

SimaPro 7

Database Manual

Methods library



product ecology
consultants

SimaPro Database Manual

Methods library

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Contents

1	INTRODUCTION	1
1.1	STRUCTURE OF METHODS IN SIMAPRO	1
1.2	CHECKING IMPACT ASSESSMENT RESULTS	2
2	METHOD DESCRIPTIONS	3
	BEES	3
2.1	3	
	2.1.1 Introduction	3
	2.1.2 Characterisation	3
	2.1.3 Normalization and weighting	3
	2.1.4 References	4
2.2	CML 1992	5
	2.2.1 Introduction	5
	2.2.2 Characterisation	5
	2.2.3 Normalisation	8
	2.2.4 Evaluation	8
2.3	CML 2001	9
	2.3.1 Introduction	9
	2.3.2 Characterisation	9
	2.3.3 Normalization and weighting	11
	2.3.4 Grouping and weighting	11
	2.3.5 References	11
2.4	CUMULATIVE ENERGY DEMAND	12
	2.4.1 Introduction	12
	2.4.2 Characterisation	12
	2.4.3 Normalisation	12
	2.4.4 Weighting	12
	2.4.5 References	12
2.5	CUMULATIVE EXERGY DEMAND (CEXD)	13
	2.5.1 Introduction	13
	2.5.2 Characterisation	13
	2.5.3 Normalisation	14
	2.5.4 Weighting	14
	2.5.5 References	14
2.6	ECO-INDICATOR 95	15
	2.6.1 Introduction	15
	2.6.2 Characterisation	15
	2.6.3 Normalisation	17
	2.6.4 Evaluation	17
2.7	ECO-INDICATOR 99	22
	2.7.1 Introduction	22
	2.7.2 Characterisation	23
	2.7.3 Uncertainties	24
	2.7.4 Normalisation	25
	2.7.5 Weighting	25
	2.7.6 Default	25
2.8	ECOLOGICAL FOOTPRINT	26
	2.8.1 Introduction	26
	2.8.2 Normalisation and weighting	26
	2.8.3 References	26
	ECOPOINTS 97 (CH)	27
2.9	27	
	2.9.1 Introduction	27
	2.9.2 Normalisation	27

2.9.3	Weighting	27
2.9.4	References	28
2.10	ECOLOGICAL SCARCITY 2006	29
2.10.1	Introduction	29
2.10.2	Characterisation	29
2.10.3	Normalisation and weighting	29
2.10.4	References	29
2.11	ECOSYSTEM DAMAGE POTENTIAL (EDP)	30
2.11.1	Introduction	30
2.11.2	Characterization	30
2.11.3	Normalization and weighting	30
2.11.4	References	30
	EDIP/UMIP 97	31
2.12	31	
2.12.1	Introduction	31
2.12.2	Characterisation	31
2.12.3	Normalisation	32
2.12.4	Weighting	32
2.12.5	References	32
2.13	EDIP 2003	33
2.13.1	Introduction	33
2.13.2	Normalisation	34
2.13.3	Weighting	34
2.13.4	Reference	34
2.14	EPD 2007	35
2.14.1	Introduction	35
2.14.2	Normalization and weighting	35
2.14.3	References	35
2.14.4	Acknowledgement	35
2.15	EPS 2000	36
2.15.1	Introduction	36
2.15.2	Classification	36
2.15.3	Characterisation	36
2.15.4	Normalization/Weighting	37
2.15.5	References:	37
2.16	IMPACT 2002+	38
2.16.1	Introduction	38
2.16.2	Characterisation	38
2.16.3	Normalization	38
2.16.4	Weighting	39
2.16.5	References	39
2.17	IPCC 2001 GWP	40
2.17.1	Introduction	40
2.17.2	Characterisation	40
2.17.3	Normalisation and weighting	40
2.17.4	References	40
2.18	IPCC 2007	41
2.18.1	Introduction	41
2.18.2	Characterisation	41
2.18.3	Normalisation and weighting	41
2.18.4	References	41
2.19	SELECTED LCI RESULTS	42
2.19.1	Introduction	42
2.19.2	References	43
2.20	TRACI 2	44
2.20.1	Introduction	44
2.20.2	Characterisation	44
2.20.3	Normalization and weighting	44
2.20.4	References	45

1 Introduction

SimaPro contains a number of impact assessment methods, which are used to calculate impact assessment results. This manual describes how the various impact assessment methods are implemented in SimaPro. For specific details on the method see the literature references given or contact the authors of the method.

AN IMPORTANT NOTE ON CHANGING METHODS

If you want to change methods in SimaPro, it is strongly advised to copy the original method to your project. By copying you make sure you always have an original method in your database. Once changes are saved, there is no undo function!

1.1 Structure of methods in SimaPro

The basic structure of impact assessment methods in SimaPro is:

1. Characterisation
2. Damage assessment
3. Normalisation
4. Weighting

The last three steps are optional according to the ISO standards. This means they are not always available in all methods. In SimaPro you can switch the optional steps on or off when you edit a method.

Characterisation

The substances that contribute to an impact category are multiplied with a characterisation factor that expresses the relative contribution of the substance. For example, the characterisation factor for CO₂ in the impact category Climate change can be equal to 1, while the characterisation factor of methane can be 21. This means the release of 1 kg methane causes the same amount of climate change as 21 kg CO₂. The total result is expressed as impact category indicators (formerly characterisation result).

Note:

1. A new substance flow introduced in ecoinvent 2.0 called 'carbon dioxide, land transformation' is included in all the methods available in SimaPro 7. This substance flow represents the CO₂ emissions from clear cutting and land transformation.
2. CO₂ uptake and emissions of CO₂ from biogenic sources were added to every method with effects on climate change except for Impact 2002+ (which standard doesn't consider CO₂ uptake).

Subcompartments

In SimaPro, subcompartments can be specified for each substance. For example, you can define an emission to water having a subcompartment Ocean. This allows you to create detailed impact assessment methods, with specific characterisation factors for each subcompartment.

Some impact assessment methods are not as detailed as the inventory in terms of specification of subcompartments. In this case SimaPro will choose the "unspecified" characterisation factor as the default factor for a substance that has a subcompartment specified in the inventory but has no specific characterisation factor in the chosen impact assessment method.

Damage assessment

Damage assessment is a relatively new step in impact assessment. It is added to make use of 'endpoint methods', such as the Eco-indicator 99 and the EPS2000 method. The purpose of damage assessment is to combine a number of impact category indicators into a damage category (also called area of protection).

In the damage assessment step, impact category indicators with a common unit can be added. For example, in the Eco-indicator 99 method, all impact categories that refer to Human health are

expressed in DALY (disability adjusted life years). In this method it is allowed to add DALYs caused by carcinogenic substances to DALYs caused by climate change.

Normalisation

Many methods allow the impact category indicator results to be compared by a reference (or normal) value. This means, the impact category is divided by the reference. A commonly used reference is the average yearly environmental load in a country or continent, divided by the number of inhabitants. However, the reference may be chosen freely. You could also choose the environmental load of lighting a 60W bulb for one hour, 100 km of transport by car or 1 litre of milk. This can be useful to communicate the results to non LCA experts, as you benchmark your own LCA against something everybody can imagine. In SimaPro, there are often alternative normalisation sets available.

After normalisation the impact category indicators all get the same unit, which makes it easier to compare them. Normalisation can be applied on both characterisation and damage assessment results.

PLEASE NOTE: SimaPro does not divide by the reference value (N), but multiplies by the inverse. If you edit or add a normalisation value in a method, you must therefore enter the inverted value (1/N).

Weighting

Some methods allow weighting across impact categories. This means the impact (or damage) category indicator results are multiplied by weighting factors, and are added to create a total or single score. Weighting can be applied on normalised or non normalised scores, as some methods like EPS do not have a normalisation step. In SimaPro, there are often alternative weighting sets available, always in combination with a normalisation set.

1.2 Checking impact assessment results

Although impact assessment methods become very extensive and include more and more substances, they still do not cover all substances that you can find in your inventory. This can be a methodological issue, as some methods for example do not include raw materials as impact category. It can be you added a new substance, which is not automatically included in the impact assessment method. Or you could have introduced synonyms by importing data from other parties.

SimaPro has a build in check to show you which substances are not included in the selected impact assessment method. For each result, the substances and their amounts not included in the method are shown under 'Checks' in the result window.

Further, under 'Inventory results' you can show the impact assessment results per substance. If a substance is not defined in the method, a pop-up hint will tell you this.

On a method level, you can run a check which will show you which of all substances, available in the SimaPro database, are included in the method on impact category level. To run this check, select a method and click the 'Check' button in the right hand side of the methods window.

2 Method descriptions

2.1 BEES

2.1.1 Introduction

BEES is the acronym for Building for Environmental and Economic Sustainability, a software tool developed by the National Institute of Standards and Technology (NIST). BEES combines a partial life cycle assessment and life cycle cost for building and construction materials into one tool. Results are presented in terms of life cycle assessment impacts, costs, or a combination of both as it can be seen in Figure 1. BEES strives to assist the architect, engineer, or purchaser choose a product that balances environmental and economic performance, thus finding cost-effective solutions for protecting the environment.

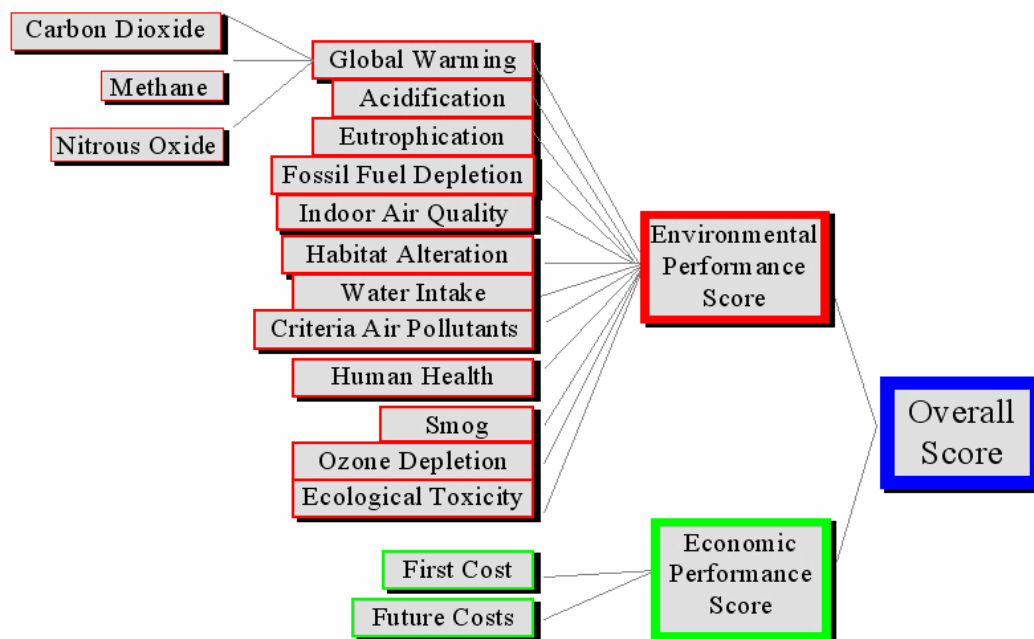


Figure 1 Structure of the BEES 4.0 methodology

2.1.2 Characterisation

BEES uses the SETAC method of classification and characterization. The following six life cycle assessment impact categories are used by BEES:

1. global warming potential
2. acidification
3. eutrophication potential
4. natural resource depletion
5. solid waste
6. indoor air quality

Smog Characterisation factors for two substances from equiv12.xls, biphenyl and diphenyl (both to air) have been averaged and assigned to biphenyl (air). Smog Characterisation factors for Butane (C₄H₁₀) and Butane-n (n-C₄H₁₀) (both to air) have been averaged and assigned to Butane (air).

2.1.3 Normalization and weighting

PRé did not take over the Normalisation figures, as they gave results that are difficult to understand or explain. For the same reason, the weighting was also not included although 4 different sets of weighting values exist.

2.1.4 References

<http://www.concretethinker.com/Papers.aspx?DocId=316>

<http://www.bfrl.nist.gov/oe/software/bees/registration.html>

2.2 CML 1992

2.2.1 Introduction

This classification method is based on the method published by CML of the University of Leiden in October 1992¹.

PRé has modified the method in a number of ways:

- the depletion and energy classes were separated and the classes for smell and biotic exhaustion were excluded.

This v2 version is adapted for SimaPro 7. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments.

This method is NOT fully adapted for inventory data from the ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

2.2.2 Characterisation

Grouped substances or sum parameters have been defined in a number of classes. This has been done because the emissions are not always specified separately in the data sources for the processes concerned. Emissions are often specified under a collective name, e.g. aromatic hydrocarbons. Since the different substances within such a group can have considerable variation in their environmental impact, the resulting effect score may not be completely reliable.

The main classes are:

1. Exhaustion of raw materials and energy

Abiotic

This term refers to energy sources and a number of scarce metals. In the CML 92 method, all the energy sources were grouped into a separate class called **Energy**.

The effect score for exhaustion is calculated on the following basis:

$\text{Exhaustion} = (\text{amount consumed (kg)} \times \{1/\text{resources (kg)}\})^2$
--

Biotic

This category is intended for rare animals and plants. This score is as yet very rudimentary and has therefore not been used.

2. Pollution

Greenhouse effect

The Global Warming Potential (GWP) is the potential contribution of a substance to the greenhouse effect. This value has been calculated for a number of substances over periods of 20, 100 and 500 years because it is clear that certain substances gradually decompose and will become inactive in the long run. For the CML 92 method, we have taken the GWP over a 100-year period because this is the most common choice.

We have added values for CFC (hard) and for CFC (soft) to the CML (1992) method, since it is not always known which CFC is released. The GWP for this category of substances has been equated to that of CFCs frequently used in industrial mass and series production; for CFC (hard) this is the value for CFC-12, and for CFC (soft) it is the value for HCFC-22.

The effect score for the greenhouse effect is calculated per substance as follows:

¹ R. Heijungs et al, *Environmental life cycle assessment of products, Guide, October 1992* CML, Leiden, The Netherlands, NOH report 9266.

² World Institute, *World Resources 1990-1991*, Oxford University Press, New York/Oxford.

$$\text{Greenhouse effect (kg)} = (\text{GWP 100} \times \text{airborne emission (kg)})^3$$

Ozone layer depletion

Ozone Depletion Potential (ODP) values have been established mainly for hydrocarbons containing combined bromine, fluorine and chlorine, or CFCs. Here too, one of the substances (CFC-11) has been adopted as a reference. As for the greenhouse effect, we have added values for CFC (hard) and CFC (soft). The ODP equivalents for these groups are again those of CFC-12 and HCFC-22 respectively.

The effect score for ozone layer depletion is calculated as follows:

$$\text{Ozone layer depletion (kg)} = (\text{ODP} \times \text{airborne emission (kg)})^4$$

Human toxicity

Criticism of the use of MAC values in the CML 1990 method led to the development of a fairly long list of substances that are poisonous to human beings. A notable feature is that human toxicity combines a score for emissions to air, water and soil. The following values have been established for most substances:

- Human-toxicological classification value for air (HCA)
- Human-toxicological classification value for water (HCW)
- Human-toxicological classification values for soil (HCS).

We have not included soil emissions in this because the program does not have an impact category for substances emitted to soil. The number of characterisation factors from soil is very limited. Moreover, it may be assumed that emissions that initially enter the soil will ultimately appear in the groundwater and hence can be dealt with as emissions to water.

We have added a number of values for *groups* to this class: metallic ions and various groups of hydrocarbons. Metallic ions have been given a value equal to that of iron. The values of the hydrocarbons are given in Table 7. An equivalent has also been selected for most other values that were not defined; e.g. for chlorine, the equivalent value of bromine has been used.

Substances	Equivalents			
	human toxicity air	human toxicity Water	ecotoxicity water	smog air
CxHy	isopropanol	Isopropanol	crude oil	aliphatics average
CxHy aliphatic	isopropanol	Isopropanol	crude oil	aliphatics average
CxHy aromatic	benzene	Benzene	benzene	aromatics average
CxHy chloro	1,2, dichloroethane	1,2, dichloroethane	1,2, dichloroethane	average chlorinated org. compounds
PAH	benzo(a)pyrene	benzo(a)pyrene	benzo(a)pyrene	aromatics average

Table 7 Substances from which HCA/HCW, ECA and POCP values for hydrocarbons are taken.

The human toxicity effect score is calculated as follows:

$$\text{Human toxicity (kg)} = (\text{HCA (kg.kg}^{-1}) \times \text{emission to air (kg)} + \text{HCW (kg.kg}^{-1}) \times \text{emission to water (kg)})^5$$

³ Houghton, Callender & Varney, *Climate Change 1992. The supplementary report to the IPCC scientific assessment*, Cambridge University Press, Cambridge, UK, 1992.

⁴ World Meteorological Organisation, *Scientific assessment of ozone depletion 1991*, Global Ozone Research and Monitoring Project - Report no. 25, 1991.

⁵ Vermeire, T.G et al., *Voorstel voor de humaan-toxicologische onderbouwing van C - (toetsings)waarden* [Proposal for the human-toxicological basis of test values], RIVM, Bilthoven, The Netherlands, 1991.

Ecotoxicity

Substances in this class are given values for toxicity to flora and fauna. The main substances are heavy metals. Values have been established for emissions to water and to soil, i.e.:

- Aquatic ecotoxicity (ECA)
- Terrestrial ecotoxicity (ECT)

Only the ECA values have been included in the CML 92 method because emissions to soil eventually appear in the groundwater and are thus already covered.

We have added a number of values for groups of hydrocarbons to this class. Values for the hydrocarbons are shown in Table 4. An equivalent has been selected for most other values that were not defined.

The effect score for ecotoxicity is calculated as follows:

$$\text{Ecotoxicity (m}^3\text{)} = (\text{ECA (m}^3 \cdot \text{kg}^{-1}\text{)} \times \text{waterborne emission (kg)})^6$$

Smog

The photochemical ozone creation potential (POCP) indicates the potential capacity of a volatile organic substance to produce ozone. Values have been published for a wide range of volatile organic substances. The value for ethene has been set at 1. The values for most other substances are less than this. The POCP of these sumparameters such as alcohols, ketones, aldehydes and various groups of hydrocarbons groups is the average of all the relevant substances in the CML (1992) list. The values for the hydrocarbon groups are given in Table 4. NO_x is omitted in the CML 92 method.

The effect score for smog is calculated as follows:

$$\text{Smog (kg)} = (\text{POCP} \times \text{airborne emission (kg)})^7$$

Acidification

The Acidification Potential (AP) is expressed relative to the acidifying effect of SO₂. Other known acidifying substances are nitrogen oxides and ammonia. SO_x has been added, with the same value as SO₂.

Acidification effect scores are calculated as follows:

$$\text{Acidification (kg)} = (\text{AP} \times \text{airborne emission (kg)})$$

Note that the results of the acidification classes from CML (1990) and CML (1992) are not calculated in the same way.

Eutrophication

The Nutriphication Potential (NP) is set at 1 for phosphate (PO₄). Other emissions also influence eutrophication, notably nitrogen oxides and ammonium.

The eutrophication effect score is calculated as follows:

$$\text{Eutrophication (kg)} = (\text{NP} \times \text{airborne emission (kg)})$$

⁶ Slooff, W., *Maximum tolerable concentrations, ecotoxicological effect assessment*, RIVM no. 719102018, Bilthoven, The Netherlands.

⁷ Protocol to the convention on long-range transboundary air pollution concerning the control of emissions of volatile organic compounds or their transboundary fluxes, United Nations - Economic Commission for Europe (UNECE), Geneva, Switzerland, 1991.

Odour

Weighting factors for stench have been developed, although their use is unusual in LCAs. In these, ammonia is given the value 1.

This class is not included in the CML 92 method because it is a highly localised environmental effect, and the degree of stench nuisance depends largely on local circumstances.

Solids

This class is not included in the original CML 1992 classification. We have added the solids class to the method because solid emissions form an important environmental problem in their own right. The weight of the waste emission is used for calculation, and no weighting factors are involved.

$$\text{Solids (kg)} = (\text{solid emission output (kg)})$$

2.2.3 Normalisation

The first and probably most widely used normalisation set was published in 1993 by Guinée from the CML. This set was compiled by extrapolating 1988 data from the Dutch Emission Registration. Most of the data was simply multiplied by a factor 100, to extrapolate them to the world level, as The Netherlands contribute about 1% to the Gross National Product figures in the World. An exception was made for greenhouse and ozone depleting emissions. These were taken directly from IPCC. The figures are supposed to reflect the world emissions. In order to make the figures more manageable, we have divided them by the world population of 6.000.000.000. A very recent project executed by IVAM-ER, NWS (University of Utrecht) and PRé, under commission from VROM and RIZA, in the Netherlands has resulted in three new sets of normalisation figures. They are for a large part based on the Emission registration (base year 1994), and several other sources. The results of this project have been peer reviewed by Guinée. The normalisation levels are:

- Dutch territory. All emissions registered emitted within the Netherlands and all raw materials consumed by the Dutch economy.
- Dutch consumer. The effect of imports have been added, the effects of exports have been subtracted. The calculation was performed using the Dutch input-output matrix.
- European territory (EC, Switzerland, Austria and Norway). Most data are from original European data. In some cases data was extrapolated from Dutch and Swiss data. The energy consumption within a region was taken as a basis for extrapolation.

2.2.4 Evaluation

Although several organisations have developed evaluation factors using panel methods, there is no generally recognised method to evaluate the results obtained with the CML method.

2.3 CML 2001

2.3.1 Introduction

In 2001 a group of scientists under the lead of CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterisation methods for the impact assessment step. A “problem oriented approach” and a “damage approach” are differentiated. Since the damage approaches chosen are the Eco-indicator 99 and the EPS method, the impact assessment method implemented in ecoinvent as CML 2001 methodology is the set of impact categories defined for the midpoint approach.

There will be two version of this method available in SimaPro 7: a ‘baseline’ version; and an extended version with ‘all impact categories’.

Impact category names	
Name in ‘all impact categories’ version	Name in ‘baseline’ version
Ozone layer depletion steady state	Ozone layer depletion (ODP)
Human toxicity infinite	Human toxicity
Fresh water aquatic ecotox. infinite	Fresh water aquatic ecotox.
Marine aquatic ecotoxicity infinite	Marine aquatic ecotoxicity
Terrestrial ecotoxicity infinite	Terrestrial ecotoxicity
Photochemical oxidation	Photochemical oxidation
Global warming 100a	Global warming (GWP100)
Acidification	Acidification
Abiotic depletion	Abiotic depletion
Eutrophication	Eutrophication

Table 2 List of impact category names in both CML 2001 versions - baseline version and all impact categories version

2.3.2 Characterisation

The CML Guide provides a list of impact assessment categories grouped into

- A: Obligatory impact categories (Category indicators used in most LCAs)
- B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)
- C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories, a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at “mid-point level” (problem oriented approach)” and are presented below. Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.

Depletion of abiotic resources

This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

Climate change

Climate change can result in adverse affects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of

characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale. Some Characterisation factors were added from the IPCC 2001 GWP 100a method: Methane, bromodifluoro-, Halon 1201, Methane, dichlorofluoro-, HCFC-21, and Methane, iodotrifluoro-.

Stratospheric Ozone depletion

Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinity.

Human toxicity

This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterisation factors, Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale

Fresh-water aquatic eco-toxicity

This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco-toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances. The time horizon is infinite Characterisation factors are expressed as 1,4-dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/ regional and local scale.

Marine eco-toxicity

Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description fresh water toxicity).

Terrestrial ecotoxicity

This category refers to impacts of toxic substances on terrestrial ecosystems (see description fresh water toxicity).

Photo-oxidant formation

Photo-oxidant formation is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with "summer smog". Winter smog is outside the scope of this category. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission. The time span is 5 days and the geographical scale varies between local and continental scale.

Acidification

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potentials (AP) for emissions to air are calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO₂ equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

Characterisation factors including fate were used when available. When not available, the factors excluding fate were used (In the CML baseline version only factors including fate were used). The method was extended for Nitric Acid, soil, water and air; Sulphuric acid, water; Sulphur trioxide, air; Hydrogen chloride, water, soil; Hydrogen fluoride, water, soil; Phosphoric acid, water, soil; Hydrogen sulfide, soil, all not including fate. Nitric oxide, air (is nitrogen monoxide) was added including fate.

Eutrophication

Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO₄ equivalents/ kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

The method available with all impact categories has, comparing with the baseline version, the following impact categories available:

- Global warming (different time frames)
- Upper limit of net global warming
- Lower limit of net global warming
- Ozone layer depletion (different time frames)
- Human toxicity (different time frames)
- Fresh water aquatic ecotoxicity (different time frames)
- Marine aquatic ecotoxicity (different time frames)
- Terrestrial ecotoxicity (different time frames)
- Marine sediment ecotoxicity (different time frames)
- Average European (kg NO_x-eq); Average European (kg SO₂-eq)
- Land competition
- Ionising radiation
- Photochemical oxidation; Photochemical oxidation (low NO_x)
- Malodours air
- Equal benefit incremental reactivity
- Max. incremental reactivity; Max. ozone incremental reactivity

2.3.3 Normalization and weighting

Normalisation is regarded as optional for simplified LCA, but mandatory for detailed LCA. For each baseline indicator, normalisation scores are calculated for the reference situations: the world in 1990, Europe in 1995 and the Netherlands in 1997. Normalisation data are described in the report: Huijbregts et al LCA normalisation data for the Netherlands (1997/1998), Western Europe (1995) and the World (1990 and 1995).

The normalized result for a given impact category and region is obtained by multiplying the characterisation factors by their respective emissions. The sum of these products in every impact category gives the normalization factor.

2.3.4 Grouping and weighting

Grouping and weighting are considered to be optional step. No baseline recommended rules or values are given for these steps. Therefore these steps are not available in SimaPro 7.

2.3.5 References

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.4 Cumulative Energy Demand

2.4.1 Introduction

The method to calculate Cumulative Energy Demand (CED) is based on the method published by ecoinvent version 1.01 and expanded by PRé Consultants for energy resources available in the SimaPro database. Extra substances, according to the Ecoinvent database version 2.0, are implemented.

2.4.2 Characterisation

Characterisation factors are given for the energy resources divided in 5 impact categories:

1. Non renewable, fossil
2. Non renewable, nuclear
3. Renewable, biomass
4. Renewable, wind, solar, geothermal
5. Renewable, water

2.4.3 Normalisation

Normalisation is not a part of this method.

2.4.4 Weighting

In order to get a total ("cumulative") energy demand, each impact category is given the weighting factor 1.

2.4.5 References

Frischknecht R., Jungbluth N., et.al. (2003). *Implementation of Life Cycle Impact Assessment Methods*. Final report ecoinvent 2000, Swiss Centre for LCI. Dübendorf, CH, www.ecoinvent.org

2.5 Cumulative Exergy Demand (CExD)

2.5.1 Introduction

The indicator Cumulative Exergy Demand (CExD) is introduced to depict total exergy removal from nature to provide a product, summing up the exergy of all resources required. CExD assesses the quality of energy demand and includes the exergy of energy carriers as well as of non-energetic materials. The exergy concept was applied to the resources contained in the ecoinvent database, considering chemical, kinetic, hydro-potential, nuclear, solar-radiative and thermal exergies. Details on the CExD method may be found in Bösch *et al.* (2007).

In order to quantify the life cycle exergy demand of a product, the indicator Cumulative Exergy Demand (CExD) is defined as the sum of exergy of all resources required to provide a process or product.

Exergy is another way to express quality of energy rather than energy content. Both are expressed in MJ. Exergy is a measure for the useful “work” a certain energy carrier can offer. For instance natural gas has a high exergy value, as it can be used to create high temperatures and high pressured steam. If natural gas is used to heat a house in a highly efficient boiler, very little energy content is lost, but the exergy content is almost entirely lost (there is very little one can do with water between 50 and 80 degrees).

In this method exergy is used as a measure of the potential loss of “useful” energy resources.

This method has been directly taken from ecoinvent 2.0. The amount of substances present is compatible with the EI 2.0 database and extended for other databases.

2.5.2 Characterisation

The impact category indicator is grouped into the eight resource categories fossil, nuclear, hydropower, biomass, other renewables, water, minerals, and metals. However, in SimaPro 10 different impact categories are presented:

- Non renewable, fossil
- Non renewable, nuclear
- Renewable, kinetic
- Renewable, solar
- Renewable, potential
- Non renewable, primary
- Renewable, biomass
- Renewable, water
- Non renewable, metals
- Non renewable, minerals

Exergy characterisation factors for 112 different resources were included in the calculations.

$$CExD = \sum_i m_i * Ex_{(ch),i} + \sum_j n_j * r_{ex-e(k,p,n,r,t),j}$$

CExD = cumulative exergy demand per unit of product or process (MJ-eq)

m_i = mass of material resource i (kg)

Ex_{(ch),i} = exergy per kg of substance i (MJ-eq/kg)

n_j = amount of energy from energy carrier j (MJ)

r_{ex-e(k,p,n,r,t),i} = exergy to energy ratio of energy carrier j (MJ-eq/MJ)

ch = chemical

k = kinetic

p = potential

n = nuclear

r = radiative

t = thermal exergy

The assignment of the adequate type of exergy depends on resource use:

- Chemical exergy is applied on all material resources, for biomass, water and fossil fuels (i.e. all materials that are not reference species in the reference state)
- Thermal exergy is applied for geothermy, where heat is withdrawn without matter extraction
- Kinetic exergy is applied on the kinetic energy in wind used to drive a wind generator
- Potential exergy is applied on potential energy in water used to run a hydroelectric plant
- Nuclear exergy is applied on nuclear fuel consumed in fission reactions
- Radiative exergy is applied on solar radiation impinging on solar panels

2.5.3 Normalisation

Normalisation is not a part of this method.

2.5.4 Weighting

In order to get a total (“cumulative”) exergy demand, each impact category is given the weighting factor 1.

2.5.5 References

Bösch M.E., Hellweg S., Huijbregts M.A.J., and Frischknecht R. (2007) *Applying Cumulative Energy Demand (CExD) Indicators to the ecoinvent Database*. In: Int J LCA 12 (3) pp. 181-190.

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.6 Eco-indicator 95

2.6.1 Introduction

Eco-indicator 95 is adapted for SimaPro 7. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments.

This method is NOT fully adapted for inventory data from the ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

Due to continual adjustments of the method and/or inventory data sets the Eco-indicator 95 in SimaPro 7 will not give the same result as the original printed version.

2.6.2 Characterisation

The only difference between the characterisations in the SimaPro 2 CML and SimaPro 3 Eco-indicator 95 methods is in the ecotoxicity and human toxicity effect definition. Both toxicity scores have been replaced by:

- Summer smog (already available in the SimaPro 2 CML method)
- Winter smog
- Carcinogens
- Heavy metals to air and water
- Pesticides

The characterisation values are based on the following data:

Effect score of persistent toxic substances in air and water

This effect score relates in particular to heavy metals because long-term exposure at low levels brings clear health risks. The risks relate particularly to the nervous system and the liver and can be assessed for toxicity to both human beings and ecosystems. It is assumed in general (Globe, Air Quality Guidelines) that human toxicity is the most important limiting factor. The Air Quality Guidelines specify the following admissible air concentrations for annual exposure to humans:

	Maximum concentration (µg/m ³)	Weighting factor	Main health effect
Cadmium	0.02	50	Kidneys
Lead	1	1	Blood biosynthesis, nervous system and blood pressure
Manganese	7	0.14	Lungs and nervous system (shortage cause skin complaints)
Mercury	1	1	Brain: sensory and co-ordination functions

Table 3 Air Quality Guidelines admissible air concentrations for annual exposure to humans

Chromium and nickel are regarded as carcinogens because the risk of cancer is greater than the toxicological effect.

Based on this concentration a weighting factor can be determined which is equal to the inverse of the admissible concentration. This agrees with the critical volume approximation that used to be applied with the MAC value. We have expressed the effect score as a lead equivalent.

The WHO 'Quality guidelines for drinking water' specify a number of values for persistent substances based on long-term, low-level exposure. These criteria have been drawn up to evaluate drinking water, based on established health effects. A selection is given below of substances that are persistent to a greater or lesser extent and that therefore accumulate in the environment.

Substance	Norm (mg/litre)	Weighting factor	Effect
Antimony	0.005	2	Glucose and cholesterol content of blood
Arsenic	0.01	1	Probability of skin cancer $6 \cdot 10^{-4}$
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	Heredity (carcinogenity only applicable in event of inhalation)
Copper	2	0.005	Generally no problems, sometimes liver abnormalities
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 (methyl mercury)
Molybdenum	0.07	0.14	No clear description
Nickel	0.02	0.5	Weight loss, great uncertainty

Table 4 WHO based substances that are persistent

With this effect score the weighting factor is determined in order to be able to calculate the lead equivalent. SimaPro merges the scores for water and air. This is possible because they are both expressed as a lead equivalent and because the target reductions for air and water are the same.

We have combined the two scores for heavy metals. This was possible since they are both expressed as a lead equivalent and since the weighting factors are identical.

$$\text{Heavy metal to air (kg lead eq.)} = (\text{AQG (lead)}/\text{AQG (substance)}) * \text{emission}$$

$$\text{Heavy metal to water (kg lead eq.)} = (\text{GDWQ (lead)}/\text{GDWQ (substance)}) * \text{emission}$$

Carcinogenic substances

The 'Air Quality Guidelines' do not specify acceptable levels, but calculate the probability of cancer at a level of $1 \mu\text{g}/\text{m}^3$. In the table below this probability is expressed as the number of people from a group of 1 million who will develop cancer with the stated exposure.

	Probability of cancer at $1 \mu\text{g}/\text{m}^3$	Weighting factor for PAH equivalent	Type of cancer
Arsenic	0.004	0.044	General, also mutagenic effects
Benzene	0.000001	$1.1 \cdot 10^{-5}$	Leukaemia
Nickel	0.04	0.44	Lung and larynx
Chromium (VI)	0.04	0.44	Lung, among others, and mutagenic effects
PAHs (benzo(a)pyrene)	0.09	1	Lung cancer but also other types of cancer

Table 5 Number of people from a group of 1 million who will develop cancer with the stated exposure.

It is worth considering whether to include asbestos in this list. The difficulty with this is that asbestos emissions cannot be expressed meaningfully in a unit of weight. The number and type of fibres is the determining factor.

It is not entirely clear whether these numbers can be used directly as a weighting factor in order to calculate, for example, a PAH equivalent. This is because it is not known exactly whether a linear correlation may be assumed between probability and exposure. At present we assume that this is so.

$$\text{Heavy metal to air (kg lead eq.)} = (\text{AQG (lead)}/\text{AQG (substance)})$$

Winter smog

Only dust (SPM) and SO₂ are factors in this problem. For both substances the 'Air Quality Guidelines' specify a level of 50 µg/m³. The weighting factors are thus both 1.

$$\text{Winter smog (SO}_2 \text{ or SPM eq.)} = \text{SO}_2 \text{ emission} + \text{SPM emission}$$

Pesticides

The Globe report describes pesticides as a problem for two reasons:

- Groundwater becomes too toxic for human consumption.
- Biological activity in the soil is impaired, as a result of which vegetation is damaged.

This means that account must be taken in the effect score weighting of both ecotoxicity (soil) and human toxicity (water). The target reduction is based on human toxicity. Globe distinguishes between

- disinfectants
- fungicides
- herbicides
- insecticides

Within these groups all the different sorts are listed, based on their active ingredient content. We propose also doing this for this effect score and shall also list the various mutual categories.

$$\text{Pesticides (kg)} = (\text{active ingredients})$$

2.6.3 Normalisation

The normalisation values are based on average European (excluding the former USSR) data from different sources. The reference year is 1990. In many cases we had to extrapolate data from one or more individual countries to the European level. As an extrapolation basis we used the energy consumption of the countries. In order to make the figures more manageable we divided the figures by the population of Europe: 497,000,000.

2.6.4 Evaluation

In the SimaPro 3 and the ecopoints methods the distance-to-target principle is used to calculate evaluation values. The basic assumption is that the seriousness of an impact can be judged by the difference between the current and a target level.

In the SimaPro 3 method the target is derived from real environmental data for Europe (excluding the former USSR), compiled by the RIVM. In the text below this report is referred to as Globe (The Environment in Europe: A Global Perspective).

The targets are set according to the following criteria:

- At target level the effect will cause 1 excess death per million per year
- At target level the effect will disrupt fewer than 5% of the ecosystems in Europe
- At target level the occurrence of smog periods is extremely unlikely

Greenhouse effect

At present, temperatures are rising by 0.2% every ten years. Under the current policy this rate will increase to 0.3% every ten years. The consequence will be a large temperature change by 2050. In Northern and Eastern Europe the winters will be more than 5° warmer, and in Southern Europe the summers will be 4° warmer. Areas in particular that have no other systems in their vicinity that can exist in such climatic conditions will suffer serious damage. This will affect approximately 20% of Europe.

The Globe report indicates that fewer than 5% of the ecosystems will be impaired if the greenhouse effect is reduced by a factor of 2.5.

Ozone layer depletion

In accordance with the Montreal Protocol and its London amendment all CFC emissions must be reduced to zero. For the less persistent HCFCs it has been agreed that the contribution to the effect in 1989 may not exceed 2.6% of the total adverse effect of CFCs. After this, the use of these substances too is to be reduced gradually by 2015.

If that 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 inhabitants. It does not yet seem directly necessary to reduce all HCFC emissions to zero because the norm (2 ppbv) is going to be achieved, even if after 2100. For these gases the target reduction is linked to the greenhouse effect⁸.

Based on this reduction for greenhouse gases, we therefore assume, for the moment, that the target reduction for HCFCs is of the order of 60%. Based on the premise that the HCFCs presently cause 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 thus 100. There is a great deal of uncertainty about this figure.

Acidification

There is a great variety in Europe in the ability of ecosystems to withstand acidification. In Scandinavia, for example, problems can occur with deposits of 100 eq/ha.yr, while in some places in the Netherlands and Germany the soil can withstand a deposit of more than 2000 eq/ha.yr.

Actual deposition appears to reach its highest level in Central Europe, particularly as a result of the use of lignite.

If the deposition and ability to withstand acidification are combined with each other, it seems that major problems are occurring particularly in England, the Benelux countries, Germany, Poland, the Czech Republic and Slovakia.

A provisional estimate based on the RAINS computer model shows that the reduction must be of the order of a factor of 10 to 20 to keep damage to the ecosystem below 5%.

Eutrophication

Eutrophication is seen in the Globe report particularly 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 (Germany) and Italy's Po valley plain (approx. 200 kg/ha).

In the CML classification Eutrophication refers mainly to air and water emissions. These rarely contribute more than 10% of the amount of fertiliser applied by farmers. In uncultivated biotopes, however, that are low in nutrients this eutrophication can have a serious adverse effect on biodiversity.

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

Summer smog

A hundred years ago the ozone concentration averaged over the whole year was approximately 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 this type of dangerous peak by 90% it is necessary to reduce VOCs and NO_x by 60 to 70%.

⁸ By contrast, the elimination of CFCs will also result in a significant reduction in the greenhouse effect. CFCs are responsible for 24% of this effect. Eliminating the CFCs will therefore yield a 24% reduction in the greenhouse effect.

Heavy metals

In Central Europe lead concentrations are very high, particularly in the soil and water. The air concentration is also high in towns and cities, particularly because of the use of leaded petrol. For adults the Air Quality Guideline specifies a limit in the air of 0.5 to 1 µg/m³. According to Globe this value is often exceeded by a number of times. Globe notes in passing (and without backing it up) that average lead concentrations in Poland are 20 µg/m³.

Eating locally grown vegetables would result in a blood lead level that is ten times too high. Lead levels in children's blood of 150 to 400 µg/l have been found. Such readings also occurred in the West 30 years ago, but not anymore. The figures are five to ten times lower now. 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 to 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 to 0.67 g/ha on grassland and 3.4 to 6.8 g/ha for arable land. The Southern Netherlands holds the record with a deposition rate of 7.5 to 8.5 g/ha. Furthermore, approximately 14% is distributed via the air (see winter smog).

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 to 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 of a factor of 5 for heavy metals in water.

Winter smog

The most important sources of this problem which occurs mainly in Eastern Europe are SO₂ and SPM (suspended particle matter, or small 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 SO₂ and SPM concentrations reached values of 5000 micrograms per cubic metre. In Southern Poland and Eastern Germany average readings of 200µg/m³ still occur repeatedly. The Air Quality Guidelines specify a limit of 50µg/m³ for long-term exposure to both SPM and SO₂. Based on this, a reduction of 75% would be necessary.

Globe estimates that a reduction in SO₂ 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 a defined or well measured⁹ pollutant.

We are continuing to use a factor of 5 as a target.

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) motors. In fact, the problem is only relevant in urban areas.

Globe specifies a value of 0.8 to 5 ng/m³ for Northern European towns and cities. The Air Quality Guideline specifies a value of 1 ng/m³ in American cities without coke furnaces in the vicinity and 1 to 5 ng/m³ in cities with coke furnaces. In European towns and cities in the 60s, when open coal fires were still very much in use, the average concentrations were in excess of 100 ng/m³. 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 smoking takes place can contain 20 ng/m³.

⁹ A major shortcoming of the CML classification system is the lack of a weighting factor for particulate matter in calculating human toxicity. According to the Globe report, SPM is one of the most injurious substances to health.

The Air Quality Guideline specifies a threshold concentration of 0.01 ng/m³ 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 cities¹⁰. If we assume that one in every three cancer cases is terminal and if we only take the urban population the risk of death is about ten times lower. Based on this, there would be one death per million inhabitants per year at a concentration of 0.1 ng/m³.

Based on a background concentration of 1 ng/m³ in towns and cities without coke furnaces (West European towns and cities in particular) a reduction by a factor of 10 could be estimated.

Pesticides

Leaching of pesticides threatens groundwater sources throughout the EU. The groundwater is contaminated in 65% of the EU 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.

Exhaustion of raw materials and solid waste

We have not defined any percentage reductions for exhaust of raw materials. There are two reasons for this:

No people die and no ecosystems are impaired as a result of the depletion of raw materials. It mainly causes economic and social problems.

Exhaustion is difficult to quantify because there are alternatives for most materials. For example, copper has already been replaced on a very wide scale by glass-fibre (communications) and aluminium (electricity-conducting medium). There are also good prospects for substituting materials in energy generation if the market is prepared to pay more for energy. In fact, the problem with energy is not the depletion of fossil fuels but the environmental impacts of combustion. Explicit account is taken of these in the indicator. In other words, you need not think that all the oil reserves that are presently known have actually been used. That would be an environmental disaster.

We have not defined any percentage reduction for waste. A similar reason applies to waste as to energy. No people die and only very small sections of ecosystems are threatened by the use of space for waste (apart from litter or fly-tipped waste). Emissions from incineration, the decomposition of waste and the leaching of, for example, heavy metals are major problems. These emissions are properly specified in a good LCA. Waste is thus included in similar fashion, but it is assessed in terms of its emissions.

We do not have any score for ecotoxicity and human toxicity, as is usually the case. Instead we have a score for carcinogenic substances, heavy metals, winter smog and pesticides. The reason for this is that we could not find any reduction target for such a vague concept. We therefore opted to specify the term "toxicity" in individual problems.

As a result of these changes, the Eco-indicator can be viewed as an indicator for emissions, and raw materials exhaustion and the use of space for waste must be assessed individually for the moment. Despite this limitation we feel that the indicator is a powerful tool. Emissions will be our greatest concern if we wish to protect health and ecosystems.

Summary of weighting factors

The table below summarises the values and the criteria used in determining them. The choice of these criteria is very important because there is a direct correlation with the reduction factors. If 5% ecosystem damage is compared with ten deaths per year rather than one, then all reduction factors based on the number of deaths criterion will fall by a factor of ten, assuming there is a linear correlation between an effect and the number of deaths.

The table gives you an opportunity to calculate other weightings for yourself if you wish to use different criteria.

¹⁰ Eurostat, estimate based on data for 6 EU member states

	Characterisation	Reduction factor	Criterion
Greenhouse	CML (IPCC)	2.5	0.1° per decade, 95th percentile?
Ozone layer	CML (IPCC)	100	Probability of 1 death per year per million inhabitants
Acidification	CML	10	95th percentile
Eutrophication	CML	5	Rivers and lakes damage to an unknown number of aquatic ecosystems? (95th percentile?)
Summer smog	CML	2.5	Prevent smog periods, health complaints, particularly amongst asthma patients and the elderly
Winter smog	Air Quality Guidelines	5	Prevent smog periods, health complaints, particularly amongst asthma patients and the elderly
Pesticide	Active ingredient	25	95th percentile ecosystems
Heavy metals in air	Air Quality Guidelines	5	Lead content in blood of children, limited life expectancy and learning performance in an unknown number of people
Heavy metals in water	Quality Guidelines for water	5	Cadmium content in rivers, ultimately also has an effect on people (see air)
Carcinogenic substances	Air Quality Guidelines	10	Probability of 1 death per year per million inhabitants

Table 6 Background weighting factors

2.7 Eco-indicator 99

2.7.1 Introduction

Eco-indicator 99 is the successor of Eco-indicator 95. Both methods use the damage-oriented approach. The development of the Eco-indicator 99 methodology started with the design of the weighting procedure. Traditionally in LCA the emissions and resource extractions are expressed as 10 or more different impact categories, like acidification, ozone layer depletion, ecotoxicity and resource extraction. For a panel of experts or non-experts it is very difficult to give meaningful weighting factors for such a large number and rather abstract impact categories. It was concluded that the panel should not be asked to weight the impact categories but the different types of damage that are caused by these impact categories. The other improvement was to limit the number of items that are to be assessed. As a result the panel, consisting of 365 persons from a Swiss LCA interest group, was asked to assess the seriousness of three damage categories:

1. Damage to Human Health, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the Worldbank and WHO.
2. Damage to Ecosystem Quality, express as the loss of species over an certain area, during a certain time
3. Damage to Resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels.

In order to be able to use the weights for the three damage categories a series of complex damage models had to be developed. In figure 2 these models are represented in a schematic way.

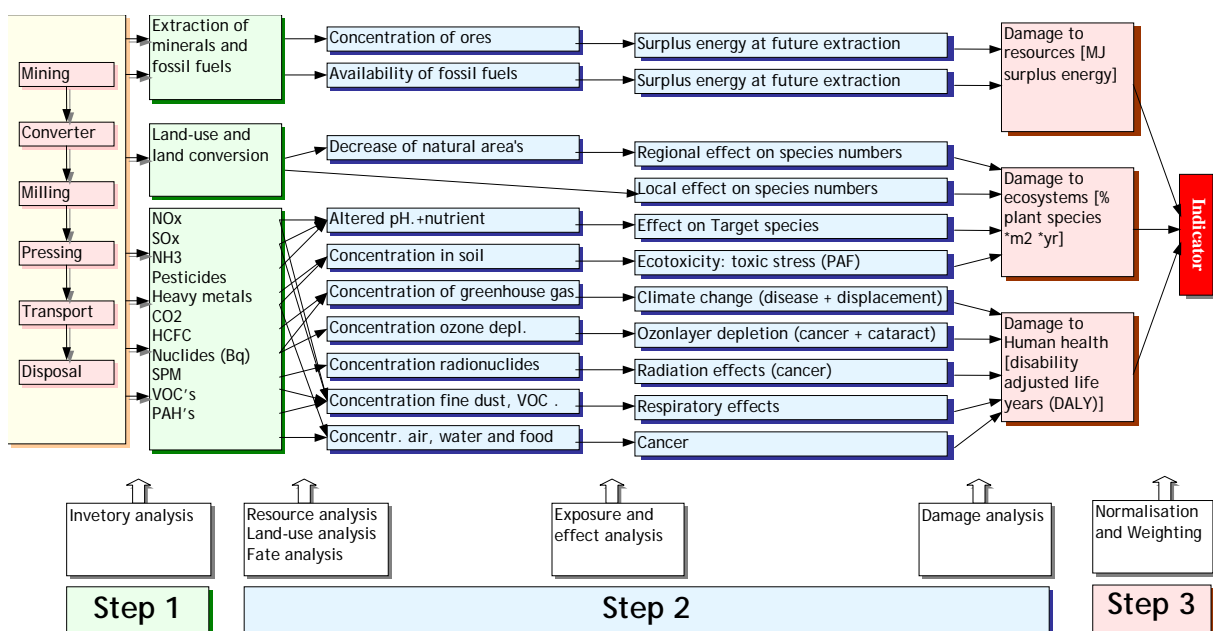


Figure 2 Detailed representation of the damage model

In general, the factors used in SimaPro do not deviate from the ones in the (updated) report. In case the report contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names in the database are used. A distinction is made for emissions to agricultural soil and industrial soil, indicated with respectively (agr.) or (ind.) behind substance names emitted to soil.

2.7.2 Characterisation

Emissions

Characterisation factors are calculated at end-point level (damage). The damage model for emissions includes fate analysis, exposure, effects analysis and damage analysis.

This model is applied for the following impact categories:

- **Carcinogens**
Carcinogenic effects due to emissions of carcinogenic substances to air, water and soil. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.
- **Respiratory organics**
Respiratory effects resulting from summer smog, due to emissions of organic substances to air, causing respiratory effects. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.
- **Respiratory inorganics**
Respiratory effects resulting from winter smog caused by emissions of dust, sulphur and nitrogen oxides to air. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.
- **Climate change**
Damage, expressed in DALY/kg emission, resulting from an increase of diseases and death caused by climate change.
- **Radiation**
Damage, expressed in DALY/kg emission, resulting from radioactive radiation
- **Ozone layer**
Damage, expressed in DALY/kg emission, due to increased UV radiation as a result of emission of ozone depleting substances to air.
- **Ecotoxicity**
Damage to ecosystem quality, as a result of emission of ecotoxic substances to air, water and soil. Damage is expressed in Potentially Affected Fraction (PAF)*m²*year/kg emission.
- **Acidification/ Eutrophication**
Damage to ecosystem quality, as a result of emission of acidifying substances to air. Damage is expressed in Potentially Disappeared Fraction (PDF)*m²*year/kg emission.

Land use

Land use (in manmade systems) has impact on species diversity. Based on field observations, a scale is developed expressing species diversity per type of land use. Species diversity depends on the type of land use and the size of the area. Both regional effects and local effects are taken into account in the impact category:

- **Land use**
Damage as a result of either conversion of land or occupation of land. Damage is expressed in Potentially Disappeared Fraction (PDF)*m²*year/m² or m²a.

Resource depletion

Mankind will always extract the best resources first, leaving the lower quality resources for future extraction. The damage of resources will be experienced by future generations, as they will have to use more effort to extract remaining resources. This extra effort is expressed as "surplus energy".

- **Minerals**
Surplus energy per kg mineral or ore, as a result of decreasing ore grades.

- **Fossil fuels**
Surplus energy per extracted MJ, kg or m3 fossil fuel, as a result of lower quality resources.

2.7.3 Uncertainties

Of course it is very important to pay attention to the uncertainties in the methodology that is used to calculate the indicators. Two types are distinguished:

1. Uncertainties about the correctness of the models used
2. Data uncertainties

Data uncertainties are specified for most damage factors as squared geometric standard deviation in the original reports, but not in the method in SimaPro. It is not useful to express the uncertainties of the model as a distribution. Uncertainties about the model are related to subjective choices in the model. In order to deal with them we developed three different versions of the methodology, using the archetypes specified in Cultural Theory. The three versions of Eco-indicator 99 are:

1. the egalitarian perspective
2. the hierarchist perspective
3. the individualist perspective

Hierchist perspective

In the hierarchist perspective the chosen time perspective is long-term, substances are included if there is consensus regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a and 2b are included, while class 3 has deliberately been excluded. In the hierarchist perspective damages are assumed to be avoidable by good management. For instance the danger people have to flee from rising water levels is not included. In the case of fossil fuels the assumption is made that fossil fuels cannot easily be substituted. Oil and gas are to be replaced by shale, while coal is replaced by brown coal. In the DALY calculations age weighting is not included.

Egalitarian perspective

In the egalitarian perspective the chosen time perspective is extremely long-term, Substances are included if there is just an indication regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a, 2b and 3 are included, as far as information was available. In the egalitarian perspective, damages cannot be avoided and may lead to catastrophic events. In the case of fossil fuels the assumption is made that fossil fuels cannot be substituted. Oil, coal and gas are to be replaced by a future mix of brown coal and shale. In the DALY calculations age weighting is not included.

Individualist perspective

In the individualist perspective the chosen time perspective is short-term (100 years or less). Substances are included if there is complete proof regarding their effect. For instance only carcinogenic substances in IARC class 1 included, while class 2a, 2b and 3 have deliberately been excluded. In the individualist perspective damages are assumed to be recoverable by technological and economic development. In the case of fossil fuels the assumption is made that fossil fuels cannot really be depleted. Therefore they are left out. In the DALY calculations age weighting is included.

Damage assessment

Damages of the impact categories result in three types of damages:

1. Damage to **Human Health**, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and the WHO.
2. Damage to **Ecosystem Quality**, express as the loss of species over an certain area, during a certain time
3. Damage to **Resources**, expressed as the surplus energy needed for future extractions of minerals and fossil fuels.

2.7.4 Normalisation

Normalisation is performed on damage category level. Normalisation data is calculated on European level, mostly based on 1993 as base years, with some updates for the most important emissions.

2.7.5 Weighting

In this method weighting is performed at damage category level (endpoint level in ISO). A panel performed weighting of the three damage categories. For each perspective, a specific weighting set is available. The average result of the panel assessment is available as weighting set.

2.7.6 Default

The hierchist version of Eco-indicator 99 with average weighting is chosen as default. In general, value choices made in the hierachist version are scientifically and politically accepted.

2.8 Ecological Footprint

2.8.1 Introduction

The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct and indirect land occupation, related to nuclear energy use and to CO₂ emissions from fossil energy use:

$$EF = EF_{direct} + EF_{CO_2} + EF_{nuclear}$$

2.8.2 Normalisation and weighting

Normalisation is not a part of this method.

In order to get a footprint, each impact category is given the weighting factor 1.

2.8.3 References

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.9 Ecopoints 97 (CH)

2.9.1 Introduction

The Swiss Ministry of the Environment (BUWAL) has developed the Ecopoint system, based on actual pollution and on critical targets that are derived from Swiss policy. It is one of the earliest systems for impact assessment with a single score. Like the Eco-indicator 95 method, described above, it is based on the distance-to-target method. The Swiss Ecopoints 1997 (also called Swiss ecoscarcity) is an update of the 1990 method.

There are three important differences:

1. The Ecopoint system does not use a classification. It assesses impacts individually. Although this allows for a detailed and very substance-specific method, it has the disadvantage that only a few impacts are assessed.
2. The Ecopoint system uses a different normalisation principle. It uses target values rather than current values.
3. The Ecopoint system is based on swiss policy levels instead of sustainability levels. Policy levels are usually a compromise between political and environmental considerations.

The following data are necessary in calculating a score in ecopoints for a given product:

- quantified impacts of a product;
- total environmental load for each impact type in a particular geographical area;
- maximum acceptable environmental load for each impact type in that particular geographical area.

2.9.2 Normalisation

In SimaPro you will find 3 normalisation sets: Target; Actual; and Ecopoints.

1) Normalisation on Target Value or Critical Emission (N=Target)

The original formula is used to calculate the Ecopoints:

$$\text{Ecofactor} = \frac{1}{Fk} \times \frac{F}{Fk} \times \text{Const}$$

$$\frac{1}{Fk} = \text{normalisation factor}$$

$$\frac{F}{Fk} \times \text{Const} = \text{evaluation factor}$$

2) Normalisation based on Actual Emission (N= Actual)

The adapted formula is used to calculate the Ecopoints so that normalization based on actual emissions can be done:

$$\text{Ecofactor} = \frac{1}{F} \times \frac{F}{Fk} \times \frac{F}{Fk} \times \text{Const}$$

$$\frac{1}{F} = \text{normalisation factor}$$

$$\frac{F}{Fk} \times \frac{F}{Fk} \times \text{Const} = \text{evaluation factor}$$

$$F = \text{Actual Swiss emission per year}$$

$$Fk = \text{Critical Swiss emission per year Const.} = 10^{12} / \text{year}$$

3) Ecopoints

Ecofactors given in the evaluation step, normalization factors=1.

2.9.3 Weighting

Ecopoints (weighting factors) are calculated using the following formula:

$$f = \frac{1}{Fk} \times \frac{F}{Fk} \times 10^{12} = \frac{F}{Fk^2} \times 10^{12}$$

f: ecofactor

Fk: target norm for total load

F: actual total current load
 10^{12} constant

The first term (1/Fk) expresses the relative contribution of the load to the exceeding of the target norm. It is the normalization step. The second term (F/Fk) expresses the extent to which the target norm is already being exceeded.

Please note that not all sum parameters such as (heavy) metals, AOX contributants, are included in the method.

2.9.4 References

Braunschweig A. et al. (1998) *Bewertung in Ökobilanzen mit der Methode der ökologischen Knappheit*. Ökofaktoren, Methodik Für Oekobilanzen, Buwal Schriftenreihe Umwelt Nr 297.

2.10 Ecological scarcity 2006

2.10.1 Introduction

The “ecological scarcity” method (also called Ecopoints or Umweltbelastungspunkte method) is a follow up of the Ecological scarcity 1997 method, be named in SimaPro method library as Ecopoints 97 (CH). The method follows, for the impact assessment of Life Cycle Inventories, the “distance to target” principle.

The ecological scarcity 2006 method is directly taken from Ecoinvent 2.0. The amount of substances present are compatible with the EI 2.0 database and partly extended with other substances. There might be some deviations if the method is used with other SimaPro libraries. The data have been implemented by ESU-services Ltd. All files are provided without liability.

In order to erase the large amount of zero entries in the method, and at the same time being compliant with inventory data that doesn't always consider subcompartments, the following three rules are implemented:

1. *Substances emitted to subcompartment unspecified, with characterization factor zero are excluded from the method*
2. *Substances emitted to a specific subcompartment with characterization factor zero while a non zero factor is provided for the sub compartment unspecified remain in the list*
3. *For substances emitted to the subcompartment agricultural, (i) the substances are replaced by the sub compartment unspecified with the same characterization factor of subcompartment agricultural and (ii) a subcompartment industrial with characterization factor zero is added.*

Frischknecht et al. (2007) describes that a characterisation factor of zero is also a factor and doesn't mean the substance is missing from the impact category. Only substances emitted to a specific compartment not mention in the method are indeed missing and not available yet. We are aware that by implementing the above rules the method in SimaPro does not fully comply with the original method and ideas of Frischknecht et al. (2007). However, we believe that excluding factors with a factor zero is more realistic.

2.10.2 Characterisation

The Eco-invent implementation contains seven specific impact categories, with for each substance a final UBP (environmental loading points) score as characterisation factor.

2.10.3 Normalisation and weighting

Normalisation is a part of this method but not traceable in SimaPro 7.

Because all impact categories are expressed in the same unit UBP, PRé Consultants added a weighting step. The “weighting” step simply adds up the scores.

2.10.4 References

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.11 Ecosystem Damage Potential (EDP)

2.11.1 Introduction

The Ecosystem Damage Potential (EDP) is a life cycle impact assessment methodology for the characterization of land occupation and transformation developed by the Swiss Federal Institute of Technology (ETH), Zürich. It is based on assessment impacts of land use on species diversity.

2.11.2 Characterization

This method was created using empirical information on species diversity from Central Europe. With information about species diversity on 5581 sample plots, Characterization factors for 53 land use types and six intensity classes were calculated. The typology is based on the CORINE Plus classification.

Linear transformations of the relative species numbers are linearly transformed into ecosystem damage potentials. The damage potential calculated is endpoint oriented.

The impact factor for the unknown reference land use type (ref) before or after the land transformation is chosen as $EDP(ref) = 0.80$. This represents the maximum EDP, i.e. the land use type with the most negative impact.

The different impact categories implemented in SimaPro are:

- "land transformation" as a result of the addition of "transformation, from land use type I" and "transformation, to land use type I"
- "land occupation"

2.11.3 Normalization and weighting

Normalisation is not a part of this method.

Because the two impact categories are expressed in the same unit (points), PRé Consultants added a weighting step. Each impact category is given the weighting factor 1.

2.11.4 References

Koellner T. and Scholz R. (2007a) *Assessment of land use impact on the natural environment: Part 1: An Analytical Framework for Pure Land Occupation and Land Use Change*. In: *Int J LCA*, 12(1), pp. 16-23.

2.12 EDIP/UMIP 97

2.12.1 Introduction

The EDIP method (Environmental Design of Industrial Products, in Danish UMIP) was developed in 1996. In 2004 the characterisation factors for resources, the normalisation and weighting factors for all impact categories were updated. Excluded in this version of the method in SimaPro are working environment and emissions to waste water treatment plants (WWTP).

The method is adapted for SimaPro 7. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (raw, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

2.12.2 Characterisation

Global warming is based on the IPCC 1994 Status report. In SimaPro GWP 100 is used. Stratospheric ozone depletion potentials are based on the status reports (1992/1995) of the Global Ozone Research Project (infinite time period used in SimaPro). Photochemical ozone creation potentials (POCP) were taken from UNECE reports (1990/1992). POCP values depend on the background concentration of NO_x, in SimaPro we have chosen to use the POCPs for high background concentrations. Acidification is based on the number of hydrogen ions (H⁺) that can be released. Eutrophication potential is based on N and P content in organisms. Waste streams are divided in 4 categories, bulk waste (not hazardous), hazardous waste, radioactive waste and slags and ashes. All wastes are reported on a mass basis.

Ecotoxicity is based on a chemical hazard screening method, which looks at toxicity, persistency and bioconcentration. Fate or the distribution of substances into various environmental compartments is also taken account. Ecotoxicity potentials are calculated for acute and chronic ecotoxicity to water and chronic ecotoxicity for soil. As fate is included, an emission to water may lead not only to chronic and acute ecotoxicity for water, but also to soil. Similarly an emission to air gives ecotoxicity for water and soil. This is the reason you will find emissions to various compartments in each ecotoxicity category.

Human toxicity is based on a chemical hazard screening method, which looks at toxicity, persistency and bioconcentration. Fate or the distribution of substances into various environmental compartments is also taken account. Human toxicity potentials are calculated for exposure via air, soil, and surface water. As fate is included, an emission to water may lead not only to toxicity via water, but also via soil. Similarly an emission to air gives human toxicity via water and soil. This is the reason you will find emissions to various compartments in each human toxicity category.

Resources

As resources use a different method of weighting, it cannot be compared with the other impact categories, for which reason the weighting factor is set at zero. Resources should be handled with great care when analysing results, the characterisation and normalisation results cannot be compared with the other impact categories.

To give the user some information in a useful way all resources have been added into one impact category. As equivalency factor the result of the individual normalisation and weighting scores have been used, i.e. the resulting score per kg if they would have been calculated individually. For detailed information on resources, including normalisation and weighting, choose the "EDIP/UMIP resources only" method.

EDIP v2.0 resources only

In the "EDIP/UMIP resources only" method only resources are reported. Opposite to the default EDIP/UMIP method, resources are given in individual impact categories, on a mass basis of the pure resource (i.e. 100% metal in ore, rather than ore). Normalisation is based on global production per world citizen, derived from World Resources 1992. Weighting of non-renewables is based on the supply-horizon (World Reserves Life Index), which specifies the period for which known reserves will last at current rates of consumption. If no normalisation data are known for an individual impact category, the

normalisation value is set at one and the calculation of the weighting factor is adjusted so that the final result is still consistent. However this may give strange looking graphs in the normalisation step.

2.12.3 Normalisation

The normalisation value is based on person equivalents for 1994 (according to the update issued in 2004). For resources, normalisation and weighing are already included in the characterisation factor and therefore set at zero.

2.12.4 Weighting

The weighting factors are set to the politically set target emissions per person in the year 2004 (according to the update issued in 2004), the weighted result are expressed except for resources which is based on the proven reserves per person in 1994. For resources, normalisation and weighing are already included in the characterisation factor and therefore set at zero.

Note:

Presenting the EDIP method as a single score (addition) is allowed, however it is not recommended by the authors. Note that due to a different weighting method for resources (based on reserves rather than political targets), resources may never be included in a single score. This is the reason that the weighting factor for resources is set at zero.

2.12.5 References

Wenzel H., Hauschild M., Alting L. (1997) *Environmental Assessment of Products. Volume 1: Methodology, tools and case studies in product development*. Chapman and Hall. ISBN 0 412 80800 5. See <http://www.wkap.nl/book.htm/0-7923-7859-8>.

Hauschild M., Wenzel H., (1998) *Environmental Assessment of Products. Volume 2: Scientific background*. Chapman and Hall. ISBN 0 412 80810 2. See <http://www.wkap.nl/book.htm/0-412-80810-2>

2.13 EDIP 2003

2.13.1 Introduction

EDIP 2003 is a Danish LCA methodology that is presented as an update of the EDIP 97 methodology.

The main innovation of EDIP2003 lies in the consistent attempt to include exposure in the characterisation modelling of the main non-global impact categories. EDIP2003 can originally be used both with and without spatial differentiation. Only characterisation factor for site-generic effects, which does not take spatial variation into account, are implemented in SimaPro 7.

The EDIP 2003 methodology represents 19 different impact categories. Some of them are updated versions of EDIP 97, whereas others are modelled totally different. The table underneath gives an overview of the EDIP 2003 impact categories. The choices made for implementing the methodology into SimaPro 7, are summed up for each impact category.

Impact categories:	Implemented in original form	Choices made during implementation
Global warming		Time horizon of 100y is used and extended with extra factors from EI 2.0
Ozone depletion	x	
Acidification	x	
Terrestrial eutrophication	x	
Aquatic eutrophication (N-eq)		Only emissions to inland waters only are included. Emissions to air included
Aquatic eutrophication (P-eq)		
Ozone formation (human)	x	Extended with extra factors from EI 2.0
Ozone formation (vegetation)	x	Extended with extra factors from EI 2.0
Human toxicity (exposure route via air)		Release height of 25m
Human toxicity (exposure route via water)	x	
Human toxicity (exposure route via soil)	x	
Ecotoxicity (water acute)	x	
Ecotoxicity (water chronic)	x	
Ecotoxicity (soil chronic)	x	
Hazardous waste		Directly taken from EDIP 97 (update 2004)
Slags/ashes		Directly taken from EDIP 97(update 2004)
Bulk waste		Directly taken from EDIP 97(update 2004)
Radioactive waste		Directly taken from EDIP 97(update 2004)
Resources		Directly taken from EDIP 97(update 2004)

Table 7 Overview of the different impact categories in EDIP2003, and the changes made for implementation.

In the EDIP 2003 method, characterisation factors for aquatic eutrophication are developed for two impact categories: aquatic eutrophication (N-eq) and aquatic eutrophication (P-eq). In each impact category, characterisation factors for emissions effecting inland waters and emissions effecting marine waters are developed. This double set of characterisation factors reflects the fact that, in general, eutrophication is limited by nitrate in fresh waters, and phosphate in marine waters.

In order to avoid double counting, that would occur if both emission types are implemented simultaneously, only the characterisation factors for inland water are implemented in SimaPro 7. When characterisation factors for marine water are needed, the following list can be used and implemented in the EDIP 2003 method:

Substances	Cas no.	Impact category			
		Aquatic eutrophication		Aquatic eutrophication	
Compartment		Soil	Water	Water	Soil
Nitric acid	7697-37-2	1,24E-01	1,61E-01	0,00E+00	0,00E+00
Nitrite	14797-65-0	1,62E-01	2,10E-01	0,00E+00	0,00E+00
Cyanide	57-12-5	2,92E-01	3,78E-01	0,00E+00	0,00E+00
Nitrogen, total		5,40E-01	7,00E-01	0,00E+00	0,00E+00
Phosphate	14265-44-2	0,00E+00	0,00E+00	3,30E-01	1,98E-02
Pyrophosphate	7722-88-5	0,00E+00	0,00E+00	3,50E-01	2,10E-02

Phosphorus, total		0,00E+00	0,00E+00	1,00E+00	6,00E-02
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Table 8 Characterisation factors for Emissions to marine waters in the impact category aquatic eutrophication. Emission compartment soil corresponds with the source category waste water while water corresponds with the source category agriculture.

Because each impact category contains unique substance names, to implement these characterisation factors, we suggest to create new substance names.

The emission to soil only takes into account the effects after plant uptake. For this impact category the topsoil is part of the techno sphere.

Emissions to air are also included in the model. The data needed for this compartment is not present in the guideline, but is received from Michael Hauschild.

The EDIP2003 characterisation factors for human toxicity, exposure route via air, are enhanced. The new exposure factors are established for:

- Two different kinds of substances: short-living (hydrogen chloride) and long-living (benzene)
- Actual variation in regional and local population densities: added for each substance
- Different release heights: 1m, 25m and 100m.

The release height of 25m is presented as default in EDIP2003 and is used in SimaPro 7.

For global warming a time horizon of 100 years is recommended by EDIP2003 and is used in SimaPro 7.

In the impact category "ozone formation", for the substance isobutene, two synonyms with the same cas-number and a different characterisation factor are found. Next characterisation factors are used:

Ozone formation (human): Isobutene: 9,44E-05

Ozone formation (vegetation): Isobutene: 1,168

2.13.2 Normalisation

Except for ecotoxicity and resources, all the different impact categories are normalized in the same way as in EDIP97, only using EDIP2003 normalisation references. Due to lack of data, no EDIP2003 normalisation references for any of the ecotoxicity categories are calculated. Therefore, in SimaPro, the normalisation reference for ecotoxicity is zero. For resources, normalisation and weighing are already included in the characterisation factor and therefore set at zero.

2.13.3 Weighting

Until the EDIP weighting factors have been updated to an EDIP2003 version, the weighting factors of EDIP97 (according to the update issued in 2004), are also used in EDIP2003. Because ecotoxicity has no normalisation factors, also for weighting the value is set at zero. For resources, normalisation and weighing are already included in the characterisation factor and therefore set at zero.

2.13.4 Reference

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Hauschild M., Potting J. (2003) *Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology*. Institute for Product Development Technical University of Denmark.

2.14 EPD 2007

2.14.1 Introduction

This method is to be used for the creation of Environmental Product Declarations or (EPDs), as published on the website Swedish Environmental Management Council (SEMC).

In the standard EPDs one only has to report on the following impact categories:

<i>Original names</i>	<i>Names in SP</i>
Gross Calorific Values (GVC) (referred to as "Higher Heating Values")	Non renewable, fossil
Greenhouse gases	Global warming (GWP100)
Ozone-depleting gases	Ozone layer depletion (ODP)
Acidifying compounds	Acidification
Gases creating ground-level ozone (Photochemical Ozone creation)	Photochemical oxidation
Eutrophicating compounds	Eutrophication

Specific product category guidelines may require extra information.

Except for the Gross Calorific Value (GCV) impact categories, all impact categories are taken directly from the CML 2 baseline 2000 method, also found in SimaPro (we used release 2.03). Please note that there are some differences between the SimaPro implementation and the EPD document for the Gross Calorific Values.

SimaPro 7 used the draft version that was to be commented before March 2007, but that was still on the site when compiling this method in June 2007. It is possible the final version will have other Characterisation factors.

2.14.2 Normalization and weighting

Normalization and weighting are not a part of this method.

2.14.3 References

"Revision of the EPD® system into an International EPD®":

http://www.environdec.com/documents/pdf/rev_EPD_Section_1_Application_of_LCA_methodology.pdf

2.14.4 Acknowledgement

We thank Leo Breedveld from 2B (www.to-be.it) for his advice and support.

2.15 EPS 2000

2.15.1 Introduction

The EPS 2000 default methodology (Environmental Priority Strategies in product design) is a damage oriented method. In the EPS system, willingness to pay to restore changes in the safe guard subjects is chosen as the monetary measurement. The indicator unit is ELU (Environmental Load Unit), which includes characterisation, normalization and weighting.

The top-down development of the EPS system has led to an outspoken hierarchy among its principles and rules. The general principles of its development are:

- The top-down principle (highest priority is given to the usefulness of the system);
- The index principle (ready made indices represent weighted and aggregated impacts)
- The default principle (an operative method as default is required)
- The uncertainty principle (uncertainty of input data has to be estimated)
- Choice of default data and models to determine them

The EPS system is mainly aimed to be a tool for a company's internal product development process. The system is developed to assist designers and product developers in finding which one of two product concepts has the least impact on the environment. The models and data in EPS are intended to improve environmental performance of products. The choice and design of the models and data are made from an anticipated utility perspective of a product developer. They are, for instance not intended to be used as a basis for environmental protection strategies for single substances, or as a sole basis for environmental product declarations. In most of those cases additional site-specific information and modelling is necessary.

The EPS 2000 default method is an update of the 1996 version. The impact categories are identified from five safe guard subjects: human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational values.

This V2 version is adapted for SimaPro 7. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

This method is NOT fully adapted for inventory data from the ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

2.15.2 Classification

Emissions and resources are assigned to impact categories when actual effects are likely to occur in the environment, based on likely exposure.

2.15.3 Characterisation

Empirical, equivalency and mechanistic models are used to calculate default characterisation values.

Human Health

In EPS weighting factors for damage to human health are included for the following indicators:

- Life expectancy, expressed in Years of life lost (person year)
- Severe morbidity and suffering, in person year, including starvation
- Morbidity, in person year, like cold or flue
- Severe nuisance, in person year, which would normally cause a reaction to avoid the nuisance
- Nuisance, in person year, irritating, but not causing any direct action

Ecosystem production capacity

The default impact categories of production capacity of ecosystems are:

- Crop production capacity, in kg weight at harvest

- Wood production capacity, in kg dry weight
- Fish and meat production capacity, in kg full weight of animals
- Base cat-ion capacity, in H+ mole equivalents (used only when models including the other indicators are not available)
- Production capacity of (irrigation) water, in kg which is acceptable for irrigation, with respect to persistent toxic substances
- Production capacity of (drinking) water, in kg of water fulfilling WHO criteria on drinking water.

Abiotic stock resources

Abiotic stock resource indicators are depletion of elemental or mineral reserves and depletion of fossil reserves. Some classification factors are defined 0 (zero).

In SimaPro characterisation values for abiotic depletion result from both the impact of depletion and impacts due to extraction of the element/mineral or resource.

Biodiversity

Default impact category for biodiversity is extinction of species, expressed in Normalised Extinction of species (NEX).

Cultural and recreational values

Changes in cultural and recreational values are difficult to describe by general indicators as they are highly specific and qualitative in nature. Indicators should be defined when needed, and thus are not included in the default methodology in SimaPro.

2.15.4 Normalization/Weighting

In the EPS default method, normalization/weighting is made through valuation.

Normalization/weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

2.15.5 References:

Steen B. (1999) *A systematic approach to environmental strategies in product development (EPS). Version 2000 - General system characteristics*. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:4. Download as PDF file (246 kb) from <http://www.cpm.chalmers.se/cpm/publications/EPS2000.PDF>

Steen B. (1999) *A systematic approach to environmental strategies in product development (EPS). Version 2000 - Models and data of the default methods*. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:5. Download as zipped PDF file (1140 kb) from http://www.cpm.chalmers.se/cpm/publications/EPS1999_5.zip

2.16 Impact 2002+

2.16.1 Introduction

IMPACT 2002+ is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology - Lausanne (EPFL), with current developments carried out by the same team of researchers now under the name of ecoinvent-life cycle systems (Lausanne). The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories.

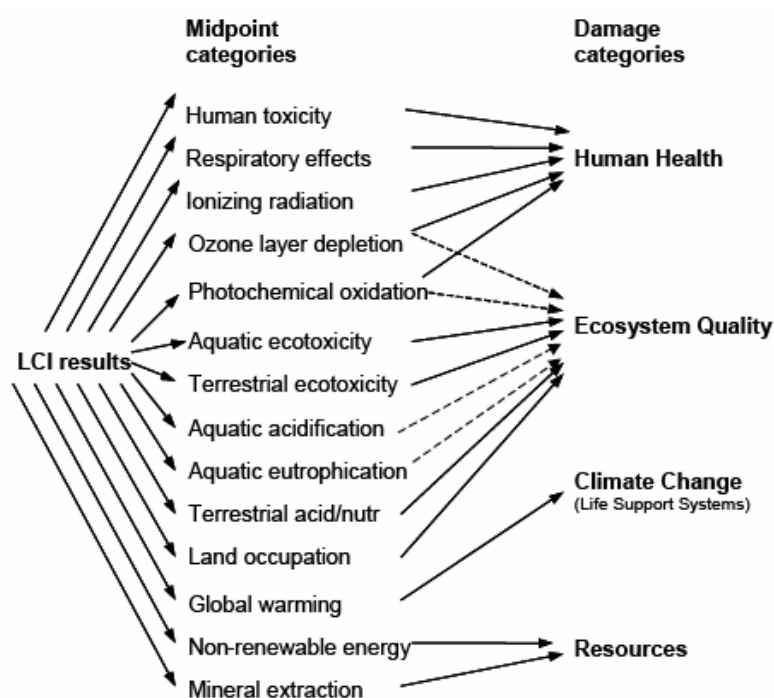


Figure 3 Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories. Based on Jolliet et al. (2003a)

2.16.2 Characterisation

The Characterisation factors for Human Toxicity and Aquatic & Terrestrial Ecotoxicity are taken from the methodology IMPACT 2002 - IMPact Assessment of Chemical Toxics. The Characterisation factors for other categories are adapted from existing characterizing methods, i.e. Eco-indicator 99, CML 2001, IPCC and the Cumulative Energy Demand.

The IMPACT 2002+ method (version 2.1) presently provides Characterisation factors for almost 1500 different LCI-results, which can be downloaded at <http://www.epfl.ch/impact>. In SimaPro 15 different impact categories are presented, as human toxicity is split up in 'Carcinogens' and 'Non-carcinogens'.

2.16.3 Normalization

The damage factor reported in ecoinvent are normalized by dividing the impact per unit of emission by the total impact of all substances of the specific category for which Characterisation factors exist, per person per year (for Europe). The unit of all normalized midpoint/damage factors is therefore

[pers*year/unit_{emission}], i.e. the number of equivalent persons affected during one year per unit of

emission. An overview of normalization factors for the four damage categories is given in table 9.

Damage categories	Normalization factors	Unit
Human Health	0.0071	DALY/pers/yr

Ecosystem Quality	13700	PDF.m ² .yr/pers/yr
Climate Change	9950	Kg CO ₂ /pers/yr
Resources	152000	MJ/pers/yr

Table 9 Normalization factors for the four damage categories for Western Europe

2.16.4 Weighting

The authors of IMPACT2002+ suggest to analyze normalized scores at damage level considering the four-damage oriented impact categories human health, ecosystem quality, climate change, and resources or, alternatively, the 14 midpoint indicators separately for the interpretation phase of LCA. However, if aggregation is needed, one could use self-determined weighting factors or a default weighting factor of one, unless other social weighting values are available.

PRé Consultants added an extra weighting step. Each damage category is given the weighting factor 1.

2.16.5 References

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*.ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.17 IPCC 2001 GWP

2.17.1 Introduction

IPCC 2001 is a method developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20, 100 and 500 years. The method from the ecoinvent 1.01 database was expanded with other characterisation factors for emissions available in the SimaPro database.

2.17.2 Characterisation

The IPCC characterisation factors for the direct global warming potential of air emissions. They are:

- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of NO_x, water, sulphate, etc. in the lower stratosphere + upper troposphere.
- not considering the range of indirect effects given by IPCC.
- including CO₂ formation from CO emissions.
- considering biogenic CO₂ uptake as negative impact.

2.17.3 Normalisation and weighting

Normalisation and weighting are not a part of this method.

2.17.4 References

Frischknecht R., Jungbluth N., et.al. (2003). Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000, Swiss Centre for LCI. Dübendorf, CH <http://www.ecoinvent.org/>

Climate Change 2001. IPCC Third Assessment Report. The Scientific Basis.
http://www.grida.no/climate/ipcc_tar/

Intergovernmental Panel on Climate Change (IPCC)
<http://www.ipcc.ch/>

2.18 IPCC 2007

2.18.1 Introduction

IPCC 2007 is an update of the method IPCC 2001 developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20, 100 and 500 years.

2.18.2 Characterisation

IPCC characterisation factors for the direct (except CH₄) global warming potential of air emissions. They are:

- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of NO_x, water, sulphate, etc. in the lower stratosphere + upper troposphere.
- not considering the range of indirect effects given by IPCC.
- not including CO₂ formation from CO emissions.
- considering biogenic CO₂ uptake as negative impact.

2.18.3 Normalisation and weighting

Normalisation and weighting are not a part of this method.

2.18.4 References

Climate Change 2007. IPCC Fourth Assessment Report. The Physical Science Basis.
<http://www.ipcc.ch/ipccreports/ar4-wg1.htm>

Intergovernmental Panel on Climate Change (IPCC)
<http://www.ipcc.ch/>

2.19 Selected LCI results

2.19.1 Introduction

The selected life cycle inventory indicators are, in most cases, the summation of selected substances emitted to all different subcompartments.

The list of selected LCI indicators is divided in two. The first list contains the common set of elementary flows shown in the results discussion of the ecoinvent reports. One example is "fossil CO₂ emissions to air". The second list contains additional elementary flows used in at least one of the ecoinvent reports. One example of this extended list is "actinides emitted to water". These two lists are implemented as two different methods into SimaPro: Selected LCI results and SelectedLCI results, additional.

SubCategory	Name	Location	Unit	Used in ecoinvent report
resource	land occupation	GLO	m2a	all
resource	water	GLO	m3	No. 6 VIII
resource	carbon, biogenic, fixed	GLO	kg	No. 17
air	carbon monoxide	GLO	kg	No. 11 II
air	CO ₂ , fossil	GLO	kg	all
air	lead	GLO	kg	No. 6 VI
air	methane	GLO	kg	No. 6 IV
air	N ₂ O	GLO	kg	No. 6 VI
air	nitrogen oxides	GLO	kg	all
air	NMVOG	GLO	kg	all
air	particulates, <2.5 um	GLO	kg	all
air	particulates, >2.5 um and <10 um	GLO	kg	No. 6 VI
air	particulates, >10 um	GLO	kg	No. 6 VI
air	partculates	GLO	kg	No. 11 II
air	sulphur dioxide	GLO	kg	all
air	zinc	GLO	kg	No. 6 VI
air, radioactive	radon (+ radium)	GLO	kBq	No. 6 VI
air, radioactive	noble gas	GLO	kBq	No. 6 VI
air, radioactive	aerosole	GLO	kBq	No. 6 VI
air, radioactive	actinides	GLO	kBq	No. 6 VI
soil	cadmium	GLO	kg	all
water	BOD	GLO	kg	all
water, radiactive	radium	GLO	kBq	No. 6 VII
water, radiactive	tritium	GLO	kBq	No. 6 VII
water, radiactive	nuclides	GLO	kBq	No. 6 VII
water, radiactive	actinides	GLO	kBq	No. 6 VII
total	oils, unspecified	GLO	kg	No. 6 IV
total	heat, waste	GLO	MJ	No. 6 VII

Table 10 List of selected life cycle inventory indicators implemented in ecoinvent data v2.0

The selection does not necessarily reflect the environmental importance of the listed pollutants and resources. The pollutants and resources are selected in view of a better characterisation of the analysed products and services.

The selection helps practitioners to get a more convenient access to a selection of LCI results of products and services. It does not replace the use of the complete set of LCI results and the application of LCIA methods.

2.19.2References

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

2.20 TRACI 2

2.20.1 Introduction

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), a stand-alone computer program developed by the U.S. Environmental Protection Agency specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined.

TRACI facilitates the Characterisation of environmental stressors that have potential effects, including ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human health criteria-related effects, human health cancer effects, human health noncancer effects, fossil fuel depletion, and land-use effects. TRACI was originally designed for use with life-cycle assessment (LCA), but it is expected to find wider application in the future.

This method presented in SimaPro 7 is originally based on TRACI v2.00 but it has expanded data derived from the release of TRACI at ecoinvent 2.0. Some impact categories were deleted to avoid double counting and some were renamed. This method replaces the “old” TRACI method in SimaPro.

2.20.2 Characterisation

Impact categories were characterized at the midpoint level for reasons including a higher level of societal consensus concerning the certainties of modeling at this point in the cause-effect chain. Research in the impact categories was conducted to construct methodologies for representing potential effects in the United States.

TRACI is a midpoint oriented LCIA method including the following impact categories:

- Ozone depletion
- Global warming
- Acidification
- Eutrophication
- Photochemical oxidation (smog)
- Ecotoxicity
- Human health: criteria air pollutants
- Human health: carcinogenics
- Human health: non-carcinogenics
- Fossil fuel depletion(not implemented in SimaPro)
- Land use (not implemented in SimaPro)
- Water use (not implemented in SimaPro)

For substances emitted to the sub compartment agricultural within the impact categories Ecotoxicity, Carcinogens and Non-carcinogens, the sub compartment is replaced by the sub compartment unspecified.

2.20.3 Normalization and weighting

The TRACI version implemented in ecoinvent data 2.0 is the one provided by Jane Bare in 2007, which does not contain Normalization factors. The normalization factors were recently published in ES&T (Bare and Gloria, 2007).

PRé did not take over the Normalisation figures, as they are provided per compartment, what cannot be handled by SP yet. Moreover, using the total normalized values gave results that are difficult to understand or explain.

impact category	normalized value air	normalized value water	total normalized value	normalized unit
acidification	$2.08 \times 10^{+12}$	NA	$2.08 \times 10^{+12}$	H ⁺ equiv/yr
ecotoxicity	$2.03 \times 10^{+10}$	$2.58 \times 10^{+08}$	$2.06 \times 10^{+10}$	2,4-D equiv/yr
eutrophication	$1.44 \times 10^{+09}$	$3.58 \times 10^{+09}$	$5.02 \times 10^{+09}$	N equiv/yr
global warming	$6.85 \times 10^{+12}$	NA	$6.85 \times 10^{+12}$	CO ₂ equiv/yr
human health cancer	$7.03 \times 10^{+07}$	$1.76 \times 10^{+06}$	$7.21 \times 10^{+07}$	benzene equiv/yr
human health noncancer	$3.69 \times 10^{+11}$	$4.24 \times 10^{+10}$	$4.11 \times 10^{+11}$	toluene equiv/yr
human health criteria	$2.13 \times 10^{+10}$	NA	$2.13 \times 10^{+10}$	PM2.5 equiv/yr
ozone depletion	$8.69 \times 10^{+07}$	NA	$8.69 \times 10^{+07}$	CFC-11 equiv/yr
photochemical smog	$3.38 \times 10^{+10}$	NA	$3.38 \times 10^{+10}$	NO _x equiv/yr
fossil fuel depletion	NA	NA	$1.14 \times 10^{+07}$	surplus mega-Joules of energy/yr

Table 11 Summary of normalized values for TRACI Impact Categories for 1999

impact category	normalized value air per capita	normalized value water per capita	total normalized value per capita	normalized unit per capita
acidification	$7.44 \times 10^{+03}$	NA	$7.44 \times 10^{+03}$	H ⁺ equiv/yr/capita
ecotoxicity	$7.29 \times 10^{+01}$	9.24×10^{-01}	$7.38 \times 10^{+01}$	2,4-D equiv/yr/capita
eutrophication	$5.15 \times 10^{+00}$	$1.28 \times 10^{+01}$	$1.80 \times 10^{+01}$	N equiv/yr/capita
global warming	$2.45 \times 10^{+04}$	NA	$2.45 \times 10^{+04}$	CO ₂ equiv/yr/capita
human health cancer	2.52×10^{-01}	6.30×10^{-03}	2.58×10^{-01}	benzene equiv/yr/capita
human health noncancer	$1.32 \times 10^{+03}$	$1.52 \times 10^{+02}$	$1.47 \times 10^{+03}$	toluene equiv/yr/capita
human health criteria	$7.63 \times 10^{+01}$	NA	$7.63 \times 10^{+01}$	PM2.5 equiv/yr/capita
ozone depletion	3.11×10^{-01}	NA	3.11×10^{-01}	CFC-11 equiv/yr/capita
photochemical smog	$1.21 \times 10^{+02}$	NA	$1.21 \times 10^{+02}$	NO _x equiv/yr/capita
fossil fuel depletion	NA	NA	4.08×10^{-02}	surplus mega-Joules of energy/yr/capita

Table 12 Summary of normalized values for TRACI Impact Categories for 1999 on a per capita basis

TRACI is a midpoint oriented life cycle impact assessment methodology, consistently with EPA's decision not to aggregate between environmental impact categories.

Arguing that normalization and valuation is still very much under debate and because of possible misinterpretation and misuse, the authors of TRACI determined that the state of the art for the normalization and valuation processes did not yet support inclusion in TRACI.

2.20.4 References

Bare, J.C., Norris, G.A., Pennington, D.W., McKane, T. 2003. *TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts*. Journal of Industrial Ecology.

http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf

Frischknecht R., Jungbluth N., Althaus H.J., Doka G., Dones R., Hirschier R., Hellweg S., Humbert S., Margni M., Nemecek T., Spielmann M. (2007) *Implementation of Life Cycle Impact Assessment Methods: Data v2.0*.ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Bare J., Gloria T., Norris G. (2006) *Development of the Method and U.S. Normalization Database for Life Cycle Impact Assessment and Sustainability Metrics*. In: *Envir Sc Tech*, 40(16), pp. 5108-5115.