LoRe-LCA

Low Resource consumption buildings and constructions by use of LCA in design and decision making

Indicators and weighting systems, including normalisation of environmental profiles

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Definitions and Abbreviations

ADP	Abiotic resource Depletion Potential
AHP	Analytic Hierarchy Process
AP	Acidification Potential
BIO	Biodegradable factor
BRE	Building Research Establishment
CED	Cumulative Energy Demand
CEN	Europen Committee for Standardization
DALY	Disability Adjusted Life Years
DS	Dry Substance
ELU	Environmental Load Unit
EP	Eutrophication Potential
EPD	Environmental Product Declaration
EQ	Ecosystem Quality
FAETP	Fresh water Aquatic Eco Toxicity
GWP	Global Warming Potential
HTF	Human Toxicity Factor
HTP	Human Toxicitiy Potential
HU	Hazard Units
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LOEC	Lowest Observed Effect Concentration
MAETP	Marine Aquatic Eco Toxicity
MET	Mean Extinction Time
NOEC	No Observable Effect Concentration
ODP	Ozone Depletion Potential
OTV	Odour Threshold Value
PAF	Potentially Affected Fraction
PDF	Potentially Disappeared Fraction
PDI	Predicted Daily Intake
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration

POCP	Photochemical Ozone Creation Potential
RAD	Restrictive Active Day
UCTE	Union for the Coordination of production and Transmission of Electricity
USES	Uniform System for Evaluation of Substances
VOC	Volatile Organic Compound
WFII	Water footprint impact index
WP	Work Package
WTP	Willingness To Pay
YLD	Years of Life Disabled
YLL	Years of Life Lost

1 Introduction

"Low Resource consumption buildings and construction by use of LCA in design and decision making (LoRe-LCA)" is a project within the EU-FP 7.

LoRe-LCA aims to coordinate activities regarding the application of LCA in the European construction sector, focusing on comparing and improving the functional units used for LCA for whole buildings, improving the possibilities to compare results for different alternatives during design stage, and for comparison of results for different buildings. The project focuses on harmonisation and use of LCA-methods in design and decision-making for reaching overall goals of reduced resource consumption.

The main objectives of WP5 are to collect and analyse information on how LCA results are or could be interpreted including analysis of different indicators, normalisation and weigthing systems and sensitivity of the results.

2 Purpose and scope

The main purpose of this report is to collect information on different impact category indicators, including analysis of some controversial indicators, and collect data on different normalisation and weighting systems used in LCA tools, and, if possible, recommend a system for weighting to obtain a few, or a single number.

Interpretation is the phase of an LCA in which the results of the analysis and all choices and assumptions made during the assessment are evaluated and overall conclusions are drawn.

In accordance with ISO 14043, interpretation includes:

- identification of significant issues, based on the results of the LCI and LCIA phases of LCA
- evaluation, comprising completeness, sensitivity and consistency checks,
- conclusions, recommendations and reporting.

In accordance with EN ISO 14044, normalisation is the calculation of the magnitude of the category indicator results relative to reference information, while weighting is a method in which the (normalised) indicator results for each impact category assessed are assigned to numerical factors according to their relative importance, multiplied by these factors and possibly aggregated.

3 Study of relevant indicators

3.1 Introduction

In accordance with ISO 14040, an indicator is a quantifiable representation of an impact category. Description of the most common, controversial and CEN indicators belonging to different impact categories can be found in the following sections.

3.2 Description of the most common indicators

(Source: Enslic State of the Art Report)

3.2.1 Resources

- **Depletion of abiotic resources, CML 1992**

Abiotic resources are non-living natural resources, like iron ore or crude oil. The efficient use of these resources is one of the most important criteria of sustainability. Most abiotic resources are non-renewable (except, for example, wind).

In 1992 according to Heijungs [Heijungs et al, 1992] for a given resource *i*, abiotic depletion was defined as the ratio between the quantity of resource extracted (m_i) and the recoverable reserves of that source (*Mi*):

$$abiotic\ depletion = \sum_i \frac{m_i}{M_i}$$

The units used for both extractions and reserves could thus be freely selected, as long as this was consistent for a given source. Ores were normally expressed in kg and natural gas in m^3, although MJ could be used as an alternative. Heijungs observed that this is a simplified method and that should ultimately be extended to include the extraction rate, expressed in kg/year or m^3/year.

- **Depletion of abiotic resources (antimony equivalent), CML1995 and 2001**

Guinée and Heijungs [Guinée and Heijungs, 1995] proposed a characterisation factor called ADP (Abiotic Depletion Potential). The new characterisation factor was based on the resource state and the extraction rate, expressed in kg of a reference resource (antimony):

$$abiotic\ depletion = \sum_i ADP_i \times m_i$$

ADP_i = Abiotic Depletion Potential of resource *i* [kg of antimony equivalent/kg];
m_i = mass of the substance *i*, inventoried in the process [kg].

$$ADP_i = \frac{DR_i}{(R_i)^2} \cdot \frac{(R_{ref})^2}{DR_{ref}}$$

R_i = ultimate reserve of resource *i*, [kg];
DR_i = extraction rate of resource *i*, [kg*year^{-1}]
R_{ref} = ultimate reserve of antimony, [kg];
DR_{ref} = extraction rate of antimony [kg*year^{-1}];

The model is considered operational for 84 elements and 30 configurations (resources composed of different elements fossil fuels excluded).

A development of this method was made [Van Oers et al, 2002] in order to extend the calculation to the fossil fuels category: fossil fuels can be considered equivalent to resources and then can be mutually replaced, so we can calculate a global ADP for all fossil fuels regarding the use of a 1 MJ of fuel, according to the following expression:

$$ADP_{fossil\ energy} = \frac{DR_i}{(R_i)^2} \cdot \frac{(R_{ref})^2}{DR_{ref}} = 4{,}81 \times 10^{-4}$$

$ADP_{fossil\ energy}$= Abiotic Depletion Potential of fossil fuels [kg/MJ];
R_i = ultimate reserve of fossil fuel *i*, 4,72*10^{20} MJ;
DR_i = production of fossil energy, 3,03*10^{-15} MJ*year^{-1};
R_{ref} = ultimate reserve of antimony, 4,63*10^{15} kg;
DR_{ref} = extraction rate of antimony 6,06*10^{7} kg*year^{-1}

The ADP of each fuel is then obtained by multiplying the $ADP_{fossil\ energy}$ with the energy content *E* of each considered fuel:

$$ADP_{fuel} = ADP_{fossil\ energy} \times E_i$$

ADP_{fuel}= Abiotic Depletion Potential specific of the fossil fuel [kg];
$ADP_{fossil\ energy}$= Abiotic Depletion Potential global of the fossil fuel [kg/MJ];
E = energy content of the fossil fuel *i,* [MJ];

Between 1992 and 1997 several research groups studied and proposed methods for abiotic depletion evaluation. In 1997 Heijungs made a distinction between resources that can be depleted and those that are competitively used: resources that are depleted should be assessed by a method based on depletion, as stated above and those that are competitively used should be assessed by a method based on competition. One implication of this is that the aggregation of abiotic measures into a single measure is not meaningful. Several solutions were proposed, but reviewing authors differ in their conclusions, and today there is no general consensus about what constitutes the best category indicator.

- **Cumulative energy demand (total and non renewable part)**

a)
The Cumulative Energy Demand (CED) has already been used since the seventies as an indicator for energy systems. The assessment of the environmental impacts related to a product or process is based on one parameter: the total energy demand for production, use and disposal expressed in primary energy. Energy resources that can be found in nature, such as coal, crude oil and natural gas are called primary energy resources. Their transformation into „secondary“ energy resources, such as gasoline, diesel or electricity involves losses, which depend on the efficiency and level of the transformation.
Every direct and indirect (e.g. construction of infrastructure) energy input is taken into account, obtained from process or input-output analysis. It is important to distinguish between non-renewable (fossil, nuclear) and renewable primary energy use (hydro, wind, solar, biomass etc.).

b)
ECOSOFT uses Primary Energy non-renewable (PEI_{ne}) as an indicator for the cumulative energy demand of building materials. This indicator is calculated as gross calorific value of all non-renewable resources used in the process chain. It is expressed in MJ/m^2 of construction area.

- **Water consumption**

Desiccation refers to a group of related environmental problems caused by water shortages due to groundwater extraction for industrial and drinking water supply, enhanced drainage and water management. No method has been yet developed for incorporating desiccation in LCA under the form of a desiccation potential [Guinée et al, 2001]. As in the case of most potential impacts (GWP, AP, EP, POCP, ODP, etc.), an impact will not take place necessarily, but a potential indicator is useful in order to evaluate the potential risk of a real impact production.

In the building sector, the water consumption is nevertheless an important matter [Polster, 1995]. In the absence of a characterisation factor for desiccation, we propose an indicator also used by [Frischknecht et al, 1996], which regards simply the quantity of water used:

$$\textit{water used} = Q$$

Q = quantity of freshwater used [m^3].

This indicator uses the water consumption figures included in the inventories (e.g. materials and electricity production). Some types of water sources (e.g. sea water) are not accounted for.

- **Water footprint**

The water footprint is an indicator of freshwater use that looks not only at the direct water use of a consumer or producer, but also the indirect water use. The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by type of pollution.

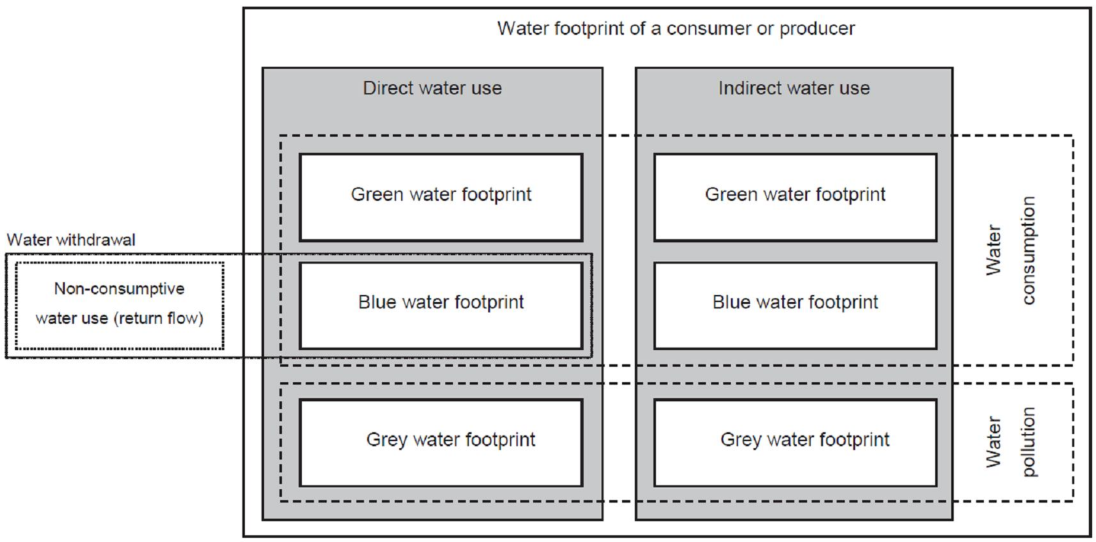

Figure 1 Schematic presentation of the components of a water footprint, showing that the non-consumptive part of the water withdrawals (the return flow) is not a part of the water footprint
(Source: The Water Footprint Assessment Manual)

A full water footprint assessment consist of four distinct phases:

1. Setting goals and scopes
2. Water footprint accounting
3. Water footprint sustainability assessment
4. Water footprint formulation

For carrying out a life cycle assessment (LCA), it is desired to summarize the information on the sustainability of a product water footprint into index or a few indices, all impact need to be expressed by single indices, which requires aggregation of more specific information. The green, blue and grey water footprints are good indicators of total water resource consumption and waste assimilation capacity related to the product. The footprints can thus directly be used as indicators in LCA.
The water footprint of a product can be calculated with a chain-summation approach or a stepwise accumulative approach.

The local environmental impact depends on the water scarcity (ignoring the larger issue of global water scarcity) and water pollution level in the catchment in which the water footprint of the product is located.
When two products have the same water footprint, they make similar claim on the globe's limited water resources, even though, when made in different places, the local environmental impact may be different.

The water footprint impact index (WFII) is an aggregated and weighted measure of the environmental impact.

$WFII = WFII_{green} + WFII_{blue} + WFII_{grey} =$

$$\sum_x \sum_t [(\mathbf{WFgreen}][x,t] * \mathbf{WSgreen}[\mathbf{x},\mathbf{t}])$$

$$+ \sum_x \sum_t [(\mathbf{WFgreen}][x,t] * \mathbf{WSgreen}[\mathbf{x},\mathbf{t}])$$

Frameworks such as MFA, LCA and input-output modeling consider the use of various types of environmental resources and look at the various types of impact on the environment, while ecological footprint, water footprint and embodied energy analyses take the perspective of one particular resource or impact. Although the "footprints" are precisely the indicators typically used in MFA, LCA and input-output studies, the methods applied do not form one coherent framework of methods. It is claimed that the water perspective is not addressed in a sufficient ways in the above mentions studies.

Water footprint assessment phase	Outcome	Physical meaning	Resolution	LCA phase
Product water footprint accounting	Green, blue and grey water footprints (volumetric)	Water volume consumed or polluted per unit of product	Spatiotemporally explicit	Life cycle inventory
Product water footprint sustainability assessment	An evaluation of the sustainability of a green, blue and grey product water footprint from an environmental, social and economic perspective	Various measurable impact variables	Spatiotemporally explicit	Life cycle impact assessment
Aggregation of selected information from the water footprint sustainability assessment	Aggregated water footprint impact indices	None	Non spatiotemporally explicit	

Table 1 How water footprint assessments can feed LCA

- **Surplus energy to extract minerals and fossil fuels**

Minerals:
Surplus energy per kg mineral as a result of the reduction of the mineral class. The geographic reach is global.

Fossil fuels:
Surplus energy to extract MJ, kg or m^3 of fossil fuel, like result of the lower quality of resources. Geographic reach is global.

The previous impact categories are grouped in three damage categories, applying the corresponding damage characterization factors. The intention of this grouping is to combine the impact categories that have the same indicator unit into damage categories and thus to simplify subsequent interpretation by reducing the number of impact categories. The results of the impact categories are grouped in the following types of damages:

Damage to Resources (Resources):
It is expressed as the energy required [MJ] for the future extraction of minerals and fossil fuels. Human activity will always extract the best resources first, leaving lower quality resources for future extraction. This damage will be experienced by future generations who will have to invest greater effort in extracting the remaining resources. This extra effort is expressed as surplus energy. It includes the following impact categories: Minerals and Fossil Fuels.

- **Land use**

There are many consequences of human use of land. Land is regarded in the subcategory „land competition“ as a resource, which is temporarily unavailable during its use [Guinée, 2002].
Land use is highly relevant for the building and construction sector from two different points of view:
direct land use of the building which occupies land;
land use and transformation for the production of building materials (mineral extraction, agriculture, silviculture)
These issues are currently not reflected in most LCAs. Several methods have been developed for including land use in LCA, but determining the effects on the ecosystem is a very complex task. It is not only the occupied area itself which is relevant, but also the degree of change. For example, one square metre of sealed ground cannot be compared to one square metre of plantation forest. The model in *Guinée* does not distinguish between the different types of use: the indicator results from an unweighted aggregation of all land uses related to the product life. Research on land use in general is currently undertaken by a number of organisations. However, direct land use of buildings is a largely new field in the area of LCA.

- **Resource factor**

For EcoEffect we have designed a resource use factor based on an AHP process (Analytic Hierarchy Process). Resources were divided in four categories – metals, fuels, minerals and biomass. The weighting aspects were: supply horizon, exploitation rate, value (monetary), accessibility, regeneration rate and recovering energy.

- **Cumulative exergy demand**

Exergetical life cycle assessment is a suitable tool for resource accounting. Exergy is the quality of energy or the work potential of energy with respect to environmental conditions [Szargut et al., 1988]. In energy conversion processes, energy is conserved, but exergy is consumed, as formulated by the second law of thermodynamics. While the exergy content of electrical, chemical, kinetic and potential energy is close to the amount of energy, low temperature heat is low quality energy. The exergy to energy ratio is described by the Carnot factor.

The exergy concept can be applied to energy forms, but also to material resources. Besides kinetic and potential exergy, physical and chemical exergy can be defined. The exergy value of a substance equals the work that can be extracted when the substance is brought to equilibrium with the surrounding environment by reversible processes. Generally, average global conditions are applied to express the physical exergy (298 K temperature and 101325 Pa atmospheric pressure). Chemical exergy can be calculated based on the chemical composition of the atmosphere, seawater and the earth's crust and describes to what extent the substance stands out from the environment from a chemical point of view.

Based on the work of *Szargut* [Szargut et al., 1988], the exergy content of energy and material resources were calculated by *De Meester and Dewulf* and included in the software tool eXoinvent [De Meester and Dewulf, 2006]. eXoinvent is based on the Swiss ecoinvent database. With the help of eXoinvent, it is possible to convert the reference flows of ecoinvent into exergy and calculate the cumulative exergy content of products.

Exergy is a suitable indicator to account for resource consumption. The advantage of exergy vs. the traditionally used energy is – besides taking into consideration the quality of energy –, that energy and material use are accounted for on the same scale. In LCA, for instance, oil is considered either as material or energy consumption, depending on its use as energy carrier or feedstock for plastic production. With exergy, these energy-material trade-off problems can be resolved.

Exergetical life cycle assessment can be applied to evaluate the cumulative resource consumption of building materials, building elements or whole buildings. Exergetical LCA of buildings is a relatively new field and only few case studies have been done so far.

3.2.2 Air pollution

- **Global warming potential, IPCC, 1994 and 2001**

The anthropogenic greenhouse effect caused by the emissions of human activities has to be distinguished from the natural greenhouse effect. The natural greenhouse effect is of vital importance for living beings on the Earth. But the human emission of so-called greenhouse gases, such as carbon dioxide and methane enhances the heat radiation absorption of the atmosphere, which results in the rise of the earth's surface temperature. During the 20th century, the average global temperature increased by about 0,6 °C due to the enhanced greenhouse effect. The consequences might involve a change in climate patterns, the shift of vegetation zones and of the precipitation distribution, and the rise of the sea level due to the melting ice caps. The impact of an emitted gas is expressed in terms of its global warming potential (GWP) in CO_2-equivalents [Guinée, 2002].

A Global Warming Potential indicator (GWP) can be evaluated based on the 2001 or 2007 IPCC characterisation factors[1] :

$$climate\ change = \sum_i GWP_i \times m_i$$

GWP_i = Global Warming Potential of substance *i* [kg of CO_2 equivalent/kg];
m_i = mass of the substance *i*, inventoried in the process [kg];
The time horizon can be 20, 100 or 500 years.

- **Ozone depletion potential, CML 1992, 1995 and 2001**

Stratospheric ozone depletion is the thinning of the stratospheric ozone layer as a result of anthropogenic emissions, such as CFCs and halons [Guinée, 2002]. This causes a greater fraction of solar UV-B radiation to reach the Earth's surface, with a potential damage to human health, ecosystems, biochemical cycles and materials. The natural seasonal Antarctic 'ozone hole' has been growing since the early 1980s. On a global scale, the decline of ozone in the stratosphere has recently slowed. The depletion is mainly caused by CFCs which are used in aerosols, air conditioning, and refrigerators. Halon, which is a fire retardant, is one of the key ozone-depleting gases. However, the use of this substance has been reduced significantly and will soon be phased out completely due to the successful implementation of the Montreal Protocol. It is therefore important to state in the impact assessment how much of the Ozone Depletion Potential (ODP) is due to halon.

[1] Albritton D. L. and Meira-Filho L. G. : Technical Summary. In: Climate Change 2001: The Scientific Basis - Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (ed. Houghton J. T., Ding Y., Griggs D. J., Noguer M., van der Linden P. J. and Xiaosu D.). IPCC, Intergovernmental Panel on Climate Change, Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge, UK, retrieved from: www.ipcc.ch/pub/reports.htm

ODP is the ratio between the amount of ozone destroyed by a unit of a substance “x” and a reference substance, normally taken as CFC-11. The unit of the ODP is therefore kg CFC-11 equivalent.

$$ODP(x) = \frac{Global\,loss\,of\;ozon\,(x)}{Global\,loss\,of\;ozone\,by\,(CFC-11)}$$

Source: US EPA (2003) Class II Ozone-Depleting Substances. U.S. Environmental Protection Agency. Accessed at < http://www.epa.gov/ozone/ods2.html> on October 6, 2003.

- **Acidification potential, CML 1992, 1995 and 2001**

a) CML 1992, 1995 and 2001
The acidity of water and soil systems can be increased due to acid deposition from the atmosphere, mainly in the form of rain. Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emitted by combustion processes are responsible for most acid deposition, commonly called “acid rain”. Potential consequences are forest decline, soil acidification and damage to building materials. The effect of substances is expressed in terms of acidification potential (AP) in kg SO_2-equivalents [Guinée, 2002]. At the interpretation of the indicator result regional differences have to be considered, since a basic soil, for instance, can neutralise the effects.

b) Haushild

AP(SO_2^- equivalents) = [n/(2*M_w)]*64,06 = (n/ M_w)*32,03

M_w is mol mass of the emitted substance (g/mol)

n is the number of hydrogen ions emitted to the recipient
64,06 g/mol is the mol mass of SO_2
Source:
Haushild M et al (1996). *Bakgrund for miljøvurdering av produkter UMIP.* Instittuet for Produktutvikling DTU, DTU,Miljø- og energiministeriet, Miljøstyrelsen, Dansk Industri

Wenzel H., Hauschild M. and Alting L. 1997. Environmental Assessment of Products. Volume 1: Methodology, tools and case studies in product development. Chapman & Hall, ISBN 0-412-80800-5

- **Winter smog, CML 1992 and 1995**

The main contributors to winter smog are the particles (dust) and sulphur emissions. These aspects are accounted for in toxicity and acidification indicators, therefore a specific indicator for winter smog is not commonly used.

- **Photochemical oxidant formation (summer smog), CML 1992, 1995 and 2001**

a) CML 1992, 1995 and 2001
This indicator describes the formation of reactive chemical compounds from certain air pollutants by the action of sunlight. Ethylene, carbon monoxide, sulphure dioxide, methane and NMVOC, for example, are important emissions. Ozone (O_3), a form of oxygen, is the most important chemical compound in this group. In contrast to the protecting role of the ozone layer in the stratosphere, ozone in the troposphere is toxic. Ozone formation, sometimes referred to as "summer smog" is mainly an issue on sunny days in larger cities with a lot of traffic. Ethylene is the reference substance for the assessment.

b) Jenkin
Photochemical Ozone Creation Potentials, POCP for a specific VOC is defined as the ratio between the ozone formation by an additional release of the VOC and the additional ozone formation by the same release of the reference substance eten.

$$POCP_i = \frac{\text{ozon increase from the i:th VOC}}{\text{Ozonincrease from eten}}$$

Source: Michael E. Jenkin 1 , Sandra M. Saunders 2 and Richard G. Derwent. (2000). Photochemical Ozone Creation Potentials for Aromatic Hydrocarbons: Sensitivity to Variations in Kinetic and Mechanistic Parameters. "Chemical Behaviour of Aromatic Hydrocarbons in the Troposphere" in Valencia, Spain, February 27 - 29, 2000. Accessed at < http://www.physchem.uni-wuppertal.de/PC-WWW_Site/pub/valencia2000/proceedings/Jenkin.pdf > on June 8, 2003

- **Odours, CML 1992 and 2001**

The odour threshold value of a substance is defined as the concentration of that substance under defined standard conditions at which 50% of a representative sample of the population can detect the difference between a sample of air mixed with that substance and a sample of clean air [Heijungs et al, 1992].

Heijungs developed a simple method in 1992, which is still used today. In his approach substances were classified using a critical volume approach, by dividing the emission of a potentially malodours substance by the odour threshold value (OTV) of that substance. A distinction must be made between emissions of potentially malodorous substance to the atmosphere and to water. Each is associated with a different odour threshold value, as defined in the following expressions:

$$malodorous\ air = \sum_i \frac{m_{i,air}}{OTV_{i,air}}$$

$$malodorous\ water = \sum_i \frac{m_{i,water}}{OTV_{i,water}}$$

$OTV_{i,air}$, $OTV_{i,water}$ = the odour threshold value in *air*, *water* of substance *i* [kg*m^{-3}];
$m_{i,air}$, $m_{i,water}$ = the quantity of substance *i* emitted in *air*, *water* [kg].

3.2.3 Water pollution

- **Eutrophication potential, CML 1992, 1995 and 2001**

a) CML 1992, 1995 and 2001
Eutrophication occurs when there is an increase in the concentration of nutrients, mainly nitrogen (N) and phosphorus (P) in a body of water or soil, occuring both naturally and as a result of human activity [Guinée, 2002]. It may be caused by the run-off of synthetic fertilisers from agricultural land, or by the input of sewage or animal waste. It leads to a reduction in species diversity as well as changes in species composition, often accompanied by massive growth of dominant species such as "algae bloom". In addition, the increased production of dead biomass may lead to depletion of oxygen in the water or soil since its degradation consumes oxygen. This contributes to changes in species composition and death of organisms. The reference substance for the calculation of the eutrophication potential for each emission is phosphate (PO_4^{3-}), which has a eutrophication potential of 1.

b) EDIP
EcoEffect uses the Danish EDIP concept. EDIP claims that the general formula for aquatic organisms is $C_{106}H_{263}O_{110}N_{16}P$, which means that phosphorus will contribute to eutrophication 16 times more than nitrogen. A substance with formula $C_aH_bN_cO_dS_eP_f$ and the molar weight M_W then have the following eutrophication ability when NO_3^- is taken as the reference:
EP(NO_3^- equivalents) = [(c+16f)*62,0]/ M_W
M_W = molar weight of the compound
c and f refers to the number of N and P atoms in the compound

Source:
Haushild M et al (1996). *Bakgrund for miljøvurdering av produkter UMIP.* Instittuet for Produktutvikling DTU, DTU,Miljø- og energiministeriet, Miljøstyrelsen, Dansk Industri
Wenzel H., Hauschild M. and Alting L. 1997. Environmental Assessment of Products. Volume 1: Methodology, tools and case studies in product development. Chapman & Hall, ISBN 0-412-80800-5

- **Aquatic Eco-toxicity, CML 1992 and 2001**

This indicator is described in section 3.1.3.2.

3.2.4 Soil pollution and waste

- **Terrestrial ecotoxicity, CML 1992 and 2001**

This indicator is described in section 3.4.2.

- **Amount of solid waste**

The building sector generates large quantities of inert waste and this issue must be considered in a LCA study regarding this field [Polster, 1995]. In this context, we propose an indicator also used by [Frischknecht et al, 1996], which evaluates the quantity of inert waste:

$$waste\ creation = W$$

W = mass of waste [kg].
This definition implies to model all waste treatment processes until the ultimate landfill, and to account for all corresponding impacts.

- **Amount of radioactive waste**

There are several types of radioactive waste according to their activity and their time of storing (e.g. the time of storing may vary from 30 to 10,000 years). The quantity of radioactive waste is a useful indicator in the absence of an indicator for ionizing radiation, because the process of nuclear energy production may be advantaged if we regard only the main environmental impacts: e.g. considering only CO_2 emissions we may get the impression that the nuclear energy is a “clean” way to produce electricity.

60% of Europe's electricity use is associated with buildings (residential and tertiary sector) [EC-DGTREN, 2004] and according to UCTE (Union for the Coordination of Production and Transmission of Electricity), in Europe nuclear plants are the first source of electricity delivering, approximately 32% of the electricity [EC-DGTREN, 2004]. Therefore the radioactive waste issue cannot be neglected in a LCA referring to the building sector and an indicator regarding this category was proposed by Polster [Polster, 1995]. This indicator took into account the Oekoinventare database approach [Frischknecht et al, 1996], which evaluates the volume of radioactive waste in order to define the storing capacity needed:

$$radioactive\ waste = V_{rw}$$

V_{rw} = radioactive waste volume (including all types, provided by inventories).

The further use of a characterization factor corresponding to the waste radioactivity may complement this view.

3.2.5 Damages, health and biodiversity

- **Human toxicity, CML 1992 and 2001**

This indicator is described in section 3.4.1.

- **Heavy metals, CML 1995**

More global indicators are now generally preferred regarding toxicity, see DALY indicator in section 3.4.1.

- **Carcinogenics, CML 1995**

More global indicators are now generally preferred regarding toxicity, see DALY indicator in section 3.4.1.

- **Disability Adjusted Life Years, (DALY) Ecoindicator 1999**

This indicator is described in section 3.4.1.

- **Ionising radiation, CML 2001**

The impact related to the ionising radiation includes the effects of releases of radioactive substances as well as direct exposure to radiation. In some cases we may speak of a daily radiation, like in the case of inhabitants who are exposed to building materials radiation. Exposure to this type of radiation is both harmful for humans and animals.

Ionising radiation is expressed in terms of the number of atoms disintegrating per unit of time (one Bq corresponds to one disintegration per second). Radioactivity declines in the course of time. The half-life of a substance is the time taken for the radioactivity of a given substance to decline by half.

- **Depletion of biotic resources, CML 1992 and 2001**

More global indicators are now generally preferred regarding eco-toxicity, see Potentially Disappared Fraction of species (PDF) in section 3.4.2.

- **Impacts of land use, CML 2001**

More global indicators are now generally preferred regarding eco-toxicity, see Potentially Disappared Fraction of species (PDF) in section 3.4.2.

- **Potentially Disappeared Fraction of species (PDF), Ecoindicator 1999**

This indicator is described in section 3.4.2.

3.3 List of indicators recommended by CEN/TC 350

European standard EN 15978 : 2011 prepared by Technical Committee CEN/TC 350 requires using all of the following indicators:

Indicators describing environmental impacts

- Global warming potential (GWP100a) [kg CO_2 equiv]
- Depletion potential of the stratospheric ozone layer (ODP) [kg CFC 11 equiv]
- Acidification potential of land and water sources (AP) [kg SO^{2-} equiv]
- Eutrophication potential (EP) [kg $(PO_4)^{3-}$ equiv]
- Formation potential of tropospheric ozone photochemical oxidants (POCP) [kg Ethene equiv]
- Abiotic Resource Depletion Potential for elements (ADP_elements) [kg Sb equiv]
- Abiotic Resource Depletion Potential of fossil fuels (ADP_fossil fuels) [MJ]

Indicators describing resource use

- Use of renewable primary energy resources used as raw material [MJ, net calorific value]
- Use of renewable primary energy resources used as raw material [MJ, net calorific value]
- Use of non-renewable primary energy excluding primary energy resources used as raw material [MJ, net calorific value]
- Use of non-renewable primary energy resources used as raw material [MJ, net calorific value]
- Use of secondary material [kg]
- Use of renewable secondary fuels [MJ]
- Use of non-renewable secondary fuels [MJ]
- Use of net fresh water [m^3]

Indicators describing waste categories

- Hazardous waste disposed [kg]
- Non-hazardous waste disposed [kg]
- Radioactive waste disposed [kg]

Indicators describing the output flows leaving the system

- Components for re-use [kg]
- Materials for recycling [kg]
- Materials for energy recovery (not being waste incineration) [kg]
- Exported energy [MJ for each energy carrier]

3.4 Analysis of controversial indicators

3.4.1 Human toxicity vs. DALY

Different indicators are presented hereunder, and a synthesis is proposed in a second step. *(Source: Enslic State of the Art Report)*

Human toxicity

a) CML 1992[2] and 2001[3]

This impact category covers the impacts on human health of toxic substances present in the environment. The effect is induced by the dose of pollutant received (inhaled or ingested) by an individual person and not simply by its concentration in the environment. The real impact on humans depends also on the population density around the emission point, thus in the deserted zones the human toxicity can be neglected. In reality it is impossible to determine exactly the real magnitude of a local impact, especially in the present global context, when the life cycle phases of a product can take place on different continents. E.g. a product can be conceived and tested on a continent, produced on another continent using raw materials from a third continent, and afterwards used on a fourth. In these conditions, the use of planetary reference was preferred in LCA for human toxicity. However some attempts are made in order to refine the assessment [Finnveden, 2009].

Heijungs defined in 1992 the human toxicity as sums of impacts of toxic substances into 3 compartments of air, water and soil, potentially threatened by pollution.

$$human\ toxicity = \sum_i (HCA_i \times m_{ai}) + (HCW_i \times m_{wi}) + (HCS_i \times m_{si})$$

HCA_i, HCW_i, HCS_i = characterisation factors for human toxicological impacts resulting from emissions to air, water, soil of substance *i* [kg body weight/kg substance];
m_{ai}, m_{wi}, m_{ws}= emissions of substance *i* to air, water or soil [kg].

[2] R. Heijungs, Environmental life cycle assessment of products, Centre of environmental science (CML), Leiden, 1992

[3] Guinée J. B., (final editor), Gorrée M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H. A., de Bruijn H., van Duin R., Huijbregts M. A. J., Lindeijer E., Roorda A. A. H., Weidema B. P. : Life cycle assessment; An operational guide to the ISO standards; Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, Pays Bas, 2001, 704 p.

Heijungs considers as references for the three compartments:
- the volume of air in the troposphere for a 6 km height at 1 atmosphere,
- the volume of water for 10 m deep, calculated for 70% of globe area,
- the weight of 15 cm of soil for 30% of globe area.

In this approach, the same substance emitted in air or water or soil has 3 different characterisation factors:

$$HCA_i = \frac{VI_a \times W}{V_a \times ADI_i}$$

$$HCW_i = \frac{VI_w \times W}{V_w \times ADI_i}$$

$$HCS_i = \frac{M \times W \times N}{Vs \times Cvalue_i}$$

where
VI_a, VI_w=daily intakes of air and water: 20 m^3 air/day/person, 2 l water /day/person;
W = world population, considered $5*10^9$ persons at that time;
V_a, V_w,V_s= volume of air, water and mass of the soil of the global model: $3*10^{18}$ m^3 air, $3*10^{18}$ l water and $2.7*10^{16}$ kg dry soil;
ADI_i = acceptable daily intake for substance *i* [kg of substance i /day/kg body weight]:
M = human body weight, 70 kg body weight;
N = uncertainty factor for the acceptable daily intake;
$Cvalue_i$ = human toxicological intervention value [kg of substance *i* /kg of soil].

The acceptable Daily Intake is defined in two ways:
- for substances with a threshold value (i.e. an environmental concentration or intake value below which no harmful effects have been observed on human, plants or animals), it represents the daily intake that can be sustained life-long without adverse effects;
- for substances with no such threshold, it is the daily intake resulting in a risk of 1 extra case of cancer per 1000 life-long exposures.

A similar method to that employed for air and water calculation was used to calculate the toxicity for the soil, but taking into account that the substances present in soil are taken up by humans indirectly. The toxic substances are transported by groundwater and accumulate in vegetation. Humans may ingest these toxic substances directly through vegetables, fruits, etc., or indirectly through meat, milk, and other animal origin products. The relevant intake routes and the magnitude of the resulting intakes have been modelled, and as a result, provisional human toxicological C values were developed on the acceptable daily intake basis. The C value is a measure of the substance concentration in soil, which, if exceeded, poses a serious threat to the public health.

Since 1992 several authors complemented the human toxicity definition in order to take into account the fate, the effects and the substance transfer. Hereunder we give the general formula of Heijungs in 1999, which takes into account fate, exposure/intake and effect [Guinée et al, 2001]:

$$HTP_{i,ecomp} = \sum_{fcomp} \sum_{r} F_{i,ecomp,fcomp} \times T_{i,fcomp,r} \times I_r \times E_{i,r}$$

where

$HTP_{i,ecomp}$= the Human Toxicity Potential, the characterisation factor for the human toxicity of substance *i* emitted to emission compartment *ecomp*. In some methods the contributions via exposure routes *r* are not summed, yielding several HTPs;

$F_{i,ecomp,fcomp}$= a fate factor, representing intermedia transport of substance *i* from emission compartment *ecomp* to final (sub)compartment *fcomp*, and degradation within compartment *ecomp*; in some methods intermedia transport is indicated separately by $f_{i,ecomp,fcomp}$ and biodegradation by BIO (see "rule of the thumb" model hereunder);

$T_{i,fcomp,r}$= the transfer factor, the fraction of substance *i* transferred from *fcomp* to exposure route *r*, i.e. air, drinking water, fish, plants, meat, milk, etc.;

I_r= an "intake factor", representing human intake via exposure route *r*, thus, a function of daily intake of air, drinking water, fish, etc.;

$E_{i,r}$= an "effect factor" representing the toxic effect of intake of substance *i* via exposure route *r*.

HTP is often defined in relation to a reference substance (*ref i*):

$$HTP_{i,ecomp} = \frac{\sum_{fcomp} \sum_{r} F_{i,ecomp,fcomp} \times T_{i,fcomp,r} \times I_r \times E_{i,r}}{\sum_{fcomp} \sum_{r} F_{refi,ecomp,fcomp} \times T_{refi,fcomp,r} \times I_r \times E_{refi,r}}$$

Three types of characterisation models defining the degradation and intermedia transport for human toxicity, superseded the provisional method developed by Heijungs in 1992:

i) models based on the "rules of the thumb", like the one developed by Hauschild and Wenzel in 1998, yields three separate not aggregated indicators for each principal exposure routes *r* (air, water, soil) [Hauschild and Wenzel, 1998]:

$$human\ toxicity = \sum_{i} \sum_{ecomp} m_{i,ecomp} \times HTP_{i,ecomp,r}$$

$$HTP_{i,ecomp,r} = \sum_{fcomp} f_{i,ecomp,fcomp} \times BIO_i \times T_{i,fcomp,r} \times I_r \times E_{i,r}$$

where
$HTP_{i,ecomp,\ r}$= the Human Toxicity Potential, the characterisation factor for the human toxicity of substance *i* emitted to emission compartment *ecomp* and leading to exposure via router *r*;
$f_{i,ecomp,fcomp}$= the intermedia transport factor, the fraction of substance *i* emitted to emission compartment *ecomp*, that reaches the final compartment *fcomp*. This factor is based on the rule of thumb and not to a fate model. It is not a continuous value, but assumes a limited number of values as 0.2 and 1;

BIO_i= the biodegradability factor of substance *i*.

ii) models based on empirical relation derived from measurement data and single medium models, summarized in the following formula yielding a single indicator result for human toxicity, related to toxic effect of lead emissions into air [Huijbregts, 1999b]:

$$human\ toxicity = \sum_i \sum_{ecomp} m_{i,ecomp} \times HTP_{i,ecomp}$$

$$HTP_{i,ecomp} = \sum_{fcomp} \left[\frac{E_{i,fcomp} \times F_{i,ecomp,fcomp}}{E_{Pb,air} \times F_{Pb,air,air}} \right]$$

where
$E_{i,fcomp}$= the “effect factor”, representing the human-toxic impact of substance *i* in the final compartment *fcomp* and there defined as the reciprocal of the total acceptable annual dose per m^2: for air the NEC (No Effect Concentration in kg m^{-3}) times the total volume of air inhaled by human beings per year and per m^2, and for water and soil the ADI (in kg*kg body weight^{-1}*day^{-1}) times total body weight per m^2 and number of days per year (365).

iii) model simulated on the computer, Guinée et al in 1996 and afterwards Huijbregts in 1999 [Huijbregts, 1999b] developed characterisation factors for human toxicity including degradation and intermedia transport using the USES model, Uniform System for Evaluation of Substances. The first USES model [Guinée et al in 1996] incorporated as a separate module, the multimedia model Simplebox [Van de Meent, 1993]. Simplebox calculates the Predicted Environmental Concentration (PEC) in four environmental compartments, represented as “boxes”: air, water, agricultural soil, industrial soil due to a constant flux, taking into account six exposure routes (air, fish, drinking water, crops, cattle meat and milk), allowing substance fate to be modelled including degradation and immobilisation.

Huijbregts modified the second version of the USES model in order to calculate characterisation factors for human toxicity (as well as for aquatic sediment and terrestrial ecotoxicity, see next paragraph) using the same method as Guinée [Guinée et al, 1996] but allowing the model of the substances fate at global level. In USES 2.0 there are five spatial scales (regional, continental, global tripartite to reflect the arctic, temperate and tropical climate zones of the northern hemisphere). For regional and continental scales, Huijbregts divided the water into freshwater and seawater. Therefore 6 compartments are defined (air, freshwater, seawater, natural soil, agricultural soil and industrial soil). At global scale, modelled as a closed system, only three main compartments (air, water, soil) are regarded. The dependence between substances properties and temperature in this model is accounted for, as well as their dependence with soil depth.

The measuring unit of HTP is the equivalent quantity of 1,4 dichlorobenzene: the indicator can be expressed as the quantity of 1,4 DCB giving, in the same conditions (compartment ecomp and for scale s), the same effect as the emitted quantity of substance *i* [Huijbregts, 1999b].

$$HTP_{i,ecomp} = \frac{\sum_r \sum_s PDI_{i,ecomp,r,s} \times E_{i,r} \times N_s}{\sum_r \sum_s PDI_{1,4-dichlorbenzene,air,r,s} \times E_{1,4-dichlorbenzene,air,r,s} \times N_s}$$

where

N_s = the population density at scale *s*;

$PDI_{i,ecomp,r,s}$= the predicted daily intake via exposure route *r* at scale *s* for substance *i* emitted to emission compartment *ecomp* [day^{-1}];

$E_{i,r}$= the "effect factor", representing the human-toxic impact of substance *i*, here representing the acceptable daily intake via exposure route *r* [day].

In order to better evaluate the potential short-term impacts of product systems and the model sensitivity to the choice of spatial horizons, Huijbregts ran a number of scenarios to assess the influence of these choices for horizons of 20, 100 and 500 years by integrating over these periods the amount of substance present in compartment *fcomp* after an emission pulse released to the compartment *ecomp*, and compared that with the value obtained by integration to infinity. The indicator result for human toxicity and a specific time horizon *t* can also be calculated using the formula:

$$human\ toxicity = \sum_i \sum_{ecomp} m_{i,ecomp} \times HTP_{i,ecomp,t}$$

As a conclusion, fate is a particularly important consideration for human toxicity and it would not be appropriate to neglect it. Huijbregts models the fate more realistically compared to the rule of the thumb or empirical models.
The impact category results are subject to a high degree of uncertainty because there is an ongoing discussion about the characterisation models and factors of these categories and the scientific basis is still very much under development [Guinée, 2002]. Therefore, the significance of the category results is questionable. Further research is performed in this field [Finnveden, 2009].

b) EDIP

The Danish EDIP method[4] is based on the volume (m^3) of air, soil and water which is needed to dilute a gram of the hazardous substance to make it harmless to man and ecosystems.

Characterisation factor for human toxicity : CF (ht)

$$CF(ht) = f \times BIO \times I \times T \times {}^{1}\!/\!_{HRD} = f \times BIO \times I \times T \times HTF$$

where
f = Distribution factor to air, soil and surface water. Depends on where the poisonous substance is released.
BIO = Biodegradable factor. Numbers are taken from experiments.
I = Daily intake, the amount poisonous substance in water, soil or food which is consumed per kg bodyweight and day, g/kg
T = Transport- and transfer factor. The ability of the substance to be transferred from the source to a human body.
HRD/HRC = Tolerable daily dose in g per kg body weight and day
HTF = Human toxicity factor = 1/HRD.

[4] Potting, J. and Hauschild, M. (2005). Spatial differentiation in life cycle impact assessment – the EDIP2003 methodology. Environmental News no. 80. The Danish Ministry of the Environment, Environmental Protection Agency, Copenhagen.

Disability Adjusted Life Years (DALY), e.g. Ecoindicator 1999

The eco-indicator 99 is an LCA weighting method, elaborated by Dutch and Swiss research organisations under the leadership of PRé Consultants [Goedkoop and Spriensma, 2001]. Unlike the CML-method, Eco-indicator looks at the end-point of the cause and effect chain: it is a damage-oriented, distance-to-target approach. Human health is one of the three damage categories considered in this method. The corresponding indicator is the DALY (Disability Adjusted Life Years), which is an index also used by the World Bank[5] that, considering equal importance of 1 year of life lost for all ages and not discounting for future damages, represents the sum of the years of life lost by premature mortality (YLL, years of life lost) and the lost years of productive life due to incapacity (YLD, years of life disabled). YLD is the product of the duration of the desease by a disability weight (e.g. 0,07 for pharyngitis, 0,67 for Alzheimer[6]).

The risk is evaluated according to chemicals fate in the environment, human exposure and toxicological response. Models have been developed to study the chemicals fate, including :

- transport of pollutants among diverse ecological compartments (air, rivers, groundwater, ground, sediments …) through various phenomena (wind, diffusion, absorption, sedimentation, erosion, deposition, flows…),
- (bio)degradation (photochemistry, hydrolysis…),
- transfer to potable water and food, bioaccumulation.

Concentration of pollutants can then be evaluated at different locations, for which information regarding the exposed population is available. Assuming an exposure duration and intake parameters (e.g. air volume breathed, water and food absorbed by children, women and men, body weights), doses can be derived and dose-response functions allow risks to be estimated.

Different similar models have been developed, for instance USES-LCA [van Zelm et al. 2009], USETox [Rosenbaum et al., 2008], IMPACT2002 [Jolliet et al. 2003], [Pennington et al. 2005], CalTox [Bare et al. 2003], [Hertwitch et al. 2001], EDIP1997 [Potting et al. 2005].

The method used in Eco-indicator 99 provides characterization factors for a large number of substances, and accounts for the following effects on health. It is valid for Europe.

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[5] Murray C. and Lopez, A. : The Global Burden of Disease, WHO, World Bank and Harvard School of Public Health, Boston, 1996, 990p.

[6] GLOBAL BURDEN OF DISEASE 2004 UPDATE: DISABILITY WEIGHTS FOR DISEASES AND CONDITIONS, World Health Organization, 2004

- Respiratory effects

Some respiratory effects are caused by the emission of particulate matter, Sox, Nox, ozone, CO and various organic substances to the air. Fate factors for particules have been estimated using a simple model according to residence time and dilution height [Hofstetter, 1998]. The Photochemical Ozone Creation Potential (POCP) has been used to differentiate fate factors for hydrocarbons. Epidemiological information is used to estimate dose-response relations. Damage is expressed as DALY/kg emission. The scope of this indicator is global, regional and local.

- Carcinogenic Substances:

Substances identified as carninogenic by the International Agency for Research on Cancer are considered. Fate factors are calculated using the EUSES model, providing a link between an emission in Europe (kg/year) and a steady state concentration in air, drinking water and food resulting from this emission. The cancer incidence is estimated using the unit risk concept, probability that an average individual will develop cancer when exposed to a pollution at an ambient concentration of one microgram per cubic meter for the individual's life (assumed 70 years). The affected population depends on the substance residence time: the population density of Western Europe (resp. of the world) is considered for a residence time of one day (resp. one year).

YLL and YLD are estimated according to the type of cancer, survival rate, and severity of the disability. The damage is expressed in DALY /kg emitted. The scope of this indicator is global and local.

- Climatic Change:

Climate change may affect human health by direct exposure to thermal extremes and weather events, but also indirectly by infective parasites, altered food productivity, sea level rise, air pollution through pollens and spores, and socio-economic effects. A model has been developed to evaluate the marginal damage of one supplementary emitted ton per year of CO_2, CH_4 and N_2O using a scenario defined by the Intergovernmental Panel for Climate Change (IPCC). Global warming potential in the time span from 100 years have been used to evaluate the damage for other greenhouse gases. The equivalence factor has been divided into three groups: gases with an atmospheric life of less than 20 years that are assumed to behave like methane; gases with an atmospheric life of between 20 and 100 years that behave like CO_2; gases with atmospheric life longer than 100 years that behave like N_2O. Damage is expressed as DALY/kg emission - result of an increase or decrease in the occurrence of diseases and deaths caused by climate change. The scope of this indicator is global.

- Ionising radiation:

Air- and waterborne radionuclides are released to the environment in the nuclear fuel cycle, but also phosphate, coal, oil and gas extraction. The impact evaluation pathway starts with the release at the point of emission, expressed in Becquerel (Bq). Then the fate analysis estimates the contamination of the environment taking into account the transport, the dispersion and the deposition. The time horizon in the fate model is 100,000 years in order to account for the long life time of some substances, though the half-life is 1.6 10^7 years for iodine 129 and 7.1 10^8 years for uranium 235. The exposure analysis estimates in Sievert (Sv) the effective dose according to the irradiation conditions, consumption of contaminated aliments, water, etc. Several routes are accounted for in the evaluation of exposure: inhalation, ingestion of water and food, radiation from the ground etc. Dose-response factors are expressed in number of fatal and non fatal cases per man.Sv (Sievert unit accounts for the sensitivity of different body tissues). Damage is expressed as DALY/emission (Bq), as a result of radioactivity. The scope of the indicator is regional and local.

- Ozone layer depletion:

The values of ozone depletion potential (ODP) have been established for hydrocarbons that contain chlorine, flourine and bromine combined or CFCs. This indicator has been developed by WMO (World Meteorological Organization) for different substances. Damage is expressed as DALY/kg emission, due to the increase of UV radiation as a result of ozone damaging substances to the air. The geographic reach for this indicator is at a global scale.

- Damages to Human Health (Human Health):

It is expressed as the sum of the number of lost years of life and the number of years lived incapacitated (DALY). In this damage category the following impact categories are included: Carcinogenic Substances, breathed Organic and Inorganics substances, Climatic Change, radioactivity and Ozone layer.

Discussion

Models underlying the evaluation of damage oriented indicators integrate a large number of physical, biological and behavioural phenomena. These models require a lot of data, which is mostly uncertain or even lacking. For instance, among around 100,000 chemicals on the market, only around 250 can be modeled due e.g. to the needed physical parameters in the fate analysis. Exposure and intake fractions are related to uncertain parameters like the presence of a certain population, and the consumption of water and food. Dose-response functions do not neither exist for most substances, safety factors are not accurate. Interactions between substances may not be negligible.

Weighting different types of disability is highly subjective and may depend on local conditions (social and economic context, climate...). Indicators refer to a specified region and time frame, extrapolation to other contexts is unprecise. For all these reasons, it is not possible to impose or even recommend one of the existing models at the moment.
On the other hand, an LCA without any health indicator would not be comprehensive. Therefore it seems advisable that tool developers choose at least one of the existing toxicity indicators, preferably ”reflecting latest scientific research that can be applied in practical form” (according to ILCD).

3.4.2 Eco-toxicity versus pdf x m^2 (ARMINES)

Eco-toxicity

a) CML 1992 and 2001

- Aquatic eco-toxicity

The CML impact assessment method considers among others the aquatic eco-toxicity category. This impact category covers the impacts of toxic substances on aquatic ecosystems. The area of protection is the natural environment (and natural resources).
Aquatic eco-toxicity can be dived into fresh water and marine aquatic eco-toxicity.

Fresh Water Aquatic Eco-toxicity (FAETP)

Fresh water aquatic eco-toxicity refers to the impact of toxic substances emitted to freshwater aquatic ecosystems.

$$fresh\ water\ aquatic\ eco\ toxicity = \sum_{i} \sum_{ecom} FAETP_{ecom,\,i} \times m_{ecom,\,i}$$

$m_{ecom,i}$ is the emission of substance *i* to the medium *ecom*

The characterisation factor is the potential of fresh water aquatic toxicity of each substance emitted to the air, water or/and soil $FEATP_{ecom,i}$. The unit of this factor is kg of 1,4-dichlorobenzene equivalents (1,4-DCB_{eq}) per kg of emission.

Marine Aquatic Eco-toxicity (MAETP)

Marine aquatic eco-toxicology refers to the impact of toxic substances emitted to marine aquatic ecosystems.

$$\text{marine aquatic eco toxicity} = \sum_{i} \sum_{ecom} MAETP_{ecom,i} \times m_{ecom,i}$$

The characterisation factor is the potential of marine aquatic toxicity of each substance emitted to the air, water or/and soil $MEATP_{ecom,i}$. The unit of this factor is kg of 1,4-dichlorobenzene equivalents (1,4-DCB_{eq}) per kg of emission.

- Terrestrial ecotoxicity

Terrestrial eco-toxicity refers to the impact of toxic substances emitted to terrestrial ecosystems.
The characterisation factor is the potential of terrestrial toxicity of each substance emitted to the air, water or/and soil. The unit of this factor is kg of 1,4-dichlorobenzene equivalents (1,4-DCB_{eq}) per kg of emission.

b) EDIP

The Danish EDIP work[7] is based on the volume (m^3) of air, soil and water which is needed to dilute a gram of the hazardous substance to make it harmless to man and ecosystems.

Characterization factor for eco-toxicity :

$$CF(et) = f \times BIO \times \frac{1}{PNEC} = f \times BIO \times ETF$$

where
f = Distribution factor to air, soil and water
BIO = Biodegradable factor.
PNEC or LOEC= Predicted No Effect Concentration and Lowest Observed Effect Concentration
ETF = Eco toxicity factor =1/PNEC

Damage oriented indicator for ecotoxicity (pdf x m²)

The most commonly used endpoint indicator is the Potentially Disappeared Fraction of species (PDF), which is the fraction of species that has a high probability of no occurence in a region due to unfavourable conditions. It is expressed as the loss of species in a certain area over a specific time period (PDF.m^2.year) It includes the following impact categories: Ecotoxicity, Acidification, Eutrophication and Land Use/transformation.

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7 Potting, J. and Hauschild, M. (2005). Spatial differentiation in life cycle impact assessment – the EDIP2003 methodology. Environmental News no. 80. The Danish Ministry of the Environment, Environmental Protection Agency, Copenhagen.

- Ecotoxicity, damages to ecosystem quality as a result of the emission of toxic substances to the air, water and earth

The main toxic substances are heavy metals, chromium being the reference substance. Eco-toxic effects from chemicals on different species are estimated using laboratory tests. Sensitivity distribution curves are determined for a selection of species, allowing the fraction of species exposed above the level which affects them (the Potentially Affected Fraction of species, PAF) or above the level where the species will disappear (PDF) to be evaluated. Damage is expressed as a PAF or PDF over a certain territory and a certain duration per kg of emitted pollutant, (PAF or PDF.m^2.year /kg emission). The scope is global, regional and local.

The calculation of the damage to ecosystem quality is made using the EUSES model [EUSES, 1996] in three steps [Goedkoop and Spriensma, 2000]:

- fate analysis, 4 emission compartments are considered: air, water, agricultural soil and industrial soil. The damage to ecosystems is determined by the resulting concentrations in 4 relevant receiving compartments: water compartment, pore water of agricultural soil, industrial soil and natural soil. Fate factors are then calculated for the 4 emission compartments and 4 relevant receiving compartments.
- effect analysis, the toxicity of substances is characterised by standardized concentrations, called Hazard Units (HU). In order to calculate the HU, the marginal concentration increase of a substance is divided by the average NOEC for that substance. This calculation procedure is similar to the PEC/PNEC ratio (see Ecotoxicity paragraph of the problem oriented approach);
- damage analysis which relates the dimension of the standardised concentration to a certain PAF.

A substance specific dose-effect curve representative for an organism can be obtained from single species toxicity tests. This can be combined with statistical analysis tools to quantify the stress related to environmental concentrations in the ecosystem as a whole. The result of such analyses is the species sensitivity distribution, which represents a function fitted to match a plot of sensitivity results from toxicological tests on a single species [Pettersen,2003].

It is assumed that the dose-effect curve can be described by the log logistic distribution function (logarithmic Gaussian curve) of chronic NOECs. The log logistic distribution function is estimated from single species toxicity data. PAF is the cumulative fraction, i.e. the percentage of species that are exposed to concentrations above their NOEC. PAF can be used to represent the stress caused to an ecosystem by a single chemical or the total stress as a result of the concentration of several chemicals, but possible interaction between chemicals is not accounted for.

PAF is calculated from the combination of the estimated distribution function and the calculated field concentration [Goedkoop and Spriensma, 2000]:

$$PAF(c) = \frac{1}{1 + e^{(\alpha - \log c)/\beta}}$$

where
c = concentration of substance [mass/volume];
α = parameter calculated from the average NOEC for a single substance for all species [dimensionless];
β = coefficient derived from the standard deviation of the NOECs for the substance [dimensionless].

PNEC (Predicted No Effect Concentration) is defined as the concentration giving a PAF of 5 % (single substance PAF). The relation for PNEC is:
$PNEC = C_{PAF=0.05}$

Since spatial and temporal information is not included in LCA, the model takes into account an average background concentration for all substances, equal in all areas of Europe. The marginal damage to ecosystems from a marginal increase of the concentration of a single substance depends on the present level of damage from the mixture of substances already present in the environment. The slope of a single substance PAF curve is not relevant, since a marginal increase of the concentration of one single substance has only a very small influence on the average situation in Europe. In order to assess the marginal damage from an emission, we must determine first the slope of the overall PAF curve, based on mixtures of substances present in the European environment. The combined effect of several substances is estimated for hydrophobic and inert substances, by the sum of relative concentrations and for other substances, by the sum of effects calculated with PAF. The effects of different levels of pollution by presumably relative invariable environmental mixtures, standardised to Hazard Units are shown in the next figure.

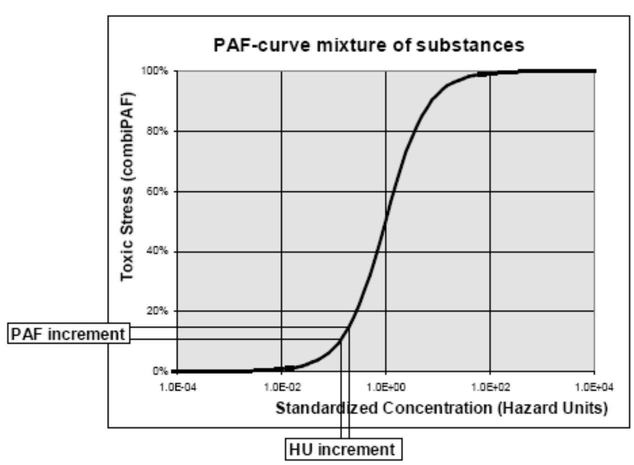

Figure 2 PAF curve for mixture of substances [Goedkoop and Spriensma, 2000]

Hazard Units (HU) are defined as the ratio of concentration to the geometric mean of no observable effect concentrations (NOEC) for all species. The geometric mean is the average of logarithmic NOECs. Increase in HU (ΔHU) is calculated from the increase of concentration (ΔC*)* resulting from an initial discharge, evaluated using Simplebox [Van de Meent, 1993]. The expression for ΔHU is [Pettersen, 2003]:

$$\Delta HU = \Delta C / 10^{\alpha}$$

The damage depends on the slope of the PAF curve in a working point. The working point is determined by the present damage: the present combiPAF in Europe. CombiPAF, or multiple substances PAF, is used to map the stress to an ecosystem of a number (*n*) of chemicals. This combined stress can be found with the formula [Pettersen, 2003]:

$$combiPAF = 1 - \prod_{i=1}^{n} (1 - PAF_i)$$

A relationship yields the total toxic stress as a function of the sum of hazard units in the mixture [Hamers et al, 1996], which can be viewed as the toxicologically standardised mixture concentration. For instance, at HU=1 all species are exposed to a background level equal to the average of logarithmic NOEC (which is based on the distribution of NOECs of all species). Since 50% of the species has a NOEC below this average, this implies that these 50% of all species are affected. This explains that at HU=1 the potentially affected fraction is 50% [Goedkoop and Spriensma, 2000].

Therefore the global procedure for damages calculation (PAF*m²*year) in response to the emission of n substances includes:

- the determination of the marginal increase of each substance concentration in a specific compartment using EUSES;
- the determination of the increase in standardised toxicity units (hazard units) from the concentration increase of the substance for each emitted substance that may cause an impact on Ecosystem Quality using the average NOEC of each substance and to sum the total increase in hazard units*;*
- the choice, according to the cultural perspective, of a reference value for the slope of the combiPAF curve of substance mixtures representing the present ambient level of toxic stress (working point). The average combiPAF value for Europe lies between 10 and 50%. In the egalitarian perspective (precaution principle) the slope is quite steep (combiPAF = 0.5), therefore a small increase in HU gives a high increase in PAF, while in the individualist perspective it is the opposite (combiPAF = 0.1), and in hierarchist perspective, a geometric mean between the two is used (combiPAF = 0.24);

- the determination from the total increase in hazard units of the temporary marginal damage in the considered environmental compartment, using the slope of the combiPAF function at the working point and through multiplication of the calculated increase in combiPAF with the total area of the environmental compartment. For one specific emission, each relevant receiving compartment has a specific concentration. Also each compartment has a specific area [EUSES, 1996]. Therefore, for each compartment the damage is assessed separately and afterwards summed in order to obtain the total damage at the European level.

The unit of the ecotoxicity in Ecoindicator '99 is the PAF.m².year. On the other hand the damage to Ecosystem Quality, which includes ecotoxicity is expressed in potentially disappeared fraction units (PDF.m².year). In order to include the ecotoxicity contribution in the damage to Ecosystem Quality category, a conversion factor (PDF = 10 PAF) is used.

- Land Use:

Land use has impact on the diversity of species depending on the type of use and the characteristics of the area, based on observations. Damages as a result of the conversion or occupation of land is expressed as a fraction of species potentially disappeared over a certain territory and a certain duration, the indicator being PDF.m^2.year/m^2.

The relation between the size of area and the species diversity is:

$$S = a \cdot A^{b}$$

where
S = species diversity;
a = species richness factor, usually between 20 and 2000;
A = area [hectares];
b = species accumulation factor, usually between 0.2 and 0.5.

The potentially disappeared fraction (PDF) of vascular plant species is expressed as the relative difference between the number of species S in the reference conditions and the conditions created by the conversion, or maintained by the occupation. Different types of land-use will have different effects. For instance a paved parking lot will have less plant species than an organic meadow. On the basis of field observation studies [Kollner, 1999] a scale was developed expressing the species diversity (species richness) per type of land use and area.

The PDF can be generalised as [Goedkoop and Spriensma, 2000]:

$PDF = (S\,ref\ - S\,use) / S\,ref$

where
Sref = species diversity on the reference area type;
Suse = species diversity on the converted or occupied area.

As for the previous impact category, the unit measure for land use is PDF.m².year, and therefore, in order to calculate the damage to Ecosystem Quality (*EQ*), the PDF value is multiplied with the appropriate area and time span:

$$EQ = \frac{S_{ref} - S_{use}}{S_{ref}}.A.t$$

where
A = the occupied area [m²];
t = time [years].

This general formula can be used for both conversion (when land is converted from one state to another) and occupation (land has been converted earlier and is occupied for a number of years) and both at regional and local effects level, but the factors in equation above have different significations (see Table 2 below).

Table 2 Overview of the parameters determining the 4 types of land use [Goedkoop and Spriensma, 2000]

EQ	**S_{ref}**	**S_{use}**	**A**	**t**
Conversion local	Original state	S on new land-use	Converted area	Restoration time
Occupation local	Natural state	S on new land-use	Occupied area	Occupation time
Conversion regional	Original state	Smaller natural area*	Natural area**	Restoration time
Occupation regional	Natural state	Smaller natural area*	Natural area**	Occupation time

* the reduction of species number occurs when the natural area is reduced by conversion or is kept small due to occupation

** the species reduction occurs in the natural area outside the converted or maintained land

The restoration time is relative because in most cases the restoration will never reach the exact situation of the land before use. Therefore several default values were proposed, for instance:

- restoration time for conversions agricultural to urban land and vice-versa is 5 years;
- restoration time for conversions natural areas to urban or agricultural areas is proposed to be at least 30 years, or even greater when necessary.

For several land types (e.g. arable surfaces, meadows, etc.) a correction factor of 2 was introduced to the Kollner's data, because Goedkoop considered that the observations were made at the edge of the ecosystem and therefore are not representative for the very high species richness in the centre of these systems. The PDF values from natural to use state are calculated using the species richness of the Swiss lowlands as reference values. Also, another correction is applied after PDF calculation, because it is considered that in the industrial areas the uncertainty of PDF is higher.

The model also integrates the fact that the species diversity depends on the size of an area. This means that the construction and use of a parking lot does not only have an effect on the actual area of the lot, but also on the surrounding region, as due to the parking lot the natural areas will become slightly smaller. This is considered as a regional effect and both the regional and the local effect are taken into account. In order to reflect the total damage caused by land-use changes or land occupation, the regional and local effect are added:

$$EQ_{occupation} = EQ_{occupation,local} + EQ_{occupation,regional}$$
$$EQ_{conversion} = EQ_{conversion,local} + EQ_{conversion,regional}$$

- Acidification and Eutrophication

Acidification is caused by the emission of protons in terrestrial and aquatic ecosystems. In terrestrial systems the effects are observed as a reduction in forest growth and finally their disappearance; in aquatic systems the consequences are acidic lakes and ultimately, no type of wild life. Eutrophication or excess of nutrients (nutrification) in aquatic and terrestrial systems can be caused by an excess of nitrogen, phosphorus and biodegradable organic matter. Nutrient enrichment of aquatic ecosystems increases the production of plankton algae and higher aquatic plants that deteriorate water quality and diminish the utility of the ecosystem. The decomposition of organic matter is a process that consumes oxygen sometimes causing anaerobic conditions. The damage to the ecosystem as a result of the emissions of substances contributing to acidification and eutrophication is expressed as Potentially Disappeared Fraction (PDF).m^2.year/kg emission. The geographic reach is similar to that of the previous indicator.

The characterization model is the "Nature planner" which models the fate of substances (SMART module) and damage (MOVE module) for grid-cells of 250*250 m. This model has been developed in the Netherlands and therefore the characteristics of MOVE correspond to this country.

SMART is a dynamic model, which includes the cycle of nitrogen, the biochemical processes and a simplified hydrological model. This model forecasts the pH changes of soil and the availability of N in every zone, on an annual yearly basis, in response to a marginal deposit of ten molls of NOx, SOx and NH_3 per km^2 of each cell.
The vegetation model MOVE contains dose-response functions for 900 Dutch plant species, describing the relation between the potentially disappeared fractions (PDF) and the soil acidity, the availability of nutriments and the humidity content, and their mutual interactions.

The model MOVE can calculate the potentially disappeared fraction for these values per grid-cell. A species is considered to meet unfavourable conditions if the PDF value is lower than a threshold value of 2.5%. The stressed target species are counted per grid-cell and the results can be aggregated for the total natural area of the Netherlands, resulting in a percentage of threatened species caused by a specific deposition. Afterwards the result of the damage is given for a deposition of 1 kg per square metre in a natural area of undefined size, considering the natural characteristics of the Netherlands and 100% deposition in natural areas. For Europe, 60% of the total area consists of natural areas, and the figures for deposition in natural areas are adapted to this ratio.

Discussion

Like for toxicity related impacts, evaluating the effects of a system on biodiversity is a complex task due to the multiple interactions between different populations and their physical and chemical surroundings. Models should account for chemicals' fate in the environment (transport, degradation, accumulation...), species exposure (trophic levels, cumulative exposure), and toxicological response (cause-effect chains, analogous to toxicity effects on human health). The PDF approach addresses the population diversity (species) and not the genetic and ecosystem diversity. Functions like biomass production, mineralisation, energy transfer and nutrient cycling are also important for the natural environment, therefore biodiversity is not the only possible endpoint. Other indicators like the mean extinction time (MET) are based on stochastic population approaches in order to quantify the expected survival of species exposed to a habitat reduction or a pollutant. The ecosystem's carrying capacity for a population and the growth rate of this population are essential characteristics of such a dynamic assessment [Itsubo et al., 2003].

3.5 General LCA practice on the choice of LCIA indicators for buildings in different tools

The table below shows the LCIA indicators used in some different LCA calculation tools.

Indicator category	Indicator	Ecoeffect	Enslic	EQUER	Ecosoft	Envest
Resources	Depletion of abiotic resources					
	Depletion of abiotic resources (antimony equivalent)			X		
	Cumulative energy demand (total)			X		
	Cumulative energy demand (non renewable part)				X	
	Water consumption			X		X
	Water footprint					
	Surplus energy to extract minerals and fossil fuels					X
	Land use					
	Resource factor					
	Cumulative exergy demand					
Air pollution	Global warming potential	X	X	X	X	X
	Ozone depletion potential	X				X
	Acidification potential	X		X	X	X
	Winter smog					
	Photochemical oxidant formation (summer smog)	X		X		X
	Odours			X		
Water pollution	Eutrophication potential	X		X		X
	Aquatic Eco-toxicity	X				X
Soil pollution and waste	Terrestrial ecotoxicity	X				X
	Amount of solid waste			X		X
	Amount of radioactive waste			X		X
Damages, health and biodiversity	Human toxicity	X				X
	Heavy metals					
	Carcinogenics					
	Disability Adjusted Life Years, (DALY)			X		
	Ionising radiation	X				
	Depletion of biotic resources					
	Impacts of land use					
	Potentially Disappeared Fraction (PDF)			X		

Table 3

3.6 Recommendations on the use of indicators

As there are several indicators used in different tools, in order to get closer to a more harmonised European system, use of indicators contained in the accepted standard EN 15978 : 2011 is recommended as a minimum, while the use of other indicators outside the scope of the standard can be applied voluntarily depending on the scope of the LCA.

Further study on prioritisation methods of indicators is recommended based on aspects such as geographic scale of an impact (planetary, continental, regional, local), the importance of the effects (severity of damages on health, eco-systems), their irreversibility, their duration (e. g. nuclear waste).

It is also important to gather adequate harmonised general input data for impact category indicators which can be adopted in all member states and determine a common approach in relation to specific data through EPDs.

4 Normalisation of environmental profiles and analysis of different weighting systems

4.1 Normalisation

Normalisation is one of the optional elements of LCIA. In accordance with EN ISO 14044, normalisation is the calculation of the magnitude of the category indicator results relative to reference information.
The reference information may relate to a given community (e.g. The Netherlands, Europe or the world), person (e.g. Danish citizen) or other system, over a given period of time (e.g. one year). Future target situation may also be used as a reference. The main aim of normalising the category indicator results is to better understand the relative importance and magnitude of these values for the studied system. Normalisation can also be used to check for inconsistencies, to provide and communicate information on the relative significance of the category indicator results and to prepare for additional procedures such as weighting and interpretation.
Normalised values can be calculated by dividing the indicator results from characterisation by normalisation factors connected to the reference information. These factors are usually various in different assessment methods as detailed in section 4.3.

4.2 Weighting

Weighting is also an optional step of impact assessment, in which the (normalised) indicator results for each impact category assessed are assigned to numerical factors according to their relative importance, multiplied by these factors and possibly aggregated. Weighting is based on value choices, e.g. monetary values (estimated using a willingness to pay method, or cost estimate, however suffering from serious data gaps), standards or policy targets (e.g. distance to target method), expert panel (preferably organized in a specific context). There is no best available method, and no recommended set of weighting factors. Some examples for weighting in different assessment methods are given in 4.3.

4.3 Different methods for normalisation and weighting

4.3.1 CML 2002

Normalisation is strongly recommended by CML, suggesting also choosing the whole world or an average world citizen for one year as reference system for all impact categories.

Impact categories	Netherlands, 1997	West-Europe, 1995	World, 1995
Depletion of abiotic resources, kg antimony.yr^{-1}.cap^{-1}	110	32.6	27.7
Climate change, kg CO_{2eq}.yr^{-1}.cap^{-1}	16 100	14 600	6 830
Stratospheric ozone depletion, kg CFC_{11eq}.yr^{-1}.cap^{-1}	0,0626	0,256	0,0911
Human toxicity, kg 1,4-DCB_{eq}.yr^{-1}.cap^{-1}	12 100	23 300	8 800
Fresh water aquatic ecotoxicity, kg 1,4-DCB_{eq}.yr^{-1}.cap^{-1}	483	1550	359
Marine ecotoxicity, kg 1,4-DCB_{eq}.yr^{-1}.cap^{-1}	2,73E+05	3,49E+05	9,05E+05
Terrestrial ecotoxicity, kg 1,4-DCB_{eq}.yr^{-1}.cap^{-1}	61,5	146	47,4
Photo-oxidant formation, kg C_2H_{4eq}.yr^{-1}.cap^{-1}	11,7	25,4	8,04
Acidification, kg SO_{2eq}.yr^{-1}.cap^{-1}	42,9	84,2	52,9
Eutrophication, kg $PO_4^{3-}{}_{eq}$.yr^{-1}.cap^{-1}	32,1	38,4	22,8

Table 4 Example normalisation factors, annual per capita reference [Guinée et al., 2001]

The CML guide recommends first to formulate the conclusions that can be drawn from an LCA study without weighting. Using a panel method is recommended, considering ranges of weighting factors based on the different views in the consultation panel.

4.3.2 Eco-indicator 99

Introduction

Eco-indicator 99 was developed with the aim to simplify the interpretation and weighting of results. One of the intended applications was the calculation of single-point eco-indicator scores that can be used by designers in day to day decision making. The EPS method and the predecessor, the Eco-indicator 95 method, were important inputs to the development, while on its turn, the Eco-indicator 99 has been the starting point for the development of the LIME and the Impact 2002 method. The method is being followed-up by the ReCiPe method, which integrates with the CML 2002 method. At the time of publication it contained several new principles, such as the use of the damage approach in three damage categories (Human Health, Ecosystem Quality and Resources), and the use of three perspectives as a way to deal with subjective choices on endpoint level (egalitarian, individualist and hierarchist).
The simplified characterisation of these perspectives:
- Egalitarian: long time perspective: even a minimum of scientific proof justifies inclusion
- Individualist: short time perspective: only proven effects are included
- Hierarchist: balanced time perspective: consensus among scientist determines inclusion of effects.

The Hierarchist version is chosen as default.

The methodology covers 11 midpoint impact categories grouped into the three damage categories as shown in the table below. Depending on the perspective, the methodology covers approximately 391 substances.

Damage category	Midpoint impact category
Damage to Human Health	Carcinogenic effects
	Respiratory effects (inorganic)
	Respiratory effects (organic)
	Climate change
	Radiation
	Ozone depletion
Damage to Ecosystem Quality	Ecotoxicity
	Acidification / eutrophication (combined)
	Land use
Damage to Resources	Minerals
	Fossil

Table 5

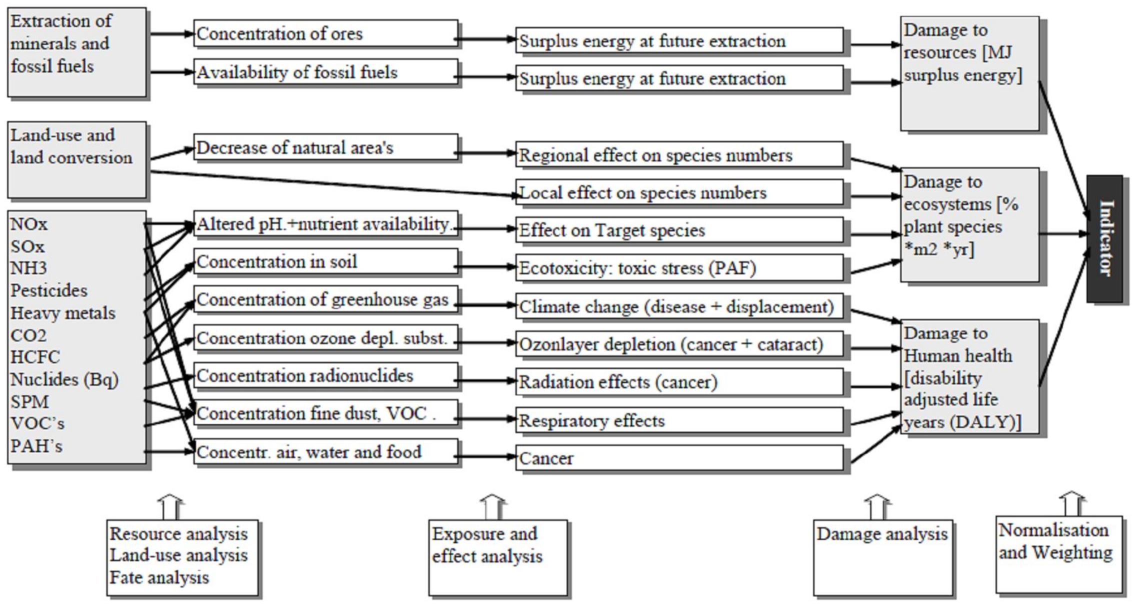

Figure 3 Impact categories and pathways covered by the Eco-indicator 99 methodology (Source: EC JRC, ILCD Handbook 2010)

Normalisation

Normalisation is not done per impact category, but per damage category. Normalisation factors are calculated using the same method.
European normalisation factors used in Eco-indicator 99 are summarised in the tables below.

Hierarchist perspective

Impact category	Air	Water	Industrial soil	Agricultural soil	Total	Per inhabitant
Human Health (DALY/yr)						
Carcinogenic effects	1,99E+05	3,10E+05	1,83E+05	6,77E+04	7,60E+05	2,00E-03
Respiratory effects (inorganic)	4,05E+06				4,05E+06	1,07E-02
Respiratory effects (organic)	2,60E+04				2,60E+04	6,84E-05
Climate change	9,08E+05				9,08E+05	2,39E-03
Radiation	1,01E+03	9,84E+01			1,02E+04	2,68E-05
Ozone depletion	8,32E+04				8,32E+04	2,19E-04
Total (HH)	**5,27E+06**	**3,10E+05**	**1,83E+05**	**6,77E+04**	**5,84E+06**	**1,54E-02**

Ecosystem Quality (PDFm^{2}yr/yr)						
Ecotoxicity	7,02E+10	7,87E+08	2,37E+11	4,32E+07	3,08E+11	8,11E+02
Acidification / eutrophication	1,43E+11				1,43E+11	3,75E+02
Land use	1,50E+12				1,50E+12	3,95E+03
Total (EQ)	**1,71E+12**	**7,87E+08**	**2,37E+11**	**4,32E+07**	**1,95E+12**	**5,13E+03**
Resources (MJ/yr)						
Minerals					5,61E+10	1,48E+02
Fossil					3,14E+12	8,26E+03
Total (R)					**3,20E+12**	**8,41E+03**

Table 6

Egalitarian perspective

Impact category	Air	Water	Industrial soil	Agricultural soil	Total	Per inhabitant
Human Health (DALY/yr)						
Carcinogenic effects	1,99E+05	3,10E+05	1,83E+05	6,77E+04	7,60E+05	2,00E-03
Respiratory effects (inorganic)	4,09E+06				4,09E+06	1,08E-02
Respiratory effects (organic)	2,60E+04				2,60E+04	6,84E-05
Climate change	9,08E+05				9,08E+05	2,39E-03
Radiation	1,01E+03	9,84E+01			1,02E+04	2,68E-05
Ozone depletion	8,32E+04				8,32E+04	2,19E-04
Total (HH)	**5,31E+06**	**3,10E+05**	**1,83E+05**	**6,77E+04**	**5,88E+06**	**1,55E-02**
Ecosystem Quality (PDFm^{2}yr/yr)						
Ecotoxicity	7,02E+10	7,87E+08	2,37E+11	4,32E+07	3,08E+11	8,11E+02
Acidification / eutrophication	1,43E+11				1,43E+11	3,75E+02
Land use	1,50E+12				1,50E+12	3,95E+03
Total (EQ)	**1,71E+12**	**7,87E+08**	**2,37E+11**	**4,32E+07**	**1,95E+12**	**5,13E+03**
Resources (MJ/yr)						
Minerals					5,61E+10	1,48E+02
Fossil					2,20E+12	5,79E+03
Total (R)					**3,20E+12**	**5,94E+03**

Table 7

Individualist perspective

Impact category	Air	Water	Industrial soil	Agricultural soil	Total	Per inhabitant
Human Health (DALY/yr)						
Carcinogenic effects	1,40E+04	6,20E+04	3,06E+03	0,00E+00	7,91E+04	2,08E-04
Respiratory effects (inorganic)	2,09E+06				2,09E+06	5,50E-03
Respiratory effects (organic)	2,42E+04				2,42E+04	6,37E-05
Climate change	8,72E+05				9,09E+06	2,29E-03
Radiation	9,38E+02	5,74E+01			9,95E+02	2,62E-06
Ozone depletion	6,73E+04				6,73E+04	1,77E-04
Total (HH)	**3,07E+06**	**6,21E+05**	**3,06E+05**	**0,00E+00**	**3,13E+06**	**8,25E-03**
Ecosystem Quality (PDFm^{2}yr/yr)						
Ecotoxicity	7,37E+09	5,10E+08	6,14E+10	4,32E+07	6,93E+10	1,82E+02
Acidification / eutrophication	1,43E+11				1,43E+11	3,76E+02
Land use	1,50E+12				1,50E+12	3,95E+03
Total (EQ)	**1,65E+12**	**2,62E+08**	**6,14E+10**	**4,32E+07**	**1,71E+12**	**4,51E+03**
Resources (MJ/yr)						
Minerals					5,61E+10	1,48E+02
Fossil					0,00E+00	0,00E+00
Total (R)					**5,61E+10**	**1,50E+02**

Table 8

Weighting

There are three options:

1. Default weighting sets determined by a panel procedure
2. Weighting triangle has been developed for decision-making without explicit weighting (i.e. equal weighting)
3. Some authors proposed monetisation methods, but these are not widely used.

The default weighting sets for the three different perspectives are shown in the table below.

Perspective	Environmental damage category	Weighting factor (%)	Impact category	Weighting factor (%)
Hierarchist	Human Health	40	Carcinogenic effects	5,2
			Respiratory effects (inorganic)	27,8
			Respiratory effects (organic)	0,2
			Climate change	6,2
			Radiation	0,1
			Ozone depletion	0,6
	Ecosystem Quality	40	Ecotoxicity	6,3
			Acidification / eutrophication	2,9
			Land use	30,8
	Resource	20	Minerals	0,4
			Fossil	19,6
Egalitarian	Human Health	30	Carcinogenic effects	3,9
			Respiratory effects (inorganic)	20,9
			Respiratory effects (organic)	0,1
			Climate change	4,6
			Radiation	0,1
			Ozone depletion	0,4
	Ecosystem Quality	50	Ecotoxicity	7,9
			Acidification / eutrophication	3,7
			Land use	38,4
	Resource	20	Minerals	0,5
			Fossil	19,5

Perspective	Environmental damage category	Weighting factor (%)	Impact category	Weighting factor (%)
Individualist	Human Health	55	Carcinogenic effects	1,4
			Respiratory effects (inorganic)	37,8
			Respiratory effects (organic)	0,4
			Climate change	15,8
			Radiation	0,0
			Ozone depletion	1,2
	Ecosystem Quality	25	Ecotoxicity	1,0
			Acidification / eutrophication	1,9
			Land use	19,8
	Resource	20	Minerals	20,6
			Fossil	0,0

Table 9

For those who do not want to use the default weighting factors, the mixing triangle developed by Hofstetter is recommended. The triangle shown below can be used to graphically depict the outcome of product comparisons for all possible weighting sets. Each point within the triangle represents a combination of weights that add up to 100%.

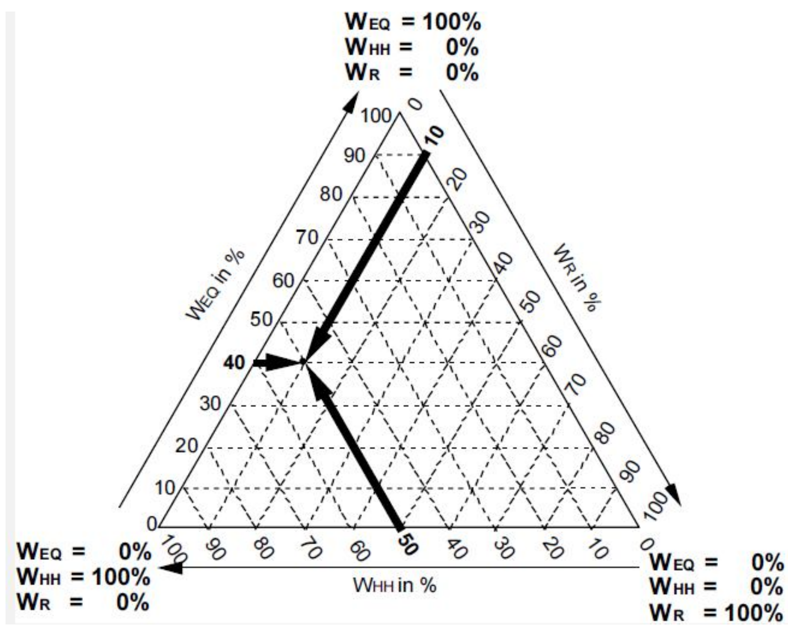

Figure 4 The mixing triangle (based on Hofstetter 1998).
Source: Eco-indicator 99 Methodology Report, 3rd edition, 22 June 2001

4.3.3 BRE Ecopoints

Introduction

Building Research Establishment (BRE) developed the Environmental Profiles Methodology with its associated database for construction products in the UK in 1999 for the first time. It was followed by an updated edition in 2008 as a result of a wide research programme started in 2005.
There are three main types of Environmental Profiles as follows:

- a ‘cradle-to-gate’ Environmental Profile for construction materials reported on a ‘per tonne’ basis
- a ‘cradle-to-site’ Environmental Profile for installed building elements reported on a ‘per square metre of installed element’ basis
- a ‘cradle-to-grave’ Environmental Profile for building elements over a 60-year study period reported on a ‘per square metre of installed element’ basis taking into consideration installation, maintenance, replacement and disposal.

The current Environmental Profile Methodology 2008 takes into account the following 13 environmental impact categories:

- climate change
- stratospheric ozone depletion
- eutrophication
- acidification
- photochemical ozone creation (summer smog)
- human toxicity
- ecotoxicity to water
- ecotoxicity to land
- fossil fuel depletion
- waste disposal
- water extraction
- mineral resource depletion
- nuclear waste

The Approved Environmental Profiles are Type III third party verified environmental product declarations (EPDs). In the methodology Ecopoints in each impact category are aggregated into a single Ecopoint score after normalisation and weighting.
Based on their Ecopoint score, products, materials or building element are rated into classes from A+ to E depending on their nature, the function of the building they are installed to and the Ecopoint range determined by the lowest and highest score for each product/material/element category.

The normalisation and weighting method described below is applied at product level. However, the normalised and weighted data results in a rating ranging from A+ to E for products/materials/elements, which is used as input data in the BRE's Environmental Assessment Method (BREEAM) when the whole building is assessed.

Normalisation

Normalisation factors are different in the 1999 and 2008 versions as they relates to UK citizens and Western European citizens respectively. Normalised data is calculated by dividing the characterised data by the normalisation factor in each impact categories. The normalisation factors applied are summarised in Table 10.

Environmental Profile Methodology 1999		Environmental Profile Methodology 2008	
Impact category and unit	Normalisation factors based on UK citizen's impacts [annual per capita]	Impact category and unit	Normalisation factors based on Western European citizen's impacts [annual per capita]
Climate change [kg CO_2 eq (100 years)]	12 269	Climate change [kg CO_2 eq (100 years)]	12 300
Acid deposition [kg SO_2 eq]	58,9	Acidification [kg SO_2 eq]	71,2
Ozone depletion [kg CFC 11 eq]	0,3	Ozone depletion [kg CFC 11 eq]	0,217
Pollution to air: human toxicity [kg tox]	90,7	Ecotoxicity to land [kg 1,4 DB-eq]	123
Pollution to air: low level ozone creation [kg ethene eq (POCP)]	32,2	Photochemical ozone creation [kg ethene eq]	21,5
Fossil fuel depletion and extraction [toe]	4,09	Fossil fuel depletion [GJ]	273
Pollution to water: human toxicity [kg tox]	0,01	Human toxicity [kg 1,4 DB-eq]	19 700
Pollution to water: ecotoxicity [m^3tox]	117 948	Ecotoxicity to freshwater [kg 1,4 DB-eq]	1 320
Pollution to water: eutrophication [kg PO_4 eq]	8,0	Eutrophication [kg PO_4 eq]	32,5
Minerals extraction [tonnes]	5,0	Mineral resource extraction [tonnes]	24,4
Water extraction [litres]	417 583	Water extraction [m^3]	378
Waste disposal [tonnes]	7,2	Waste disposal [kg]	3 750
Transport pollution and congestion: freight [tonne km]	4 141	Nuclear waste (higher level) [m^3 high level waste]	2,37E-05

Table 10

Weighting

Weighting factors also differ in the two versions and they are shown in Table 11:

Environmental Profile Methodology 1999		Environmental Profile Methodology 2008	
Impact category and unit	Weighting factor [%]	Impact category and unit	Weighting factor [%]
Climate change [kg CO_2 eq (100 years)]	35,0	Climate change [kg CO_2 eq (100 years)]	21,6
Acid deposition [kg SO_2 eq]	5,0	Acidification [kg SO_2 eq]	0,05
Ozone depletion [kg CFC 11 eq]	8,0	Ozone depletion [kg CFC 11 eq]	9,1
Pollution to air: human toxicity [kg tox]	6,5	Ecotoxicity to land [kg 1,4 DB-eq]	8,0
Pollution to air: low level ozone creation [kg ethene eq (POCP)]	3,5	Photochemical ozone creation [kg ethene eq]	0,20
Fossil fuel depletion and extraction [toe]	11,0	Fossil fuel depletion [GJ]	3,3
Pollution to water: human toxicity [kg tox]	2,0	Human toxicity [kg 1,4 DB-eq]	8,6
Pollution to water: ecotoxicity [m^3tox]	4,0	Ecotoxicity to freshwater [kg 1,4 DB-eq]	8,6
Pollution to water: eutrophication [kg PO_4 eq]	4,0	Eutrophication [kg PO_4 eq]	3,0
Minerals extraction [tonnes]	3,0	Mineral resource extraction [tonnes]	9,8
Water extraction [litres]	5,0	Water extraction [m^3]	11,7
Waste disposal [tonnes]	6,0	Waste disposal [kg]	7,7
Transport pollution and congestion: freight [tonne km]	7,0	Nuclear waste (higher level) [m^3 high level waste]	8,2
Total	100 %		100 %

Table 11

Ecopoints are calculated by multiplying the normalised data by the weighting factor for each impact category and the Ecopoints in each category are summarised to get a single Ecopoint score.

4.3.4 IMPACT 2002+

This section is based mainly on the IMPACT2002+, User guide, draft version 2.1 by Sébastien Humbert et al. 2005.[8]

The impact2002+ method is a new version of the IMPACT2002 method, where there have been developed new concepts and methods. The IMPACT2002+ has been especially improved for the comparative assessment of the impact categories eco-toxicity and human toxicity. For the remaining categories, the Eco-indicator 99 (Goedkoop and Spriensma 2000) and the CML 2002 (Guinée et al. 2002) have been the basis for the methods.

The IMPACT 2002+ includes14 midpoint categories:

Midpoint categories in the IMPACT2002+

- Human Toxicity (carcinogens + non-carcinogens)
- Respiratory (inorganics)
- Ionizing radiations
- Ozone layer depletion
- Photochemical oxidation (Respiratory (organics)for human health)
- Aquatic eco toxicity
- Terrestrial eco toxicity
- Terrestrial acidification/nitrification
- Aquatic acidification
- Aquatic eutrophication
- Land occupation
- Global warming
- Non-renewable energy

In IMPACT2002 + all of the midpoint scores are expressed in units of a reference substance and related to the following four damage categories:

- Human health,
- Ecosystem quality
- Climate change
- Resources

[8]http://www.sph.umich.edu/riskcenter/jolliet/IMPACT2002+/IMPACT2002+_UserGuide_for_v2.1_Draft_October2005.pdf

Normalization

The authors of IMPACT2002 + recommend users to analyze normalized scores at damage level, not at midpoint level. The normalization factors used in IMPACT2002+ for the damage categories are listed in Table 12.

Damage categories	**Normalizations factors**	**Unit**
Human Health	0.0077	Daly/pers/yr
Ecosystem Quality	4650	PDF●m2●yr/pers/yr
Climate Change	9950	Kg CO2/pers/yr
Resources	152000	MJ/pers/yr

Table 12 Normalization factors for the four damage categories for Western Europe (Jolliet et al. 2003)

For those who choose nevertheless to perform normalization on midpoint level, the authors provide normalization factor also for the midpoint level those normalization factors are listed in Table 13.

	Normalization factors		**Unit**
Midpoint categories	**Version 1.0 and 1.1**	**Version 2.0 and 2.1**	
Human Toxicity (carcinogens + non-carcinogens)	218	219	kg eq chloroethylene into air
Respiratory (inorganics)	9.98	8.8	kg eq PM2.5 into air
Ionizing radiations	6.04E+5	5.33E+5	Bq carbon-14 into air
Ozone layer depletion	0.225	0.204	kg eq CFC-11 into air
Photochemical oxidation (Respiratory (organics)for human health)	14.1	12.4	kg eq ethylene into air
Aquatic eco toxicity	3.02E+4	1.36 E+6	kg eq triethylene glycol into water
Terrestrial eco toxicity	7160 kg eq triethylene glycol into water (v1.0) 1.68E+4 (v1.1)	1.20E+6	kg eq triethylene glycol into soil
Terrestrial acidification/nitrification	358	315	kg SO2 into air
Aquatic acidification	75.1	66.2	kg SO2 into air
Aquatic eutrophication	13.4	11.8	kg eq PO4 3- into water

	Normalization factors		Unit
Midpoint categories	**Version 1.0 and 1.1**	**Version 2.0 and 2.1**	
Land occupation	3930	3460	M2 eq organic arable land year
Global warming	9950	9950	kg eq CO2 into air
Non-renewable energy	152000	152000	MJ Total primary non-renewable energy
	1770	3330	kg eq crude oil (860 kg m3)
Mineral extraction	24.7	292	MJ additional energy
	485	5730	kg eq iron (in ore)

Table 13 Normalization factors for IMPACT 2002 + from Humbert et al.

Weighting

(Directly from the User Guide)

"The authors suggest considering the four damage oriented impact categories human health, ecosystem quality, climate change, and resources 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. A smart way of analyzing the different weightings possible can be done applying the mixing triangle. This method is presented in Annex 5 (of the User Guide).
Finally, the authors would like to stress again that, according to ISO norms, weighting is not usable for comparative assertions disclosed to the public (ISO 14042)."

4.3.5 LUCAS

LUCAS (Toffoletto C., et al., 2007) was first developed in 2005 with the goal of providing a methodology adapted to the Canadian context. It is based on existing characterisation models from existing LCIA methodologies such as TRACI 2002 and IMPACT 2002+, which are re-parameterised and further developed to assess better Canadian life cycle inventories. LUCAS covers 11 midpoint impacts (see Table 14) and includes 800 substances and 2,000 toxic emissions approximately.

Climate change
Ozone depletion
Acidification
Photochemical smog
Respiratory effects
Aquatic eutrophication
Terrestrial eutrophication
Ecotoxicity (aquatic and terrestrial)
Human toxicity
Land-use
Abiotic resource depletion

Table 14 Midpoint impacts covered in LUCAS
(Source: EC JRC, ILCD Handbook 2010)

Currently, midpoint indicators are preferred over endpoint. For now the methodology framework is not modelled up to endpoint (currently under development).

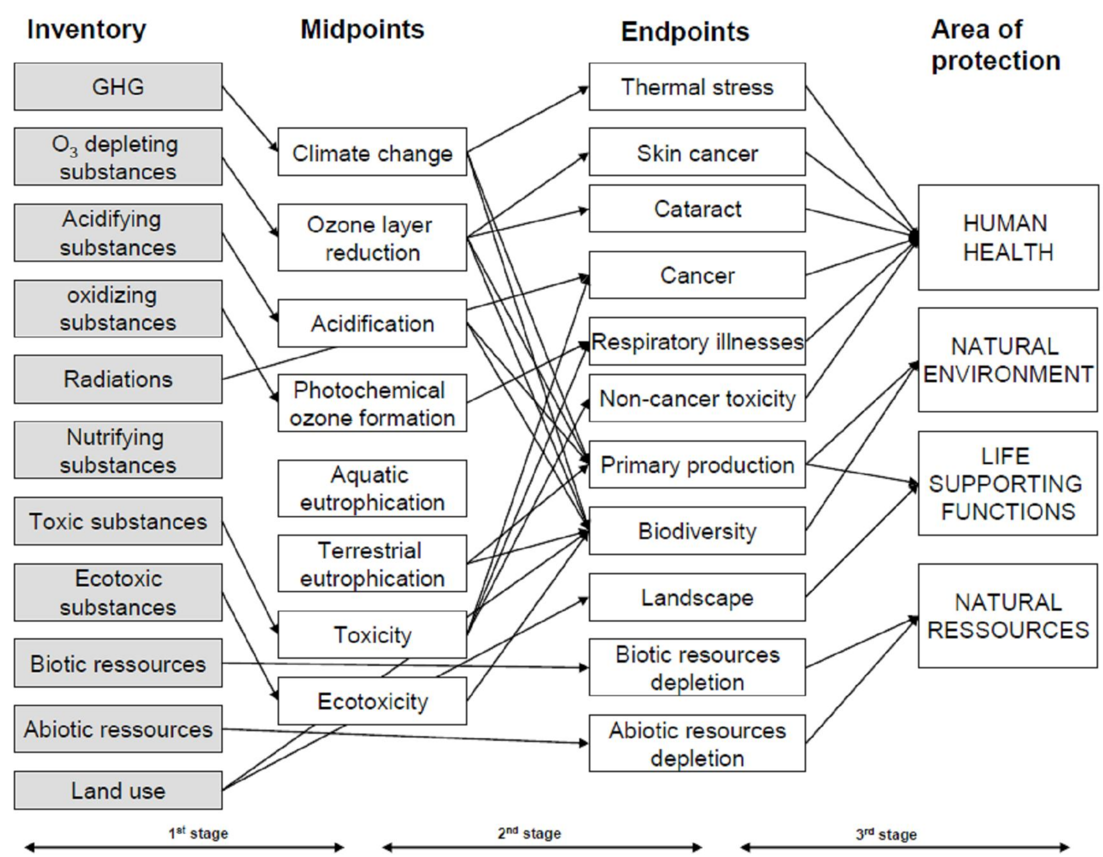

Figure 5 Impact categories and pathways covered by the LUCAS methodology
(Source: EC JRC, ILCD Handbook 2010)

For each indicator separate normalisation factors are calculated using the same basic normalisation data: Total impact of annual emission in Canada / Population in Canada. Normalisation is determined by the ratio of the impact per unit of emission divided by the total impact of all substances contributing to the specific impact category, per person. Normalisation factors are currently being updated.

Weighting is not performed in LUCAS method.

4.3.6 ReCiPe

ReCiPe is a follow up of Eco-indicator 99 and CML 2002 methods. It integrates and harmonises midpoint and endpoint approach in a consistent framework. Although initially integration of the methods was intended, all impact categories have been redeveloped and updated, except ionising radiation (De Schryver A.M., et al., 2007; Huijbregts M.A.J., et al., 2005a-b; Sleeswijk A.W, et al., 2008).

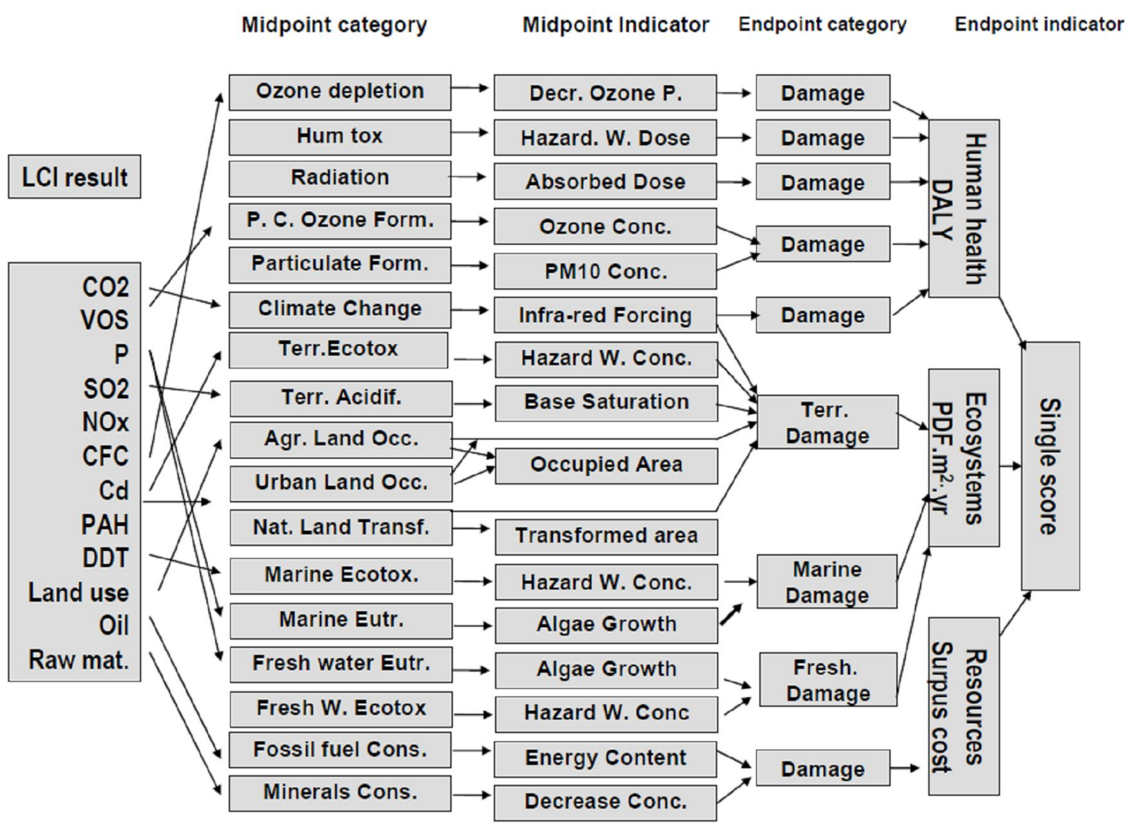

Figure 6 Impact categories and pathways covered by the ReCiPe methodology (Source: EC JRC, ILCD Handbook 2010)

Midpoint and endpoint characterisation factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources. Each method (midpoint, endpoint) contains factors according to the three cultural perspectives. These perspectives represent a set of choices on issues like time perspective or expectations that proper management or future technology development can avoid future damages.

- Egalitarian: long term based on precautionary principle thinking.
- Hierarchist: Consensus model, as often encountered in scientific models, this is often considered to be the default model.
- Individualist: short term, optimism that technology can avoid many problems in future.

ReCiPe covers 18 midpoint impacts and 3 endpoint impacts and includes 3,000 substances approximately. Normalisation data are available for Europe and the world in year 2000. Table 15 presents midpoint impacts included in ReCiPe and normalisation factors. Normalisation data on fresh water depletion is not included.

Midpoint impact	Unit	Normalisation value (Europe) Egalitarian version	Normalisation value (World) Egalitarian version	Normalisation value (Europe) Hierarchist version	Normalisation value (World) Hierarchist version	Normalisation value (Europe) Individualist version	Normalisation value (World) Individualist version
climate change	kg CO_2	0,000103	0,000182	8,9E-05	0,000146	7,06e-5	0,000106
ozone depletion	kg CFC-11 eq	45,4	26,8	45,4	26,8	45,4	26,8
human toxicity	kg 1,4-DB eq	0,000226	0,00102	0,00165	0,00835	0,00305	0,0117
photochemical oxidant formation	kg NMVOC	0,0177	0,0202	0,0177	0,0202	0,0177	0,0202
particulate matter formation	kg PM10 eq	0,067	0,0716	0,067	0,0716	0,067	0,0716
ionising radiation	kg ^{235}U eq	0,00016	0,000766	0,00016	0,000766	0,000486	0,00233
terrestrial acidification	kg SO_2 eq	0,026	0,0239	0,029	0,0264	0,0309	0,0282
freshwater eutrophication	kg P eq	3,97	7,93	3,97	7,93	3,97	7,93
marine eutrophication	kg N eq	0,0806	0,111	0,0806	0,112	0,0806	0,111
terrestrial ecotoxicity	kg 1,4-DB eq	0,0715	0,0253	0,122	0,155	0,122	0,155
freshwater ecotoxicity	kg 1,4-DB eq	0,087	0,123	0,0924	0,235	0,0925	0,236
marine ecotoxicity	kg 1,4-DB eq	0,000437	0,00052	0,242	0,756	0,304	0,947
agricultural land occupation	m^2a	0,000221	0,000186	0,000221	0,000186	0,000221	0,000186
urban land occupation	m^2a	0,00245	0,0013	0,00245	0,0013	0,00245	0,0013
natural land transformation	m^2	6,18	0,0837	6,18	0,0837	6,18	0,0837

Midpoint impact	Unit	Normalisation value (Europe) Egalitarian version	Normalisation value (World) Egalitarian version	Normalisation value (Europe) Hierarchist version	Normalisation value (World) Hierarchist version	Normalisation value (Europe) Individualist version	Normalisation value (World) Individualist version
depletion of freshwater resources	m^3	0	0	0	0	0	0
depletion of mineral resources	kg Fe eq	0,0014	0,00226	0,0014	0,00226	0,0014	0,00226
depletion of fossil fuel resources	kg oil eq	0,000526	0,000733	0,000526	0,000733	0,000526	0,000733

Table 15 Midpoint impacts covered in ReCiPe and normalization factors (Source: SimaPro v7.2)

The next tables present normalisation and weighting factors of endpoint impacts included in ReCiPe. There are 12 normalisation and weighting set values:

- Europe E/A refers to the normalisation values of Europe with the average weighting set (recommended) in the ReCiPe egalitarian version.
- Europe E/E refers to the normalisation values of Europe with the weighting set belonging to the egalitarian perspective in the ReCiPe egalitarian version.
- World E/A refers to the normalisation values of the world with the average weighting set in the ReCiPe egalitarian version.
- World E/E refers to the normalisation values of the world with the weighting set belonging to the egalitarian perspective in the ReCiPe egalitarian version.
- Europe H/A refers to the normalisation values of Europe with the average weighting set (recommended) in the ReCiPe hierarchist version.
- Europe H/H refers to the normalisation values of Europe with the weighting set belonging to the hierarchist perspective in the ReCiPe hierarchist version.
- World H/A refers to the normalisation values of the world with the average weighting set in the ReCiPe hierarchist version.
- World H/H refers to the normalisation values of the world with the weighting set belonging to the hierarchist perspective in the ReCiPe hierarchist version.
- Europe I/A refers to the normalisation values of Europe with the average weighting set (recommended) in the ReCiPe individualist version.
- Europe I/I refers to the normalisation values of Europe with the weighting set belonging to the individualist perspective in the ReCiPe individualist version.
- World I/A refers to the normalisation values of the world with the average weighting set in the ReCiPe individualist version.
- World I/I refers to the normalisation values of the world with the weighting set belonging to the individualist perspective in the ReCiPe individualist version.

Endpoint impact	Unit	Normalisation values											
		Europe E/A	Europe E/E	World E/A	World E/E	Europe H/A	Europe H/H	World H/A	World H/H	Europe I/A	Europe I/I	World I/A	World I/I
human health	DALY	24.3	24.3	42.2	42.2	49.5	49.5	74.6	74.6	47.6	47.6	67	67
ecosystems	species. yr	3.73e3	3.73e3	433	433	5.72e3	5.72e3	1.17e3	1.17e3	5.53e3	5.53e3	1.34e3	1.34e3
resources	$	3.27e-5	3.27e-5	4.56e-5	4.56e-5	3.27e-5	3.27e-5	4.56e-5	4.56e-5	7.2e-5	7.2e-5	0.0001	0.0001

Table 16 Normalisation factors of endpoint impacts covered in ReCiPe (Source: SimaPro v7.2)

Endpoint impact	Unit	Weighting values											
		Europe E/A	Europe E/E	World E/A	World E/E	Europe H/A	Europe H/H	World H/A	World H/H	Europe I/A	Europe I/I	World I/A	World I/I
human health	DALY	400	300	400	300	400	300	400	300	400	550	400	550
ecosystems	species. yr	400	500	400	500	400	400	400	400	400	250	400	250
resources	$	200	200	200	200	200	300	200	300	200	200	200	200

Table 17 Weighting factors of endpoint impacts covered in ReCiPe (Source: SimaPro v7.2)

4.3.7 Ecological Scarcity

The method of ecological scarcity (Brand G., et al., 1998; Frischknecht R., et al., 2006a-b), sometimes called Swiss Ecoscarcity or Swiss Ecopoints method, allows a comparative weighting and aggregation of various environmental interventions by use of so-called eco-factors.

The method supplies these weighting factors for different emissions into air, water and top-soil/groundwater as well as for the use of energy resources. The eco-factors are based on the annual actual flows (current flows) and on the annual flow considered as critical (critical flows) in a defined area (country or region).

The eco-factors were originally developed for the area of Switzerland (see references below). There, current flows are taken from the newest available statistical data, while critical flows are deduced from the partly scientifically supported goals of the Swiss environmental policy, each as of publication date. Later, sets of eco-factors were also made available for other countries, such as Belgium and Japan etc.

The method was first published in Switzerland in 1990. A first amendment and update was made for 1997. A next version, based on 2004 data, has been developed in 2006.

In the ecological scarcity method, normalisation is performed by dividing by 2004 emission flows, and weighting is performed by multiplying by the square of the ratio of actual flow/critical flow.

The next table presents the 7 specific impact categories included in Ecological Scarcity 2006, with for each substance a final UBP (environmental loading point) score as characterization factor. Because all impact categories are expressed in the same unit (UBP), the weighting step simply adds up the scores.

Impact category	Unit	Weighting values	Main characterisation values				
Emission into air	UBP	1	Dioxins (UBP/kg)	Cadmium (UBP/kg)	Mercury (UBP/kg)	Methane, bromotrifluoro (UBP/kg)	Methane, bromochlorodiifluoro (UBP/kg)
			5.7e13	4.6e8	2.1e8	1.1e8	3.3e7
Emission into surface water	UBP	1	Iodine-129 (UBP/kBq)	Curium alpha (UBP/kg)	Americium 241 (UBP/kg)	Actinides (UBP/kg)	Plutonium alpha (UBP/kg)
			9.3e4	5.3e4	2.9e4	1.1e4	6.9e3
Emission into ground water	UBP	1	Nitrate (UBP/kg)	-	-	-	-
			2.71e4	-	-	-	-
Emission into top soil	UBP	1	Iodosulfuron (UBP/kg)	Cadmium (UBP/kg)	Metsulfuron-methyl (UBP/kg)	Triasulfuron (UBP/kg)	Metalaxil (UBP/kg)
			4.1e8	3.1e8	2.5e8	2.2e8	2.0e8
Energy resources	UBP	1	Gas natural,inground (UBP/m^3)	Gas mine,off-gas,process, coal mining (UBP/m^3)	Uranium,in ground (UBP/kg)	Oil crude, n ground (UBP/kg)	Coal,hard, in ground (UBP/kg)
			1.33e2	1.31e2	1.85e6	1.51e2	6.30e1
Natural resources	UBP	1	Water,well, inground (UBP/m^3)	Water,natural origin (UBP/m^3)	Water,river (UBP/m^3)	Water,process,natural origin (UBP/m^3)	Water,process&cooling,natural origin (UBP/m^3)
			97	97	97	97	97
Deposited waste	UBP	1	Volume occupied,final repository for radiactive waste (UBP/m^3)	Volume occupied,final repository for low-active radiactive waste (UBP/m^3)	Volume occupied,underground deposit (UBP/m^3)	Total Organic Carbon-TOC (UBP/kg)	-
			1.8e10	3.3e9	4.3e7	6.28e4	-

Table 18 Impact categories covered in Ecological Scarcity 2006: weighting and main characterisation values (Source: SimaPro v7.2)

4.3.8 EPS 2000

Introduction

The EPS 2000 methodology identifies five areas of protection, as shown in Table 19. These areas are based on those identified by the Rio protocol (Steen, 1999b). The table further shows that each of these areas of protection is further broken down into impact categories with associated quantitative indicators. Table 19 also shows weighting factors, which will be considered later.

Area of protection	Impact category	Category indicator	Indicator unit	Weighting factor, ELU/unit
Human Health	Life expectancy	Years of life lost (YOLL)	Person years	85000
	Severe morbidity	Severe morbidity	Person years	100000
	Morbidity	Morbidity	Person years	10000
	Severe nuisance	Severe nuisance	Person years	10000
	Nuisance	Nuisance	Person years	100
Ecosystem production capacity	Crop growth capacity	Crop	Kg	0.15
	Wood growth capacity	Wood	Kg	0.04
	Fish and meat production capacity	Fish and meat	Kg	1
	Soil acidification	Base cat-ion capacity of soil	Mole H^+-equivalents	0.01
	Production capacity for irrigation water	Irrigation water	Kg	0.003
	Production capacity for drinking water	Drinking water	Kg	0.03
Abiotic stock resources (fossil fuels and elements	Depletion of resource	Reserves of resource	Kg of resource	Significant variation
Biodiversity	Species extinction	NEX	dimensionless	1.1×10^{11}
Recreational and cultural values	Not defined			

Table 19 Areas of protection, associated impact category indicators, indicator units and weighting factors

Figure 7 shows the methodology by which impacts on areas of protection are calculated from inventoried releases, extractions and other effects. Characterisation factors are established for each separate identified pathway by which a given release, type of land use or littering impacts identified areas of protection.

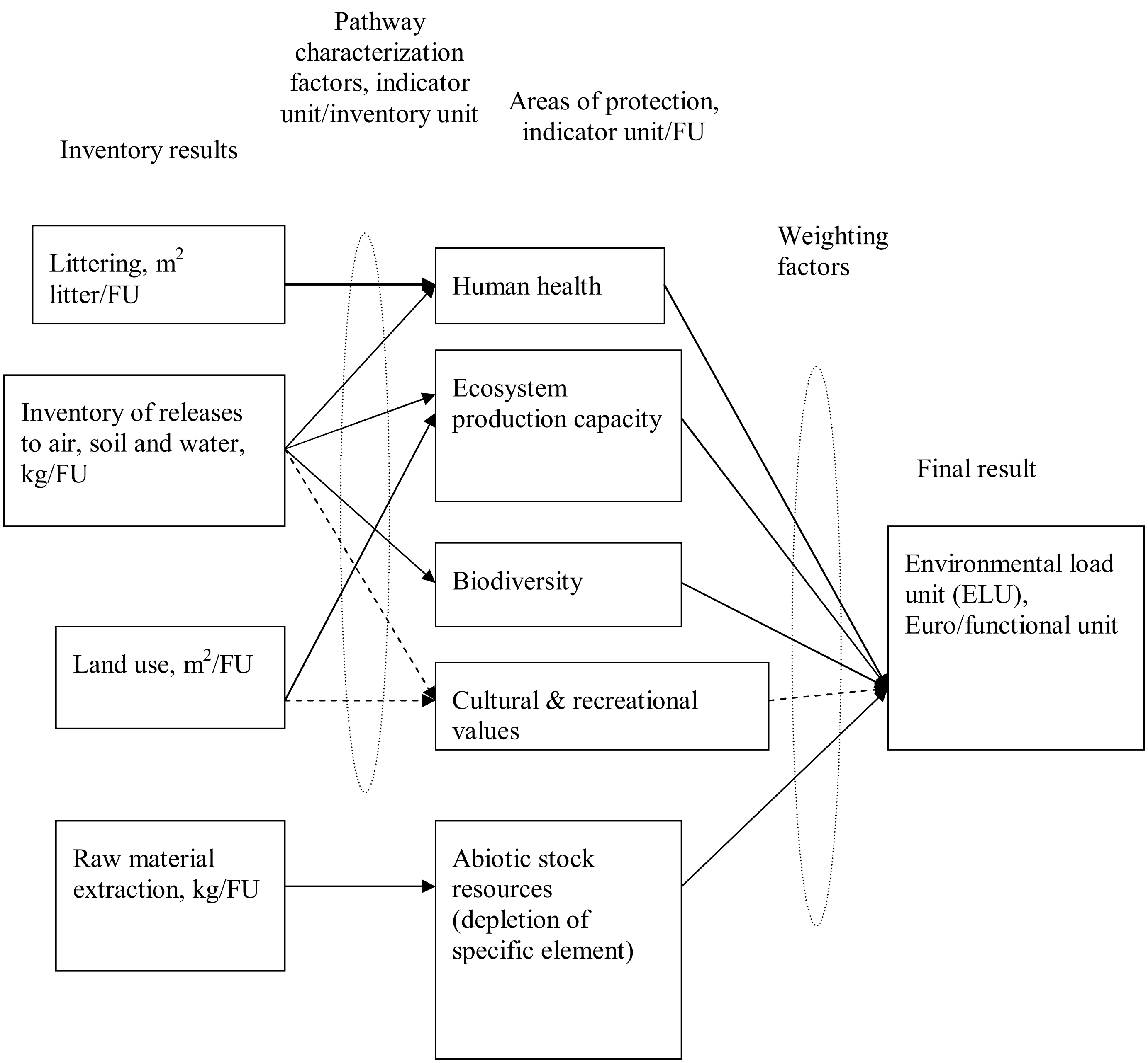

Figure 7 Schematic of LCIA methodology for EPS 2000. Based on (Steen, 1999a)

To exemplify, all identified *pathways* for emissions to air, water and soil are shown in Table 20. There is no application of characterisation factors in the case of inventoried raw materials since impacts are expressed in terms of mass of depletion of a specific element (i.e. characterisation factor = 1).

It can be inferred from Figure 7 that EPS 2000 does not explicitly aggregate midpoint impacts, such as climate change, acidification or human toxicity, rather this type of impact is taken into account in the pathway specific characterisation factors.

Identified pathways between inventoried releases, extractions and effects and endpoint impacts		
acidification	direct exposure	nutrification
acute health	eutrophication	odour
brain damage	fishing restrictions	oral intake
cancer	flooding	oxidant formation
chronic health	global warming	oxidants
climate change	heat stress	reproduction
CO_2 fertilisation	inhalation	secondary particles
corrosion	malaria	starvation
desertification	N-nutrification	visibility

Table 20 Identified pathways between inventories releases, extractions and effects and areas of protection. Based on (Steen, 1999a).

Normalisation

The EPS 2000 methodology does not attempt to express normalised impacts and there are as such no normalisation factors established in the methodology.

Weighting

Figure 7 further shows that the EPS 2000 methodology does on the other hand specify a method for weighting impact categories that facilitates aggregation into a single quantitative result. The aggregation is based on a willingness to pay (WTP) principle. A full description of the consideration behind the weighting values is given in Steen (1999a).

In the area of human health, WTP is established as follows:

Life expectancy: The weighting factor here is based on the concept of the value of a statistical life, the WTP to prevent one death. This is based on the results of the ExternE project (1995), and recalculated to 1998 € values to 3,2 M€/prevented death.
It is assumed that the average lifespan in an OECD country is 75 years, and therefore when a death occurs due to an accident to a randomly selected person in the population, the expectation value for years of life lost for the randomly selected person is 37,5 years of life lost (YOLL). The weighting factor for life expectancy is therefore 3.2 M€/37.5 years = 85000 €/person-year.

Severe morbidity: For severe morbidity the weighting factor is 100000 €/person-year. This is again based on 2 values from ExternE project (1995): Firstly, a value per restrictive active day (RAD) of 62 €/day = 22600 €/year is given. This is added to a cost of chronic illness where the valuation is the same as for life expectance at 85000 €/person-year. The sum of these two aspects is added and rounded up to give the value of 100000 €/person-year.

Morbidity: The WTP to avoid morbidity (normal illness) is estimated at 10000 €/person-year, based on the WTP for medication to avoid common ailments such as cough or wheezing.

Severe nuisance: Severe nuisance in EPS 2000 is considered to be health impairments that do not necessarily imply a totally restricted activity, but rather impaired activity such as shortness of breath, or headache. WTP to avoid severe nuisance are estimated to be the same as those to avoid morbidity, 10000 €/person-year.

Nuisance: EPS 2000 assumed nuisance to be constituted by a mild nuisance that does not constantly irritate people, exemplified by visibility reduction, dirty surfaces, a moderate noise level or even concern for health effects. The WTP to avoid this is based on a study by Hylland and Strand (1983), who found a WTP of 112.5 €/person-year for a considerable improvement of visibility due to improvement of air quality. The value is rounded down in EPS 2000 to 100 €/person-year.

Crops: A WTP of 0,15 €/kg for all kinds of crops is used, based on FAO's international market prices for grain crops (wheat, rye, oats, barley, maize) and potatoes.

Wood: WTP for wood is based on the price for harvested wood in Swedish conditions, according to Braconier (1999). The figure given in this reference, of 0.050 €/kg dry substance (DS) is reduced somewhat in light of the fact that prices in other parts of the world are not as high as in Sweden, and EPS 2000 default value is 0.04 €/kg dry substance (DS).

Fish and meat: Price for fish and meat are approximated in the model according to a world price of pork at 1 €/kg from the Financial Times (1999).

Base cat-ion capacity of soil: WTP to avoid is based on approximate limiting costs for applying dolomite to rectify reduction of soil pH and set at 0.01 EUR/mole H^+.

Water: WTP for water is based on alternative production methods in case of scarcity. While the applied factors are global averages, it is acknowledged that scarcity is much less an issue in northern latitudes than southern. EPS 2000 subdivides water into irrigation water and drinking water. WTP for irrigation water used in the model is 0.003 €/kg (based on assumed costs for transportation) whilst for drinking water it is 0.03 €/kg (based on cost to produce water of sufficiently high quality).

Both estimates are global averages, where the differences between areas of water scarcity and abundance have been taken into account.

In the area of protection abiotic resources, the basic principle by which WTP is established is the cost for sustainable production of those resources in the future. This in general assumes that non-renewable resources such as fossil fuels are not used. Specific assumptions and values are as follows:

Chemical elements: In the production of pure forms of various elements, it is assumed that these elements are extracted from ores where the concentration of the element in question is equal to its known average concentration in the earth's crust.

Substance category	€/kg substance
Aluminium	0,439
Iron	0,961
Copper, zinc (and other sulphide ores)	208
Other materials from earth's crust, e.g. Ag, As, Pb, Zn, Cd, Au, Cr, P, U etc.	Based on cost for copper relative to inverse proportions for copper and element in question in earth's crust
Elements from sea water (Na, K, Cl, Mg, S, B, Br, I)	Between 0 and 0.1, due to assumed simple extraction after sea water
Elements from air (Ar, He, Ne, N, O)	0 (regarded as a sustainable resource)

Table 21 Weighting factors used for various elements in EPS 2000

Fossil oil: WTP is based on the cost for sustainable production of oil replacement from oilseed rape. With present technology, and taking into account environmental externalities, this cost is set at 0.925 €/kg. The value used by EPS is 0.506 €/kg, based on an assumption of optimization from a sustainability point of view.

Fossil coal: WTP is based on cost for sustainable production of the element carbon in the form of charcoal as a replacement for coal as a carbon source (not as an energy source). Frischknecht et al (1994) estimate this cost to be 0.151 €/kg for present technology, and it is further assumed that with optimized technology this can be reduced to 0.0498 €/kg.

Natural gas: WTP here is based on the cost for producing biogas of the same composition as natural gas from the Swedish Ministry of Industry, Employment and Communication (SOU, 1998) and set at 1.1 €/kg.
In the biodiversity area of protection, WTP for avoiding one extinct species is based on estimated costs in Sweden of 178 M€, and the value used in EPS 2000 is 1.1 x 10^{11}.

4.3.9 Eco-effect

Introduction

The EcoEffect method was developed with the aim of quantitatively describing environmental and health effects from real estate and buildings and to provide decision support for comparisons and decisions that can lead to reduced environmental impacts. The following account of the tool is based on the methodological description (Glaumann & Malmqvist, 2005) and on the tool summary (Glaumann & Malmqvist, 2004). Table 22 shows the areas that are evaluated in the method and the methods that are used for each overall area.

Overall evaluation area	Evaluation method	Evaluation area in EcoEffect
External environmental impacts	LCA	Energy usage
		Material usage
Internal environmental impacts	Multi-criteria analysis	Indoor environment *on property*
		Outdoor environment *on property*
Environmental costs during the lifetime of the building	Net present cost calculation of certain internalized costs	Life-cycle costs (LCC)

Table 22 Evaluation areas in EcoEffect and methods for evaluation

Specifically relevant for this report is the LCA evaluation method that is used to evaluate external environmental impacts from energy and material usage. In the case of emissions to soil, air and water, inventory data for a given building is extracted from a database for energy vectors and building materials in the EcoEffect software. The impacts of emissions are then classified and characterized according to the software's impact categories and mid-point indicators shown in Table 23, which also shows the normalisation factors that are used in the tool.

Impact category	**Indicator unit, per person, year**	**Normalisation value**	**Norma-lisation region**	**Source**
Climate change	gCO_2-e	8 700 000	World	(Wenzel, Hauschild, & Alting,
Stratospheric ozone	g CFC11-	202	World	(Wenzel, Hauschild, & Alting,
Acidification	gSO_2-e	124 000	Sweden	(Swedish EPA, 2002)
Eutrophication	g NO_3-e	298 000	Sweden	(Swedish EPA, 2002)
Low-level ozone	g C_2H_4-e	20 000	Denmark	(Wenzel, Hauschild, & Alting,

Impact category	Indicator unit, per person, year	Normalisation value	Norma-lisation region	Source
Human toxicity	m^3/g	Depends on substance	Denmark	(Wenzel, Hauschild, & Alting, 1997)
Ecotoxicity	m^3/g	Depends on substance	Denmark	(Wenzel, Hauschild, & Alting, 1997)
Ionising radiation	kWh	7 422	Sweden	(Energimyndigheten, 2003)
Bulk Waste	g	1 350 000	Denmark	(Wenzel, Hauschild, & Alting,
Slag and ash	g	350 000	Denmark	(Wenzel, Hauschild, & Alting,
Hazardous waste	g	20 700	Denmark	(Wenzel, Hauschild, & Alting,

Table 23 Impact categories, indicator units and normalisation factors according the EcoEffect method for Impact evaluation. Ecotoxicity impact categories are normalized with respect to volume of air, water or soil that is required to render 1 g of a released substance benign.

An overview of the calculation method that is used in the EcoEffect LCA methodology is shown in Figure 8.

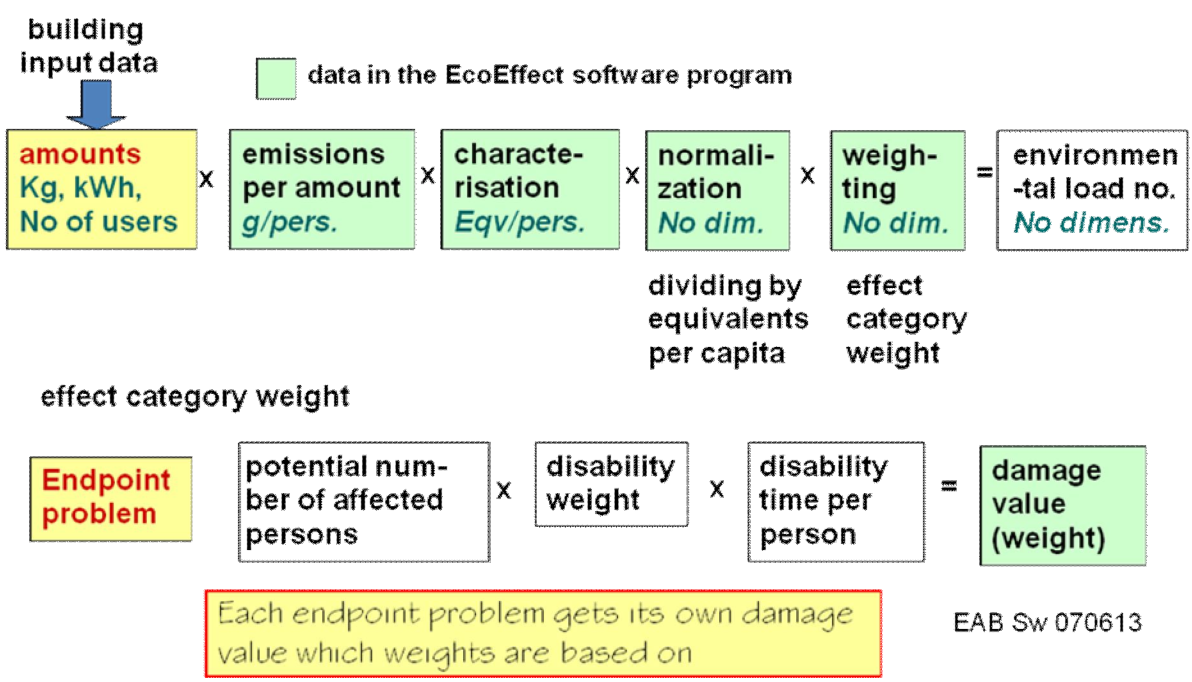

Figure 8 Schematic overview of calculation methodology used for emissions to land, air and water in EcoEffect (Glaumann & Malmqvist, 2005)

Normalisation in EcoEffect

Normalization in Eco-effect is carried out assessed by impact per capita. The EcoEffect method mentions that in determining normalization factors per capita it is important to connect emissions to a probability of causing damage. In turn, it is important to pay attention to where emissions occur, and how they disperse in the environment. However, in determining default factors, it is also accepted in EcoEffect that it is very difficult to establish accurate normative factors based on this principle, since in reality emissions occur in so many different locations, considering the life-cycle of the building. Having said that, as shown in Table 23 some differentiation of the probability of causing damage is expressed, by choosing global normalization factors for impact categories considered to be global, namely global warming potential and ozone depletion potential, whilst for other factors local or regional factors are chosen. The tool was developed for Swedish conditions and Danish values are used since corresponding Swedish values were lacking. Normalization is also carried out for inventoried data in depletion of natural resources, expressed in kg/person, year. In this case, values of world consumption per person per year are used, shown in Table 24.

	Normalisation factor, kg/person, year	Effect factor, (weights)
Copper	1,9	1
Aluminium	3,6	0,59
Lead	0,5	1
Iron	176	0,68
Chrome	2,1	0,33
Nickel	0,2	0,67
Zinc	1,3	1,04
Oil	591	0,73
Coal	186	0,35
Fossil gas	271	0,52
Sand	20	0,6
Cement	257	0,46
Phosphate	23	0,95
Wood	587	0,38
Peat	4,5	0,25
Uranium	5,4	0,3
Gypsum	29,4	0,43

Table 24 Normalisation factors and weighting factors used for natural resources in EcoEffect. Based on yearly world consumption figures.

Weighting

In EcoEffect, weighted impacts are reported *separately* for a. emissions to air, land and water, b. waste production and c. depletion of natural resources. The way the tool deals with weighting in each of these categories is described below.

a.) Emissions to air, land and water

Group damage values

To achieve weighted and aggregated results, firstly for each midpoint indicator in Table 23 above, a number of endpoint impact categories are identified. The endpoint categories are defined as impacts that directly affect humans. Examples of these for the midpoint impacts climate change and human and ecotoxicity are given in Table 25and Table 26 respectively.

End point impacts for Midpoint category Climate Change
Malaria
Dengue fever
Cardiovascular disease
Respiratory disease
Reduced harvest (equated with reduced employment in agricultural sector)
Reduced forest growth (equated with reduced employment in agricultural sector)
Starvation
Drowning accidents
Population migration

Table 25 End-point impact categories identified for mid-point category climate change

End point impacts for Midpoint categories human and ecotoxicity
Skin problems
Eye problems
Poisoning
Breathing problems
Asthma
Allergies
Lung cancer

End point impacts for Midpoint categories human and ecotoxicity
Skin cancer
Liver cancer
Stomach cancer
Nerve damage
Neurological damage
Infertility
Foetal damage
Inherited injuries
Physical disability
Reduced harvest (equated with reduced employment in agricultural sector)

Table 26 End-point impact categories for midpoint impact category human and ecotoxicity

End-point impacts are quantitatively assessed using damage values, expressed in years, calculated according to the DALY system. *Group* damage values for midpoint impacts are calculated as the sum of damage values for respective identified end-point impacts, as shown in Table 27. Weighting values so calculated can then be multiplied with their respective normalized mid-point impact values for the functional unit under consideration and summed to give an overall quantified environmental impact in DALY.

	Total Damage Value (DV), DALY, 10^6 years	Discounted damage values (DV), natural logarithm of total damage value
Climate change	109 455	25,42
Stratospheric ozone depletion	11	16,29
Acidification	2	14,65
Eutrophication	143	18,78
Low-level ozone	45	17,64
Human and ecotoxicity	28 156	24,06

Table 27 Damage values that are used for impact weighting, aggregated according to mid-point impact

Discounted weighting values

The creators of EcoEffect also chose to use discounted weighting factors. As shown in Table 27 , these discounted weighting values are calculated as the natural logarithm of the non-discounted DALY weights. In view of the creators awareness of the controversy surrounding discounting in environmental impact assessment, (Glaumann & Malmqvist, 2005) give an interesting account of the reasoning by which discounted weighting was chosen.
The thrust of the discussion is that on the one hand from an ethical point of view, it is unconscionable to distinguish between a future life and a life lived now. Therefore, we should not distinguish between health effects of environmental problems due to our decisions based on time and place, as discounting explicitly aims to do.
On the other hand, and ultimately the reason why some kind of discounting is suggested in EcoEffect, is that the way we act and make decisions in practice is not according to impartial ethical principle described in the paragraph above. Rather it is suggested that humans abide to a certain extent by loosely defined proximity relations, as displayed in Table 28 and Table 29. The idea here is that certain time aspects of climate change and eutrophication are on a much longer timescale that any of the human proximity relations of time displayed in Table 28. Having said that, given the assessed weight that should be given to climate change (see Table 27) a non-discounted weighting would suggest that climate change and only climate change is the only environmental aspect that should be considered, irrespective of the effect of less long-lived impacts such as acidification or ozone depletion. Therefore, discounting is suggested, not with the aim of reducing the importance of future environmental impacts, rather to ensure that impacts that we are experiencing in our own life-times that have to be tackled here and now are not overwhelmed by future impacts.

Furthermore, the ethical principle that we value all lives equally, irrespective of when or where those lives are lived does not seem to be a sound description of the way humans act in practice. This is exemplified by the fact that Swedish authorities do not divide acquired healthcare resources based on maximizing an increase in DALY per unit resource (by distributing resources to countries with low life-expectancies), rather it gives priority to Swedes. Therefore, creators of EcoEffect conclude, discounting of weighting factors successfully describes the way humans do act in reality, as opposed to prescribing how they should act.

Having suggested discounting as a method in establishing weighting factors, another question is how discounted weighting factors should be quantified. As shown in Table 27, the natural logarithm of the weighting factor is chosen, on the basis that it is considered to adequately reflect the criteria that the whole time span between a couple of years and 100 000 years could be taken into account.

Aspect	Years
Business planning in a company	1 – 5
National environmental quality objectives	25
A person's values	25
A person's memory	50
Contact with future generations	50
Average lifespan	80
Knowledge of ancestry	< 200

Table 28 Human proximity relations of time

Personal relationships	
Aspect	**Number of**
Family/relations	< 50
Close friends	< 10
Acquaintances	< 100
City district	< 1000
City	< 1 000 000
Country	< 50 000 000

Table 29 Human proximity relations with others

Time aspects of environmental impacts	
Aspect	**Years**
Marine oil spill	1
Littering	25
Acidification	10
Eutrophication	300
Climate change	500
Radioactive waste	100 000

Table 30 Time aspects of environmental issues

b.) Weighting for waste production

In the EcoEffect weighting system, the category waste is treated separately in the weighting process, using weighting factors based on those used in UMIP (Wenzel, Hauschild, & Alting, 1997) as shown in Table 31.

Category	Weighting factors
Bulk waste	1.1
Hazardous waste	1.1
Slag and ash	1.1

Table 31 Weighting factors for waste used in EcoEffect, based on UMIP (Wenzel, Hauschild, & Alting, 1997)

c.) Weighting for Depletion of Natural Resources

To aggregate all natural resource consumption into a single category, the significance of consumption of a unit of that resource is related to the significance of consumption of a single material, in this case copper. The weighting factors that are used are shown in Table 24.

For each material including copper, indicators relating to the aspects shown in Table 32 are calculated. This weighting is based on an Analytic Hierarchy Process (AHP) method, explained in detail in (Romero, 1999). For a given non-copper substance, the indicator value for that substance is compared to the corresponding indicator value for copper, and given an indicator score based on that comparison. For the non-copper substance, indicator comparison scores are aggregated according to the relative aspect weightings in Table 32, to give the final weightings shown in Table 24.

Evaluation Aspects	Relative Weight
Supply horizon	0,467
Exploitation change rate	0,117
Market value	0,135
Recovering energy	0,047
Regeneration time	0,234
Sum	1,000

Table 32 Aspects that are used to establish weighting parameters for resource depletion in EcoEffect (Romero, 1999)

4.3.10 Eco-Soft

ECOSOFT was developed by IBO (Österreichisches Institut für Baubiologie und Bauökologie) for the Austrian market. IBO is also responsible for management and distribution of the tool. In almost all Austrian provinces a simplified version, the so-called “OI3 – Index of the thermal building envelope” has been established as an assessment tool used for housing subsidy. This version is a rating system showing the ecological quality of the building materials, based on indicators PEIne (primary energy use from non-renewable), GWP (global warming potential), AP (acidification potential). ECOSOFT is based on the IBO database for building materials and calculates material, transport and energy inputs, as well as emissions on air, soil, water and waste.

ECOSOFT offers a weighting system for building materials called “OI3-Index”. This Index is based on three indicators: Primary Energy non-renewable (PEI_{ne}), Global Warming Potential (GWP) and Acidification Potential (AP). Case studies of buildings with different construction systems (light weight construction, solid buildings, e.g.) have generated benchmarks for this weighting system. Depending on the values for PEI_{ne}, GWP and AP points from 0 -100 can be achieved, the functional unit is 1 m^2 construction area. Final result is the OI3-index calculated as below-mentioned:

OI3-Index = 1/3 OI_{PEIne} + 1/3 OI_{GWP} + 1/3 OI_{AP}

For the housing subsidy system in most of the Austrian provinces the OI3-Index has to be calculated for construction areas of the thermal building envelope ($OI3_{TGH}$), sometimes under inclusion of a correction factor for the shape/volume ratio ($OI3_{TGH,\ lc}$). $OI3_{TGH,\ lc}$ – values under 20 points represent a very high ecological standard.

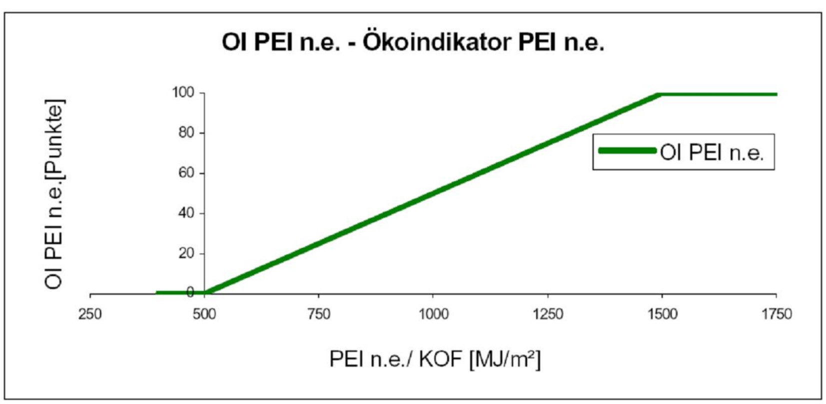

Figure 9 Point system for Primary Energy non-renewable ($OI_{TGH}PEI_{ne}$)

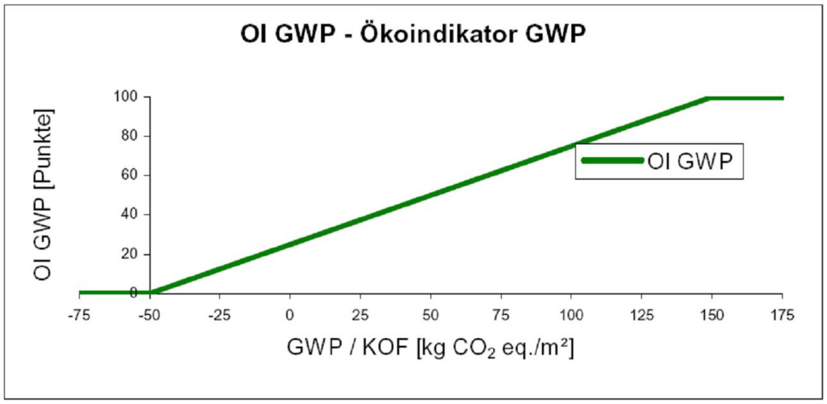

Figure 10 Point system for Global Warming Potential ($OI_{TGH}GWP$)

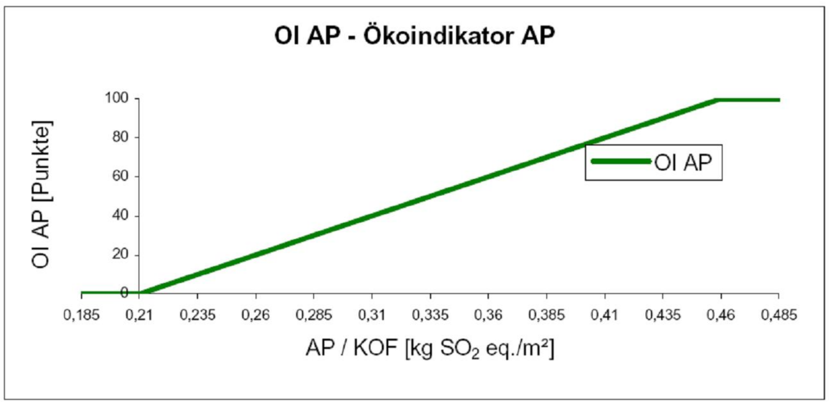

Figure 11 Point system for Acidification Potential ($OI_{TGH}AP$)

4.3.11 EQUER

At the moment national statistics per capita and per year are used to derive normalisation factors, e.g. kg $CO_{2eq}.yr^{-1}.cap^{-1}$, see the table hereunder.

Impact categories	Normalisation factor
Climate change, kg $CO_{2eq}.yr^{-1}.cap^{-1}$	8 680
Primary energy demand, kWh.$yr^{-1}.cap^{-1}$	48 670
Acidification, kg $SO_{2eq}.yr^{-1}.cap^{-1}$	62,3
Photo-oxidant formation, kg $C_2H_{4eq}.yr^{-1}.cap^{-1}$	19,7
Eutrophication, kg $PO_4{}^{3-}{}_{eq}.yr^{-1}.cap^{-1}$	38,1
Water consumption, $m^3.yr^{-1}.cap^{-1}$	339
Radioactive waste, $dm^3.yr^{-1}.cap^{-1}$	0,51
Other waste, kg.$yr^{-1}.cap^{-1}$	10 400
Depletion of abiotic resources, kg antimony.$yr^{-1}.cap^{-1}$	32,6
Human toxicity, DALY.$yr^{-1}.cap^{-1}$	0,0068
ecotoxicity, (PDF.m^2.yr).$yr^{-1}.cap^{-1}$	13 700

Table 33 Normalisation factor used in the EQUER method

It is planned to allow different values to be input by the user of the tool, according to the location of the building project.

No grouping and no weighting is performed.

4.4 Recommendations on normalisation and weighting

It can be seen, that there are several assessment method systems, and some of them using different normalisation and weighting systems.

In relation to normalisation, comparing of different normalised single data for the same indicator is possible since it depends on the normalisation factor used to divide the characterized value only. However, when a normalised data is given, the reference group needs to be identified as well to get information whether the normalisation factor relates to the whole world, Europe, or a single country.
Harmonising such factors within Europe might be difficult since citizens in each member state can have different behaviour and normalisation factors can vary in Western or Eastern, and Northern or Southern Europe. These factors can also change with time.

However, it is recommended investigating the possibility of harmonising the method of normalisation, which is applied to generate normalisation factors for different areas.

As opposed to normalised data, making a direct comparison between results obtained from different weighting systems seems to be impossible. This is due to the fact, that each assessment method uses different set of indicators and data for all relevant indicators in a given system is needed to carry out such a weighting exercise.
However, sensitivity analysis can be performed to find out whether using of different weigthing systems has an effect on ranking of two different design alternatives.
On the other hand, weighting is a useful tool when we are interested in the total environmental impact of a building which can be given as a single aggregated value.

At present time no existing weighting methods investigated can be recommended using at the whole European level.

Before thinking about a common approach in weighting systems, the method of normalisation should be harmonised, as only normalised data can be weighted. It is recommended investigating the possibility of developing common methods to define weighting systems. In such an investigation issues regarding weighting aspects specific to buildings, e.g. long lifetime of buildings, or relation of local and global systems due to different locations of manufacturing plants and contruction sites could be addressed.

Considering the pros and cons of the above, developing common weighting systems can be useful but should stay as an optional voluntary elements.

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