LCA Methodology

The Eco-Indicator 98 Explained

[1]Mark Goedkoop, [2]Patrick Hofstetter, [3]Ruedi Müller-Wenk, [1]Renilde Spriemsma

[1] PRé Consultants, Plotterweg 12, 3821 BB-Amersfoort, The Netherlands; email: Goedkoop@pre.nl, URL: www.pre.nl
[2] ETH-UNS, ETH Zentrum HAD F1, CH 8092 Zurich, email: hofstetter@uns.umnw.ethz.ch
[3] IWÖ-HSG, Tigerbergstrasse 2, CH 9000 St. Gallen, email: Ruedi.mueller-wenk@IWO.UNISG.CH

Abstract

The Eco-Indicator 98 project aims at a complete revision of the Eco-Indicator 95 methodology. Like its predecessor, the target is to develop single scores for designers. The method now includes resources and land use. Important improvements are: the use of fate analysis, the much better definition of the damage categories concerned with human health and ecosystem health, using the PAF (Potentially Affected Fraction) and DALY (Disability Adjusted Life Years) concept, and a completely new approach to modelling resources and land use. Perhaps the most fundamental improvement is the management system for value choices. The result of this management system is that there will be three instead of one indicator. Each version is based on a different cultural perspective. The method should be updated continuously. It is proposed to set up an independent organisation to guide this future development.

Keywords: DALY concept; damage categories; Disability Adjusted Life Years (DALY); Eco-Indicator 98; ecosystem health; fate analysis; human health; land use; management system for value choices; modelling resources and land use; PAF concept; Potentially Affected Fraction (PAF); resources, supply of; safeguard subjects

1 Introduction

This paper gives an overview of the Eco-Indicator 98 methodology that is currently being developed by an international group of LCA and environmental experts under commission of the Dutch Ministry for Environment. (VROM) with co-financing by the Priority Programme Environment sponsored by the Swiss National Science Foundation. The Eco-Indicator 98 project aims to review and improve the Eco-Indicator 95 impact assessment methodology (GOEDKOOP, 1995). The aim is the same, to develop a method to express the total environmental burden of a process in a single score. The method is intended for internal use in companies, especially for product development applications. If the Eco-indicator 98 is used in an LCA application, which has to be in accordance to the upcoming ISO 14042, then the assessment result should be restricted to internal use.

Before the end of 1998, a detailed methodology report will be made available. This report is followed by a "Manual for Designers" that will contain a new list of about 150 Standard Eco-Indicator scores for commonly used materials and processes, as well as a description of the application and the limitations of the method. As the development is in the final stages of completion, but not yet completed, the final methodology description may differ from this paper.

The methodology presented here is the result of the work of many specialists. The contributors are all listed in the annexe.

1.1 The Eco we indicate

The development of an Eco-Indicator methodology is not possible without a clear definition of the term environment. In our society, "environment" is used in many different contexts. In fact, the word is a mental construct with which we mean a very large range of effects.

After considerable studies on possible definitions, we define the term environment as:

.... *a set of biological, physical and chemical parameters influenced by man, that are conditions to the functioning of man and nature. These conditions include human health, ecosystem health and sufficient supply of resource.*

Other definitions are also possible, but lead to a different methodology. For instance, we could have substituted resources for "material welfare", but we have chosen to consider material welfare as an issue for economists.

From this definition, we conclude that there are basically three items that need protection:

- Human health
- Ecosystem health
- The resource base

We named these three items damage categories. Other terms could have been Safeguard Subjects, as is done by (STEEN et al., 1992), Endpoints, such as is done in the current ISO discussion, or the very objective term Change Categories, as we should first calculate the changes and then attach a positive or negative value to them.

Int. J. LCA 3 (6) 352 – 360 (1998)

1.2 "Less is better" or "only above threshold"

Traditionally, LCA is based on the "less is better" approach. This means impacts are assessed on their potential effect and not on their actual effects. Calculating actual effects is possible when more information is available, for instance, on background concentration or exposure. Several studies have shown that the site dependent factors are very important if we want to base our assessment on real damages (POTTING et al., 1998).

The problem is that temporal and spatial information is lacking in almost all LCAs. This means that if we want to assess the real damage caused by a product, we should assess every emission (i.e. from every power plant of a power grid), taking into account the local and temporal characteristics. This would increase the data amount beyond practicable limits.

Our solution is that we develop a model for assessing the average damage in Europe. This means that instead of looking into specific conditions for each emission, we look at the average conditions in a region as large as Europe. This also means that we assume that every emission is diluted instantly all over Europe. This compromise is a coarse approximation, as we are aware that the differences in Europe are extremely big. However, without this "solution", it is presently impossible to use the damage modelling approach.

Although we develop this methodology especially for Europe, there are no fundamental reasons that would restrict the applicability to other regions. Preliminary studies have been made on adapting the method on Japan and Colombia (GOMEZ, 1998). If we could achieve developing models for a dozen regions in the world, we could assess each industrial process in its own region, taking into account the specific sensitivities of the environment on the continental scale. Later, the method could be refined and adapted to smaller scales. Ultimately, it must be possible to combine the LCA approach with very site-specific conditions.

2 The Core Concept of the Damage Approach

The Eco-Indicator score should somehow represent the perceived seriousness of the environmental load of a product. Perceived seriousness is subjective by definition, as the seriousness of something is very much dependent on values.

The problem is that natural science cannot determine what the term "seriousness" means. This does not mean there is no role for natural science. On the contrary, the role is very important. We need natural science to be able to calculate the relation between the impacts from a product lifecycle and the damages resulting from this.

The Eco-Indicator methodology thus consists of two parts (→ *Fig. 1*):

1. Natural science is used to calculate changes in the environment caused by the environmental flows from a product lifecycle.

2. A weighting procedure is used to establish the seriousness of these changes. In the text these changes are referred to as damages.

The method is developed in a modular way. Different value systems can be incorporated and it is possible to modify or replace the building blocks used in the natural science part.

Although the first part of the modelling is dominated by natural science, it is also not free of subjectivity. In the design of the modelling, we are confronted with choices that have subjective elements. Instead of trying to suppress or

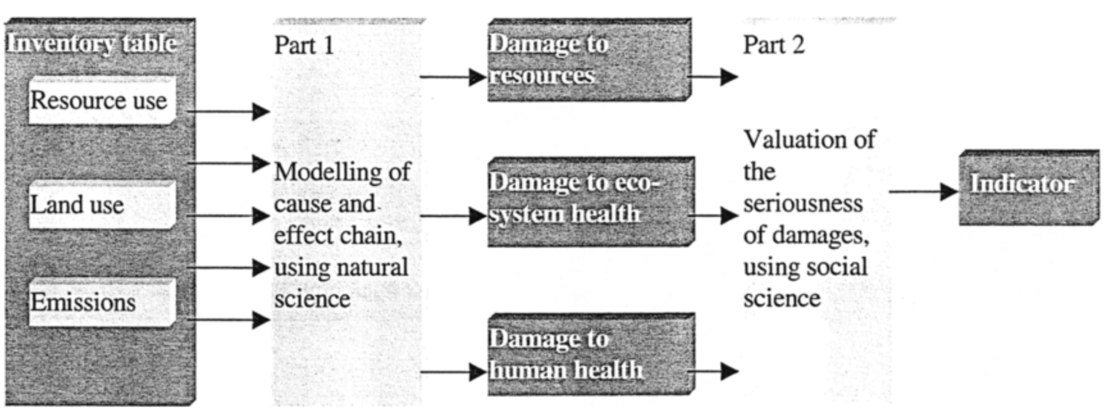

Fig. 1: The core concept of the Eco-Indicator 98 methodology. There are two parts. In the first part, the best available scientific information is used to calculate the average damages caused by an inventory table. In the second part, societal preferences are used to assess the seriousness of the damage

eliminate the subjective elements, we try to MANAGE them using methods developed in social science.

3 Modelling the Damages

As explained before, the first part of the method is to link the emissions, the land use and the resource extractions in an inventory table to potential damages. We use four different procedures to establish this link:

1. Fate analysis, which establishes the relation between an emission (mass) and a temporary concentration increase
2. Resource analysis, which establishes the relation between a resource extraction and the effect on the concentrations
3. Impact analysis, once we have established the concentrations, we analyse to which extent a substance contributes to an impact
4. Damage analysis, which establishes the relation between the impact categories and the damage to human health, ecosystem health and resources

Figure 2 gives an overview of the whole method and shows the position of the four analysis types.

3.1 Fate analysis

An important feature, or rather a limitation, of the inventory table is the lack of spatial and temporal information. Lead emissions that occur in the raw material extraction phase are added to lead emissions that occur from electricity generation (in a usually large number of power plants). Next they are added to emissions from leachates from the future decomposition of products in many landfills over hundred or more years. This means we only know the total quantity of an emission, without knowing when and where the emissions occur and what the concentrations in the environment are. The only limitation we make is that the emissions are supposed to be released within Europe.

In the Eco-Indicator 98 methodology, we use the European Uniform System for the Evaluation of Substances (EUSES: JAGER et al., 1996) (→ *Fig. 3*). This model is the follow-up of the USES model that was applied by (GUINÉE et al., 1996). Unlike the earlier model, all defaults can be set by the user. Furthermore the system comes with a number of defaults that are accepted by the European Commission to be proper averages for the European environment.

EUSES is not really meant for LCA applications. This means that we had to find solutions for the following problems (SPRIENSMA, 1997):

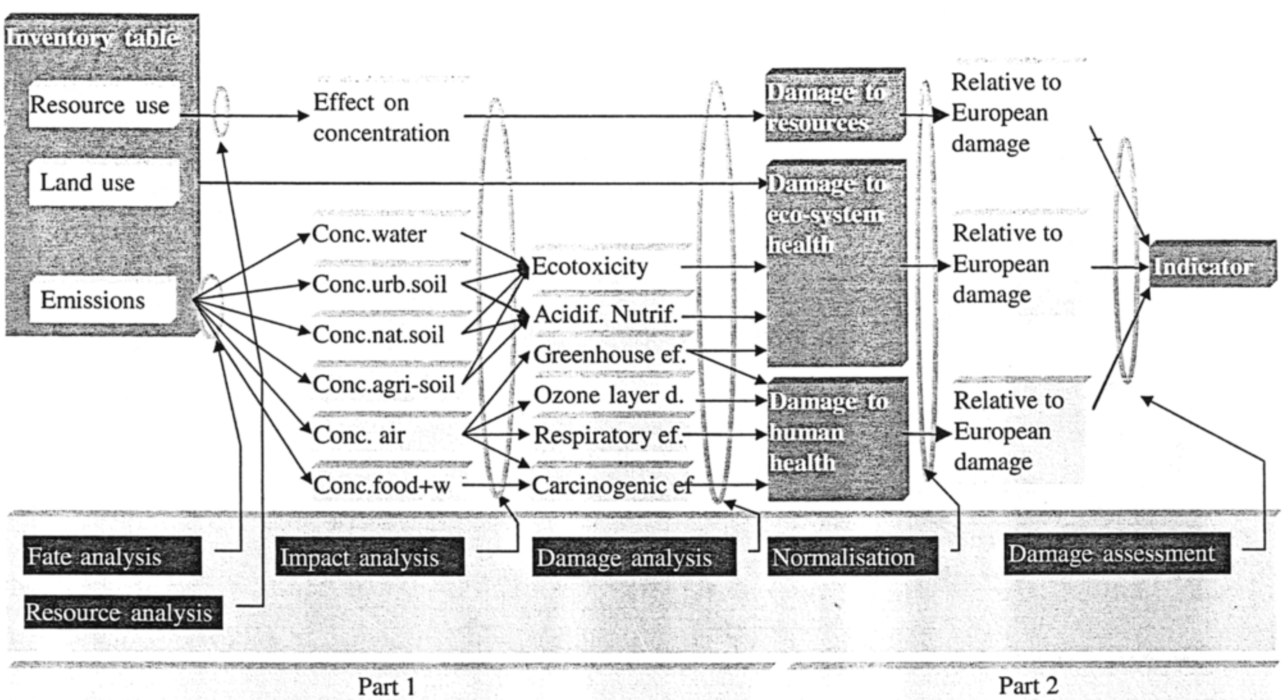

Fig. 2: General representation of the methodology. The boxes below refer to procedures, the other boxes refer to (intermediate) results as they will be made explicit in the method

- A fate model can calculate concentrations that are the result of a steady state flow. In the inventory table, only mass-loadings are specified. We solved this with an allocation procedure that translates the massloading into a temporal concentration increase. This is another approach then presented in (GUINÉE et al., 1996).

- EUSES is made for organic substances, and not for inorganic substances or dust. We found that the behaviour of heavy metals in air can best be described with measured deposition velocities. (HOFSTETTER, 1998)

- EUSES uses three nested compartments, a local, a regional and a continental scale. We use the regional scale. Normally, the regional scale is open. The wind and the runoff transfer emissions out of the regional scale. For LCA, such a transfer is not permitted as this would mean parts of the emissions get lost. This meant we have to minimise the wind speed and the runoff in the model. However, these artificial settings influence the inner workings of the model. Especially the build-up of heavy metals in soil and water are distorted.

3.2 Resource analysis

In the Eco-Indicator 98 methodology we only model mineral resources and fossil fuels. The use of agricultural and silvicultural biotic resources and the mining of resources such as sand or gravel, are considered to be adequately covered by the effects on land-use.

In the case of non-renewable resources (minerals and fossil fuels), it is clear that there is a limit to the resources. However, it is also clear that it is extremely difficult to determine how large the resources are, simply because industry does not explore new resources if the known resources can cover several decades; furthermore, the resource estimates are heavily influenced by political considerations (CAMBELL and LAHERRÈRE, 1998). Another obstacle is that the depletion of a single resource does not have to be a big problem if this resource can be substituted by another resource.

Because of these problems, the Eco-Indicator 98 methodology does not consider resource quantity, but resource quality. We have chosen to take the average resource concentration as the indicator for the resource quality. This means that the result of the resource analysis is very comparable to the fate analysis, instead of modelling the increase of the concentration of pollutants, we model the decrease of the concentration of mineral resources.

In geo-statistic models, it is generally accepted that the distribution of concentrations of mineral resources is log-normal if we plot quantities against grade. This phenomenon is sometimes referred to as Laski's law. Although real proof for this relation is not easy to provide, an illustrative example for the case of uranium is available from Deffeyes (DEFFEYES, 1964). Deffeyes also presents data on the distribution of other resources. This data, which is critically analysed in (MÜLLER-WENK, 1998-1), forms the basis for the resource analysis.

3.3 Impact analysis

For some, but not all, impact categories it is useful to include an impact analysis step. The procedure is known in the LCA methodology as classification (grouping) and characterisation (addition using equivalence factors). The result is a number of impact categories.

In other cases it appears to be best to model the damages for individual substances directly, without using a characterisation. Only in the case of greenhouse effect and ozone layer depletion it turns out to be useful to use equivalence factors.

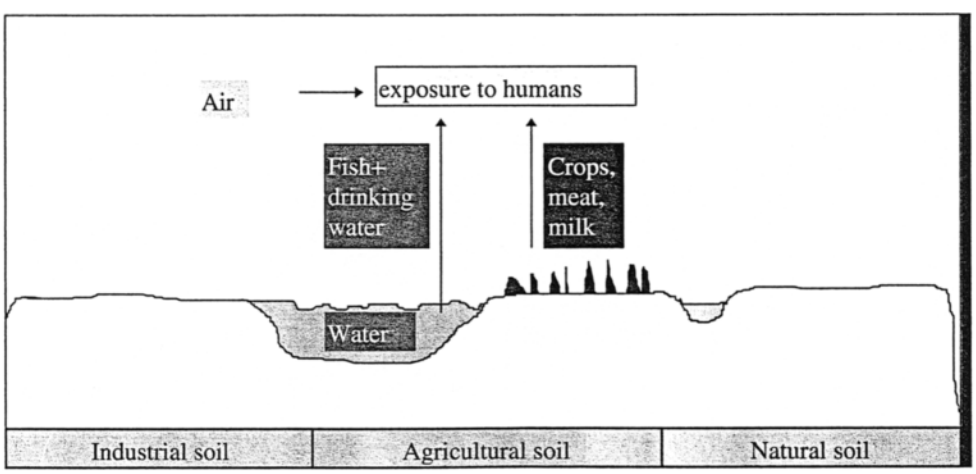

Fig. 3: Representation of the EUSES model

However, to enhance the compatibility of our method with other LCIA methods, we will present the values for the impact categories as an intermediate result. Only for eutrophication and acidification this specification is not possible as these effects cannot be separated in damage modelling.

3.4 Damage analysis

Damage analysis is one of the most extensive parts of the methodology. It links the impact categories to the three damage categories:

1 Damage to human health
2 Damage to ecosystem health
3 Damage to resources

The process can at best be understood when we start with the description of the exact definition of the damage categories.

3.4.1 The human health damage category

We consider the links between human health and emissions causing respiratory effects or cancer, the ozone layer effect, and the greenhouse effect. We assume the links to other impact categories are of lower importance.

When we follow the cause and effect chain, we will see that there are a large number of health effects, important health damages are caused by carcinogenity and respiratory effects. All these effects cause a certain level of disability, probably ranging from a cough, to an asthma attack, a period of serious suffering due to cancer or even premature death.

If we want to have a single indicator for human health we need to be able to weight these different disabilities. We have chosen to use the DALY (Disability Adjusted Life Years) scale, which has been developed by (Murray and Lopez, 1996) for the WHO and Worldbank. The original purpose was to have a tool to analyse the rationale of national health budgets.

The core of the DALY system is a disability weighting scale. This scale has been developed in a number of panel sessions. The scale lists about 20 different disabilities on a scale between 0 and 1 (= death).

Example
Carcinogenic substances cause a number of deaths each year. In the DALY health scale, death has a disability rating of 1. If a type of cancer is on average fatal ten years prior to the normal life expectancy, we would count 10 lost life years for each case.

This means that each case has a value of 10 DALY's.
During a summer smog period, many people have to be treated in hospital for a number of days. This type of treatment in a hospital has a rating of 0.392 on the DALY scale. If the hospital treatment lasts 0.01 years on average (3.65 days), each case would be weighted 0.004 DALY's.

With this system, we can calculate the number of Disability Adjusted Life Years if we know how many people in Europe are exposed to a background concentration above threshold levels in air, drinking water and food.

Hofstetter, who has studied the use of DALY's in LCA, supplies most data for respiratory and carcinogenic effects. Next to this data, we use the proposal of Frischknecht and Braunschweig (Frischknecht, 1998), to include the effect of nuclear radiation. This impact category can also be used to include the effects of ozone depletion.

Estimating the health effects of the greenhouse effect proves to be a very difficult matter, as there are large uncertainties as to the consequences of this effect. As a temporary solution, we have based our findings on the ExternE project (ExterneE: Mayerhofer et al., 1997).

3.4.2 The ecosystem health damage category

Eco-systems are very complex, and it is very difficult to determine all damages inflicted on them. An important difference with human health is that even if we could, we are not really concerned with the individual organism, plant or animal. The species diversity is usually much more of a concern. This means we cannot use the DALY concept. Instead, we express the ecosystem damage as a percentage of species that are threatened or that disappear from a given area.

We have looked for a parameter that only describes the threat to lower organism species such as algae, worms and plants. The assumption is that these are good proxies for the total ecosystem health. The lower organisms are at the start of the food chain in all ecosystems. If their health is affected, all species will suffer.

For ecotoxicity, we will use a method recently developed by RIVM for the Dutch Environmental Outlook (Meent and Klepper, 1997). This method determines the Potentially Affected Fraction (PAF) of species in relation to the concentration of toxic substances. The PAF's are determined for the lower organisms, like worms, algae and other lower organisms in soil or water. It can at best be described as a cumulative combination of NOEC values for a number of species. The higher the concentration, the larger the number of species is affected. The PAF damage function has a typical shape as shown in **Figure 4**.

The steepness of the curve depends on the background concentration. However, instead of using the background concentration, we determine a work point on the vertical axis. This work point is the total combined PAF or COMBI-PAF in Europe.

The procedure to calculate ecosystem health damage can be described as follows:

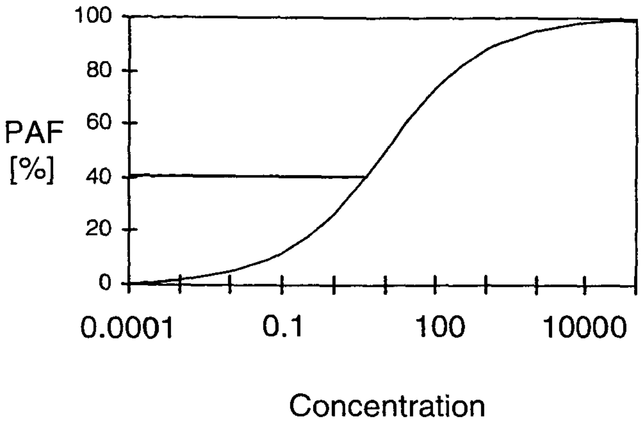

Fig. 4: A logistic PAF-curve expressing the potential affected fraction of species at different concentrations of a substance

- Determine the PAF function for each emission.
- Determine the temporary, marginal increase of the concentration from the fate model.
- Determine the marginal damage from this increase using the slope of the PAF function at the workpoint.

Being based on NOEC, A PAF does not necessarily produce observable damage. Therefore, even a high PAF value of 50% or even 90% does not have to result in a really observable effect.

For Acidification and Nutrification, we cannot use the PAF concept directly, as the link between these impact categories and NOECs for lower organisms is not a good proxy for damage. Instead, we will have to look at the effects of plants. Another problem is that we cannot use a NOEC for plants; instead we must look at the chance that a plant species still occurs in an area. This is called the Probability Of Occurrence or POO (WIERTZ, 1992). Perhaps surprisingly for the LCA community, it turns out that it is impossible to separate the damages caused by acidification and eutrophication in damage modelling. We can only establish a link between the POO and the deposition of Ammonia, Sulphates and Nitrates, but we cannot see if plants disappear from nitrification or acidification. When the POO is plotted against the deposition of these substances, we get a similar, but inverse curve as in **Figure 4**. A similar calculation is in principle also possible for a relation between POO and CO_2 concentrations, it is yet however unclear if sufficient reliable data will be available.

To establish the POO in relation to these effects, we can use one of the several plant data bases. A particular difficulty is to weight the POO and PAF result. We will have to make an assumption on comparable damage levels expressed in really threatened species and species affected by a toxic stress.

For land use, we will use the percentage of plant species that are threatened as an indicator. (MÜLLER-WENK, 1998-2) and (KÖLLNER, 1998) have shown that there are two effects when land is converted. The species diversity on the land itself, but also the species diversity on the remaining land is influenced.

It is a commonly accepted fact that the species diversity in an area is not only a function of the area quality, but also on the area size. This means that the reduction or enlargement of natural areas in a region will directly influence the number of species in the whole region.

In the LCA field, there is a debate whether land-use changes or land occupation should be modelled. We will do both. If land is transformed, the restoration time must be included. If land was already transformed, but is used for a year, we only count one year.

3.4.3 The resources damage category

The data of DEFFEYES (explained in the resource analysis) has been used by Chapman and Roberts (CHAPMAN and ROBERTS, 1983) to develop an assessment procedure for the seriousness of resource depletion. They developed a method in which the energy needed to extract a resource is analysed in relation to the concentration. The basic idea is that the energy requirement to extract a resource is ultimately the limiting factor for the resource availability. They take into account two trends:

1 The increase in energy consumption due to the fact that resource concentration decreases

2 The decrease in energy consumption due to the expected considerable efficiency increases in mining techniques.

In short, they state that, although there is a fundamental limit to the efficiency increase, the concentration decrease will continue forever if we assume the log-normal distribution is correct. This means that there will be an energy decrease for many decades to come for all minerals, followed by an energy increase due to the lowering of the concentrations.

Müller-Wenk (MÜLLER-WENK, 1998-1) has proposed to use the so-called surplus energy, that is the additional energy that is needed to compensate for the future decrease of concentrations. He argues that it is not appropriate to include the expected efficiency increase, as this is never done in LCA.

In our project, we intend to follow the approach of MÜLLER-WENK, this means that resource depletion is expressed as surplus energy, per kg extracted pure mineral or fossil fuel.

4 Modelling Subjectivity

In the previous chapter, we have shown how we can calculate the damage to the three damage categories human health, ecosystem health and resource quality. In this process, we can use the best available natural science. However, as we indicated in the introduction, we cannot use natural science to determine how serious this damage is perceived. Furthermore, we have experienced that the so called natural science part is not free of values either.

For instance, if we want to assess the damage caused by carcinogenic substances, we will see that there are 3 groups in the IARC classification. Group one contains the substances for which the carcinogenic effect is proven, while group 3 contains only substances for which there is a suspicion that they are carcinogenic. The question of course is, which groups do we take into account. If we follow the precautionary principle, we would include all groups. If we were very pragmatic and we were to believe only in "hard scientific facts", we would probably only take group 1 and 2.

This example can be complemented by several other problems we have run into during the development work. We have to make subjective choices and we must be aware of this. Our solution is not to stop thinking when we encounter such a choice but to set up a management system for the subjectivity in each step.

4.1 Cultural theory as a modelling tool for subjectivity

Hofstetter (HOFSTETTER, 1998) has analysed the problem of modelling subjectivity thoroughly and he proposes to use the Cultural Theory (THOMPSON et al., 1990) to distinguish five basic value systems. Thompson derives these value systems by looking at the strength of the relation people have with their group and the degree an individual's life is circumscribed by externally imposed prescriptions. The viable combinations of the position of each individual in this group-grid typology and their cultural bias are called way of life. The assumption is that these viable combinations have a large influence on the value system of individual's and their groups.

These value systems have been used by several authors in risk perception studies. Experiences show that this distinction is very valuable in explaining peoples attitudes. Please note the theory does not say there are only five types of people. Almost nobody really conforms to the properties of a single group. People can switch between different attitudes dependent on their context.

HOFSTETTER proposes to use only the three perspectives actively participating in societal decision making

1. Individualists
2. Egalitarians
3. Hierarchists

The basic attitudes related to these value systems are summarised in **Table 1**.

When we look at this table, we can see that the so called egalitarians would include all substances suspected to be carcinogenic, while for instance individualists would demand that there is strong evidence for carcinogenity in humans. The latter would include only group one of the carcinogenic substances in their decision support system. We have made similar assessments when we encountered other subjective choices in the modelling.

4.2 Weighting

We intend to use a panel method to set the weights between the three damage categories. The procedure will consist of three steps. The first and third steps are based on panel sessions with small groups . The second step uses a written questionnaire for a large group. A more sophisticated three-step procedure suggested by (BRUNNER, 1998) may be used in a next phase.

Earlier experiences (KORTMAN et al., 1994) and (HOFSTETTER in chapter 8 in BRAUNSCHWEIG et al., 1996) show that the behaviour of each panel is very much determined by the basic value system a person is using. This is the second area where we will use cultural theory.

Table 1: Typical values in the three different perspectives (THOMPSON et al., 1990).

	Egalitarian	**Individualist**	**Hierarchist**
Perception (myth) of nature	Nature ephemeral	Nature benign	Nature perverse/tolerant
Perception of human nature	Born good, malleable	Self-seeking	Sinful
Perception of needs and resources	Can manage needs, but not resources	Can manage needs and resources	Can manage resources, but not needs
Attitude to nature	Attentive	Laissez faire	Regulatory
Attitude towards humans	Construct egalitarian society	Channel rather then change	Restrict behaviour
Attitude towards resources	Need reducing strategy	Manage needs and resources	Increase resources
Attitude towards risk	Risk aversive	Risk seeking	Risk accepting

We intend to specify the answers in the questionnaires according to these value systems. In order to do this, we will ask each panel member a number of additional questions to get information on their basic values. The result of the panel procedure is thus three sets of valuations, one for each value system.

The benefit of this approach is that we can specify the relation between the value system and the result of the indicator methodology. Experiences with earlier value setting procedures suggest that people that adhere to a certain value system tend to agree in their opinions. This means that the uncertainty is relatively low within the same value system.

4.3 Three instead of one result

The use of cultural theory has wide implications for the methodology and the user. The most visible effect is that we will not have one result but three. We intend to develop the methodology in three different versions (HOFSTETTER, 1998):

1. In the *individualist version*, we will choose to include only proven cause effect relations, when we have the choice we will use the short-term perspective.
2. In the *hierarchical version* we will also choose to include facts that are backed up by scientific and political bodies with sufficient recognition. The hierarchical attitude is rather common in the scientific community. For insiders: a nice example is the current debate in the SETAC and ISO discussions on LCIA.
3. In the *egalitarian version*, we will consistently use a precautionary principle. We will try not to leave anything out and if in doubt we will include it and we will use the very long time perspective. The final weighting will be set according to the views of the egalitarians in the panel. It will be clear that this version is the most complete version, but it will also have the largest uncertainties.

As a consequence, we will not have a single score for a material or process, but we will have three scores depending on the perspective. This may seem like a nuisance to the user, but it actually correctly reflects the fact that the judgement of environmental problems is not objective. By presenting three choices to the user, the user can choose the most adequate perspective. Of course it is possible to make an average of the three perspectives. It is even possible to make a weighted average, as there is data on the distribution of people with a certain perspective for many European countries. However, one must be aware that the average has a rather limited meaning. It is the average of fundamentally different views. We think the best solution would be to present the results of any design alternative for the three perspectives. If all perspectives give the same conclusion, we know our answer is robust. If one of the perspectives is different, we can say that the answer depends on the perspective.

5 Conclusions and a Proposal

The new methodology introduces many new concepts. The most important innovations are:

- The consistent use of cultural perspectives to manage subjectivity. Leading to three different indicators, depending on the cultural perspective
- The modelling of the cause and effect chain for all impact categories until the damage categories or endpoints
- The modelling of resource depletion, using geostatistical models
- The modelling of land use, taking into account the effects on the remaining area of land
- The use of DALY and PAF approaches for human and ecosystem health
- The consistent development of a panel procedure using a large panel

The proposed methodology is not perfect and never will be. There is a constant need for updating as our understanding of the damage modelling and our assessment of the seriousness of the damages will continually evolve. There is a need for a continuous improvement of the methodology, and we hope to be able to develop new versions in future.

To guide this process, M. Goedkoop has taken the initiative to set up an Eco-Indicator Society. Industries, governments and scientists should steer and support this international society and they should develop a policy for further development and for public relations, as it is very important to clearly communicate the intended application of the methodology: a tool for designers, nothing more and nothing less.

6 References

BRAUNSCHWEIG, A; FÖRSTER, R; HOFSTETTER, P; MÜLLER-WENK, R. (1996): Developments in LCA Valuation. IWOE Diskussionsbeitrag Nr. 32, St. Gallen

BRUNNER, ST. (1998): Panel Methods and their Application for Weighting in LCA. UNS Working Paper for the Project Environmental Prioritising within the Framework of the Swiss Priority Programme Environment; ETH Zurich

CHAPMAN, P.F.; ROBERTS, F. (1983): Metal Resources and Energy. Butterworths Monographs in Materials

CAMBELL, C.J.; LAHERRÈRE, J.H. (1998): The End of Cheap Oil. Scientific American, March 1998, pp 60-65

DEFFEYES, K. (1964): Uranium Distribution in Mined Deposits and in the Earth Crust. Department of Energy, Grand Junction Colorado; see also Scientific American 242, 1980, p 50

EUSES (1996): JAGER, D.T. et al.: EUSES the European Union System for the Evaluation of Substances. National Institute of Public Health and the Environment (RIVM), The Netherlands; Available from the European Chemicals Bureau (EC/JRC), Ispra, Italy

ExternE (1997): Core project. Extension of the Accounting Framework; Final Report, Compiled by MAYERHOVER, P.; KREWITT, W.; FRIEDRICH, R. The European Commission, Contract JOS3-CT95-0002 Stuttgart (available on www.ExternE.jrc.sp)

FRISCHKNECHT, R. (1998): Life Cycle Inventory Analysis for Decision Making. Dissertation ETH Nr. 12599, ISBN 3-9520661-3-3, ETH Zurich

GOEDKOOP, M.J. (1995): De Eco-Indicator 95. Final report; NOH report 9523; PRé Consultants; Amersfoort (NL); ISBN 90-72130-77-4

GOMEZ, J.D. (1998): Approach for the Use of the Eco-Indicator 98 Concept in Latin America. MSc Thesis; IHE; Delft

GUINÉE, J. et al. (1996): LCA Impact Assessment of Toxic Releases. Product Policy Report 1996/21, Ministry of Environment (VROM), The Hague

HOFSTETTER, P. (1998): Perspectives in Life Cycle Impact Assessment; A Structured Approach to Combine Models of the Technosphere, Ecosphere and Valuesphere., Kluwers Academic Publishers, 1998, Info: www.wkap.nl/book.htm/07923-8377-XKORTMAN, J.G.M.; LINDEIJER, E.W.; SAS, H.; SPRENGERS, M. (1994): Towards a Single Indicator for Emissions. IDES (IVAMer) Amsterdam

KÖLLNER, T. (1998): Life-Cycle Impact Assessment for Land Use. Effect Assessment Taking the Attribute Biodiversity into Account. IWÖ Discussion Paper, unpublished first draft, 29.8.98, University St. Gallen

MEENT, D.; KLEPPER, O. (1997): Mapping the Potential Affected Fraction (PAF) of Species as an Indicator of Generic Toxic Stress. RIVM report 607504001, June 1997; RIVM. Bilthoven

MÜLLER-WENK, R. (1996): Damage Categories and Damage Functions as Core Elements of Life-Cycle Impact Assessment. IWOE Diskussionsbeitrag. 36 (Draft version 29.10.1996, Universität St. Gallen

MÜLLER-WENK, R. (1998-1): Depletion of Abiotic Resources Weighted on the Base of "Virtual" Impacts of Lower Grade Deposits in Future. IWÖ Diskussionsbeitrag Nr. 57, Universität St. Gallen, March 1998, ISBN 3-906502-57-0

MÜLLER-WENK, R. (1998-2): Land Use - The Main Threat to Species. IWOE Discussion Paper no. 64, IWOE University of St. Gallen

MURRAY, CHR.; LOPEZ, A. (1996): The Global Burden of Disease. WHO, World Bank and Harvard School of Public Health. Boston

POTTING, J.; HAUSCHILD, M.; WENZEL, H. (1998): "Less is better" and "Only above Threshold": Two Incompatible Paradigms for Human Toxicity in Lifecycle Assessment? Int. J. LCA, in print for issue 6, 1998

SPRIENSMA, R. (1997): Working Document on Fate Analysis for the Eco-Indicator 97. In: EUSES, Internal Working Document, PRé Consultants

STEEN, B.; RYDING, S.O. (1992): The EPS Enviro-Accounting Method. IVL, B-1080 Gothenburg

THOMPSON, M.; ELLIS, R.; WILDAVSKY, A.: Cultural Theory, Westview Print Boulder 1990

WIERTZ J, VAN DIJK & J.B. LATOUR (1992); MOVE: Vegetatie-module; de kans op voorlomen van 700 plantensoorten als functie van vocht, pH, nutrienten en zout. RIVM rapport nr. 711901006. Bilthoven

Appendix: Expert Team

Name	Employer	Contribution to this project
Ruedi Müller Wenk	IWÖ-HSG St. Gallen	General methodology, Resources, Land-use
Patrick Hofstetter	UNS-ETH, Zurich	General methodology, DALY, Cult. Theory
Thomas Köllner	IWÖ-HSG St. Gallen	Land-use
Thomas Mettier	UNS-ETH, Zurich	Panel procedure
Stephan Brunner	Ex-ESU-ETH, Zurich	Panel procedure
Arthur Braunschweig	IWÖ-HSG St. Gallen	General methodology, Radiation
Dick van der Meent	RIVM ECO	PAF
Mathieu Rikken	RIVM CSR	EUSES
Ton Breure	RIVM ECO	PAF
Reinout Heijungs	CML Leiden	General methodology
Erwin Lindeijer	IVAM Amsterdam	General methodology
Hein Sas	CE Delft	General methodology
Mark Goedkoop	PRé Consultants	Project leader, General methodology
Renilde Spriensma	PRé Consultants	Fate analysis, DALY and PAF

We like to thank T. Köllner, T. Mettier and A Braunschweig for their critical review and useful comments on this article