	EX-YUGOSLAVIA	1961.4	PJ		
64	Total energy use of countries with known emissions in Eastern Europe	**16081.8**	**PJ**	**9626.4**	**5359.2**
65					
66	**RESULTS**			**CO2**	**CH4**
67	Total Western Europe (extrapolated from West Europ. counties)			3.09E+06	2.61E+04
68	Total Eastern Europe (extrapolated from East. Europ. countries)			1.09E+06	1.82E+04
69	Total Eastern Europe (extrapolated from western Eur.)				
70	**Total emissions East and West Europe**			**4.18E+06**	**4.43E+04**
71		UNIT -->		Kilo-Tonnes	Kilo-Tonnes

	F	G	H	I	J	K	L	M	N	O
1	**N2O**	**CFC-11&12**	**CFC-13**	**CFC-113**	**CFC-114**	**CFC-115**	**Halon-1211**	**Halon-1301**	**CCl4**	**1,1,1-TCE**
2	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR
3	1990	1990	1990	1990	1990	1990	1990	1990	1990	1990
4	2	3	7	7	7	7	7	7	7	7
5			table pp18	table pp18	table pp18	table pp18	table pp18	table pp18	table pp18	table pp18
6	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
7		209900								
8										
9	26									
10										
11										
12	210									
13										
14										
15										
16	45									
17										
18										
19	25		3	1197	99	105	212	170	777	5540
20	16									
21	49									
22										
23	33									
24										
25	175									
26	**579**		**3**	**1197**	**99**	**105**	**212**	**170**	**777**	**5540**
27										
28										
29										
30	155									
31										
32										
33										
34	**155**									
35										
36										
37										
38										
39	1927.8									
40										
41										
42	8773.8									
43										
44										
45										
46	407.4									
47										
48										
49	2709		2709	2709	2709	2709	2709	2709	2709	2709
50	1176									
51	5359.2									
52										
53	2360.4									
54										
55	8757									
56	**31470.6**		**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**
57										
58										
59										
60	5359.2									
61										
62										
63										
64	**5359.2**									
65										
66	**N2O**	**CFC-11&12**	**CFC-13**	**CFC-113**	**CFC-114**	**CFC-115**	**Halon-1211**	**Halon-1301**	**CCl4**	**1,1,1-TCE**
67	1.15E+03	2.10E+05	6.92E+01	2.76E+04	2.28E+03	2.42E+03	4.89E+03	3.92E+03	1.79E+04	1.28E+05
68	4.65E+02									
69		5.40E+04	1.78E+01	7.11E+03	5.88E+02	6.23E+02	1.26E+03	1.01E+03	4.61E+03	3.29E+04
70	**1.61E+03**	**2.64E+05**	**8.70E+01**	**3.47E+04**	**2.87E+03**	**3.04E+03**	**6.15E+03**	**4.93E+03**	**2.25E+04**	**1.61E+05**
71	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes

	P	Q	R	S	T	U	V	W	X
1	**HCFK-22**	**HCFK 141b**	**HCFK 142b**	**CH3Br**	**Total S**	**SO2**	**NOx**	**NH3**	**PHOSPHATES**
2	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR
3	1990	1991	1990	1991	1988	1988	1988	1988	1988
4	7	7	7	7	1	1	1	1	1
5	table pp18	table pp18	table pp18	table pp18	table I-2.1.2	table I-2.1.2	table I-2.1.4	table I-2.1.5	table II-3.2.7b
6	Tonnes	Tonnes	Tonnes	Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Tonnes
7									
8					61	121.878	213	81	77528
9					207	413.586	312	94	80300
10					121	241.758	249	125	92000
11					151	301.698	276		140570
12					607	1212.786	1656	841	1459900
13					3270	6533.46	3490		992312
14								112	176420
15								3	5889
16					74	147.852	122	139	160718
17					1205	2407.59	1705	426	715459
18								6	6700
19	2120	25	1023	89	139	277.722	559	254	86257
20					33	65.934	225	41	17376
21					102	203.796	122	55	89100
22								273	462213
23					107	213.786	396	62	68200
24								61	39000
25					1907	3810.186	2642	478	433000
26	**2120**	**25**	**1023**	**89**	**7984**	**15952.032**	**11967**	**3051**	**5102942**
27									
28					1402	2801.196	965	200	460092
29					609	1216.782	259	151	347216
30					2067	4129.866	1551	55	943708
31					2400	4795.2	21	9	329296
32					1562	3120.876	388	10	258152
33					800	1598.4	480	61	261408
34					**8840**	**17662.32**	**3664**	**486**	**2599872**
35									
36									
37									
38					1209.6	1209.6	1209.6	1209.6	1209.6
39					1927.8	1927.8	1927.8	1927.8	1927.8
40					798	798	798	798	798
41					1239	1239	1239		1239
42					8773.8	8773.8	8773.8	8773.8	8773.8
43					15573.6	15573.6	15573.6		15573.6
44								861	861
45								71.4	71.4
46					407.4	407.4	407.4	407.4	407.4
47					6371.4	6371.4	6371.4	6371.4	6371.4
48								142.8	142.8
49	2709	2709	2709	2709	2709	2709	2709	2709	2709
50					1176	1176	1176	1176	1176
51					5359.2	5359.2	5359.2	5359.2	5359.2
52								3553.2	3553.2
53					2360.4	2360.4	2360.4	2360.4	2360.4
54								1180.2	1180.2
55					8757	8757	8757	8757	8757
56	**2709**	**2709**	**2709**	**2709**	**56662.2**	**56662.2**	**56662.2**	**45658.2**	**62470.8**
57									
58					3183.6	3183.6	3183.6	3183.6	3183.6
59					1260	1260	1260	1260	1260
60					5359.2	5359.2	5359.2	5359.2	5359.2
61					3007.2	3007.2	3007.2	3007.2	3007.2
62					1310.4	1310.4	1310.4	1310.4	1310.4
63					1961.4	1961.4	1961.4	1961.4	1961.4
64					**16081.8**	**16081.8**	**16081.8**	**16081.8**	**16081.8**
65									
66	**HCFK-22**	**HCFK 141b**	**HCFK 142b**	**CH3Br**	**Total S**	**SO2**	**NOx**	**NH3**	**PHOSPHATES**
67	4.89E+04	5.77E+02	2.36E+04	2.05E+03	8.80E+03	1.76E+04	1.32E+04	4.17E+03	5.10E+06
68					8.84E+03	1.77E+04	3.66E+03	4.86E+02	2.60E+06
69	1.26E+04	1.48E+02	6.07E+03	5.28E+02					
70	**6.15E+04**	**7.25E+02**	**2.97E+04**	**2.58E+03**	**1.76E+04**	**3.52E+04**	**1.69E+04**	**4.66E+03**	**7.70E+06**
71	Tonnes	Tonnes	Tonnes	Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Tonnes

	Y	**Z**	**AA**	**AB**	**AC**	**AD**	**AE**	**AF**	**AG**
1	**NITRATES**	**NMVOC**	**VOC**	**SPM**	**Disinfectants**	**Fungicides**	**Herbicides**	**Insecticides**	**Cd**
2	AIR	AIR	AIR	AIR	WATER	WATER	WATER	WATER	AIR
3	1988	1990	1988	1988	1990	1990	1990	1990	1990
4	1	2	1	1	4	4	4	4	5
5		table II-3.2.7b	table I-2.1.6		table I-2.1.5				table 8.01
6	Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
7									
8	139550		466	39					
9	180600	386			900	2160	4770	306	
10	377000				76	1555	4506	289	
11	1994499								
12	2603700	2856		284	4807	49775	36075	6657	
13	2413118		3150	2730		10151	14756	4558	
14	409216				640	10384	3411	2818	
15	11454								
16	349025	197	136						
17	924912		827	452		27934	9234	2941	
18	16400								
19	455650	460	487	93	9830	4063	3271	1554	2.4
20	110100	270	248	21					
21	665240	649	156			21288	1055	587	
22	976023				4518	33496	6360	2643	
23	209700	722	460						
24	71500			22					
25	1462000	2690	2013	533	76	5522	19625	690	
26	**13369687**	**8230**	**7943**	**4174**	**20847**	**166328**	**103063**	**23043**	**2.4**
27									
28	636207		313	1245					
29	650943								
30	1520618	1411	1000	1615					
31	662400			785					
32	427495		24	808					
33	502984								
34	**4400647**	**1411**	**1337**	**4453**					
35									
36									
37									
38	1209.6		1209.6	1209.6					
39	1927.8	1927.8			1927.8	1927.8	1927.8	1927.8	
40	798				798	798	798	798	
41	1239								
42	8773.8	8773.8		8773.8	8773.8	8773.8	8773.8	8773.8	
43	15573.6		15573.6	15573.6		15573.6	15573.6	15573.6	
44	861				861	861	861	861	
45	71.4								
46	407.4	407.4	407.4						
47	6371.4		6371.4	6371.4		6371.4	6371.4	6371.4	
48	142.8								
49	2709	2709	2709	2709	2709	2709	2709	2709	2709
50	1176	1176	1176	1176					
51	5359.2	5359.2	5359.2			5359.2	5359.2	5359.2	
52	3553.2				3553.2	3553.2	3553.2	3553.2	
53	2360.4	2360.4	2360.4						
54	1180.2			1180.2					
55	8757	8757	8757	8757	8757	8757	8757	8757	
56	**62470.8**	**31470.6**	**43923.6**	**45750.6**	**27379.8**	**54684**	**54684**	**54684**	**2709**
57									
58	3183.6		3183.6	3183.6					
59	1260								
60	5359.2	5359.2	5359.2	5359.2					
61	3007.2			3007.2					
62	1310.4		1310.4	1310.4					
63	1961.4								
64	**16081.8**	**5359.2**	**9853.2**	**12860.4**					
65									
66	**NITRATES**	**NMVOC**	**VOC**	**SPM**	**Disinfectants**	**Fungicides**	**Herbicides**	**Insecticides**	**Cd**
67	1.34E+07	1.63E+04	1.13E+04	5.70E+03	4.76E+04	1.90E+05	1.18E+05	2.63E+04	5.53E+01
68	4.40E+06	4.23E+03	2.18E+03	5.57E+03					
69					1.22E+04	4.89E+04	3.03E+04	6.78E+03	1.42E+01
70	**1.78E+07**	**2.06E+04**	**1.35E+04**	**1.13E+04**	**5.98E+04**	**2.39E+05**	**1.48E+05**	**3.31E+04**	**6.96E+01**
71	Tonnes	Kilo-Tonnes	Kilo-Tonnes	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes

	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	**Pb**	**Mn**	**Hg**	**C6H6**	**PAH**	**Sb**	**As**	**Ba**	**B**	**Cd**	**Cr(III&VI)**
2	AIR	AIR	AIR	AIR	AIR	WATER	AIR	WATER	WATER	WATER	WATER
3	1988	1990	1990	1990	1990	1990	1987	1990	1990	1990	1990
4	1	6	6	6	6	6	5	6	6	6	6
5	table I-2.1.6	table 4.1a	table 4.1a	table 4.1a	table 4.1a	table 4.2	table 8.03	table 4.2	table 4.2	table 4.2	table 4.2
6	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
7											
8	0.258										
9											
10											
11	0.45										
12											
13	3										
14											
15											
16											
17											
18											
19	0.45	22.38	2.82	737.54	183.58	0.64	1.3	1.03	31.4	3.98	16.07
20	0.28										
21											
22											
23											
24											
25	3.1										
26	**7.538**	**22.38**	**2.82**	**737.54**	**183.58**	**0.64**	**1.3**	**1.03**	**31.4**	**3.98**	**16.07**
27											
28											
29											
30	1.6										
31	0.8										
32	0.2										
33											
34	**2.6**										
35											
36											
37											
38	1209.6										
39											
40											
41	1239										
42											
43	15573.6										
44											
45											
46											
47											
48											
49	2709	2709	2709	2709	2709	2709	2709	2709	2709	2709	2709
50	1176										
51											
52											
53											
54											
55	8757										
56	**30664.2**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**
57											
58											
59											
60	5359.2										
61	3007.2										
62	1310.4										
63											
64	**9676.8**										
65											
66	**Pb**	**Mn**	**Hg**	**C6H6**	**PAH**	**Sb**	**As**	**Ba**	**B**	**Cd**	**Cr(III&VI)**
67	1.54E+01	5.16E+02	6.50E+01	1.70E+04	4.23E+03	1.48E+01	3.00E+01	2.38E+01	7.24E+02	9.18E+01	3.71E+02
68	4.32E+00										
69		1.33E+02	1.67E+01	4.38E+03	1.09E+03	3.80E+00	7.72E+00	6.11E+00	1.86E+02	2.36E+01	9.54E+01
70	**1.97E+01**	**6.49E+02**	**8.18E+01**	**2.14E+04**	**5.32E+03**	**1.86E+01**	**3.77E+01**	**2.99E+01**	**9.11E+02**	**1.15E+02**	**4.66E+02**
71	Kilo-Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes

	AS	**AT**	**AU**	**AV**	**AW**	**AX**	**AY**	**AZ**	**BA**	**BB**
1	**Cu**	**Pb**	**Mn**	**Hg**	**Mo**	**Ni**	**Ni**	**As**	**ENERGY-USE**	**WASTE**
2	WATER	WATER	WATER	WATER	WATER	WATER	AIR	WATER		
3	1990	1990	1990	1990	1990	1990	1990	1987	1988	1988
4	6	6	6	6	6	6	6	5	1	1
5	table 4.2	table 4.2	table 4.2	table 4.2	table 4.2	table 4.2	table 4.1a	table 8.0.3	table I-1.5.4	table I-2.3.3
6	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	TJ	Kilo tonnes
7										
8									1209.6	2449
9									1927.8	900
10									798	
11									1239	1285
12									8773.8	15500
13									15573.6	31623
14									861	
15									71.4	93
16									407.4	1270
17									6371.4	17300
18									142.8	170
19	17.23	17.24	500.9	0.39	2.14	20.01	4.26	56.2	2709	6500
20									1176	2000
21									5359.2	2678
22									3553.2	10600
23									2360.4	2650
24									1180.2	2850
25									8757	20000
26	**17.23**	**17.24**	**500.9**	**0.39**	**2.14**	**20.01**	**4.26**	**56.2**	**62470.8**	**117868**
27										
28									3183.6	872.2
29									1260	7000
30									5359.2	46418
31									3007.2	
32									1310.4	
33									1961.4	
34									**16081.8**	**54290.2**
35										
36										
37										
38									1209.6	1209.6
39									1927.8	1927.8
40									798	
41									1239	1239
42									8773.8	8773.8
43									15573.6	15573.6
44									861	
45									71.4	71.4
46									407.4	407.4
47									6371.4	6371.4
48									142.8	142.8
49	2709	2709	2709	2709	2709	2709	2709	2709	2709	2709
50									1176	1176
51									5359.2	5359.2
52									3553.2	3553.2
53									2360.4	2360.4
54									1180.2	1180.2
55									8757	8757
56	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**2709**	**62470.8**	**60811.8**
57										
58									3183.6	3183.6
59									1260	1260
60									5359.2	5359.2
61									3007.2	
62									1310.4	
63									1961.4	
64									**16081.8**	**9802.8**
65										
66	**Cu**	**Pb**	**Mn**	**Hg**	**Mo**	**Ni**	**Ni**	**As**	**ENERGY-USE**	**WASTE**
67	3.97E+02	3.98E+02	1.16E+04	8.99E+00	4.93E+01	4.61E+02	9.82E+01	1.30E+03	6.25E+04	1.21E+05
68									1.61E+04	8.91E+04
69	1.02E+02	1.02E+02	2.97E+03	2.32E+00	1.27E+01	1.19E+02	2.53E+01	3.34E+02		
70	**5.00E+02**	**5.00E+02**	**1.45E+04**	**1.13E+01**	**6.21E+01**	**5.80E+02**	**1.24E+02**	**1.63E+03**	**7.86E+04**	**2.10E+05**
71	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	TJ	Kilo tonnes

Annexe 3: Characterisation values

This annexe contains the characterisation values, that are used in the calculation of the indicator values and the normalisation values.

Cat.	**Substance**	**Weight factor**	**Unit**
Class: greenhouse effect, Unit GWP			
Air	1,1,1-trichloroethane	100	kg
Air	CFC (hard)	7100	kg
Air	CFC (soft)	1600	kg
Air	CFC-11	3400	kg
Air	CFC-113	4500	kg
Air	CFC-114	7000	kg
Air	CFC-115	7000	kg
Air	CFC-12	7100	kg
Air	CFC-13	13000	kg
Air	CO2	1	kg
Air	dichloromethane	15	kg
Air	HALON-1211	4900	kg
Air	HALON-1301	4900	kg
Air	HCFC-123	90	kg
Air	HCFC-124	440	kg
Air	HCFC-141b	580	kg
Air	HCFC-142b	1800	kg
Air	HCFC-22	1600	kg
Air	HFC-125	3400	kg
Air	HFC-134a	1200	kg
Air	HFC-143a	3800	kg
Air	HFC-152a	150	kg
Air	methane	11	kg
Air	N2O	270	kg
Air	tetrachloromethane	1300	kg
Air	trichloromethane	25	kg
Class: ozone depletion. Unit: ODP			
Air	1,1,1-trichloroethane	0.12	kg
Air	CFC (hard)	1	kg
Air	CFC (soft)	0.055	kg
Air	CFC-11	1	kg
Air	CFC-113	1.07	kg
Air	CFC-114	0.8	kg
Air	CFC-115	0.5	kg
Air	CFC-12	1	kg
Air	CFC-13	1	kg
Air	HALON-1201	1.4	kg
Air	HALON-1202	1.25	kg
Air	HALON-1211	4	kg
Air	HALON-1301	16	kg
Air	HALON-2311	0.14	kg
Air	HALON-2401	0.25	kg
Air	HALON-2402	7	kg
Air	HCFC-123	0.02	kg
Air	HCFC-124	0.022	kg
Air	HCFC-141b	0.11	kg
Air	HCFC-142b	0.065	kg
Air	HCFC-22	0.055	kg
Air	HCFC-225ca	0.025	kg
Air	HCFC-225cb	0.033	kg
Air	methyl bromide	0.6	kg

Air	tetrachloromethane	1.08	kg

Class: acidification, Unit: AP

Air	ammonia	1.88	kg
Air	HCl	0.88	kg
Air	HF	1.6	kg
Air	NO	1.07	kg
Air	NO2	0.7	kg
Air	NOx	0.7	kg
Air	SO2	1	kg
Air	SOx	1	kg

Class: Nutriphication, Unit: NP

Air	ammonia	0.33	kg
Air	nitrates	0.42	kg
Air	NO	0.2	kg
Air	NO2	0.13	kg
Air	NOx	0.13	kg
Air	phosphate	1	kg
Water	COD	0.022	kg
Water	NH3	0.33	kg
Water	NH4+	0.33	kg
Water	Ntot	0.42	kg
Water	phosphate	1	kg
Water	Ptot	3.06	kg

Class: heavy metals, Unit: Pb equivalent

Air	cadmium oxyde	50	kg
Air	Cd	50	kg
Air	heavy metals	1	kg
Air	Hg	1	kg
Air	Mn	1	kg
Air	Pb	1	kg
Water	As	1	kg
Water	B	0.03	kg
Water	Ba	0.14	kg
Water	Cd	3	kg
Water	Cr	0.2	kg
Water	Cu	0.005	kg
Water	Hg	10	kg
Water	Mn	0.02	kg
Water	Mo	0.14	kg
Water	Ni	0.5	kg
Water	Pb	1	kg
Water	Sb	2	kg

Class: carcinogenesis, Unit: PAH equivalent

Air	As	0.044	kg
Air	benzene	0.000011	kg
Air	benzo[a]pyrene	1	kg
Air	Cr (6+)	0.44	kg
Air	CxHy aromatic	0.000011	kg
Air	ethylbenzene	0.000011	kg
Air	fluoranthene	1	kg
Air	Ni	0.44	kg
Air	PAH	1	kg
Air	tar	0.000011	kg

Class: winter smog, Unit: SO2 equivalent

Air	dust (SPM)	1	kg
Air	SO2	1	kg
Air	Soot	1	kg

Class: summer smog, Unit: PCOP

Air	1,1,1-trichloroethane	0.021	kg
Air	1,2-dichloroethane	0.021	kg
Air	acetone	0.178	kg
Air	acetylene	0.168	kg
Air	alcohols	0.196	kg
Air	aldehydes	0.443	kg
Air	benzene	0.189	kg
Air	caprolactam	0.761	kg
Air	chlorophenols	0.761	kg
Air	crude oil	0.398	kg
Air	CxHy	0.398	kg
Air	CxHy aliphatic	0.398	kg
Air	CxHy aromatic	0.761	kg
Air	CxHy chloro	0.021	kg
Air	dichloromethane	0.021	kg
Air	diethyl ether	0.398	kg
Air	diphenyl	0.761	kg
Air	ethanol	0.268	kg
Air	ethene	1	kg
Air	ethylene glycol	0.196	kg
Air	ethylene oxide	0.377	kg
Air	formaldehyde	0.421	kg
Air	hexachlorobiphenyl	0.761	kg
Air	hydroxy compounds	0.377	kg
Air	isopropanol	0.196	kg
Air	ketones	0.326	kg
Air	methane	0.007	kg
Air	methyl ethyl ketone	0.473	kg
Air	methyl mercaptane	0.377	kg
Air	naphthalene	0.761	kg
Air	non methane VOC	0.416	kg
Air	PAH	0.761	kg
Air	pentane	0.408	kg
Air	petrol	0.398	kg
Air	phenol	0.761	kg
Air	phthalic acid anhydride	0.761	kg
Air	propane	0.42	kg
Air	propene	1.03	kg
Air	propionaldehyde (propanal)	0.603	kg
Air	styrene	0.761	kg
Air	terpentine	0.377	kg
Air	tetrachloromethane	0.021	kg
Air	toluene	0.563	kg
Air	trichloroethene	0.066	kg
Air	vinylacetate	0.223	kg
Air	vinylchloride	0.021	kg
Air	VOC	0.398	kg
Air	xylene	0.85	kg

Class: pesticides Unit: Active substance

Water	desinfectants	1	kg
Water	fungicides	1	kg
Water	herbicides	1	kg
Water	insecticides	1	kg

Annexe 4: Data sources for inventories.

The annexe report 9510A contains a full specification of the impact tables used to calculate the Eco-indicators. Since this version is only available in Dutch, we included a short list with data references in this report. The following tables contain a code in the second column representing the data source used. The third column contains some additional specification or a source that is only used once or twice. Sources printed in italics refer to commercial companies. The codes used in the second column should be read as:

B	Habesatter *et al.* Oekobilanz von Packstoffen Stand 1990 *[Environmental audit of packaging materials, as at 1990]*, ETH Zurich, Buwal publication 132, 1991, Bern, Switzerland.
bj	Bergh en Jurgens, Milieueffecten van Verpakkingsmaterialen [Environmental Impacts of Packaging Materials]; Rotterdam; August 1990
E	Frischknecht, R.; Hofstetter, P.; Knoepfel, I.; Ökoinventare für Energy Systeme [Environmental inventories for energy systems]; ETH Zurich, March 1994.
S	SPIN project: a series of publications. The authors are indicated in the tables below. Information: RIVM LAE, Bilthoven, The Netherlands.
v H	van Heijningen, R.J.J.; Castro de, J.F.M.; Meer energiekentallen in relatie tot preventie en hergebruik van afvalstromen; NOH 1992
HE	Reijnders, Handbook of emission factors, Government Publishing house, The Hague 1993
K	Kemna, R.B.J.; Energiebewust ontwerpen, TU Delft, 1981, herdruk 1992
P	PWMI, Ecoprofiles on the European Plastics Industry, PWMI 1993-95

Production of metals

	Source	**Specification**
Secondary aluminium	**bj**	
Aluminium	**B**	
Copper, primary	**E**	
Copper, 60% primary		interpolation
Secondary copper	**E**	
Other non-ferrous metals		estimate
Stainless steel	**S+E**	+ World resources [40]+ Metals and Minerals 1992
Secondary steel	**B**	
Steel	**B**	
Sheet steel	**B**	

Processing of steel

	Source	**Specification**
Bending steel	**K+S**	Spin: Roos, B; Metaalbewerking; RIVM
Bending stainless steel	**K+S**	Spin: Roos, B; Metaalbewerking; RIVM
Cutting steel	**K**	
Cutting stainless steel	**K**	
Pressing and deep-drawing	**K**	
Rolling (cold)	**K+S**	Spin: Huizinga, K.; Non ferro walserijen; RIVM; 1992
Spot-welding	**K**	
Machining	**K**	
Machining (per volume)		Calculated
Hot-galvanising	**S**	Meijer, R.P.B.; Thermisch verzinken; RIVM; 1992
Electrolytic galvanising	**K**	+ Mortier, J.W.; Galvanische processen, 1992
Electroplating (chrome)	**K**	+ Mortier, J.W.; Galvanische processen, 1992

Processing of aluminium

	Source	Specification
Blanking and cutting	**K**	
Bending	**K+S**	Spin: Roos, B; Metaalbewerking; RIVM
Rolling (cold)	**K+S**	Spin: Huizinga, K.; Non ferro walserijen; RIVM; 1992
Spot-welding	**K**	
Machining	**K**	
Machining (per volume)		Calculated
Extrusion	**K**	

Production of plastic granulate

	Source	Specification
ABS	**vH+HE**	
HDPE	**P**	
LDPE	**P**	
Natural rubber		based on "Emmissie registratie" compiled by Remmerswaal; TU Delft
PA	**bj**	
PC	**no source**	extrapolated using the energy requirements as basis
PET	**P**	
PP	**P**	
PPE/PS		based on "Emissieregistratie", compiled by Remmerswaal; TU Delft
PS rigid foam	**P**	
PS high impact (HIPS)	**P**	
PUR	**E**	+ Chemiewinkel, University of Amsterdam, 1994
PVC	**P**	

Processing of plastics

	Source	Specification
Injection mould. in general		Mulder, S; Energiebesparing spuitgietmachines; Kunststof en Rubber 9; 1994
Inject. mould. PVC & PC		Mulder, S; Energiebesparing spuitgietmachines; Kunststof en Rubber 9; 1994
RIM, PUR		*Recticel*
Extrusion blowing PE		*internal Procter and Gamble LCI spreadsheet, 1994*
Vacuum forming		*Nelipak Venray B.V.*
Vacuum pressure forming		*Nelipak Venray B.V.*
Calandering of PVC	**K**	
Foil blowing PE		*internal Procter and Gamble LCI spreadsheet, 1994*
Ultrasonic welding		*Philips CFT*
Machining	**K**	

Production of other materials

	Source	Specification
Glass	**B**	
Glass wool and glass fibre	**S**	Loos; De productie van glas en glaswol; RIVM; April 1992.
Rockwool	**S**	Kaskens, H.J.M et al; Produktie van steenwol; RIVM; Januari 1992
Ceramics	**S**	Huizinga, K; Fijnkeramische industrie; RIVM; July 1992
Cellulose board	**B**	
Paper	**B**	
Recycled paper	**B**	
Wood		H. Boorsma; Houtvademecum; Centrum Hout; Almere 1990
Cardboard	**B**	

Production of energy

	Source	**Description**
Electricity high voltage	**E**	
Electricity low voltage	**E**	
Heat from gas (MJ)	**B**	
Heat from oil (MJ)	**B**	
Mechanical (diesel, MJ)	**B**	

Transport

	Source	**Specification**
Truck (28 ton)	**E**	
Truck (75m^3)		calculated
Train	**E**	
Container ship	**E**	
Aircraft		Emissieregistratie 1990, compiled by Remmerswaal; TU Delft; + Fuel consumption and emissions of air traffic 1990; Olivier, J.;Inventory of Aircraft emissions; RIVM 1991.

Waste processing and recycling

	Source	**Specification**
All data on waste		taken form SimaPro 3.0; based on data from the AOO [Waste Consulting Body in the Netherlands]