ILCD handbook

International Reference Life Cycle Data System

Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment

Background document

First edition

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The mission of the Institute for Environment and Sustainability is to provide scientific-technical support to the European Union's Policies for the protection and sustainable development of the European and global environment.

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Preface

To achieve more sustainable production and consumption patterns, we must consider the environmental implications of the whole supply-chain of products, both goods and services, their use, and waste management, i.e. their entire life cycle from "cradle to grave".

In the Communication on Integrated Product Policy (IPP), the European Commission committed to produce a handbook on best practice in Life Cycle Assessment (LCA). The Sustainable Consumption and Production (SCP) Action Plan confirmed that *"(…) consistent and reliable data and methods are required to asses the overall environmental performance of products (…)"*. The International Reference Life Cycle Data System (ILCD) Handbook provides governments and businesses with a basis for assuring quality and consistency of life cycle data, methods and assessments.

This background document provides an analysis of existing methods for assessing the potential environmental impacts from emissions and resource use that can be attributed to specific products in Life Cycle Assessments. The main target audiences include developers of Life Cycle Impact Assessment (LCIA) methods, Life Cycle Assessment practitioners, and other technical experts in policy and business.

Executive Summary

Overview

Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are scientific approaches behind a growing number of modern environmental policies and business decision support in the context of Sustainable Consumption and Production (SCP). The International Reference Life Cycle Data System (ILCD) provides a common basis for consistent, robust and quality-assured life cycle data, methods and assessments. These support coherent and reliable business and policy instruments related to products, natural resources, and waste management and their implementation, such as eco-labelling, carbon footprinting, and, green procurement.

This document provides an analysis of existing methods for assessing the potential environmental impacts from emissions and resource use that are attributed to specific products in life cycle assessments. The main target audiences include developers of Life Cycle Impact Assessment (LCIA) methods, Life Cycle Assessment practitioners, and other technical experts in policy and business.

About Life Cycle Impact Assessment (LCIA)

In a Life Cycle Assessment, the emissions and resources consumed that can be attributed to a specific product are compiled and documented in a Life Cycle Inventory. An impact assessment is then performed, considering human health, the natural environment, and issues related to natural resource use.

Impacts considered in a Life Cycle Impact Assessment include climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related) respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion. The emissions and resources are assigned to each of these impact categories. They are then converted into indicators using impact assessment models.

Different emissions and resources consumed, as well as different product options, can then be cross-compared in terms of the impact indicators.

About the International Reference Life Cycle Data System (ILCD)

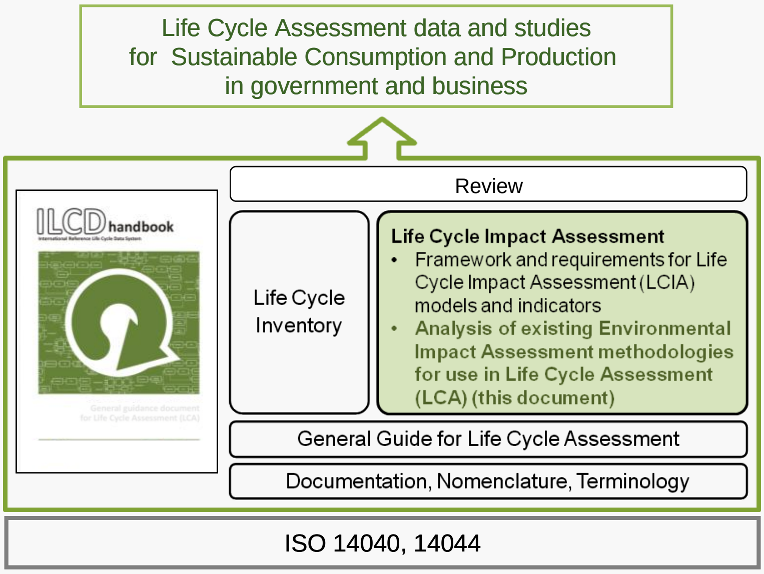
The ILCD Handbook is a series of detailed technical documents, providing guidance for good practice in Life Cycle Assessment in business and government. The ILCD Handbook can serve as “parent” document for developing sector- and product-specific guidance documents, criteria and simplified tools.

The ILCD Handbook is based on the existing international standards on LCA. The ISO 14040/44 standards provide the indispensable framework for LCA. This framework, however, leaves the individual practitioner with a range of choices that can change the results and conclusions of an assessment. Further guidance is therefore needed to support consistency and quality assurance. The ILCD Handbook has been set up to provide this guidance.

The development of the ILCD was coordinated by the European Commission and has been carried out in a broad international consultation process with experts, stakeholders, and the general public.

Role of this Guidance Document within the ILCD Handbook

This document provides a background analysis of existing methods used in Life Cycle Impact Assessment. It helps to identify differences and to select methods and models for more in depth evaluations, as a basis for recommendations. These evaluations are documented in separate documents[1]. No recommendations are provided in this document. This serves as a background document to the ILCD Handbook.



Approach and key issues addressed in this document

A wide range of existing methodologies that are, or can be, used in Life Cycle Impact Assessment are described in a structured way regarding:

- their documentation;
- the general principles applied;
- the consistency across impact categories considered;
- interesting innovative aspects.

An analysis using a set of pre-defined criteria is performed on all the described methods. Similarities and differences between methods are highlighted.

[1] Framework and Requirements for Life Cycle Impact Assessment Models and Indicators

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1 Introduction

The concept of Life Cycle Thinking (LCT) and the related quantitative tool Life Cycle Assessment (LCA) are increasingly used in the development, implementation, and monitoring of environmental policies globally, and in the private sector for continuous environmental improvement, strategic decision support and as a basis for external communication. LCA and LCT help to avoid resolving one environmental problem while creating another, avoiding the so-called “shifting of burdens”, e.g. from one part of the life cycle to another, from one region to another, from one generation to the next or amongst different types of impacts on the natural environment and on human health.

LCA is a structured, internationally standardised method and management tool (see ISO 14040 and 14044, 2006) for quantifying the emissions, resources consumed and environmental and health impacts that are associated with goods and services (products). LCAs take into account the product’s full life cycle: from the extraction of resources, over production, use and recycling up to the disposal of the remaining waste.

Steps of the impact assessment in LCA

According to ISO 14044 (2006), Life Cycle Impact Assessment (LCIA) proceeds through two mandatory and two optional steps:

1. Selection of impact categories and classification, where the categories of environmental impacts, which are of relevance to the study, are defined by their impact pathway and impact indicator, and the elementary flows from the inventory are assigned to the impact categories according to the substances’ ability to contribute to different environmental problems. (Mandatory step according to ISO).

2. Characterisation, where the impact from each emission is modelled quantitatively according to the underlying environmental mechanism. The impact is expressed as an impact score in a unit common to all contributions within the impact category (e.g. kg CO_2-equivalents for greenhouse gases contributing to the impact category climate change) by applying characterisation factors. A characterisation factor is a substance-specific factor calculated with a characterisation model for expressing the impact from the particular elementary flow in terms of the common unit of the category indicator. (Mandatory step according to ISO).

3. Normalisation, where the different characterised impact scores are related to a common reference, e.g. the impacts caused by one person during one year, in order to facilitate comparisons across impact categories. (Optional step according to ISO).

4. Weighting, where a ranking and/or weighting is performed of the different environmental impact categories reflecting the relative importance of the impacts considered in the study. Weighting may be needed when trade-off situations occur in LCAs used for comparisons. (Optional step according to ISO).

The ILCD Handbook focuses on the mandatory steps of classification and characterisation. The other two LCIA elements, normalisation and weighting, may be mentioned if they form part of the methodologies; however they are not the focus of this work.

A brief history of LCIA

The first impact assessment methodologies for Life Cycle Assessment, termed Life Cycle Impact Assessment methodologies,[2] can be traced back to before 1992:

- the EPS (Environmental Priority Strategies) methodology based on endpoint modelling expressing results in monetary values,
- Swiss Ecoscarcity (or Ecopoints) based on the distance to target principle,
- the CML 1992 (Dutch guidelines) methodology based on midpoint modelling.

These three methodologies formed the basis for three main schools that were further developed, and also today there are many LCA practitioners that belong to one of the three schools of thought.

Since the early nineties many attempts have been made to harmonise approaches. This is partly to avoid having several methodologies which provide potentially different results (depending on the methodology chosen). This has created confusion and criticism of the use of LCIA and LCA in general. The ISO 14042 standard on impact assessment published in 1999, now part of ISO 14044, brought some standardization on basic principles. However, this still allows for many different LCIA methods to be ISO compatible.

As the ISO process did not bring detailed standardisation, the SETAC working groups and recommendations, later followed by UNEP-SETAC task forces, started to work on a recommended best practice. These activities have resulted in a relatively broad consensus on the best approaches, the underlying principles, and in some cases the models (see, for example, Udo de Haes *et al.,* 2002) but they have not resulted in a uniform, globally accepted set of LCIA methods. The most promising results so far are:

- Consensus on the need to merge midpoint and endpoint models in a consistent framework to combine the advantages of both concepts (Bare *et al.,* 1999, 2000). For example, midpoint indicators for climate change, in terms of CO_2 equivalents, and endpoint indicators. in terms of impacts on ecosystems, in one consistent framework.
- A generic set of quality criteria for assessing different methods, and the application of these criteria on the most widely used impact assessment methods (Udo de Haes *et al.,* 2002, Margni *et al.,* 2007).
- Several additional and specific quality criteria for a number of impact categories.
- Greater consensus, but also the identification of disagreements, on methods.
- A growing global consensus among developers of models generally used in LCA at this time for e.g. toxicological effects (fate, exposure and effect) (Hauschild *et al.,* 2007, Rosenbaum *et al.,* 2007).

The International Reference Life Cycle Data System (ILCD) is being developed to help support the availability, exchange and use of coherent and quality-assured life cycle data, methods and studies for reliable decision support in public policy and business. In this setting, a project was launched to develop recommendations on a coherent and consistent Life Cycle Impact Assessment methodology (framework, characterisation models, and characterisation factors) based on an analysis of existing characterisation models to identify best practices, and to identify research needs due to insufficiencies in the existing methods.

[2] Throughout this document an “LCIA methodology” refers to a collection of individual characterisation “models” or characterisation “methods”, which together address the different impact categories, which are covered by the methodology. “Method” is thus the individual characterisation model while “methodology” is the collection of methods.

The focus is on characterisation while the steps normalisation and weighting are not part of the project so that the scope of the project is kept at a limited and manageable level. Recognising that most product systems in many life cycle assessments include activities at a global scale, the recommendations should aim for a global validity first, with additional emission scenario distinctions (e.g. for regions such as Europe) where this is scientifically justified. The recommendations shall address both a midpoint and an endpoint level (Area of Protection, AoP) in the environmental mechanism in a consistent framework.

The first activity is to identify the different characterisation models used by each LCIA methodology in the characterisation of impact categories and areas of protection. This constitutes an input to a detailed analysis of each impact category and AoP that has been conducted as a next step (not addressed in this report).

From the analysis of the methodologies, a pre-selection of impact categories was made, based on a number of criteria. This was done in order to avoid double work, as many method's underlying characterisation factors are very similar in different LCIA methodologies. The criteria applied to exclude a method were:

- If a method is used in multiple LCIA methodologies, only the most recent and up to date version of that method is considered, taking into account also the broadness/completeness of elementary flows included.
- If a method is used that is adapted to other regions, but the method itself is not improved or changed in any significant way, this method is excluded from the further analysis.

Similarities and differences between methods are highlighted as several LCIA methodologies apply essentially the same principles or minor variations for given impact categories. As the detailed analysis of impact categories and their characterisation models is carried out later, the analysis of the LCIA methodologies in this report is concentrated on the overall principles, the consistency across impact categories, and interesting "innovative" aspects they may have.

In order to identify candidates for a recommended practice among existing characterisation models, a first screening analysis was performed of a wide range of existing and frequently used Life Cycle Impact Assessment methodologies:

- CML 2002 (Guinée *et al.,* 2002)
- Eco-Indicator 99 (Goedkoop and Spriensma, 2000)
- EDIP (1997-2003) (Wenzel *et al.,*1997, Hauschild and Wenzel, 1998, Hauschild and Potting, 2005, Potting and Hauschild, 2005)
- EPS2000 (Steen, 1999a,b)
- Impact 2002+ (Crettaz *et al.,* 2002, Jolliet *et al.,* 2004, Payet, 2004, Pennington *et al.,* 2005, Pennington *et al.,* 2006, Rochat *et al.,* 2006, Rosenbaum, 2006, Rosenbaum *et al.,* 2007a)
- LIME (Itsubo *et al.,* 2004, Hayashi *et al.,* 2000, Hayashi *et al.,* 2004, Hayashi *et al.,* 2006)
- LUCAS (Toffoletto *et al.,* 2007)
- ReCiPe (De Schryver *et al.,* 2007, Huijbregts *et al.,* 2005a,b, Struijs *et al.,* 2007, Van Zelm *et al.,* 2007a-d, Wegener Sleeswijk *et al.,* 2008)

- Swiss Ecoscarcity or Ecological scarcity (Brand *et al.,* 1998, Müller-Wenk, 1994, Ahbe *et al.,* 1990, Frischknecht, 2006a,b)
- TRACI (Bare, 2002, Bare *et al.,* 2003, Hertwich *et al.,* 1997, Hertwich *et al.,* 1998, Hertwich *et al.,* 1999, Hertwich *et al.,* 2001, Norris, 2002)
- MEEuP methodology (Kemna *et al.,* 2005)

In addition, a limited number of models, which are not part of formal LCIA methodologies, but which have interesting features to consider in the development of recommendations, are also included in the analysis. The present report describes the results of the analysis of the LCIA methodologies.

The analysis leads to a pre-selection of characterisation models for the individual impact categories that are currently in use and appropriate for use in the context of life cycle assessments; see Table 1.

These can be evaluated against a set of pre-defined criteria with the aim of identifying a recommendation for each impact category and Area of Protection. However, this does not form part of this document.

It is acknowledged that many models exist for the assessment of impacts associated with emissions and the consumption of resources. This document focuses primarily on those already selected to be fit-for-purpose in the context of LCA, having sometimes been modified, and hence being included in available LCIA methodologies. The objective was to evaluate those models which were identified as most relevant for current and best practise in LCA. It also has to be noted that the analysis was not focused on models and approaches related to normalisation and weighting, although those steps have been taken into account if they were included in existing methods.

In some cases, there may be other, equally applicable and more robust, models available than in current use in the context of LCA. However, the ability to assess this potential and to integrate these for use in the LCA context is beyond the scope of this document, which focuses on initial evaluation of current practice in LCA. Future developments can then concentrate on improving these findings.

Table 1 Pre-selection of characterisation models for further analysis [3]

	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity[4]	Ionising radiation	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication.	Land use	Resource Consumption	Others
CML2002	O	o		M	o[5]	o	M	M	M	M	o	M	
Eco-indicator 99	E	E	E	o	o		E	E	E		E	E	
EDIP 2003/EDIP97[6]	O	M	o	M	o	M	M	M	M	M		M	Work environ-ment Road noise
EPS 2000	E	E	E	E	o	E	E	o	o	o	E	E	
Impact 2002+	O	o	E	M E	o	M E	E	M E		M E	o	E	
LIME	E	E	M	E		o	M E	M E	o	E	E	E	Indoor air
LUCAS	O	o		o		o	o	o	o	o	o	o	
MEEuP	O	o	M	M		M	M	M	M	M		water	
ReCiPe	M E	E	M E	M E	o	M E	M E	M E	o	M E	M E	E	
Swiss Ecoscarcity 07	O	o	o	o	M E	M	o	o	o	o	M E	water	Endo-crine disrupt-tors
TRACI	O	o	M	M		M	M	M	o	M		o	
Specific methods to be evaluated	Ecological footprint		[7]	USETox		USETox		Seppälä		Payet	Ecological footprint	deWulf et al.	Noise Müller Wenk
Specific methods of potential interest (not to be evaluated)				Watson (Bachmann)	Ecotoxicity of radiation (Laplace et al.)		EcoSense (Krewitt et al.)	EcoSense (Krewitt et al.)		Kärrman & Jönsson	[8]		Meijer indoor air UNEP Indoor air (Bruzzi et al., 2007)

o: Available in the methodology, but not further investigated
M: Midpoint model available and further analysed;
E: Endpoint model available and further analysed

[3] It has to be noted, that not all existing methods used in LCIA could be covered in the analysis but the focus has been on the ones which were identified as most relevant for current best practise in LCA.
[4] Cancer and non cancer effects sometimes taken separately
[5] Optional study specific impact category
[6] EDIP97 for resources, EDIP2003 for the other impact categories
[7] EcoSense, Greco et al., UNEP (Potting et al.)
[8] Bos & Wittstock, 2007, Ertzinger, Milà i Canals, Stan Rhodes

2 Analysis of the impact assessment methodologies

For the identification and description of potentially interesting LCIA methodologies and methods the following procedure was adopted:

1. Develop a standard format for description of the currently available LCIA methodologies (see Chapter 3.1).
2. Describe each methodology based on available documentation (methodology reports and other sources, e.g. journal papers and conference presentations).
3. Contact methodology developers asking for validation of the description.

Chapter 3 contains summary descriptions of the currently available Life Cycle Impact Assessment methodologies that are selected to be used as a basis for the project. The existing methods are used as a “raw material” for selecting recommended characterisation factors in a next step. Further information about the LCIA methodologies are summarised in Annex 1. In Chapter 4, the list is supplemented by a number of potentially interesting methods and concepts that are not available in these methodologies.

An important goal of this report is to document the pre-selection of impact categories, and characterisation models that deserve special attention in the further analysis and development of recommendations.

The main focus is on describing characterisation methodologies that are used to determine characterisation factors. Normalisation and weighting are also briefly mentioned, but these steps are not within the scope of this document.

2.1 Standard format for description of the methodologies

For the description of the methods, a standard format was used containing the following elements:

- Name of the methodology
- Short description of the methodology
- Source of methodology documentation
  - References, website, methodology contact persons
- General principles summarised in tabular form:

Principle	Comment
Intended purpose of the methodology:	
Midpoint/endpoint:	
Handling of choices:	
Data uncertainties:	
Regional validity:	
Temporal validity :	

Time horizon:	
How is consistency ensured in the treatment of different impacts - In characterisation - In normalisation and weighting	
Midpoint impacts covered:	
Endpoint impacts covered:	
Approximate number of substances covered:	
Other observations:	

- Normalisation and weighting

How normalisation is performed	
How weighting is performed	

- Interesting (unique) features

Here the focus is on unique features, which could be especially relevant not only for the research recommendations, but also for a better understanding of the reasons behind the selection of characterisation methods.

- Interesting impact categories

This is by far the most important section highlighting methods (characterisation models for individual impact categories under the methodology) which are seen as candidates for further evaluation.

- Graphical representation

As far as available, a flowchart of the structure of the methodology is inserted for illustrative purposes.

2.2 Additional methods

Next to the existing LCIA methodologies identified, a number of methods were added that are available in the scientific literature, and which might have an interesting potential for applications to LCIA. In Annex 1 these are briefly mentioned. Not all of these methods will indeed be further analysed, as not all of them seem to be either available in full detail, or sufficiently developed at this time to be used as a characterisation method. These methods were selected after reaching consensus in the project team based on the available knowledge.

2.3 Observations on the analysis of LCIA methodologies

It is very difficult to summarise a methodology in a few pages, without doing injustice to the amount of detail the method developers put in and what was taken into account during the development. The overview is thus coarse by definition, while generally the main advantages and limitations can be highlighted.

Another issue is the differences in background information on the methods available for the analysis.

This analysis was conducted with the support of a consortium of organisations that are as well main developers of the existing methodologies: CML 2002, Eco-indicator 99, EDIP, Impact 2002 and the ReCiPe method. This means that, in addition to publicly available documentation, detailed information was available first-hand. For the other methods, the analysis has been conducted based on contacts with method developers including advisory groups, conference presentations and the methodology reports. However, for completeness of information and to check the resulting descriptions, all method developers were consulted and asked to provide their comments.

3 Description of LCIA methodologies

This chapter contains summary descriptions of the currently available Life Cycle Impact Assessment methodologies selected. Chapter 4.12 lists potentially interesting methods that are not available in the investigated methodologies.

An important goal of this document is the selection of impact categories that deserve special attention in the further development. An inventory of interesting approaches, concepts etc. outside existing LCIA methodologies was therefore also made.

The main focus is on describing characterisation methodologies that are used to determine characterisation factors. Normalisation and weighting are also briefly mentioned, but the scope of this project does not include the provision of recommendations for these two steps. The table below identifies the methodologies analysed.

Table 2 Analysed LCIA methodologies

Methodology	**Developed by**	**Country of origin**
CML2002	CML	Netherlands
Eco-indicator 99	PRé	Netherlands
EDIP97 – EDIP2003	DTU	Denmark
EPS 2000	IVL	Sweden
Impact 2002+	EPFL	Switzerland
LIME	AIST	Japan
LUCAS	CIRAIG	Canada
ReCiPe	RUN + PRé + CML + RIVM	Netherlands
Swiss Ecoscarcity 07	E2+ ESU-services	Switzerland
TRACI	US EPA	USA
MEEuP	VhK	Netherlands

From the analysis, a pre-selection of impact categories has been made, based on a number of criteria.

The criteria applied to exclude a model were:

- If the same characterisation model is used in multiple LCIA methodologies, only the most recent and up to date version of that model is considered.
- If a characterisation model is used in versions adapted to different geographical regions, but the model itself is not improved or changed in any significant way, only the original version of the method is included.

Next to this, a number of interesting approaches were found that were not in one of the selected LCIA methodologies, but which will be included in the analysis as well. These add another 13 methods to be analysed and another 12 methods to be described in a generic way, especially in the light of making research recommendations.

3.1 CML 2002

The CML 2002 LCA Handbook (Guinée et al., 2002) is a follow up of the CML 1992 LCA Guide & Backgrounds (Heijungs et al., 1992). It aims to provide best practice for midpoint indicators, operationalising the ISO14040 series of Standards. It includes recommended methods for normalization but no recommended methods for weighting.

3.1.1 Source of methodology documentation

Guinée et al. 2002.

Website: http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

Methodology contact persons: Jeroen Guinée & Reinout Heijungs (CML)

3.1.2 General principles

Table 3 General principles of CML 2002 methodology (see also Figure 1)

Principle	**Comment**
Intended purpose of the methodology:	Providing best practice for midpoint indicators operationalising the ISO14040 series of Standards, as follow up of Heijungs et al., 1992.
Midpoint/endpoint:	Midpoint
Handling of choices:	In Guinée et al. (2002), a full chapter has been dedicated to the general foundations of LCA as have been adopted in the elaboration of this Handbook on LCA. All kinds of modelling aspects have been discussed and choices have been made in a mutually consistent way with respect to handling of time, space, non-linearities, economic/social/technological mechanisms, etc.
Data uncertainties:	Data uncertainties are discussed in the text but not quantified.
Regional validity:	Global, except for acidification (Europe) and photo-oxidant formation (European trajectory).
Temporal validity :	Present
Time horizon:	Infinity, except for GWP where the GWP100 is adopted instead of the GWP500 because of the large uncertainties attached to the GWP500, and for the modelling toxic effects of metals where it is recommended to perform a standard sensitivity analysis for shorter time horizons because of the uncertainties attached to metal modelling. As extensions (sensitivity analyses) different time horizons can be adopted for various impact categories.
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	For all emission based categories similar principles and choices are used with respect to e.g. handling of time, space, non-linearities. For each indicator separate normalisation factors are calculated using the same basic normalisation data; spreadsheet available for update and other new calculations.

<table>
<tr><th>Principle</th><th>Comment</th></tr>
<tr><td>Midpoint impacts covered:</td><td>Overview of baseline and other impact categories in relation to the availability of baseline characterisation methods.
<table>
<tr><th>Impact category</th><th>Single baseline characterisation method available in the Guide?</th><th>Other characterisation method(s) available in the Guide?</th></tr>
<tr><td colspan="3">A. Baseline impact categories (all studies)</td></tr>
<tr><td>Depletion of abiotic resources</td><td>Yes</td><td>yes</td></tr>
<tr><td colspan="3">Impacts of land use</td></tr>
<tr><td>land competition</td><td>Yes</td><td>yes</td></tr>
<tr><td>Climate change</td><td>Yes</td><td>yes</td></tr>
<tr><td>Stratospheric ozone depletion</td><td>Yes</td><td>yes</td></tr>
<tr><td>Human toxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td colspan="3">Ecotoxicity</td></tr>
<tr><td>freshwater aquatic ecotoxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td>marine aquatic ecotoxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td>terrestrial ecotoxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td>Photo-oxidant formation</td><td>Yes</td><td>yes</td></tr>
<tr><td>Acidification</td><td>Yes</td><td>yes</td></tr>
<tr><td>Eutrophication</td><td>Yes</td><td>yes</td></tr>
<tr><td colspan="3">B. Additional impact categories (dependent on study requirements)</td></tr>
<tr><td colspan="3">Impacts of land use</td></tr>
<tr><td>loss of life support function</td><td>No</td><td>yes</td></tr>
<tr><td>loss of biodiversity</td><td>No</td><td>yes</td></tr>
<tr><td colspan="3">Ecotoxicity</td></tr>
<tr><td>freshwater sediment ecotoxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td>marine sediment ecotoxicity</td><td>Yes</td><td>yes</td></tr>
<tr><td>Impacts of ionising radiation</td><td>Yes</td><td>yes</td></tr>
</table>
</td></tr>
</table>

Principle	Comment		
	Odour		
	malodorous air	Yes	no
	Noise	Yes	no
	Waste heat	Yes	no
	Casualties	Yes	no
	lethal	Yes	no
	non-lethal	No	no
	Depletion of biotic resources	No	yes
	Desiccation	No	no
	Odour		
	malodorous water	No	no
Endpoint impacts covered:	Relations of midpoints with endpoints are discussed (see e.g. figure below) but not modelled or otherwise quantified.		
Approximate number of substances covered:	Approximately 800 substances, often with characterisation factors for more than one impact category, or more than one compartment within an impact category.		
Other observations:	The results of the characterisation and normalisation steps require reporting of the calculated values for the selected impact categories, as well as information on interventions not included in the model and economic flows not followed to the system boundary, and additional qualitative information.		

3.1.3 Normalisation and weighting

Table 4 Normalisation and weighting in CML 2002

How normalisation is performed?	Baseline global normalisation factors available for 1990 and 1995 as aggregate annual world interventions or per capita as the annual interventions of an ‘average world citizen’. Background spreadsheet available so that normalisation factors can be adapted for other methods than baseline methods and for new data developments. Similar normalisation factors for the Netherlands and West-Europe are available for ‘extensions’ (sensitivity analyses). Main data sources used to calculate the normalisation factors are provided in Van Oers et al 2001 and in a downloadable spreadsheet: http://www.leidenuniv.nl/cml/ssp/databases/index.html
How weighting is performed?	Weighting is an optional step in LCA, for which no baseline method is proposed.

3.1.4 Interesting (unique) features

- Explicit scientific foundations consistently support all important choices made.
- Alternative LCIA factors provided for sensitivity analyses for each impact category.

- All LCIA factors downloadable as spreadsheet, which is regularly updated.
- Distinction between baseline, study-specific and other impact categories.
- Most impact categories have been described in peer reviewed papers.
- Principles for LCIA developed along with principles for the other elements of LCA methodology (like functional unit, allocation, etc.) in a consistent way with respect to handling of time, space, non-linearities, economic/social/technological mechanisms, etc.

3.1.5 Impact categories pre-selected for further evaluation

- Human toxicity
- Acidification
- Terrestrial and Aquatic Eutrophication
- Ozone formation
- Resources

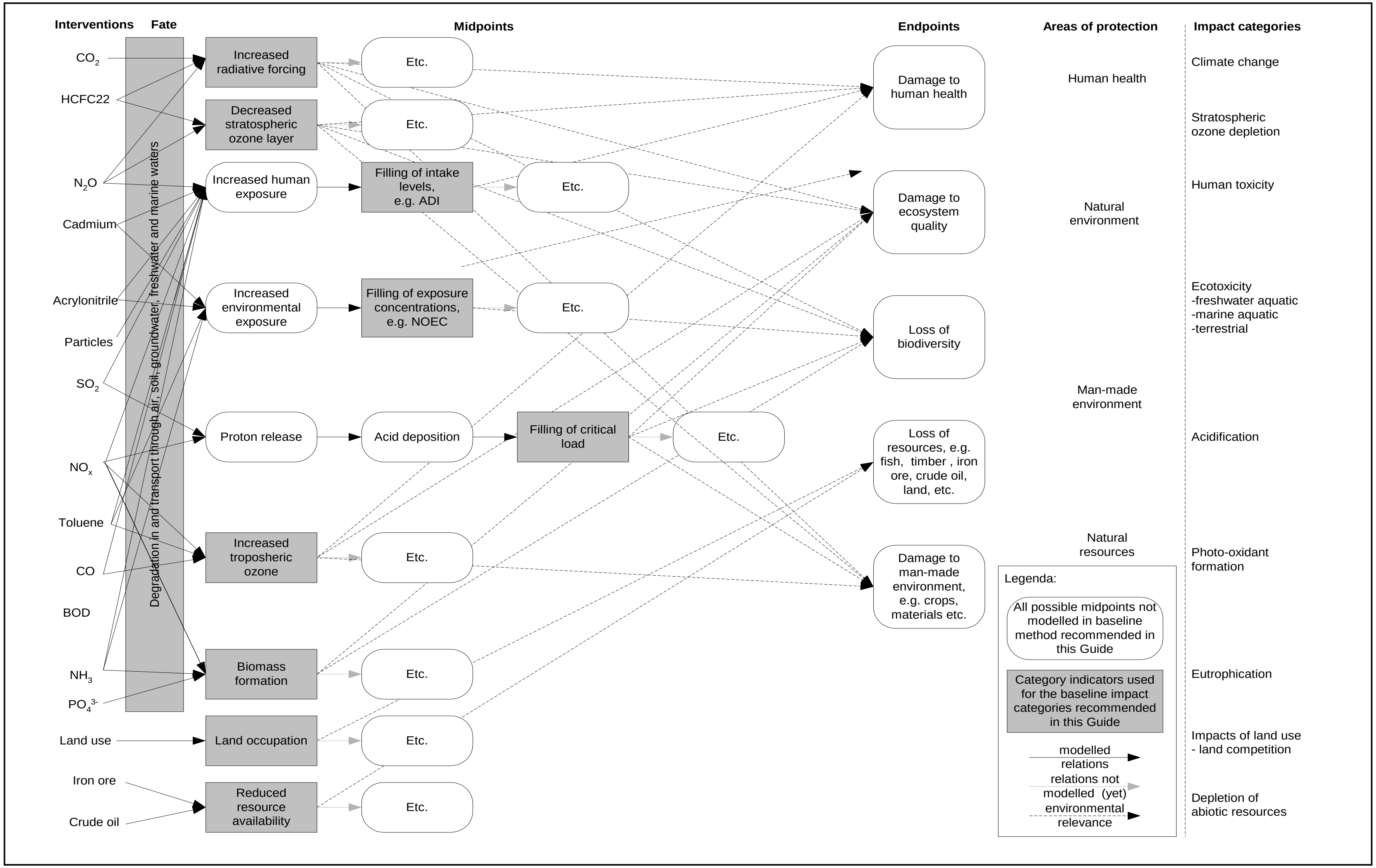

Figure 1 **Impact categories and pathways covered by the CML methodology**

3.2 Eco-indicator 99

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, but it is also used as a general purpose impact assessment method in LCA. 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. At the time of publication it contained several new principles, such as the use of the damage approach, and the use of three perspectives as a way to deal with subjective choices on endpoint level (hierarchist, individualist, and egalitarian).

3.2.1 Source of methodology documentation

Goedkoop and Spriensma, 2000.

Website: www.pre.nl/eco-indicator99

Methodology contact person: Mark Goedkoop

3.2.2 General principles

Table 5 General principles of Eco-Indicator 99 methodology (see also Figure 2)

Principle	**Comment**
Intended purpose of the methodology:	Developing of an endpoint method that can be used in any LCA, with special attention given to the facilitation of panel weighting
Midpoint/endpoint:	Endpoint method; midpoints are not separated
Handling of choices:	Three perspectives each with a consistent set of value choices, are used to specify three versions of the method
Data uncertainties:	Quantified for human health impacts and ecotoxicity, and described qualitatively for other impact categories
Regional validity:	Global impact categories for climate, ozone depletion and resources. European model for other impact categories: All emissions are assumed to take place in Europe. Damage occurring outside Europe is also considered while using the European impact situation, if atmospheric lifetime is long (some toxic substances, some radioactive substances etc. Acidification/eutrophication based on Dutch model, land-use based on Swiss model
Temporal validity :	Present
Time horizon:	Short (approx 100 year) for individualist perspective, long/indefinite for other perspectives
How is consistency ensured in the treatment of different impacts In characterisation	All environmental mechanisms are marginal. The three perspectives ensure high consistency of choices in all models, within a perspective. The use of just three impact category indicators also forces harmonisation in models. Normalisation is not done per impact category, but per area

Principle	Comment
In normalisation and weighting?	of protection; normalisation factors are calculated using the same method. Weighting is to be performed by a panel; default values are provided
Midpoint impacts covered:	Climate change (38) Ozone layer depletion (24) Acidification/Eutrophication (combined) (3) Carcinogenic (61) Respiratory organic (11) Respiratory inorganic (121) Ionizing radiation (48) Ecotoxicity (52) Land-use (12) Mineral resources (12) Fossil resources (9)
Endpoint impacts covered:	Human health, ecosystem quality and resource depletion
Approximate number of substances covered:	Approximately 391, depending on the perspective
Other observations:	Method is being followed-up by the ReCiPe method, which integrates with the CML 2002 method

3.2.3 Normalisation and weighting

Table 6 Normalisation and weighting in Eco-Indicator 99

How is normalisation performed?	European normalisation data are calculated with the method for each area of protection (damage category)
How is weighting performed?	Three options: 1 Panel method is used for default weights 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

3.2.4 Interesting (unique) features

- The use of three perspectives to create three consistent set of subjective choices regarding for instance the applied time perspective, significance of manageability, role of future technology development and the required level of proof of cause-effect mechanisms, is an important facilitator in endpoint modelling.
- The consistent use in a fully integrated approach of the same category indicator result unit for all impact categories resulting in damage to human health, or ecosystems or recourses respectively.

- The avoidance of double counting in the land-use category with ecotoxicity and eutrophication (observed data and model data are difficult to combine).
- The normalisation step is based on the endpoint indicators.

3.2.5 Impact categories pre-selected for further evaluation

- Land-use (based on the work of Köllner). Although this approach has been updated in the ReCiPe method, it might still be interesting, as it is a method that is easier to communicate.
- Mineral resource depletion (based on the work of Müller Wenk, uses surplus energy concept). The reason why it is interesting is that it does not apply the use to stock ratio, but has a marginal damage approach, starting with what can be seen as an inverse of the fate step (the decrease of concentration due to an extraction).
- Respiratory in-organics and organics as a separate impact category (based on Hofstetter), although this method has been updated in the ReCiPe approach, it has the benefit of being relatively straightforward.
- The combination of eutrophication and acidification on the endpoint level.
- Ozone layer depletion.
- Climate change, as it takes into account damages on different time scales.

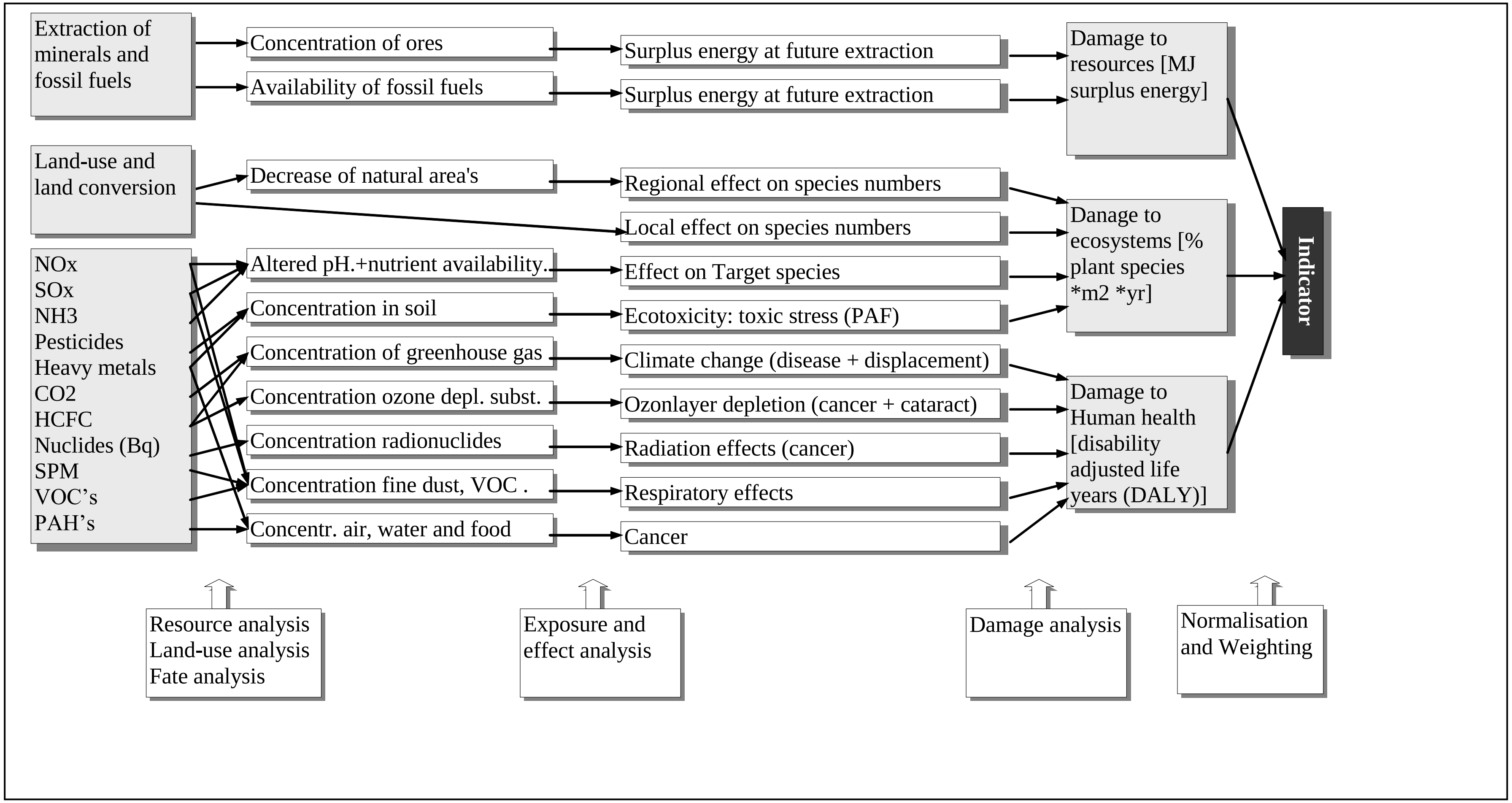

Figure 2 **Impact categories and pathways covered by the Eco-indicator 99 methodology**

3.3 EDIP97 and EDIP2003

The LCIA part of EDIP97 supports the classic emission-related impact categories at a midpoint level as well as resources and working environment. The EDIP97 LCIA method includes normalisation and weighting of environmental impacts based on political environmental targets. EDIP2003 is a follow up on the EDIP97 methodology with inclusion of exposure assessment based on regional information in the Life Cycle Impact Assessment of non-global emission-related impact categories at midpoint (photochemical ozone formation, acidification, eutrophication, ecotoxicity, human toxicity, noise). For the global impact categories, update of the EDIP97 factors is provided. The EDIP2003 methodology provides factors for normalization but not weighting. Resources are only covered in EDIP97.

3.3.1 Source of methodology documentation

EDIP97

Wenzel et al.,1997, Hauschild and Wenzel, 1998, Stranddorf et al., 2005, Hauschild et al., 2007.

Website:
http://www.dtu.dk/English/Service/Phonebook.aspx?lg=showcommon&id=166960

EDIP2003

Hauschild and Potting, 2005, Potting and Hauschild, 2005.

Website:
http://www.man.dtu.dk/English/Research/Orbit_IPL.aspx?lg=showcommon&id=177668

Methodology contact person: Michael Hauschild

3.3.2 General principles

Table 7 General principles of EDIP97 and EDIP2003 methodologies (see also Figure 3)

Principle	Comment, EDIP97	Comment, EDIP2003
Intended purpose of the methodology:	Supporting LCA of industrial products to support environmental analysis and synthesis in product development covering the three areas: Environment, resources and working environment	Providing spatially differentiated characterisation factors for the non-global emission-related impact categories and noise as follow up of EDIP97
Midpoint/endpoint:	Midpoint	Midpoint, but late in impact pathway (good basis for damage estimation)
Handling of choices:	Best estimate aimed for in impact modelling, infinite time horizon in integration of impacts, linearity generally assumed.	
Data uncertainties:	Not addressed	Uncertainties associated with spatial variation in site-generic factors (European average) are quantified. Uncertainties of applied

Principle	Comment, EDIP97	Comment, EDIP2003
		site-dependent models and their parameters are discussed in relation to the obtained reductions in spatially determined variation, and used as foundation of recommendations as to whether spatial differentiation is justified.
Regional validity:	Global	Europe (factors for up to 44 regions or countries within Europe as well as a European average value). Global for global impact categories.
Temporal validity :	Present time	Factors provided based on past emission inventories and future (2010) emission forecasts for some of the impact categories (acidification, photochemical ozone and terrestrial eutrophication)
Time horizon:	Long	Infinity
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	For all emission-based categories similar principles and choices are used. For each indicator separate normalisation factors are calculated using the same basic normalisation data.	For all emission-based categories similar principles and choices are used. For each indicator separate normalisation factors are calculated using the same basic normalisation data; spreadsheet available for update and other new calculations.
Midpoint impacts covered:	Global warming Ozone depletion Acidification Nutrient enrichment Photochemical ozone formation Human toxicity (four sub categories) Ecotoxicity (four sub categories) Resources Working environment (Seven categories: Monotonous repetitive work, noise, accidents, Cancer, Reprotoxic damage, allergy and Neurotoxic damage due to occupational exposure to chemicals)	Global warming Ozone depletion Acidification Terrestrial eutrophication Aquatic eutrophication Photochemical ozone formation Human toxicity Ecotoxicity Noise
Endpoint impacts covered:	None (although working environment impacts are presented as incidences of disease or death)	None
Approximate number of substances covered:	Approximately 500 substances, often with characterisation factors for	Approximately 500 substances often with characterisation factors

Principle	Comment, EDIP97	Comment, EDIP2003
	more than one impact category, or more than one compartment within an impact category.	for more than one impact category, or more than one compartment within an impact category.
Other observations:	Method is followed up by EDIP2003 as a spatially differentiated alternative, not as a replacement.	Method is seen as spatially differentiated alternative to EDIP97, not as a replacement.

3.3.3 Normalisation and weighting

Table 8 Normalisation and weighting in EDIP97 and EDIP2003

Principle	Comment, EDIP97	Comment, EDIP2003
How is normalisation performed?	EDIP97 normalisation factors for world (global impacts) or Europe (regional impacts) available for 1994 as annual impact scores for an average citizen for all impact categories. Also global and national normalization references for a number of European countries are available (Stranddorf et al., 2005). Background spreadsheet available so that normalisation factors can be adapted for new data developments.	EDIP2003 Normalisation factors for Europe available for 1995 as annual impact scores for an average citizen for all impact categories. Background spreadsheet available so that normalisation factors can be adapted for new data developments.
How is weighting performed?	Weighting of environmental impacts applying distance to political targets (only binding targets).	No specific weighting developed for EDIP2003. As a default, the weighting factors from EDIP97 are recommended (distance to political targets).

3.3.4 Interesting (unique) features

EDIP97

- Global warming has characterisation factors for all VOCs of petrochemical origin.
- Ozone depletion characterisation factors for shorter time horizons (5 and 20 years) of potential relevance since the main issue with the stratospheric ozone depletion will be within the next decades due to the accomplished abolishing of all CFCs and HCFCs.
- Working environment quite unique.
- External peer review of all characterisation models.

EDIP2003

- Site-dependent characterisation factors for 40+ European regions and compatible site-generic characterisation factors based on weighted European average supporting application on entire life cycle.
- Several impact categories have been described in peer reviewed papers.

3.3.5 Impact categories pre-selected for further evaluation

EDIP97

- Photochemical ozone formation has weighted average POCP values for mixed VOC emissions from typical sources. Regression equations for estimation of missing POCP values based on k_{OH} rate constants.
- Abiotic resources weighted using scarcity (supply horizons), expressed as “Person reserves”, biotic resources which are over-exploited (use exceeds regeneration) weighted in the same way.
- Work environment.

EDIP2003

- Ozone layer depletion at midpoint level, as this seems to be the most recent implementation of the WMO equivalency factors.
- Stored ecotoxicity and stored human toxicity proposed as an approach to handling the long term emissions from landfills of metals and POPs (Hauschild et al., 2007).
- Acidification, terrestrial/aquatic eutrophication and photochemical ozone formation have spatially differentiated and time dependent characterisation factors and quantification of spatially determined standard deviation of site generic average factors. Photochemical ozone formation also includes contribution from NO_x emissions.
- Spatially differentiated exposure factors for Aquatic Eutrophication, Human toxicity and Ecotoxicity to be combined with site-generic characterisation factors (e.g. EDIP97).
- Methodology for calculation of characterisation factors for Noise nuisance from transportation.

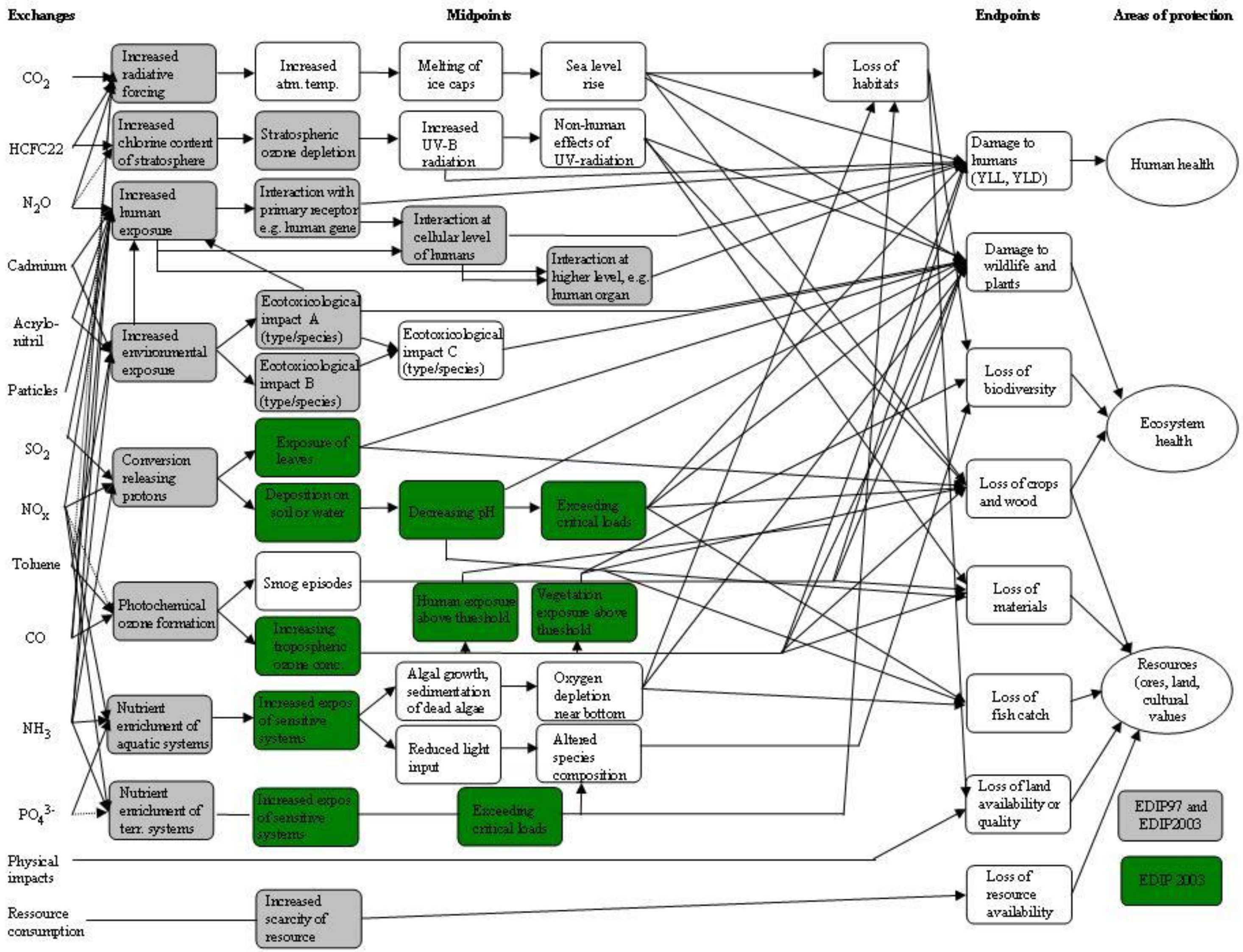

Figure 3 **Impact categories and pathways covered by the EDIP methodology.**

3.4 EPS 2000

EPS was first developed in 1990 to assist designers and product developers. The latest update took place in 2000. The method has a midpoint-endpoint structure like LIME. Especially in the beginning it was way ahead of its time; it was the first endpoint based model, the first model that used monetisation and the first model that has the uncertainties fully specified. The method is designed to be used with Monte Carlo analysis, as it is an integral part of the reasoning behind the method. Environmental mechanisms that are uncertain are included and not left out as happens in other methods. It produces category indicators at damage level expressed in monetary units, that can be added to compute a single score if desired. The monetary unit is derived on the basis of the Willingness To Pay (WTP).

3.4.1 Source of methodology documentation

Steen, 1999a, Steen, 1999b.

Website http://eps.esa.chalmers.se/ and http://www.cpm.chalmers.se/

Methodology contact person: Bengt Steen

3.4.2 General principles

Table 9 General principles of EPS 2000 methodology

Principle	**Comment**
Intended purpose of the method:	Assist designers and product developers in decision support
Midpoint/endpoint:	Endpoint characterisation factors are calculated based on the mean effect and the precautionary principle. Damage assessment is performed using WTP.
Handling of choices:	Precautionary principle is used throughout the method, if a mechanism is uncertain, a most likely case assumption is used, but also the uncertainty is clearly defined. In a Monte Carlo analysis where two product alternatives are compared, the importance of the uncertainty is evaluated, in order to determine if there is enough certainty to distinguish between product alternatives
Data uncertainties:	Data uncertainties are discussed in the text and clearly stated for each characterisation factor, and often also per step in the environmental mechanism. As environmental mechanisms are often specified per individual substances, the amount of detail is high.
Regional validity:	A clear majority of the models are global. Impacts on biodiversity and its values are the most significant exception. In these cases Swedish models are used.
Temporal validity :	The impact assessment is for present time emissions and resource extractions, but the models estimate effects as long as they exist
Time horizon:	In general a very long (indefinite or near to indefinite) time perspective is used
How is consistency ensured in the treatment of different impacts	All impact categories are modelled using similar starting points, and in all models the precautionary principle is used (meaning that impacts are included at an early stage of recognition and that no new

Principle	Comment
In characterisation In normalisation and weighting?	inventions lowering the damage values of future impacts may be assumed). All impact categories of the same area of protection have the same indicator unit. In this method monetisation is applied, which means normalisation is not used. Different types of costs (future mining costs, willingness to pay, willingness to avoid, YOLLs or protection of rare species are added without further explicit weighting (which has been criticised, as many weighting solutions are criticised)
Midpoint impacts covered:	Human health [Pers.yr]; Life expectancy; Severe morbidity and suffering; Morbidity; Severe nuisance; Nuisance Natural environment [kg] ; Crop production capacity ; Wood production capacity ; Fish and meat production capacity; Base Cation capacity [H+]; Production capacity for water (drinking water); Share of species extinction [NEX] Natural resources [kg]; Depletion of element reserves (element) Depletion of fossil reserves (Gas); Depletion of fossil reserves (Oil) Depletion of fossil reserves (Coal); Depletion of mineral reserves (ore)
Endpoint impacts covered:	Human health; Ecosystem production; Biodiversity; Abiotic Stock resource
Approximate number of substances covered:	Approximately 200 substances
Other observations:	Uncertainty is specified. The EPS method was the first endpoint method (1990)

3.4.3 Normalisation and weighting

Table 10 Normalisation and weighting in EPS 2000

How is normalisation preformed?	No normalisation; not needed in monetisation approaches
How is weighting performed?	All category indicators are expressed in monetary terms, based on willingness to pay to avoid negative changes in indicator values. The methods used to estimate WTP vary from CVM, revealed preferences and restoration costs. The uncertainty in quantifying WTP is estimated.

3.4.4 Interesting (unique) features

- Complex pathways, direct and most indirect effects are covered, which makes the method quite complete for the covered impacts and substances.
- Consistent mean approach: mean observed damage levels are related to the stressor level, from that a damage factor is estimated. This results in sometimes rough estimates, but these are deemed acceptable as long as the uncertainty involved is estimated.

- Business as usual is the default scenario for future technology results in a relatively high damage factor for resource depletion (in future minerals are extracted from average rock with present day technology).
- Five areas of protection are considered: human health, ecosystem production capacity, abiotic stock resources, biodiversity and cultural and recreational values. For the last area of protection, no general indicators are produced.
- Ecosystem damage includes effects on crop, wood, fish and meat production, as well as base cat-ion capacity of the soil and water as local source.
- All effects are calculated per substance, which is more precise than using the umbrella principle (Except for global warming, where IPCC equivalency factors are used).
- High altitude emissions from aircrafts are included.

3.4.5 Impact categories pre-selected for further evaluation

- Effect of climate change on crop and wood production, as well on species disappearance.
- Indirect pathway of climate change on plant growth through increased soil mineralization.
- Effect of smog forming on the visibility.
- Direct effects of CO on human health, as toxic gas.
- Ozone formation.
- Resources.
- High altitude emissions from aircrafts.
- Noise is included (although is a coarse way).

3.5 IMPACT 2002+

The IMPACT 2002+ Life Cycle Impact Assessment methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of Life Cycle Inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories.

For IMPACT 2002+ new concepts and methods have been developed, building on existing approaches to ensure they better fit the comparative scope of LCIA, especially for the comparative assessment of human toxicity and eco-toxicity. Human Damage Factors are calculated for carcinogens and non-carcinogens, employing intake fractions, best estimates of dose-response slope factors, as well as severities. The transfer of contaminants into the human food is no more based on consumption surveys reflecting a subsistence exposure scenario, but accounts for agricultural and livestock production levels in the region of exposure that are subsequently consumed elsewhere. For aquatic ecotoxicology, characterisation factors are based on the *mean* response of species – the geometric mean of available effect concentration 50%, providing a more suited measure for comparative assessment than the EC50s of the most sensitive species.

Collaboration was conducted with the developers of the LIME method, and other midpoint categories are adapted from existing characterizing methods (Eco-indicator 99 and CML 2002). All midpoint scores are expressed in units of a reference substance and related to the four damage categories: human health, ecosystem quality, climate change, and resources. Normalization can be performed either at midpoint or at damage level. The IMPACT 2002+ method presently provides characterisation factors for almost 1500 different LCI-results, which can be downloaded at http://www.sph.umich.edu/riskcenter/jolliet/downloads.htm .

3.5.1 Source of methodology documentation

Crettaz et al., 2002, Jolliet et al., 2004, Payet, 2004, Pennington et al., 2005, Pennington et al., 2006, Rochat et al., 2006, Rosenbaum, 2006, Rosenbaum et al, 2007a.

Website*:* http://www.epfl.ch/impact or
http://www.sph.umich.edu/riskcenter/jolliet/index.htm

Methodology contact person: Olivier Jolliet

3.5.2 General principles

Table 11 General principles of IMPACT2002+ methodology (see also Figure 4)

Principle	**Comment**
Intended purpose of the methodology:	Providing combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories: human health, ecosystem quality, climate change, and resources.
Midpoint/endpoint:	Midpoint and endpoint
Handling of choices:	Impact 2002+ has been developed with the clear aim to enable comparative assessment, avoiding the use of conservative assumptions and safety factors. A long term horizon has been systematically applied to reflect overall

Principle	Comment
	integrated effects.
Data uncertainties:	Uncertainties have been quantified by Rosenbaum (2006) for thee human toxicity impact category and by Payet (2003) for ecotoxicity.
Regional validity:	Europe for the basic version. For the intake fraction (toxicity impact category), calculations have been carried out for a spatial European model based on a 200 by 250 km grid (Pennington et al. 2005). A multi-continental version of this model has been made available by Rochat et al. (2006), for the assessment of emission inventories taking place in all the continents.
Temporal validity :	Linear modelling independent of temporal constraints
Time horizon:	Infinity (independent of substance persistence)
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	Fate, exposure and effect factors are used in a consistent way for all emission-based categories. For each indicator separate normalisation factors are calculated using the same basic normalisation data; Spreadsheet available for update and other new calculations.
Midpoint impacts covered:	Human toxicity Respiratory effects Ionizing radiation Ozone depletion Photochemical oxidant formation Aquatic ecotoxicity Terrestrial ecotoxicity Aquatic eutrophication Terrestrial eutrophication and acidification Land occupation Global warming Non renewable Energy Mineral extraction
Endpoint impacts covered:	Human health, Ecosystem quality, Climate change (as life supporting function), and Resources
Approximate number of substances covered:	Approximately 1500 substances (often with characterisation factors for more than one impact category, or more than one compartment within an impact category).
Other observations:	None

3.5.3 Normalisation and weighting

Table 12 Normalisation and weighting in IMPACT 2002+

How is normalisation performed?	Normalisation factors for Europe available for 2000 as annual impact scores for an average citizen for all impact categories at midpoint and damage levels. Background spreadsheet available so that normalisation factors can be adapted for new data developments.
How is weighting performed?	No specific weighting developed for IMPACT 2002+. As a default, the weighting factors can be taken as equal, assuming that overall present European damage on human health is comparable to impact on ecosystems and to climate change and resources impacts. Suggested to avoid explicit weighting by using the triangle approach, summing up normalized resources and climate change scores that are highly correlated.

3.5.4 Interesting (unique) features

- New concepts and methods for improved comparative assessment of human toxicity and ecotoxicity effects (both are based on mean responses rather than on conservative assumptions) were developed for IMPACT 2002+.
- For resources, the surplus energy concept from Müller Wenk, but summing MJ primary and MJ surplus energy for fossil fuels. Further developments have been carried out on indoor air exposure and direct impacts of pesticides.

3.5.5 Impact categories pre-selected for further evaluation

- Human toxicity and Ecotoxicity for the comparative approach (e.g. including geometric mean across species instead of most sensitive species) and optionally for the human health assessment of direct pesticides residues and of indoor air emissions.
- Resources, for the adaptation of the surplus energy concept from Müller Wenk, summing up present and future non renewable resources for fossil fuels (MJ primary presently used and MJ surplus energy since the MJ primary are used in an irreversible way).
- As extension of Impact 2002+ the midpoint to damage methods developed within the NEEDS project (Payet et al., 2006) provides useful inputs for the acidification and eutrophication impacts on ecosystems.
- Ozone formation.

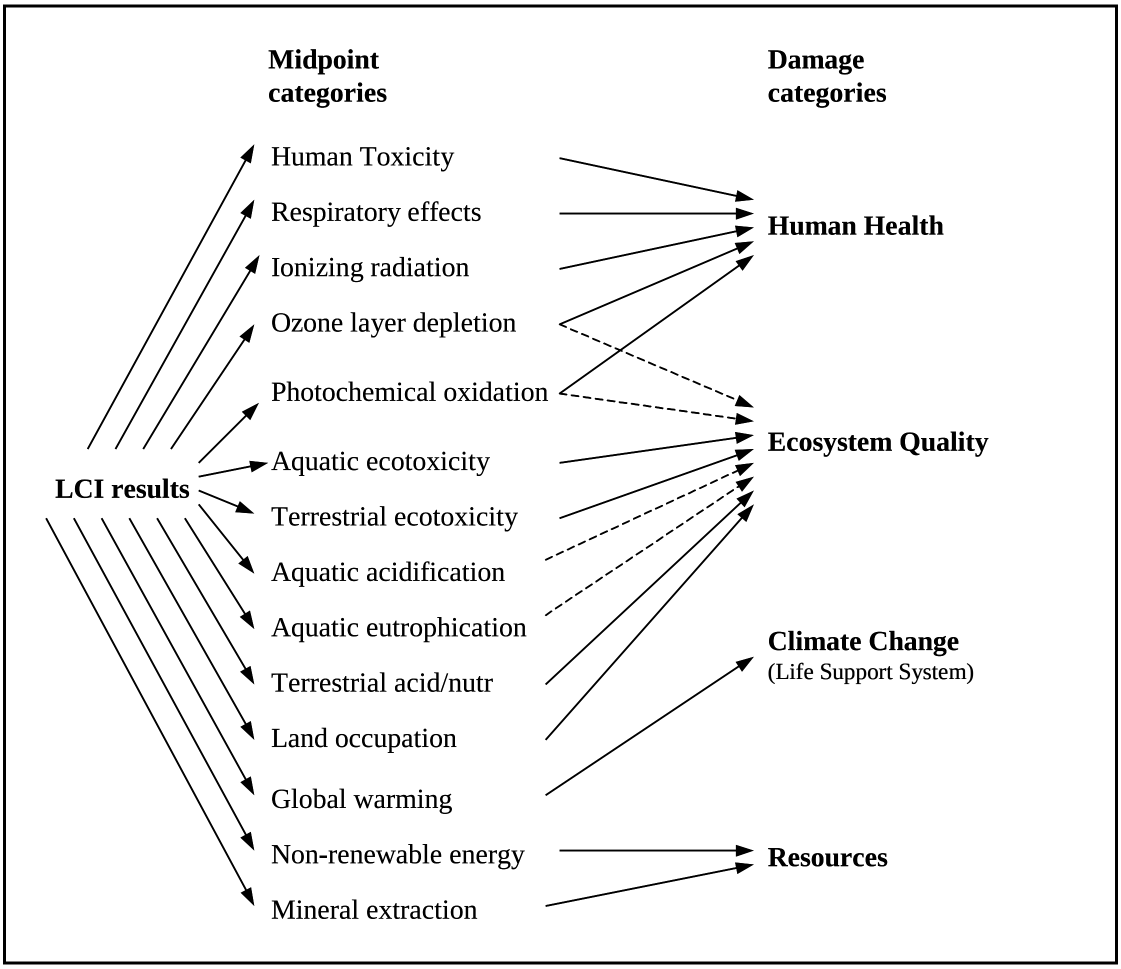

Figure 4 **Impact categories and pathways covered by the IMPACT 2002+ methodology**

3.6 LIME

The Lime method has been developed in Japan, building on various inputs from experts from around the world, and is used widely in Japan. The full documentation of the LIME 1 method, is currently being translated, while some conference papers are already available, The descriptions of the follow up, LIME 2 are mostly in Japanese. The method is mainly applied in Japan.

3.6.1 Source of methodology documentation

Itsubo et al., 2004, Hayashi et al., 2000, Hayashi et al., 2004, Hayashi et al., 2006

Methodology contact person: Norihiro Itsubo

Website. http://www.jemai.or.jp/english/lca/project.cfm

3.6.2 General principles

Table 13 General principles of LIME methodology (see also Figure 5)

Principle	**Comment**
Intended purpose of the methodology:	Develop lists of midpoint (characterization), endpoint (damage assessment) and weighting reflecting the environmental conditions of Japan.
Midpoint/endpoint:	Combined midpoint and endpoint model
Handling of choices:	Based on the agreement by the Organizing Committee which is composed by 10 authorities in the field of environmental studies.
Data uncertainties:	In the original method LIME 1 these were not addressed, but recently they have been developed for LIME 2.
Regional validity:	Japan, except for global impacts like climate change and stratospheric ozone depletion.
Temporal validity :	Present
Time horizon:	Depending on impact categories
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	Organized 3 committees (LCIA committee, damage assessment subcommittee, economic assessment (weighting) subcommittee). In each group, intense discussion has been done in order to keep consistency.
Midpoint impacts covered:	Urban air pollution Global warming Ozone layer depletion Human Toxicity Eco-toxicity Acidification Eutrophication

Principle	Comment
	Photochemical oxidant formation Land Use Consumption of minerals Consumption of energy Consumption of biotic resource Indoor air pollution Noise Waste
Endpoint impacts covered:	Thermal stress Malaria Infectious diseases, starvation, natural disasters Cataract Skin cancer Other cancer Respiratory defects Biodiversity (terrestrial) Biodiversity (aquatic) Plant Benthos Fishery Crop Materials Mineral Resources Energy resources These category endpoints are linked to four “safeguard subjects” Human health Social welfare Biodiversity Primary production
Approximate number of substances covered:	Around 1000 substances

3.6.3 Normalisation and weighting

Table 14 Normalisation and weighting in LIME

How is	No normalisation needed, as monetisation is applied at the endpoint level. In

normalisation performed?	earlier publications normalisation and weighting was described as an optional method.
How is weighting performed?	Societal costs (in Yen) are used to combine the four safeguard subjects.

3.6.4 Interesting (unique) features

- Damage associated with manmade environment is included.
- Fully developed for the Japanese natural and human conditions.
- Monetisation is used for evaluation, but it can also be used with panel weighting.
- New work is ongoing to specify uncertainty factors.
- The systematic modelling of midpoint to endpoint is the strength of the LIME methodology. and the proposed model should be systematically considered for this feature.

3.6.5 Impact categories pre-selected for further evaluation

- The eutrophication for both freshwater and marine environments are to be considered as potential alternatives.
- Climate, endpoint model.
- Ozone depletion, as it uses a different model and has more detailed data.
- Several impact categories (including midpoints) link to manmade environment and to human welfare, this is not done in other methods, It illustrates the functional view on environmental problems.
- Ecosystem damage is captured both via biodiversity and productivity; this double endpoint approach is quite unique.
- Human toxicity; there are several interesting mechanisms in the effect assessment.
- Novel approaches were used for ecosystem damage including for ecotoxicological effects (the fate and exposure modelling was originally based on the same method later further developed for Impact 2002).
- Damage indicator for biodiversity; the risk of extinction species is measured.
- Advanced weighting method (conjoint analysis) was adopted.

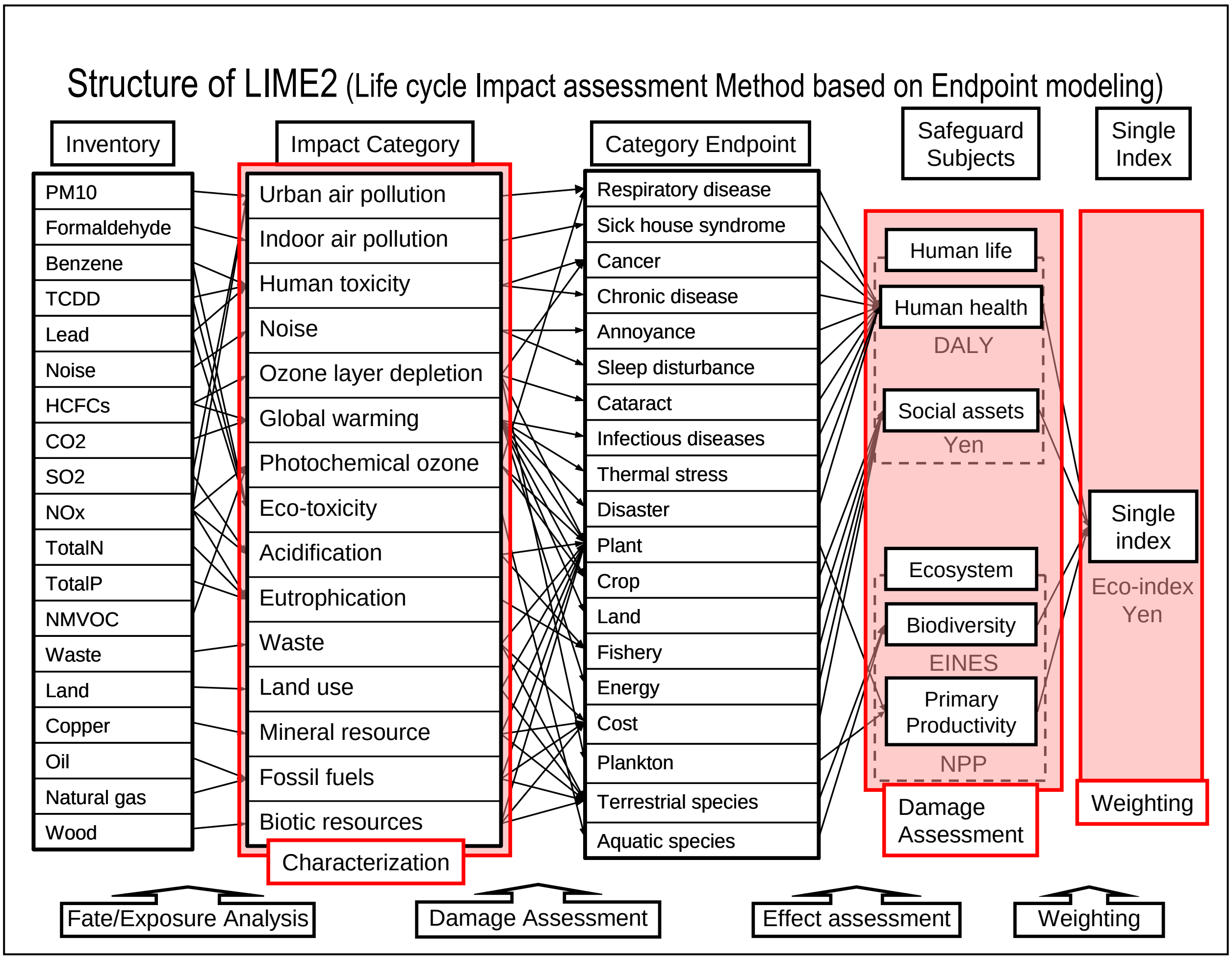

Figure 5 **Impact categories and pathways covered by the LIME methodology**

3.7 LUCAS

LUCAS 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 and IMPACT 2002+, which are re-parameterized and further developed to better assess Canadian life cycle inventories.

3.7.1 Source of methodology documentation

Toffoletto et al., 2007.

Website**:** http://www.ciraig.org

Methodology contact persons: R. Rosenbaum or V. Becaert

3.7.2 General principles

Table 15 General principles of LUCAS methodology (see also Figure 6)

Principle	**Comment**
Intended purpose of the method:	LCIA methodology adapted to the Canadian context
Midpoint/endpoint:	Midpoint methodology that will eventually be further developed to endpoint.
Handling of choices:	This method is strongly based on preliminary outcomes from the SETAC recommendations concerning best available practices in LCIA. Some models of three recent LCIA site-dependant methods, namely, EDIP2003, IMPACT2002+ and TRACI, were used in this Canadian-specific method. Characterisation models were chosen based on their level of comprehensiveness, scientific sophistication, and the possibility of integrating site-specific values in the models. SETAC recommendations (Udo de Haes et al. 2002) were strictly followed and only categories having models with (somewhat) “consensus approved” indicators were selected. The categories of odour, noise, radiation and biotic resources were not characterized in this first phase of development; however, further improvements will occur and will eventually take into consideration these impact categories.
Data uncertainties:	Not yet considered (currently in development).
Regional validity:	Global for Climate change and Ozone depletion Canada for regional impact categories, for which spatially differentiated characterisation factors are calculated. A decision is currently made, if a different regional scale should be developed.
Temporal validity :	Present time, long term time horizon
Time horizon:	Long term time horizon is favoured in each impact category
How is consistency ensured in the treatment of different impacts In characterisation	For all emission-based categories similar principles and choices are used, based on cause-effect chain mechanisms. For each indicator separate normalisation factors are calculated using the same basic normalisation data (total

Principle	Comment
In normalisation and weighting?	impact of annual emission in Canada / Population in Canada); Spreadsheet available for update and other new calculations.
Midpoint impacts covered:	Climate change Ozone depletion Acidification Photochemical smog Respiratory effects Aquatic eutrophication Terrestrial eutrophication Ecotoxicity (aquatic and terrestrial) Human toxicity Land-use Abiotic resource depletion
Endpoint impacts covered:	Currently, midpoint indicators are preferred over endpoint. For now the methodology framework is not modelled up to endpoint (currently under development).
Approximate number of substances covered:	~ 800 overall in addition to ~ 2’000 toxic emissions
Other observations:	While so far the method basically adopted existing models parameterised for Canada, promising developments are currently being undertaken for improved characterisation modelling of land-use, water-use, toxicity, and acidification indicators, uncertainty estimation/management and endpoint modelling.

3.7.3 Normalisation and weighting

Table 16 Normalisation and weighting in LUCAS

How is normalisation preformed?	It 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. Normalization factors are currently being updated.
How is weighting performed?	No weighting

3.7.4 Interesting (unique) features

- Spatial resolution for regional impact categories with a focus on Canada: acidification, photochemical smog, aquatic eutrophication, terrestrial eutrophication, ecotoxicity (aquatic and terrestrial), human toxicity.
- Development of vulnerability factors to introduce site-specificity in regional impacts for the effect modelling of acidification and eutrophication (aquatic and terrestrial).

3.7.5 Impact categories pre-selected for further evaluation

As LUCAS uses merely adaptations of other methods, no characterisation methods were selected from this methodology, as this would give no other result than the analysis of the original methods, except for the localization to Canada. However, in this context, there is a consistency with models for other regions that is interesting in the context of having global generic factors complemented by site-dependent factors where applicable.

- New on-going research on acidification, eutrophication characterisation models and on resources related impact categories will allow further improvements of the models.
- Similarly, on-going research is aiming at modelling the cause-effect chain up to damages.

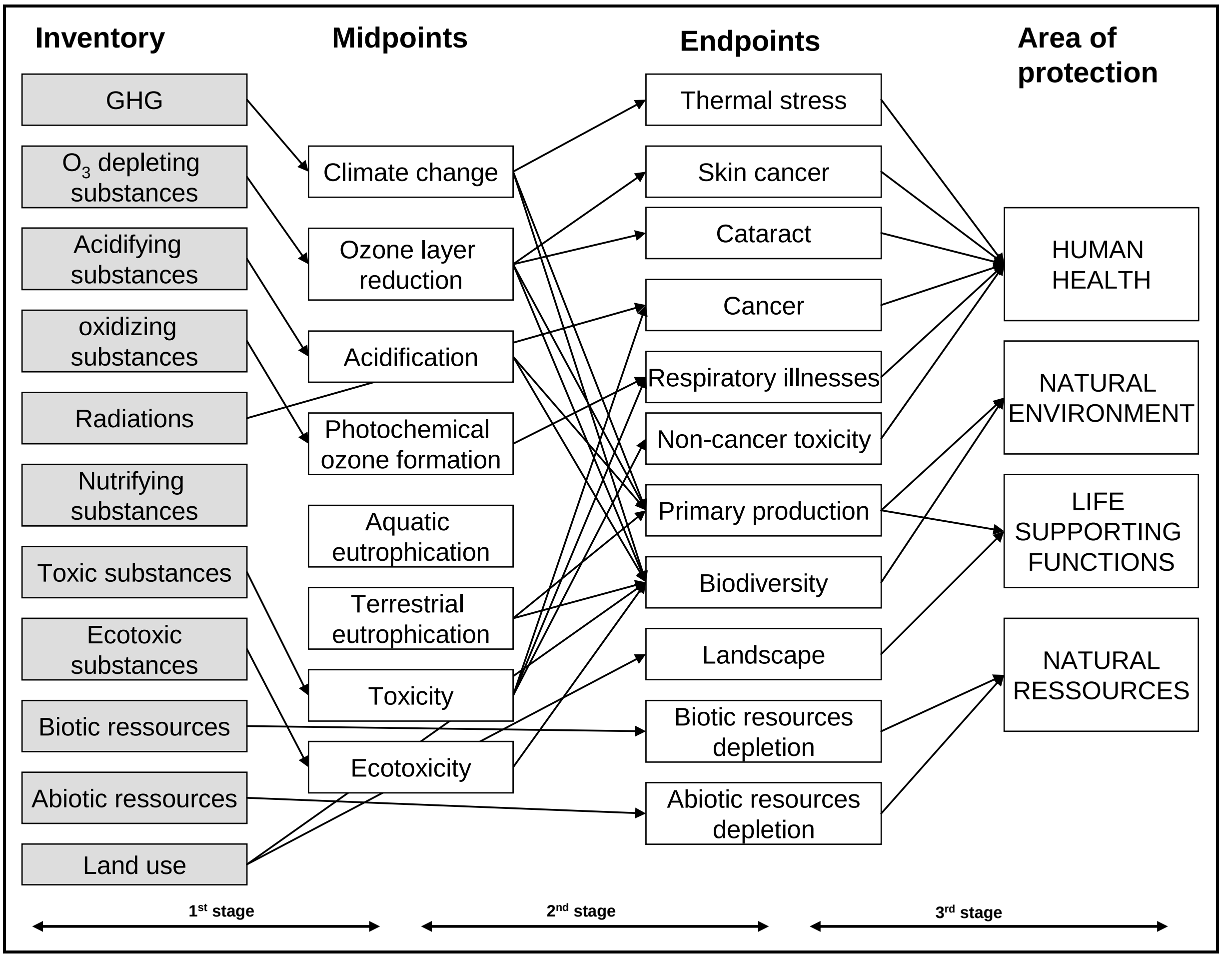

Figure 6 **Impact categories and pathways covered by the LUCAS methodology**

3.8 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). The method is not published as a single document yet, but most impact categories have been described in peer reviewed magazines.

3.8.1 Source of methodology documentation

De Schryver AM, Brakkee KW, Goedkoop MJ, Huijbregts MAJ. (2009). Characterization Factors for Global Warming in Life Cycle Assessment Based on Damages to Humans and Ecosystems. *Environmental Science and Technology* 43 (6), 1689–1695.

Huijbregts MAJ, Struijs J, Goedkoop M, Heijungs R, Hendriks AJ, Van de Meent D. (2005a). Human population intake fractions and environmental fate factors of toxic pollutants in Life Cycle Impact Assessment. *Chemosphere* 61 (10): 1495-1504.

Huijbregts MAJ, Rombouts LJA, Ragas AMJ, Van de Meent D. (2005b). Human-toxicological effect and damage factors of carcinogenic and non-carcinogenic chemicals for life cycle impact assessment. Integrated Environmental Assessment and Management 1 (3): 181-244.

Van de Meent D, Huijbregts MAJ, (2005). Evaluating ecotoxicological effect factors based on the Potentially Affected Fraction of species. Environmental Toxicolology and Chemistry 24 (6): 1573-1578.

Van Zelm R, Huijbregts MAJ, Van Jaarsveld HA, Reinds GJ, De Zwart D, Struijs J, Van de Meent D. (2007). Time horizon dependent characterization factors for acidification in life-cycle impact assessment based on the disappeared fraction of plant species in European forests. *Environmental Science and Technology* 41: 922-927.

Van Zelm R, Huijbregts MAJ, Harbers JV, Wintersen A, Struijs J, Posthuma L, Van de Meent D. (2007). Uncertainty in msPAF-based ecotoxicological freshwater effect factors for chemicals with a non-specific mode of action in life cycle impact assessment. *Integrated Environmental Assessment and Management* 3 (2): 203-210.

Van Zelm R, Huijbregts MAJ, Den Hollander HA, Van Jaarsveld HA, Sauter FJ, Struijs J, Van Wijnen HJ, Van de Meent D. (2008). European characterization factors for respiratory health damage due to PM10 and ozone in life cycle impact assessment. *Atmospheric Environment* 42 (3): 441-453.

Van Zelm R, Huijbregts MAJ, Wintersen A, Posthuma L, Van de Meent D. (2009). Pesticide ecotoxicological effect factors and their uncertainties for freshwater ecosystems. *International Journal of Life Cycle Assessment* 14 (1): 43–51

Wegener Sleeswijk A, Van Oers L, Guinée J, Struijs J, Huijbregts MAJ. (2008). Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. *Science of the Total Environment* 390 (1): 227-240

Website: www.lcia-recipe.net

Methodology contact persons: Mark Goedkoop (Pre), Mark Huijbregts (RU), Reinout Heijungs (CML), Jaap Struijs (RIVM)

3.8.2 General principles

Table 17 General principles of ReCiPe methodology (see also Figure 7)

Principle	**Comment**
Intended purpose of the method:	Combining midpoint and endpoint methodologies in a consistent way
Midpoint/endpoint:	Midpoint and endpoint characterisation factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources
Handling of choices:	Cultural perspectives are used to distinguish three different sets of subjective choices. User can choose which version to apply.
Data uncertainties:	Data uncertainties are discussed in the text but not always quantified.
Regional validity:	Europe. Global for Climate change, Ozone layer depletion and resources
Temporal validity :	Present time
Time horizon:	20 years, 100 years or indefinite, depending on the cultural perspective
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	For all emission based categories similar principles and choices are used. All impacts are marginal. All impact categories of the same area of protection have the same indicator unit. Same environmental mechanism for midpoint and endpoint calculations is used.
Midpoint impacts covered:	climate change; ozone depletion; terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; ionising radiation; agricultural land occupation; urban land occupation; natural land transformation; depletion of fossil fuel resources; depletion of mineral resources; depletion of freshwater resources
Endpoint impacts covered:	Human health (DALY); ecosystem quality (biodiversity, PDF.m^2.yr); resources (surplus cost)
Approximate number of substances covered:	Approximately 3000 substances
Other observations:	

3.8.3 Normalisation and weighting

Table 18 Normalisation and weighting in ReCiPe

How is normalisation preformed?	Normalisation data are available for Europe and the world in year 2000, for 16 midpoint categories and for the three endpoint categories. Normalisation data on land transformation and fresh water depletion are not included
How is weighting performed?	In a separate project, three methods are developed: - For endpoints a manual for panel weighting is available, but no operational generic weighting set have been developed - For the midpoints a monetisation method on the basis of prevention costs is provided. - For endpoints a monetisation on the basis of damage costs is provided. - The weighting triangle can be used at the endpoint level.

3.8.4 Interesting (unique) features

- Consistent use of midpoints and endpoints in the same environmental mechanism. Midpoints are chosen as close as possible to the LCI results (lowest uncertainty of the indicator).
- Consistent marginal approach.
- Sub compartments rural air and urban air applied in fate and exposure model for human toxicity.
- Most impact categories have been described in peer reviewed papers (some still in press).

3.8.5 Impact categories pre-selected for further evaluation

- Climate change factors, at endpoint level link to Human health (updated) and Ecosystem damage. The midpoint level uses the latest (2007) IPCC equivalency factors for three time horizons (20, 100 and 500 years).
- Ozone depletion factors (Endpoint) based on time-explicit forecast of demographic developments up to 2100.
- Acidification, link to Ecosystem damage and time horizon dependent. Midpoints and endpoints are available in the same mechanism.
- Photochemical ozone formation factors and particulate matter formation factors derived from up-to-date atmospheric models and epidemiological studies, Midpoints and endpoints are available in the same mechanism.
- Land-use distinguishes agricultural intensity.
- Non-linear marginal approach included in the calculation of human-toxicological and ecotoxicological effect factors. Midpoints and endpoints are available in the same mechanism.
- Aquatic Eutrophication for freshwaters link to Ecosystem damage.
- Resources, based on the surplus cost approach (endpoint).

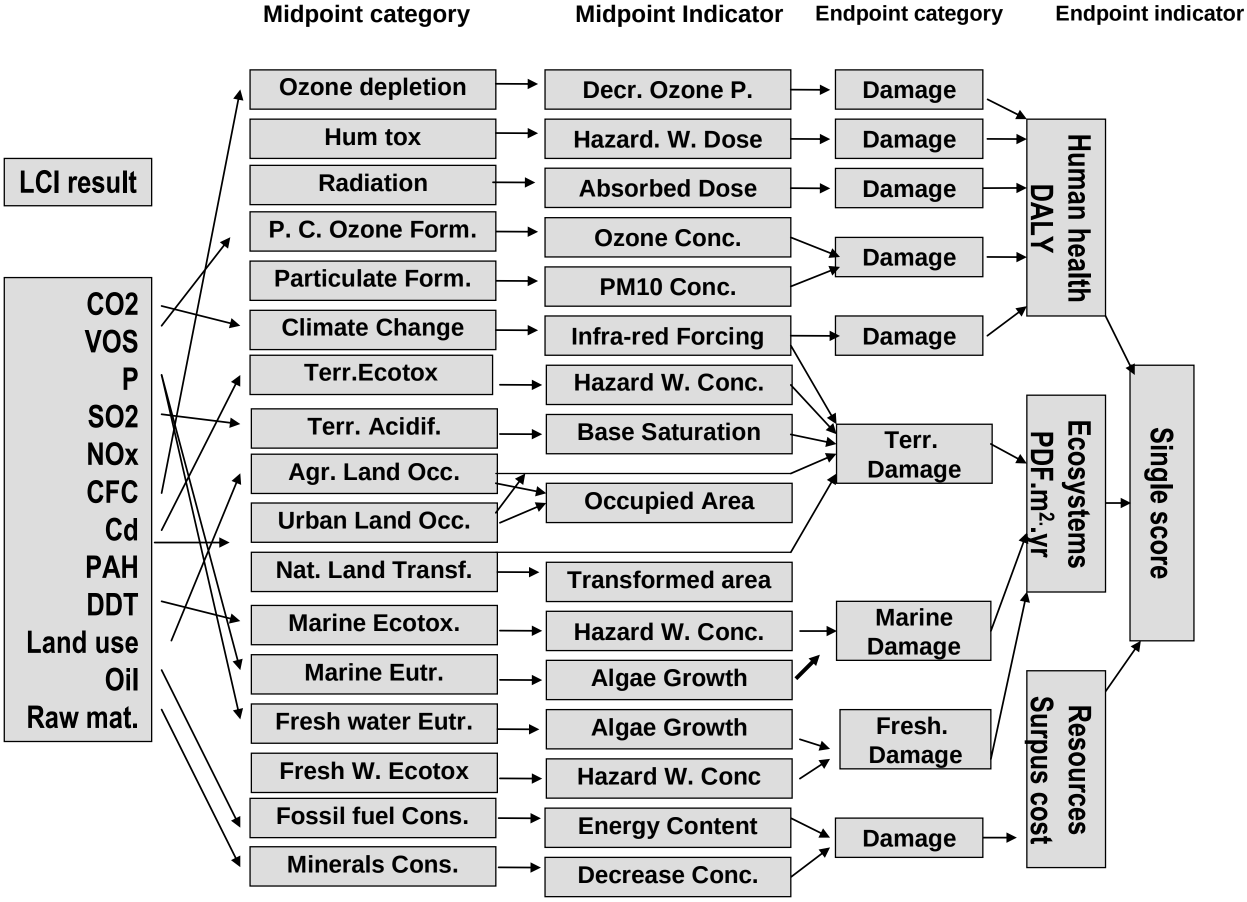

Figure 7 **Impact categories and pathways covered by the ReCiPe methodology**

3.9 Ecological Scarcity Method (Ecopoints 2006)

The method of ecological scarcity – 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 has been developed top-down and is built on the assumption that a well established environmental policy framework (incl. the international treaties) may be used as reference framework for the optimization and improvement of individual products and processes. The various damages to human health and ecosystem quality are considered in the target setting process of the general environmental policy; this general environmental policy in turn is then the basis for the critical flows. An implicit weighting takes place in accepting the various goals of the environmental policy. The ecological scarcity method contains common characterisation/classification approaches (for climate change, ozone depletion, acidification, cancer caused by radionuclides, endocrine disruptors, pesticides, primary energy resources and biodiversity losses caused by land use). Other interventions are assessed individually (e.g. various heavy metals) or as a group (e.g. NM-VOC).

The method is meant for standard environmental assessments, e.g., with specific products or processes. In addition, it is often used as an element of environmental management systems (EMS) of companies, where the assessment of the company's environmental aspects (ISO 14001) is supported by such a weighting method. The method was first published in Switzerland in 1990. A first amendment and update was made for 1997, which is the version taken into account in this document. A next version, based on 2004 data, has been developed in 2008, but has not been made publicly available in time to be included in this analysis.

3.9.1 Source of methodology documentation

Brand et al., 1998, Müller-Wenk, 1994, Ahbe et al., 1990, Frischknecht, 2006a, Frischknecht, 2006b.[9]

Website*:* http://www.e2mc.com/BUWAL297%20english.pdf, www.oebu.ch, www.bafu.admin.ch, www.esu-services.ch

Methodology contact persons*:* Rolf Frischknecht, Arthur Braunschweig

[9] In the meantime an update to the method has been published in Frischknecht R., Steiner R. and Jungbluth N. (2009)

3.9.2 General principles

Table 19 General principles of Ecopoints 2006 methodology

Principle	**Comment**
Intended purpose of the methodology:	Providing characterisation and weighting factors of various emissions and extractions based on public policy targets and objectives.
Midpoint/endpoint:	Distance to target approach. Endpoints indirectly considered by policy targets
Handling of choices:	Choices are mostly embedded in the Swiss policy targets and objectives
Data uncertainties:	Semi quantitative assessment. Three levels assessment of data quality and of the liability of the target
Regional validity:	The original method has been developed for Switzerland. Various versions of the Ecological Scarcity method have been developed for other countries or part of the world, e.g. the Japanese version published under: JEPIX - Japan Environmental Policy Priorities Index, at www.jepix.org
Temporal validity :	Actual flows reflect a 2004 situation and critical flows correspond to policy objectives in 2005. The critical flows reflect targets to be achieved within five to twenty years.
Time horizon:	Actual and critical flows are defined on a per year basis. Targets of some impacts, such as climate change, energy resource demand or heavy metals emissions reflect longer term policy objectives.
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	For all pollutants and resources policy objectives are used in a consistent way. The latest update (Frischknecht et al., 2006a) introduces in the method presentation a separate (optional) characterisation step, a normalisation step (division by actual flows), and a weighting factor. The weighting factor equals to the square of the ratio of actual to critical flow. This change in formula structure does not affect the factors themselves.
Midpoint impacts covered:	Climate change Ozone depletion Photochemical oxidant formation: NMVOC Respiratory effects: PM10, PM2.5, black carbon Air emissions: NO_x, SO_2, NH_3, HCl, HF, Heavy metals (Pb, Cd, Zn, Hg), benzene, dioxins and furans Surface water emissions: COD (DOC, TOC, BOD5), Phosphorus, N-Total, heavy metals (As, Hg, Cd, Pb, Cr, Cu, Zn, Ni), polycyclic aromatic hydrocarbons (PAH), benzo(a)pyrene, adsorbable organic halogenated compounds (AOX), chloroform, radioactive emissions, and endocrine disruptors. Cancer caused by radionuclides emitted to the Sea Emissions to groundwater: NO_3^-, Emissions to soil: heavy metals (Cd, Pb, Cu, Zn,), pesticides.

Principle	Comment
	Waste: Landfilled municipal (reactive) wastes, hazardous wastes (stored underground), radioactive wastes Water consumption Gravel consumption Primary energy resources Endocrine disruptors Biodiversity losses due to land occupation
Endpoint impacts covered:	Distance to target rather than damage oriented methods. Endpoints are defined via policy objectives
Approximate number of substances covered:	More than 400
Other observations:	None

3.9.3 Normalisation and weighting

Table 20 Normalisation and weighting in Ecopoints 2006

How is normalisation performed?	By dividing by 2004 emission flows
How is weighting performed?	By multiplying by the square of the ratio of actual flow/critical flow

3.9.4 Interesting (unique) features

This is the revision of one of the earliest impact assessment methods. It has a high internal consistency, based on policy objectives and targets. New factors are being published for water resource use as described by Frischknecht et al. (2006a). The update and extension of the method takes into account the recent developments in Swiss and European (as far as it is relevant for Switzerland) legislation and environmental targets. Furthermore, ISO standard revisions and recent developments in scientific knowledge on environmental effects are also considered where appropriate. The basic principle and main strength of the method, measuring the ecological scarcity with the help of actual pollutant (and resource) flows and maximum allowed (so-called critical) flows, remains untouched. Hence, it is still a distance to target rather than a damage oriented impact assessment method. Nevertheless, the representation of the formula is slightly changed to comply with ISO requirements, but also to allow for a more flexible and powerful interpretation of the terms.

3.9.5 Impact categories pre-selected for further evaluation

Interesting new impact categories are:

- Effects of endocrine disruptors, characterised with estrogen potentials (based on Rutishauser et al., 2004.
- Water resource use, weighting based on the water pressure index published by OECD, see Frischknecht et al., 2006b.

- Pesticides, characterised based on the inverse of the standard application rate.
- Radionuclides emitted to the Sea, characterised based on their cancer causing potential; based on Frischknecht et al (2000) this approach has also been used in several other methods, like Eco-indicator 99, CML 2002, Impact 2002, etc.
- Land occupation, characterised with their biodiversity loss potential, based on recent work of Thomas Köllner (Köllner 2007).

3.10 TRACI

TRACI was developed by the U.S. EPA as a midpoint method that represents the environmental conditions in the USA as a whole or per state. Large parts of the methods are also used in the BEES method[10], which is widely applied in the US building sector.

During the development of TRACI, consistency with previous modelling assumptions (especially of the U.S. EPA) was important for every impact category. The human health cancer and non-cancer categories were strongly based on the assumptions made for the U.S. EPA Risk Assessment Guidance for Superfund and the U.S. EPA's Exposure Factors Handbook. For categories such as acidification and smog formation, detailed US empirical models, such as those developed by the US National Acid Precipitation Assessment Program and the California Air Resources Board, allowed the inclusion of the more sophisticated location specific approaches and location specific characterisation factors. When there was no EPA precedent, assumptions and value choices were minimized by the use of midpoints.

3.10.1 Source of methodology documentation

Bare, 2002, Bare et al., 2003, Hertwich et al., 1997, Hertwich et al., 1998, Hertwich et al., 1999, Hertwich et al., 2001, Norris, 2002. Parts of the TRACI methodology are being updated but have not been made publicly available in time to be included in this document.

Website: http://www.epa.gov/ORD/NRMRL/std/sab/traci/

Methodology contact person: Jane Bare

3.10.2 General principles

Table 21 General principles of TRACI methodology (see also Figure 8)

Principle	**Comment**
Intended purpose of the methodology:	Develop an impact assessment method that represents the conditions in the USA, and that is in line with the EPA policy
Midpoint/endpoint:	Midpoint
Handling of choices:	Choices are minimised by staying on the midpoint levels. Where needed choices are based on the EPA policy
Data uncertainties:	Quantified within Bare, et al., 2002 for the case study, within Hertwich, et al, 2001 for the human toxicity potentials, and within Norris, 2002 for acidification, eutrophication, and smog formation.
Regional validity:	Emissions in the USA, impacts throughout North America for acidification, eutrophication, and smog formation, and throughout the world for ozone depletion and global warming. Human and ecotoxicity are not site specific in TRACI, but U.S. EPA values for human exposure factors and risk assessment guidelines are used.
Temporal validity :	~2002

[10] http://www.bfrl.nist.gov/oae/software/bees/

Principle	**Comment**
Time horizon:	Long term, 100 year timeframe was used for GWPs.
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	Existing methods have been analysed, and adapted, improved or harmonised, as far as possible. Normalisation values consistent with TRACI's original version are not available in early 2008. A new version of TRACI is expected in 2009/2010 which will be released with normalization data.
Midpoint impacts covered:	Ozone depletion; Global warming; Smog formation; Acidification; Eutrophication; Human health cancer; Human health noncancer; Human health criteria pollutants; Eco-toxicity; Fossil fuel depletion.
Endpoint impacts covered:	Human health, Ecosystems and Resources and manmade environment are mentioned in the selection of the impact categories, but these are not quantified
Approximate number of substances covered:	Over 900 substances were included within the original TRACI. The new version is expected to include about 3000 substances.
Other observations:	Large parts of the method are used in the BEES methodology that is widely applied in the US building sector. A new version of TRACI is expected in 2009/2010.

3.10.3 Normalisation and weighting

Table 22 Normalisation and weighting in TRACI

How is normalisation performed?	Normalisation values consistent with TRACI's original version are not available at this time. A new version of TRACI is expected in early 2008 which will be released with normalization data.
How is weighting performed?	No weighting is suggested

3.10.4 Interesting (unique) features

- This method is supported by the US EPA, and is especially relevant for emissions occurring as parts of product life cycles in the USA.
- For acidification, eutrophication, and smog formation regionally specified characterisation factors (per state) are available.

3.10.5 Impact categories pre-selected for further evaluation

- The treatment of eutrophication is of particular interest, especially since in TRACI it is properly assumed that the deposition of N (originating from NO_2 and NH_3) to the non-coastal sea area does not cause harmful effects in terms of aquatic eutrophication. This later feature is a clear methodological advantage of TRACI compared with the other methods. TRACI also includes a stream analysis which allows tracking after deposition from the deposition location all the way downstream and to the final resting place (e.g. the ocean, desert, land).
- Acidification is addressed in an interesting way, also because of the use of spatial differentiation based on an empirical model from the National Acid Precipitation Program (NAPAP).
- The MIR used for photo oxidant formation constitutes a potentially interesting alternative compared to POCPs, and was developed for USA.

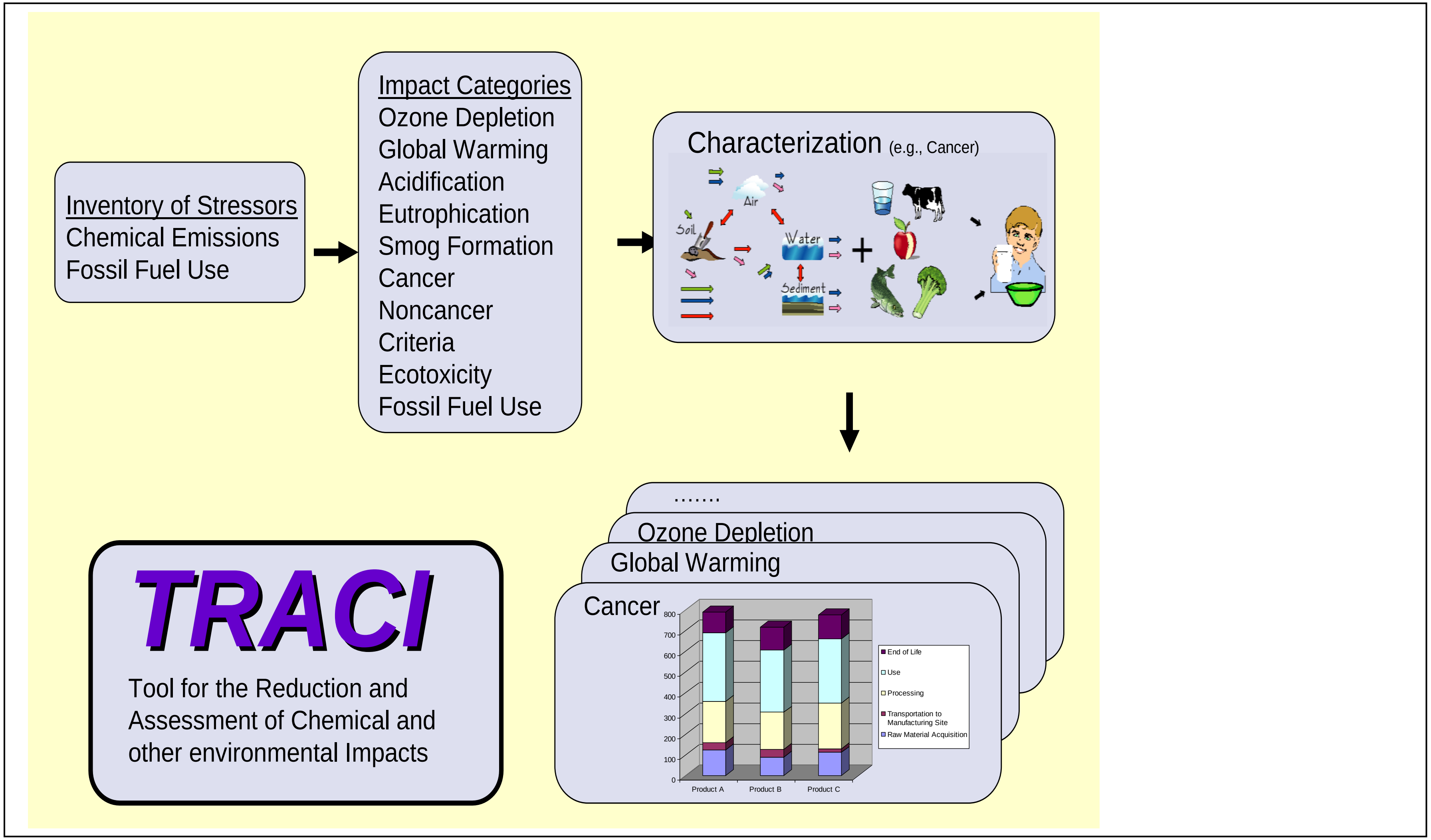

Figure 8 **Impact categories covered by the TRACI methodology**

3.11 MEEuP

The Methodology study for Eco-design of Energy-using Products (MEEuP) methodology was developed by a contractor on behalf of the European Commission (DG Enterprise) to evaluate whether and to which extent various energy-using products (EuPs) fulfil certain criteria that make them eligible for CE labelling under implementing measures foreseen under the Eco-design of EuP Directive 2005/32/EC, adopting a life-cycle approach. The methodology includes - next to inventory data and technical parameters for EuPs also specific impact assessment factors with a unique approach. The MEEuP method also is intended to support eco-design in general.

3.11.1 Source of methodology documentation

Kemna et al., 2005.

Website: http://www.vhk.nl/downloads.htm

http://ec.europa.eu/enterprise/eco_design/relactiv.htm

Methodology contact persons: René Kemna (VHK - Delft)

3.11.2 General principles

Table 23 General principles in MEEuP methodology

Principle	**Comment**
Intended purpose of the methodology:	Providing a methodology allowing to evaluate whether and to which extent various energy-using products (EuP) fulfil certain criteria that make them eligible for implementing measures under the Ecodesign of EuP Directive 2005/32/EC. These criteria are specified in Article 15 of the Directive (p.11). For the assessment of the environmental impact of a product over its life-cycle taking into account (p.30): • the assignment (see above; in the tender document, the European Commission required the quantitative assessment of a number of specific parameters (emissions and resources)) • the Ecodesign of EuP Directive and • the fact that this Directive has to be coherent and consistent with existing legislation.
Midpoint/endpoint:	Midpoint
Handling of choices:	Choices have been made in accordance with the assignment, the Eco-design of EuP Directive and existing EU legislation and international treaties in relevant areas. In case the legislation / treaties were not specific enough for classification / characterisation, alignment with other methods was sought (indicated in report)
Data uncertainties:	Data uncertainties are marginally discussed, and not quantified.
Regional validity:	The methodology is coherent with EU agreements and international treaties and as such the indicators and methods

Principle	Comment
	are related to the EU.
Temporal validity :	2005/2006 (p.90 of methodology report)
Time horizon:	Not specified.
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	The selection of impacts is steered by the assignment, the Ecodesign of EuP Directive (see "Intended purpose of the methodology"), and – particularly - the need to be coherent and consistent with existing EU legislation. The characterisation factors are based upon data from relevant EU and international legislation and treaties, presuming underlying scientific consensus but not necessarily that these were defined for use in a comparative assessment context. In case the legislation/ treaties were not specific enough for characterisation, alignment with other methods was sought (indicated in report). Normalisation and weighing were not part of the assignment.
Midpoint impacts covered:	Energy Total Gross Energy Requirement, in MJ primary Electricity, in MJ primary or kWhe Water Process water, in litre Cooling water, in litre Waste Hazardous Solid Waste, in g Non-Hazardous Waste, in g Emissions to air Global warming: GWP100, Global Warming Potential for a time horizon of 100 years, in CO_2 equivalent Stratospheric Ozone Depletion: ODP, Ozone Depletion Potential, in CFC-11 equivalent Acidification: AP, Acidification Potential, in SO_2 equivalent POP. Persistent Organic Pollutants, in this case only dioxins and furans, expressed in ng I-Teq VOC, Volatile Organic Compounds, in mg Heavy Metals, HM, in mg Ni equivalent. Human health: Polycyclic aromatic hydrocarbons, PAHs, in mg Ni equivalent. This category includes PAHs and other substances detrimental to human health, like benzene and carbon monoxide (CO). Particulate matter, PM in g. Emissions to water: Eutrophication Potential, in mg PO4 equivalent Heavy metals, in mg Hg/20-equivalent

Principle	**Comment**
Endpoint impacts covered:	None
Approximate number of substances covered:	Approximately 50 substances, with some (CO, N_2O) having characterisation factors for more than one impact category.
Other observations:	

3.11.3 Normalisation and weighting

Table 24 Normalisation and weighting in MEEuP

How is normalisation performed?	Not part of the method. Some guidance and an illustration is provided of how summing between the categories could be performed.
How is weighting performed?	Not part of the method. Some guidance and an illustration is provided of how summing between the categories could be performed.

3.11.4 Interesting (unique) features

- Used primarily by the EU for the evaluation of Energy using Products.
- Based on EU Directives or international agreements etc., which has the benefit of increased acceptance by authoritative bodies.

3.11.5 Impact categories pre-selected for further evaluation

Most impact categories in the MEEuP method (midpoint only) are known from other LCA impact assessment methods (although using a different impact assessment methodology). Unlike other methods used in a life cycle context, this method has a formal role in a policy context, in this case in the EU. It was therefore decided to incorporate all into pre-selection for further consideration.

One unusual impact category of growing importance included in MEEuP is water use (process and cooling water).

3.12 Other methods not included in the studied LCIA methodologies

3.12.1 Noise

Müller-Wenk, 2002

Originally intended as an add-on to the Eco-indicator 99, but is usable with any method that uses DALYs. The method has been developed by Müller-Wenk. Noise is not an impact category directly covered by the scope of this project, but can be seen as an area for which research recommendations could be valuable. Müller-Wenk has been continuing the development and recently a WHO report established DALY factors for noise disturbances, which is a major step forward. On the EU policy level there is a directive to establish noise maps, and noise of vehicles may become subject to taxation in the future.

3.12.2 Indoor air and work environment

Several proposals have been made to cover these impact categories, next to the methods found in LIME and EDIP. Looking at the ongoing discussion and disagreement on the inclusion of these aspects in LCA, the decision was taken not to evaluate them in more detail.

Meijer et al., 2005

An indoor air pollution add-on to human toxicity, that also expresses results in DALY, has been developed by Arjen Meijer. It is not covered in the scope of this document, but it can be described as research recommendation (similar to the working environment in EDIP and the extensions described in Impact 2002).

UNEP working group (Bruzzi et al., 2007)

The UNEP Working group on indoor air is working on a proposal, but it has not been made publicly available in time to be included in this document.

3.12.3 Eutrophication

As an extension/improvement in the treatment of eutrophication the work by (Kärrman and Jönsson, 2001) seems to be an interesting addition for consideration.

3.12.4 Acidification

Seppälä has developed an advanced, spatially differentiated approach, which deserves further analysis (Seppälä et al., 2006).

Krewitt has developed a model based on the rains model for the ExternE project, as this is a somewhat older approach it will not be analysed (Krewitt et al., 2001).

3.12.5 Ozone formation

A method of Krewitt, developed for ExternE and applying the EcoSense model, is included in the analysis (Krewitt et al., 2001).

3.12.6 Human toxicity

Next to the analysis of USE-tox (see below) it was recognised that the WATSON model proposed by Bachmann (Bachmann, 2006) is interesting for metals. However, it only proposes few additional chemicals and therefore cannot meet the requirement of covering a broad range of substances. It will therefore be considered as a useful complement for metals, as applied within the UNEP-SETAC Life Cycle Initiative.

3.12.7 Respiratory inorganics

Next to the selected methods, three other approaches are included for analysis in detail: the EcoSense model as it is used in ExternE (Krewitt et al., 1998), spatial differentiation in modelling to particles (Greco et al., 2007) and compatibility between the modelling of human exposure to inorganics and organics (Potting et al., 2007, recommendations from the UNEP-SETAC Life Cycle Initiative task force on transboundary pollutants).

3.12.8 Resources

The most recent approach based on exergy is published by Jo DeWulf (DeWulf et al., 2007) and therefore included in the more profound analysis.

3.12.9 Land-use

Next to the methods in the analysed methodologies, the following other developments have been noted.

- Baitz has published in German language a PhD thesis with a differentiated approach based on various land functions. Baitz and co-workers (LBP Stuttgart and PE International) published a brief English description (Bos and Wittstock, 2007). A detailed English documentation and complete set of factors and calculation spreadsheet have been announced, but are not yet available.
- Erzinger (FAL Switzerland). This method incorporates many aspects, but for the time being it is unclear how it can be used in practice.
- Milà i Canals, has developed a sophisticated approach, but this has not yet resulted in a comprehensive set of operational characterisation factors beyond agricultural applications (Milà i Canals et al., 2007 a,b).
- Stan Rhodes and colleagues have developed a differentiated approach to include land use impacts as part of the LCSEA framework. A comprehensive documentation is still to be published, but some documentation is found in (Rhodes et al., 2006).

3.12.10 USEtox

The toxicity model USEtox has been developed with support of the UNEP-SETAC Life Cycle Initiative to provide recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Its elaboration involved the developers of models commonly used in current practice in an LCA context: CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON, and EcoSense.

A comprehensive comparison of LCIA toxicity characterisation models was carried out to identify specific sources of differences (both in model results and structure) and the indispensable model components. This led to the development of USEtox, a scientific consensus model that is parsimonious and contains only the most influential model elements based on current best practice in the context of LCA. As relevant were seen for example process formulations accounting for intermittent rain, defining a closed or open system environment, or nesting an urban box in a continental box,.

The relative accuracy of the new characterisation factors (CFs) is estimated to be within a factor of 100-1000 for human health and 10-100 for freshwater ecotoxicity of all other models compared to 12 orders of magnitude variation between the CFs of each model respectively. The achieved reduction of inter-model variability by up to 11 orders of magnitude is a very significant improvement. USEtox provides a parsimonious and transparent tool for human health and ecosystem CF estimates. Based on a well-referenced database, it has been used to calculate CFs for several thousand substances and forms the proposed basis for the recommendations from UNEP-SETAC's Life Cycle Initiative regarding characterisation of toxic impacts in Life Cycle Assessment.

USEtox provides both recommended and interim characterisation factors for human health and freshwater ecotoxicity impacts and it will become available to practitioners for the calculation of further CFs.

3.12.10.1 Source of methodology documentation

Rosenbaum et al., 2008, Hauschild et al., 2008.

Website: http://www.springerlink.com/content/8217520256r12w36/; from mid 2009: http://www.usetox.org

Methodology contact person: Michael Hauschild

3.12.10.2 General principles

Table 25 General principles of USEtox methodology

Principle	**Comment**
Intended purpose of the methodology:	Provide characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment.
Midpoint/endpoint:	Midpoint expressed in Comparative Toxic Units (CTUh) for human health impacts equivalent to incidence of cancer or non cancer case. The Comparative Toxic Units (CTU) may be transformed into DALY assuming an average DALY per cancer or non cancer case. For ecotoxicity impacts, the impact is expressed in Ecotoxic Comparative Toxic Units (CTUe) equivalent to pdf·m^2·yr.
Handling of choices:	The user is made conscious of the comparative nature of the assessment. Intermediary variables such as intake fraction, fate (residence time in each media) and inter-media transfer factors are also provided as intermediary results.
Data uncertainties:	Model variability of 1 order of magnitude. USEtox results falls within the range of the other models.
Regional validity:	Generic continent of 300,000 inhabitants in 1013 km^2 embedded in a global world box. Urban box with 10^6 inhabitants in 10,000 km^2.
Temporal validity :	Linear modelling largely independent of temporal constraints.

Principle	**Comment**
Time horizon:	Infinity
How is consistency ensured in the treatment of different impacts In characterisation In normalisation and weighting?	For all emission-based categories fate, exposure and effect factors are used in a consistent way for both ecotoxicity and human toxicity. Spreadsheet available for update and other new calculations.
Midpoint impacts covered:	Human toxicity Ecotoxicity Possibly compatible with Respiratory effects Indoor emissions
Endpoint impacts covered:	Human health, ecosystem quality
Approximate number of substances covered:	Approximately 3000 substances for emissions to urban air, air, freshwater, agricultural soil, natural soil.
Other observations:	None

3.12.10.3 Normalisation and weighting

Table 26 Normalisation and weighting in USEtox

How is normalisation performed?	No normalisation factors have been made available yet.
How is weighting performed?	No specific weighting developed for USEtox.

3.12.10.4 Interesting (unique) features

This model has been built on parsimony with a careful focus on the most influential elements of the models considered; a more transparent model is more likely to gain and retain acceptance and wide-spread use. In addition to the obvious need for good documentation and justification of choices, transparency was enhanced by the decision to create an entirely new model, building on contributions from most of the existing models. Parsimony required consensus on essential algorithm elements and hypotheses amongst the developers, leading to a robust model providing results that are consistent with existing models. The tangible outcome is USEtox, named in recognition of the UNEP-SETAC Life Cycle Initiative in the context of which it was developed. The model is supported by all participating model teams as a basis for future global recommendations of characterisation factors. This model will be in the public domain and will provide all nations, academic institutions, companies and non-profit organizations with a cost-free opportunity to carry out integrated and state-of-the art LCIA characterisation and comparative assessment of toxic impacts.

Additional characterisation factors are presently under development to assess in a consistent way the impact of primary and secondary particulates as well as of indoor emissions.

3.12.10.5 Interesting impact categories

- Human toxicity
- Ecotoxicity
- Possibly compatible with
- Respiratory effects and indoor air exposure.

3.12.11 EcoSense

EcoSense is an integrated atmospheric dispersion and exposure assessment model which implements the Impact Pathway Approach developed within ExternE and models damages to the AOPs Human Health and Natural Environment. In addition, Ecosense models impacts on man-made materials and resources (crops and building materials).

The damages to human health are expressed in monetary terms but have underlying information about mortality and morbidity. Damages to natural environment are expressed in potentially disappeared fraction of species.

EcoSense was designed to support the assessment of impacts and damages resulting from airborne pollutants from single point sources (electricity and heat production) in Europe but can also be used for analysis of multi emission sources in certain regions. The current version covers the emission of the priority pollutants SO_2, NO_x, primary particulates, NMVOC, NH_3 and a selection of toxic metals.

It models the impacts on different spatial scales, i.e. local (50 km around the emission source), regional (Europe-wide) and (northern) hemispheric scale and in principle supports spatial differentiation.

The version EcoSenseWeb has a publicly available (at a registration fee) web-based user interface and was developed within the European Commission projects NEEDS and CASES.

Being a regularly updated model of seemingly high scientific quality developed for policy support in the European energy sector, EcoSense could be an interesting candidate for future recommendations within the impact categories which it covers partly or fully: photochemical ozone formation, acidification, eutrophication, and respiratory inorganics.

Since it does not provide characterisation factors, it cannot be considered for recommendations at this point, but investigation of the possibilities to adapt EcoSense to characterisation modelling at both midpoint level and endpoint level. Critical points to look at are the adaptability of EcoSense to other parts of the world and its ability to derive generic factors based on e.g. a distribution of local factors. These are identified as research needs under several of the impact categories.

3.12.12 Ecological footprint

The ecological footprint (EF) analysis provides an indicator of human demand on the Earth’s ecosystems and natural resources. It reflects the biologically productive land and water area a population theoretically requires to produce the resources it consumes and to absorb part of the waste generated by fossil fuels and nuclear fuel consumption, using prevailing technology and resource management (Wackernagel and Rees, 1999; Wackernagel et al. 2002). In practice, EF calculations only include a limited range of environmental issues. EF includes for example land use to provide food, timber and sequestering the carbon dioxide from burning fossil fuels, besides it also sets aside a piece of land necessary to maintain biodiversity (Ecotec, 2001).

The concept of the method was developed in 1994, as a PhD dissertation of Mathis Wackernagel supervised by William Rees. In 1996 the book “Our ecological footprint” was published and since the year 2000 the method has gained increasing political interest and a significant amount of research, debates and calculations have been performed based on the concept.

The method doesn’t include, and cannot be divided in several impact categories, therefore it has not been possible to analyse separately each impact category. By an attempt to split the method up into several impact categories, the concept of the method would be lost. As a result the ecological footprint method is not considered in the standard analysis per impact category. However, this method will be further analysed as a whole applying the criteria developed for the different impact categories which it covers.

3.12.12.1 Source of methodology documentation

Wackernagel, M., Monfreda, C., Moran, D., Wermer, P., Goldfinger, S., Deumling, D., Murray, M., 2005. “National Footprint and Biocapacity Accounts 2005: The underlying calculation method”. Global Footprint Network, Oakland, California, USA.

ECOTEC-U.K. (2001), Ecological footprinting: A technical report to the STOA Panel (Draft). Published by the European Parliament.

Florian Schaefer, Ute Luksch, Nancy Steinbach, Julio Cabeca and Jorg Hanauer (2006) Ecological footprint and biocapacity: The world’s ability to regenerate resources and absorb waste in a limited time period. Published by European communities. ISBN 92-79-02943-6.

Ecological footprint Standards 1.0 (2006). Published by global footprint network.

Website: http://www.footprintnetwork.org

Methodology contact person: Mathis Wackernagel

General principles

Table 27 General principles of Ecological footprint methodology

Principle	**Comment**
Intended purpose of the methodology:	Providing an indicator of the biological productive area needed to fulfill human demand. Compound approach.
Midpoint/endpoint:	Endpoint method that calculates the area occupied to provide resources needed and absorb the waste that is generated, using prevailing technology and resource management.
Handling of choices:	Only biological productive areas, built-up area is considered to have the same value as primary cropland. Assumed that oceans absorb 35% of emissions, rest by average forest. Nuclear waste is considered by converting the output from nuclear-fired electricity in CO_2.
Data uncertainties:	Underestimation of reality. No figure of uncertainty is mentioned.
Regional validity:	Regional differences are handled on country level, by producing country specific yield factors.
Temporal validity :	Model is largely dependent on temporal constraints.
Time horizon:	--
How is consistency ensured in the	5 types of direct land occupation (cropland, pasture, forest,

Principle	Comment
treatment of different impacts - In characterisation - In normalisation and weighting?	fisheries, built-up area) and two indirect land occupations (fossil fuels and nuclear energy) are considered. All seven factors are expressed in global hectares (standardization based on productivity), which are normalized to actual biological productive hectares available at earth.
Midpoint impacts covered:	Not applicable
Endpoint impacts covered:	Not applicable
Approximate number of substances covered:	5 land use types 1 substance: carbon dioxide
Other observations:	None

3.12.12.2 Normalisation and weighting

Table 28 Normalisation and weighting in Ecological footprint

How is normalisation performed?	Normalisation is not performed.
How is weighting performed?	No explicit value-based weighting performed, while some considerations such as nuclear energy are included by assuming equivalency with other fuels.

3.12.12.3 Interesting (unique) features

The Ecological Footprint method expresses the effects of land occupation, carbon dioxide emissions and nuclear energy use in one single indicator, namely amount of global hectares. Solely considering carbon dioxide as an emission output is very limited and is a reason for much criticism. Equally, considering nuclear energy in this context is debated. However, progress is being made on including several other greenhouse gasses, although the method developers are not convinced this would change the results dramatically (Ecotec, 2001).

The method doesn’t allow land to provide simultaneously biodiversity, wood and carbon sequestration. The separation of these functions probably overstates demand slightly. However, Wackener et al. doubt that an adjustment would make a big impact on the results (Ecotec, 2001).

3.12.12.4 Impact categories pre-selected for further evaluation

The Ecological Footprint method does not provide separate methods for characterisation of individual midpoint impacts. As it covers both land use (occupation) impacts and carbon dioxide emissions, it does offer methods which may be considered as candidates for recommended characterisation models for the impact categories land use and climate change.

4 Pre-selection of impact categories for further evaluation

From the analysis of the methodologies, a pre-selection of impact categories was made, based on a number of criteria. This was done in order to avoid double work, as many methods underlying characterisation factors are very similar in different LCIA methodologies.

The criteria applied to exclude a method were:

- If a method is used in multiple LCIA methodologies, only the most recent and up to date version of that method is considered, taking into account also the broadness/completeness of elementary flows included.
- If a method is used that is adapted to other regions, but the method itself is not improved or changed in any significant way, this method is excluded from the further analysis.

In case of doubt on a given method, it was included in the analysis. This pre-selection has resulted in a reduction of impact categories under study from a potential of 156 methods to 91 methods to be analysed.

Next to this, a number of interesting approaches were identified that were not in one of the selected LCIA methodologies, but which were also included in the analysis. These add another 14 methods to be analysed and another 12 methods to be described in a generic way, especially in the light of making research recommendations.

4.1 Discussion

The table below gives the overview of the results of the pre-selection of characterisation methods. In some methods, an indicator can be calculated on the midpoint level and on the endpoint level. M is used to indicate Midpoint level and E to indicate endpoint level. In the case of ReCiPe, LIME and Impact 2002+, both the letter M and E are used, as these methodologies have characterisation factors both for the midpoint and endpoint level.

A number of observations can be made on this selection:

The most recent methods, especially the methods that combine midpoint and endpoint factors, like ReCiPe, Impact 2002+ and LIME get more attention in the evaluation. This is mainly due to the preference given to the use of the most recent versions of similar methods.

Endpoint methods are pre-selected quite often, as there are more ways to perform an endpoint characterisation than a midpoint characterisation. This is especially clearly visible in Climate change and Ozone depletion, where the consensus on midpoint seems to be very high, but the models for endpoints differ strongly.

Table 29 Pre-selection of characterisation models for further analysis

	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity[11]	Ionising radiation	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication.	Land use	Resource Consumption	Others
CML2002	o	o		M	o[12]	o	M	M	M	M	o	M	
Eco-indicator 99	E	E	E	o	o		E	E	E		E	E	
EDIP 2003/EDIP97[13]	o	M	o	M	o	M	M	M	M	M		M	Work environ. Road noise
EPS 2000	E	E	E	E	o	E	E	o	o	o	E	E	
Impact 2002+	o	o	E	M E	o	M E	E	M E		M E	o	E	
LIME	E	E	M	E		o	M E	M E	o	E	E	E	Indoor air
LUCAS	o	o		o		o	o	o	o	o	o	o	
MEEuP	o	o	M	M		M	M	M	M	M		water	
ReCiPe	M E	E	M E	M E	o	M E	M E	M E	o	M E	M E	E	
Swiss Ecoscarcity 07	o	o	o	o	M E	M	o	o	o	o	M E	water	Endocrine disruptors
TRACI	o	o	M	M		M	M	M	o	M		o	
Specific methods to be evaluated	Ecological footprint		[14]	USETox		USETox		Seppälä		Payet	Ecological footprint	deWulf et al.	Noise Müller Wenk
Specific methods of potential interest (not to be evaluated)				Watson (Bachmann)	Ecotoxicity of radiation (Laplace et al.)		EcoSense (Krewitt et al.)	EcoSense (Krewitt et al.)		Kärrman & Jönsson	[15]		Meijer indoor air UNEP Indoor air (Bruzzi et al., 2007)

o: Available in the methodology, but not further investigated

M: Midpoint model available and further analysed

E: Endpoint model available and further analysed

[11] Cancer and non cancer effects sometimes taken separately

[12] Optional study specific impact category

[13] EDIP97 for resources, EDIP2003 for the other impact categories

[14] EcoSense, Greco et al., UNEP (Potting et al.)

[15] Bos & Wittstock, 2007, Ertzinger, Milà i Canals, Stan Rhodes

For some impact categories, many alternative methods have been selected. This can be seen as a sign that there is no clear consensus on how to model such a method. Clear examples are acidification, eutrophication, land use and resources.

For noise and for indoor or work environment, several solutions seem to be available.

For ionizing radiation only one operational method has been identified, which goes back to Frischknecht et al (2000). This method is also used in Eco-indicator 99, CML 2002, Impact 2002+, ReCiPe and the Swiss Ecoscarcity 2006 method. As the latter is the latest implementation, this was the pre-selected version.

Characterisation models from the LUCAS methodology are not analysed in any impact category. This does not mean that it is not a good methodology, but it has been completely based on methods from other methodologies; the only change has been the adaptation to Canadian environmental conditions. Comparisons between the European and North American conditions typically shows very modest variations (less than factor 2-3) in characterisation factors across a broad selection of substances (Rochat et al., 2006). This is important when site-dependent factors are considered to be used in some applications, versus e.g. use of generic global averages.

Characterisation models from the MEEuP method have been included, even though these methods are partly taken from older versions of the other methodologies, such as the CML 1992 methodology. The approach used for the MEEuP primarily reflects weighting of emissions/resources using other legislative limits to provide indicators. From a scientific perspective, these indicators may not be the most suitable for use in relative comparisons across emissions and resources consumed as required in a life cycle assessment. However, it was decided to incorporate several MEEuP characterisation models as one example due to the political relevance of this type of methodology and of the indicators adopted.

The Ecological Footprint method has been considered as candidate for recommended characterisation models for the impact categories land use and climate change. Value-based extensions to other impact categories are not considered further.

In addition to the methods described above other methods might be in line with the ISO Standards 14040/14044. However, if a study wants to claim to be in line with the ILCD then further requirements might have to be followed.

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6 Annex 1: Overview of existing environmental impact assessment methodologies for LCA

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
Website Access Point	http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html	www.pre.nl/eco-indicator99/	http://www.tempo.ipl.dtu.dk/users/mic/Projects.htm#EDIP97	http://www.tempo.ipl.dtu.dk/users/mic/Projects.htm#EDIP2003
Key Contacts	Jeroen Guinée	Mark Goedkoop	Michael Hauschild	Michael Hauschild
Midpoint Impact Categories				
Climate change	(93) kg CO_2-eq./kg emitted to air	(38) DALYs/kg emission	(77 + factors for organics) kg CO_2-eq./kg emitted	(77 + factors for organics) kg CO_2-eq./kg emitted
- model	GWP100 (J. T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden and D. Xiaosu (Eds.), 2001. IPCC Third Assessment Report: Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK.)	Effects of rising sea level, malaria and heat on Human health damage are considered. Fund 1.6 model is used to calculate damage for CO_2, CH_4 and N_2O. Umbrella principle of Hofstetter (1998) is used for extrapolation to other gasses (Schimmel et al. 1996).	GWP100, Albritton, D.L. and Meira Filho, L.G. (eds.): Climate Change 2001: The scientific basis. ISBN: 0521014956, Earthprint Ltd. U.K., 2001.	GWP100, Albritton, D.L. and Meira Filho, L.G. (eds.): Climate Change 2001: The scientific basis. ISBN: 0521014956, Earthprint Ltd. U.K., 2001.
Ozone depletion	(24) kg CFC-11-eq./kg emitted to air	(23) DALYs/kg emission	(20) kg CFC-11-eq./kg emitted	(20) kg CFC-11-eq./kg emitted

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
- model	ODP steady state (WMO (World Meteorological Organisation), 1992: Scientific assessment of ozone depletion: 1991. Global Ozone Research and Monitoring Project - Report no. 25. Geneva. WMO (World Meteorological Organisation), 1995: Scientific assessment of ozone depletion: 1994. Global Ozone Research and Monitoring Project - Report no. 37. Geneva. WMO (World Meteorological Organisation), 1999: Scientific assessment of ozone depletion: 1998. Global Ozone Research and Monitoring Project - Report no. 44. Geneva.)	Fate model of Slaper et al. (1992) is used. Exposure is based on the observed ozone trend by TOMS (total Ozone mapping spectrometer). Effect data from UNEP 1994 and 1998. Damage factors derived from Hofstetter (1998)	Ajavon, A.N.et al. (eds.): Scientific assessment of ozone depletion: 2002. World Meteorological Organisation Global Ozone Research and Monitoring Project – report no. 47, WMO Geneva, 2002.	Ajavon, A.N.et al. (eds.): Scientific assessment of ozone depletion: 2002. World Meteorological Organisation Global Ozone Research and Monitoring Project – report no. 47, WMO Geneva, 2002.
Human toxicity, including workplace and indoor pollutants	(859) kg 1,4-DCB-eq. emitted to air/kg emitted to air water, soil	(55) & (6) (DALYs/kg emission)	(181) m^3 air/g emitted to air, water or soil; m^3 water/g emitted to air, water or soil; m^3 soil/g emitted to air, water or soil	(181) person

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
- model	HTP infinite (Huijbregts, M.A.J., 1999a: Priority assessment of toxic substances in LCA. Development and application of the multi-media fate, exposure and effect model USES-LCA. IVAM environmental research, University of Amsterdam, Amsterdam. Huijbregts, M.A.J., 2000. Priority Assessment of Toxic Substances in the frame of LCA. Time horizon dependency of toxicity potentials calculated with the multi-media fate, exposure and effects model USES-LCA. Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, The Netherlands. (http://www.leidenuniv.nl/interfac/cml/lca2/) Huijbregts, M.A.J., U. Thissen, J.B. Guinée, T. Jager, D. van de Meent, A.M.J. Ragas, A. Wegener Sleeswijk & L. Reijnders, 2000. Priority assessment of toxic substances in life cycle assessment, I: Calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES-LCA. Chemosphere 41: 541-573. Huijbregts, M.A.J., J.B. Guinée & L. Reijnders, 2000. Priority assessment of toxic substances in life cycle assessment, III: Export of potential impact over time and space. Chemosphere (accepted).)	Fate: EUSES Effect: Unit risk concept, factors from IRIS (US EPA). Damage factors derived from Murray et al. (1996)	EDIP97 model for human toxicity (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 7)	Hazard factor (EDIP97 model, toxicity and site-generic fate) multiplied by site-dependent exposure factor based on combined Gaussian plume and trajectory modelling for four European regions (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 8)
Ionising radiation		(25) DALYs/kg emission)	-	-

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
- model	not baseline	Calculated using the steps fate-exposure-effect-damage. Fate model based on the French nuclear fuel cycle (Dreicer et al 1995).Transformed to Man Sievert for tritium, carbon-14, Krypton-85 and Iodine-129. Fate, effect and damage calculated by Frischknecht et al. (1999). Direct cancer effects and hereditary effects are considered Damage from Hereditary effect estimated based on Hofstetter.		
Photochemical ozone creation	(127) kg ethylene-eq./kg emitted to air	(50) DALYs/kg emission)	(81 individual VOCs, 13 VOC mixtures and CO) kg ethylene-eq./kg emitted.	(81 individual VOCs, 13 VOC mixtures, CO and NOx) m^2 ecosystem *ppm*hours/g emitted; pers*ppm*hours/g emitted
- model	POCP (Jenkins, M.E. & G.D. Hayman, 1999: Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. Atmospheric Environment 33: 1775-1293. Derwent, R.G., M.E. Jenkins, S.M. Saunders & M.J. Pilling, 1998. Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. Atmospheric Environment, 32. p 2429-2441; high NO_x).	Fate model taking into account residence time and dilution height. Umbrella principle for individual VOCs. Dosis-response relationships are used to calculate the effects. Damage factors derived from Hofstetter (1998)	POCP over 4-9 days estimated with UK AEA's Photochemical Trajectory model (Derwent and Jenkins) for high NOx background concentration (>=10 ppbv annual average) and with IVL's adaptation (Andersson-Sköld et al.) for low NOx background concentration (> 10 ppbv) (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 3).	Site-dependent regression equation derived for RAINS model (for VOC and NOx) corrected for substance properties using POCP factors from Derwent and Jenkins (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 7)
Acidification	(5) kg SO_2-eq./kg emitted to air	(3) PDF/m^3/yr)	(12) kg SO_2-eq. /kg emitted	(12) m^2 unprotected ecosystem/g emitted

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
- model	AP (Huijbregts, M., 1999b: Life Cycle Impact Assessment of acidifying and eutrophying air pollutants. Calculation of equivalency factors with RAINS-LCA. Interfaculty Department of Environmental Science, Faculty of Environmental Science, University of Amsterdam, The Netherlands; average Europe total, A&B)	Only airborne emissions taken into account, This impact category is combined with Eutrophication. It uses a GIS system for the Netherlands. Dutch model MOVE developed by RIVM, combines fate with effect, translates changes in deposition in changes in species disappearance. Effect is modelled by SMART (RIVM), and assesses disappearance of target species	Acidification potential based on maximum release of protons upon environmental mineralisation. Correction with site factor possible (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 4).	RAINS model version 7.2 (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 4)
Terrestrial eutrophication	(54) kg PO_4^{3-}-eq./kg emitted to air, water, soil	(3) DALYs/kg emission)	(12) kg NO_3^--eq./kg emitted; kg N-eq/kg emitted; kg P-eq/kg emitted;	(12) m^2 unprotected ecosystem/g emitted;
- model	Generic EP for each eutrophying emission to air, water and soil, fate not included (Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, H.P. de Goede, 1992: Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Sciences (CML), Leiden University, Leiden.)	Terrestrial eutrophication grouped with terrestrial acidification. The damage caused by fertilisers that are deliberately applied on agricultural soil is already included in the land-use damage factors, and should not be considered in the acidification category.	Treated in same way as aquatic eutrophication (for airborne emissions).	RAINS model version 7.2 (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 5)
Aquatic eutrophication	(54) kg PO_4^{3-}-eq./kg emitted to air, water, soil	(200) PDF/m^3/yr/kg emission	(12) kg NO_3^--eq./kg emitted; kg N-eq/kg emitted; kg P-eq/kg emitted	(12) kg NO_3^--eq./kg emitted; kg N-eq/kg emitted; kg P-eq/kg emitted
- model	generic EP for each eutrophying emission to air, water and soil, fate not included (Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, H.P. de Goede, 1992: Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Sciences (CML), Leiden University, Leiden.)	Fate: EUSES. Effect: dose-response curves and based on non observed effect concentration, expressed as PAF. Main route is water.	Nutrient enrichment (N and P) calculated separately with possibility of differentiation between N-limited and P-limited recipients but also with possibility of aggregation based on Redfield ratio (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 5)	Nutrient content based on EDIP97 factors multiplied by fate factor derived using the CARMEN (v. 1.0) model (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 6).

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
Ecotoxicity	(892) kg 1,4-DCB-eq. emitted to fresh water, sea water or soil/kg emitted	m^2.yr	(192) m^3 water/g emitted to air, water or soil; m^3 soil/g emitted to air, water or soil	(192) m^3 water/g emitted to air, water or soil; m^3 soil/g emitted to air, water or soil
- model	3 separate impact categories for resp. Fresh Aquatic, Marine Aquatic and Terrestrial Ecotoxicity; FAETP infinite, MAETP infinite and TETP infinite (Huijbregts, 1999 & 2000; see above)	Land transformation and occupation is included. Based on species-area relationship, mainly based on the work of Köllner and Rüdi Müller-Wenk	EDIP97 model for ecotoxicity (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 6)	Hazard factor (EDIP97 model, ecotoxicity and site-generic fate) multiplied by site-dependent exposure factor based on typical behaviour patterns in four European regions (Hauschild and Potting: Spatial differentiation in Life Cycle Impact Assessment - the EDIP2003 methodology, 2005, Chapter 9)
Land use	m2.yr/m2.yr	MJ surplus energy, Resources, based on Chapman and Roberts (1982), and Müller-Wenk (1998);	-	-
- model	Land competition, unweighted aggregation of land use (15. Guinée, J.B. (Ed.), M. Gorrée, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. Wegener Sleeswijk, S.Suh, H.A. Udo de Haes, J.A. de Bruijn, R. van Duin and M.A.J. Huijbregts, 2002. Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Series: Eco-efficiency in industry and science. Kluwer Academic Publishers. Dordrecht).	For fuels: When conventional sources are depleted, a future energy mix of shale, oil or gas is used. Surplus energy concept from Muller-Wenk. For minerals: Chapman and Roberts 1982 describes the relation between resource availability and the concentration. After extraction, extra energy is needed to extract the same amount.	-	-
Resource consumption	(88) kg antimony eq./kg extracted	(0) DALYs/Pa^2.s)	(33) Person reserve	As EDIP97

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
- model	ADP based on ultimate reserves and yearly extraction rates (15. Guinée, J.B. (Ed.), M. Gorrée, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. Wegener Sleeswijk, S.Suh, H.A. Udo de Haes, J.A. de Bruijn, R. van Duin and M.A.J. Huijbregts, 2002. Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Series: Eco-efficiency in industry and science. Kluwer Academic Publishers. Dordrecht). Primary energy carriers and minerals assessed together. For biotic resources no baseline; reserves and deaccumulation rate as alternative	MJ surplus energy, Resources, based on Chapman and Roberts (1982), and Müller-Wenk (1998);	Severity based on global annual consumption and supply horizon representing economically exploitable reserve 2004) (Hauschild and Wenzel: Environmental Assessment of Products vol. 2, 1998, Chapter 8, updated figures). For renewable resources only factor if regeneration rate exceeded by extraction (regional dependency)	As EDIP97
Noise	no baseline	Missing	-	pers*sec
- model	no baseline		-	Integrated product of noise nuisance factor (based on exceedance of background noise level) and population density within area where noise exceeds background level. Model operational for noise from road or rail transport (Potting and Hauschild: Background for Spatial differentiation in LCA impact assessment, 2005, Chapter 10).
Accidents	no baseline	Missing	-	-
- model	no baseline			
Endpoint impact categories				
Human Health (HH)		DALYs		

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
Climate change, midpoint to damage HH				
Ozone depletion to HH				
Human toxicity, including workplace and indoor pollutants to HH				
Ionizing radiation to HH				
Photochemical ozone creation to HH				
Noise to HH				
Natural environment (NE)		PDF-m^2-yr		
Climate change, midpoint to damage NE				
Acidification to NE damage				

LCIA METHODOLOGY	CML 2002 (baseline; spreadsheet)	Eco-indicator 99	EDIP97	EDIP2003
Aquatic and terrestrial eutrophication to NE				
Aquatic and terrestrial ecotoxicity to NE				
Land use to NE				
Natural resources	(98) Primary energy carriers and minerals assessed together. ADP based on ultimate reserves and extraction rates	MJ surplus energy, Resources	All non-renewable resources assessed together based on scarcity - see description of midpoint model.	As EDIP97
Energy to NR				
Minerals to NR				
Water to NR				

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
Website Access Point	http://eps.esa.chalmers.se/	http://www.epfl.ch/impact	http://www.jemai.or.jp/lcaforum/index.cfm	soon to come www.ciraig.org
Key Contacts	Bengt Steen	Olivier Jolliet	Norihiro Itsubo	Ralph Rosenbaum
Midpoint Impact Categories				
Climate change		(69) kg CO_2eq.	(76) kg CO2eq./kg emitted	(95) kg CO2-eq./kg emitted
- model		GWP500, IPCC Climate Change 2001: The scientific basis" report (http://www.grida.no/climate/ipcc_tar/wg1/248.htm		GWP500, Albritton, D.L. and Meira Filho, L.G. (eds.): Climate Change 2001:The scientific basis. ISBN: 0521014956, Earthprint Ltd. U.K., 2001.
Ozone depletion		(97) kg CFC-11 eq. into air	(*) kg CFC-11eq./kg emitted	(19) kg CFC-11-eq./kg emitted
- model		US EPA Ozone Depletion Potential List, column ODP1 WMO 2002: (http://www.epa.gov/ozone/ods.html). HALON-2311" and "Methyl chloride" midpoint CF derived from Eco-indicator 99 (EI99-2ndv).		Montzka, S.A., Frazer, P.J. and co-authors: Controlled substances and other source gases. Chapter 1 in: Ajavon, A.N., Albritton, D.L., Mégie, G., and Watson, R.T. (eds.): Scientific assessment of ozone depletion: 2002. World Meteorological Organisation Global Ozone Research and Monitoring Project – report no. 47, WMO Geneva, 2002
Human toxicity, including workplace and indoor pollutants		(800 in air, soil, agricultural soil and water) kg chloroethylene into air eq. into air (cancer & non cancer) kg PM2.5eq. into air (respiratory inorganics)	(81) kg Benzene-eq. emitted to air/kg emitted	(~1000) kg chloroethylene-eq. into air (cancer & non cancer)/kg emitted

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
- model		Impact 2002 model for cancer and non-cancer (Pennington et al., 2005; Crettaz et al, 2002 for human dose-response). Ecoindicator 99 for respiratory inorganics. Midpoint is backcalculated from damage.		Impact 2002 model parameterised for Canadian conditions for cancer and non-cancer (Pennington et al., 2005; Crettaz et al, 2002 for human dose-response). Ecoindicator 99 for respiratory inorganics.
Ionising radiation		(21 in air, 13 in water) Bqeq carbon-14 into air		not included
- model		From Ecoindicator 99		not included
Photochemical ozone creation		(132) kg ethylene eq. into air	(686) kg ethylene-eq./kg emitted	(530) kg ethylene-eq. into air/kg emitted
- model		From Ecoindicator 99		Maximum Incremental Reactivities (MIR) from Carter, W. 1994. "Development of ozone reactivity scales for volatile organic compounds". Journal of the Air and Waste Management Association. 44:881-899. and Carter, W.P.L. 1998. Updated maximum incremental reactivity scale for regulatory applications. University of California, Riverside, 73p.
Acidification		(12 in air, 6 in soil, 6 in water) kg SO_2 eq. into air	(6) kg SO_2-eq./kg emitted, D: NPP/kg emitted, JY/kg emitted	(22) SO_2-eq./kg emitted

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
- model		Aquatic acidification From CML 2002, v2.6: "impact assessment juli 2002.xls/characterisation factors. (Data are the same as in CML92). Terrestrial acidification as in Ecoindicator 99 together with terrestrial eutrophication (see below)		Deposition model: ASTRAP (Advanced Statistical Trajectory Regional Air Pollution), a North-American deposition model, to assess SO_2 and NO_x fate in acidification, photochemical smog and eutrophication (aquatic and terrestrial). Outputs from ASTRAP (SO_2 and NO_x deposition matrices) are used to assess the fate in acidification and photochemical smog with the same calculation procedure than that developed by Norris (2003) for TRACI (Norris G (2003): Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts – Methods for acidification, eutrophication and ozone formation. J Ind Ecol 6(3-4) 79-100).
Terrestrial eutrophication		(9 in air) kg SO_2 eq. into air		(11) kg N-eq./kg emitted
- model		Terrestrial eutrophication grouped with terrestrial acidification as in Ecoindicator 99. The damage caused by fertilisers that are deliberately applied on agricultural soil is already included in the land-use damage factors, and should not be considered in the acidification category.		Fate based on ASTRAP (see acidification model) model, considering only the fraction not contributing to aquatic eutrophication and allocated as a function of each ecozone forest area (considered as the only ecosystem affected by terrestrial eutrophication).
Aquatic eutrophication		(10) kg PO_4^{3-} eq. into water	(14) kg PO_4^{3-}-eq./kg emitted	(17) kg NO_3^--eq./kg emitted; kg N-eq/kg emitted; kg P-eq/kg emitted;

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
- model		Aquatic By default, freshwater ecosystems are assumed to be P-limited. Only phosphate emissions considered. Values are from CML 2002, v2.6: "impact assessment juli 2002.xls/characterisation factors". The damage caused by fertilisers that are deliberately applied on agricultural soil is already included in the land-use damage factors, and should not be considered in the aquatic eutrophication category		Atmospheric deposition based on ASTRAP (see acidification model) model, considering only the fraction not contributing to terrestrial eutrophication and allocated as a function of each ecozone surface water area. Further sources as nutrient loading (L) by point (wastewater) and non-point sources (agriculture from manure and fertilizers) and phosphorus loading from agriculture were assessed using the CARMEN (CAuse effect Relation Model for Environment policy Negociations) model (Haan BJ, Klepper O, Sauter FJ, Heuberger PSC, Rietveld AJ (1996): The Carmen status report 1995. Bilthoven, the Nederlands. RIVM report 461501005). The total discharge of nitrogen and phosphorus is calculated by combining land-based (atmospheric and agricultural) and population-based (wastewater) inputs per region.
Ecotoxicity		(431 in air, soil & water) kg triethylene glycol eq. into water / soil	(81) kg benzene-eq. emitted to water/kg emitted	(~2000) kg triethylene glycol-eq. into water/kg emitted
- model		Impact 2002 model (Pennington et al., 2005). Midpoint is backcalculated from damage.		Impact 2002 model regionalised and parameterised to Canadian ecozones (Pennington et al., 2005)
Land use		(15) m^2 organic arable crop	(85) (occupation) m^2.yr, (transformation) m^2	currently in development
- model		Mainly from Eco-indicator 99, only land occupation considered		currently in development
Resource consumption		(9) MJ total for energy, (20) MJ surplus: Additional cumulative non renewable primary energy demand to close life cycle	(4) MJ total for energy, (23) The inverse of resource reserve for minerals	(56) mineral extraction MJ surplus, (24) Fossil fuel, MJ surplus

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
- model		Surplus energy concept from Müller-Wenk, but summing MJ primary and MJ surplus energy for fossil fuels		Surplus energy concept from Müller-Wenk (1998)
Noise		None		not included
- model		-		not included
Accidents		Compatible with accident statistics (DALY)		not included
- model				not included
Endpoint impact categories				
Human Health (HH)	'(169) (pyears) (158) YOLL-years of lost life, (161) severe morbidity, (1) severe nuisance and (7) nuisance	6 midpoint categories contribute to human health damage: ozone depletion, cancer, con-cancer, respiratory inorganics, ionizing radiation and photochemical ozone; DALYs Human Health includes mortality and morbidity. The considered DALYs are DALY(0,0) without age correction nor discounting.	DALYs	not included
Climate change, midpoint to damage HH	Global warming pathway calculated for CO2. Effects of temperature stress, starvation, flooding and malaria are considered. IPCC 100yr is used to calculate equivalency factors with CO2 as reference.	Climate change is kept as an independent damage category relating to Life Support Systems		not included
Ozone depletion to HH	Empirical model of CFC-11, taking into account severe morbidity and YOLL due to skin cancer. ODP of IPCC 100yr is used to calculate other equivalency factors withCFC-11 as reference.	1.05E-3 DALY/kg CFC-11, taken from Ecoindicator 99		not included

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
Human toxicity, including workplace and indoor pollutants to HH	Empirical method. Using USEPA AIRS and IARC as data sources. Mortal and non mortal cancer is considered.	2.8E-6 DALY/kg Chloroethylene, based on 13.0 DALY/cancer case and 1.3 DALY/non cancer case, 7.E-4 DALY/kg PM2.5 emitted, based on 70 kg DALY/kg PM2.5 inhaled.		not included
Ionizing radiation to HH	Missing			not included
Photochemical ozone creation to HH	Dose response relationship of PM10 based on Rabl (1997). Extrapolation for all other substances.			not included
Noise to HH	Empirical model. Nuisance calculated taking into account exposure when noise level is above 65dB.			
Natural environment (NE)	(160) NEX, normalized extinction of species, dimensionless	4 midpoint categories contribute to natural environment: PDF-m2-year; 1 PDF*m^2-year = 1/2 PAF-m^3-year/mean depth	EINES (Expected Increase in Number of Extinct Species)	not included
Climate change, midpoint to damage NE	Global warming pathway calculated for CO2. Effects on species disappearance, crop production and wood production (due to temperature rise and fertilization) are considered. IPCC 100yr is used to calculate equivalency factors with CO2 as reference.	kg CO2 eq. Climate change kept as separate damage on life support system		not included
Acidification to NE damage	Acidification pathway calculated for SO2. Effects on fish and meat production, extinction of species and base-cation capacity for soil are considered. IPCC 100yr is used to calculate equivalency factors with SO2 as reference.	Aquatic acidification not used for damage so far, model developed later within the NEEDS EU-project (Payet et al). Terrestrial acidification from Ecoindicator 99: 1.04 PDF-m^2-yr/kgSO_2		not included

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
Aquatic and terrestrial eutrophication to NE	Eutrophication pathway calculated for NO_x. Effects on extinction of species are considered. IPCC 100yr is used to calculate equivalency factors with NO_x as reference.	Aquatic eutrophication not used for damage so far, model developed later within the NEEDS EU-project (Payet et al). Terrestrial eutrophication from Ecoindicator 99 : 1.04 PDF-m^2-yr/kgSO_2		not included
Aquatic and terrestrial ecotoxicity to NE	Ecotoxicity by metal emission to water, soil or air is based on mercury emission to air. Rough guess that 1% of the NEX is threatened by mercury. Observational data of Sweden is used to estimate the influence of mercury on fish production.	5.02E-5 PDF*m^2-year/kg triethylene_glycol to water and 7.91E-3 PDF*m^2-year/kg triethylene_glycol to soil		not included
Land use to NE	Normalised Extinction of species (NEX) is calculated for use of arable land, forest and roads. Based on Swedish study. Rough estimation.	as in Ecoindicator 99		not included
Natural resources	(81) kg / kg reserves (1) Fossil oil, (1) fossil coal, (1) fossil natural gas and (78?) element reserves, (112) crop production, (112) wood production, (9) fish & meat production, (2) Drinking water and Irrigation water, (7) mole H+ equivalents Base cat-ion capacity of soil, Recreational and cultural values. Market scenario where future generation pays for present abiotic stock resources (for a sustainable alternative).	2 midpoint categories contribute to natural resources: energy and mineral resources; MJ primary non renewable energy	(Japanese Yen) Loss of economic value defined as an element of 'Social assets', mineral resources and fossil fuels, damage on crops, fishery and forestry. (dry kg) NPP Net Primary Productivity	not included

LCIA METHODOLOGY	EPS 2000d	IMPACT 2002(+)	LIME	LUCAS
Energy to NR	Energy sources included: fossil oil, fossil coal, natural gas. The WTP is calculated using an optimised technology. Alternative for fossil oil is rapeseed oil. The alternative for coal as energy carrier is not included in the method. The alternative for coal as source of the element carbon is charcoal. The alternative for natural gas is bio-gas.	MJ surplus energy + MJ non renewable energy		not included
Minerals to NR	Ore production from average earth crust composition, using present day technology. For approximately 80 minerals.	MJ surplus energy		not included
Water to NR				not included

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Website Access Point	-	http://www.umwelt-schweiz.ch/buwal/eng/fachgebiete/fg_produkte/umsetzung/oekobilanzen/index.html	http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm	http://www.vhk.nl/downloads.htm http://ec.europa.eu/enterprise/eco_design/relactiv.htm	-
Key Contacts	Mark Goedkoop	Rolf Frischknecht (2006), Arthur Braunschweig (1997)	Jane Bare	René Kemna	Michael Hauschild
Midpoint Impact Categories					
Climate change	(64) CO_2-eq / kg emitted	(48) CO_2-eq / kg emission	(24) CO_2-eq. / kg emission	(85) kg CO_2-eq./kg emitted	
- model	GWP100, IPCC Climate Change 2007	Based on GWP according to IPCC 2001. For CO_2, Critical flow of 1t/pers-year. For other greenhouse gases, based on GWP100 equivalency with CO_2	GWP100, IPCC Climate Change 2001: The scientific basis" report (http://www.grida.no/climate/ipcc_tar/wg1/248.htm)	GWP100, Albritton, D.L. and Meira Filho, L.G. (eds.): Climate Change 2001:The scientific basis. ISBN: 0521014956, Earthprint Ltd. U.K., 2001.	
Ozone depletion	(22) CFC-11-eq. / kg emitted	(26) CFC-11-eq. / kg emission	(89) CFC-11-eq. / kg emission	(73) CFC-11-eq. / kg emission	
- model	WMO (2003), World Meteorological Organization 2003. Scientific Assessment of Ozone Depletion: Global Ozone Research and Monitoring Project - Report No. 47.	Comparison between ozone depleting substances based on ODP	ODPs published in the Handbook for the International Treaties for the Protection of the Ozone Layer (UNEP-SETAC 2000: www.uneptie.org/pc/sustain/lca/letter-of-intent.htm)	ODPs published in: REGULATION (EC) No 2037/2000 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 June 2000 on substances that deplete the ozone layer.	

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Human toxicity, including workplace and indoor pollutants	(1000) 1,4-DCB to air/kg emission for toxic impacts; (4) PM10-eq/kg emission for respiratory impacts	-33	(386) Benzene-e/kg emissions (Cancer), toluene-e/kg emissions (NonCancer), DALYs/tonne emissions (Criteria) calculated using the CalTox model.	(17) ng TEQ (TCDD-eq) to air/ng emission of POP; (1) PM10 g emission for smog Human Toxicity; (10) Heavy Metals (HM) in mg Ni-eq emitted to air/mg HM emitted to air; (3) "PAH" (general header for PAH, benzene and CO) in mg Ni-eq emitted to air/mg "PAH"emitted to air; (9) Heavy Metals (HM) in mg Hg/20-eq emitted to water/mg HM emitted to water	CTU humans: Comparative Toxic Units - humans
- model	USES-LCA 2.0 for toxic pollutants (metals and organics). Effect factors are based on the inverse of ED50 extrapolated to humans. The atmospheric European transport model EUTREND for primary and secondary aerosols	critical flow for PM10 and other toxics (heavy metals), partly derived from 1998 maximal admissible concentration	Human toxicity potentials (HTPs) are derived using a closed-system, steady-state version of CalTOX (Version 2.2) (McKone 1993), a multimedia fate and multiple-exposure pathway model with fixed generic parameters for the United States.	TEQ values are taken from Annex I of the Waste Incineration Directive 2000/76/EC; PM10 emission is taken as emission without any further assessment in g; HM air and "PAH" is a construct based on European Community legislation and strategies, and on The United Nations Economic Commission for Europe (UNECE) protocol; HM water is an estimated constructed from Guinée et al. (2002) Handbook on LCA and EPER (European Pollutant Emission Register) reports.	USEtox: UNEP-SETAC consensus model for comparative assessment of toxics
Ionising radiation	(21 air, 14 river, 14 ocean) kBq U-235 air-eq/kBq emitted	(2) volume		not included	
- model	Frischknecht et al 2000	Radiation is treated in two ways: One is related to the emissions to the sea and the second to the radioactive waste, for which the critical flow at 50% of present volume of radioactive wastes is taken		not included	

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Photochemical ozone creation	(126) kg NMVOC-eq./kg emitted	NMVOC	(529) g - NOx-e / m / kg emission	(1) VOC in mg	
- model	Atmospheric European transport model LOTOS-EUROS for calculation NMVOC and NOx midpoint factors. Further subdivision in individual NMVOCs, based on POCP-values of Derwent and others	Critical flow for NMVOC corresponding to Swiss political aims. i.e. emission flow in year 1960	Carter's reactivity calculations (Carter, W. 2000. Updated maximum incremental reactivity scale for regulatory applications. Sacramento, CA: California Air Resources Board.). U.S.-specific modelling for region specific differential influence on fate, transport, and expected effects.	VOC is taken as group parameter and VOC measured from different sources (production processes, fossil fuel extraction & distribution, combustion, solvent and other product use, mobile sources, agriculture and waste) are aggregated without any further characterisation	
Acidification	(4) kg SO_2-eq. /kg, time horizon 500 years	(3 resp. 5) H+ moles-e / kg emission	(17) H+ moles-e / kg emission	(16) g SO_2-eq. /g emitted	
- model	Combination of atmospheric European transport model EUTREND and European soil model SMART 2.0	(3 resp. 5) HCl and HF factors derived from the SO_2 factor based on H+ moles-e / kg emission	Empirically calibrated atmospheric chemistry and transport model to estimate total North American terrestrial deposition of expected H_ equivalents due to atm. emission of NOx and SO2, as a function of location. (Norris, G. 2002. Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts: Methods for acidification, eutrophication, and ozone formation. Journal of Industrial Ecology 6(3/4): 83–105.)	Acidification potential based on maximum release of protons upon environmental mineralisation (Sources: 1) The United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) (Gothenburg Protocol); 2) Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede, 1992. Environmental Life Cycle Assessment of products. Guide and Backgrounds. CML, Leiden University, Leiden.).	
Terrestrial eutrophication	not included			not included	
- model	not included	NH3 critical flow derived from deposition object		not included	

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Aquatic eutrophication	(4) kg N-eq/kg emission for marine eutrophication (2) kg P-eq/kg emission for freshwater eutrophication. Factors for water and soil emissions are given for N and P total emissions. This can be converted to any N and P species emitted to water or soil, based on molecular weight	(4) g N and g P	(18) N-e / kg emission	(11) mg PO_4^{3-}-eq./mg emitted	
- model	Combination of atmospheric European transport model EUTREND and European water model CARMEN	Critical flow for P based on maximal admissible concentration. For N, based on emission reduction objectives	U.S.-specific modelling is used. Product of nutrient factor (algae growth) and transport factor (probability that the release arrives in an aquatic environment). (Norris, G. 2002. Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts: Methods for acidification, eutrophication, and ozone formation. Journal of Industrial Ecology 6(3/4): 83–105.)	Eutrophication potential based on the Redfield ratio as implemented in Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede, 1992. Environmental Life Cycle Assessment of products. Guide and Backgrounds. CML, Leiden University, Leiden, with some extensions.	
Ecotoxicity	(2654) 1,4-DCB to water or soil/kg emission. Categories are freshwater, marine water and soil ecosystems	(42) g	(161) 2,4-dichlorophenoxyacetic acid/ kg emission	As far as considered, it is integrated in the human toxicity approach	CTU ecosystems: Comparative Toxic Units - ecosystems

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
- model	USES-LCA 2.0 for toxic pollutants (metals and organics). Effect factors are based on the inverse of the average toxicity derived from EC50 data	Critical flow for toxics (heavy metals) derived from maximal admissible concentration	Set of ETP estimates use the modified version of CalTOX and the chemical and landscape data sets employed by Hertwich and colleagues (2001) (Hertwich, E. G., S. F. Mateles, W. S. Pease, and T. E. McKone. 2001. Human toxicity potentials for life cycle analysis and toxics release inventory risk screening. Environmental Toxicology and Chemistry 20: 928–939)	As far as considered, it is integrated in the human toxicity approach	USEtox: UNEP-SETAC consensus model for comparative assessment of toxics
Land use	(occupation) m^2.yr, (transformation) m^2	(4) Ecofactors per m2 landfill area occupied	Use of a certain amount of land. (m^2)	not included	
- model	From CML 2000. With differentiation between urban and agricultural occupation, and transformation of natural areas.	Volume and weight of controlled waste deposition (use of scarce space for waste depositions). 4 land types for landfills according to CORINE are differentiated.	As a proxy of environmental importance, the density of threatened and endangered species in a specific area is considered.	not included	
Resource consumption	(..) mineral extraction Mc values [-/kg], (..) Fossil fuel, upper heating value [MJ/kg]	Energy inputs, expressed as energy content of consumed energy carriers. New approach for water in the 2007 update	Water use: not characterized yet.	water use and energy use	
- model		Critical flow based on energy consumption in 1990		Water use, process water (litres) and Cooling water (litres). Energy, as Total Gross Energy Requirement (in MJ primary) and Electricity (in MJ primary or in kWhe).	
Noise	not included	not included		not included	
- model	not included	not included		not included	
Accidents	not included	not included		not included	

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
- model	not included	not included		not included	
Endpoint impact categories					
Human Health (HH)	6 midpoint categories contribute to human health damage: global warming; ozone depletion; human toxicity; fine particulate matter, ionizing radiation and photochemical ozone; DALYs Human Health includes mortality and morbidity. The considered DALYs are DALY(0,0) without age correction nor discounting.	Inventory flows are normalised by the actual flows and then weighted by the square of the ratio of the actual to the critical flow			USEtox stops at CTU - representing cases of cancer and non-cancer
Climate change, midpoint to damage HH	Pulse temperature model of Meinshausen for CO2 combined with DALY estimates by WHO-study (McMichael et al 2003). Extrapolation to other greenhouse gases with GWP100	For CO_2, Critical flow of 1t/pers-year based on sustainable level worldwide			
Ozone depletion to HH	Model AMOUR, available at RIVM	For CFC 11, based on tolerable emissions for 2001 to 2011: 850 t/year for Switzerland			

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Human toxicity, including workplace and indoor pollutants to HH	USES-LCA 2.0 for toxic pollutants (metals and organics) extended with slope factors of non-linear dose-response curves and DALYs specified for cancer and non-cancer effects separately. EUTREND for primary and secondary aerosols, combined with epidemiological dose-response data and DALY estimates for chronic mortality, acute mortality, respiratory morbidity and cardiovascular morbidity related to PM10 exposure	critical flow for PM10 and other toxics (heavy metals), partly derived from 1998 maximal admissible concentration			Though not recommended by USEtox a possibility is to account for e.g. an average severity of 11.5 or 13.0 DALY/case (13 includes other cancers) if cancer is taken as a basis. The considered DALYs are DALY(0,0) without age correction nor discounting.
Ionizing radiation to HH	Frischknecht et al 2000	Emission of radiation not included in the Ecofactors 1997 version, however, treated in two ways in the 2006 method: One is related to the emissions to the sea and the second to the radioactive waste, for which the critical flow at 50% of present volume of radioactive wastes is assumed			
Photochemical ozone creation to HH	LOTOS-EUROS for ozone formation due to NMVOC and NO_x emissions, combined with epidemiological dose-response data and DALY estimates for acute mortality related to ozone	Critical flow for NMVOC corresponding to Swiss political aims. i.e. emission flow in year 1960			

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
	exp.				
Noise to HH					
Natural environment (NE)	5 midpoint categories contribute to natural environment: PDF-m^2-year or Number of Disappeared Species*yr;				
Climate change, midpoint to damage NE	Pulse temp model of Meinshausen for CO2 combined with disappearance of species related to temp change by Thomas et al (2004). Extrapolation to other greenhouse gases with GWP100	no explicit calculation, emission political objective			
Acidification to NE damage	Combination of atmospheric European transport model EUTREND, European soil model SMART 2.0 and dose-response relationships of > 200 plant species in Europe	Critical flow corresponding to Swiss political aims. i.e. emission flow in year 1950			
Aquatic and terrestrial eutrophication to NE	European water model CARMEN combined with macro fauna STOWA dataset for freshwater eutrophication only	Critical flow corresponding to Swiss political aims. i.e. emission flow in year 1960			
Aquatic and terrestrial ecotoxicity to NE	USES-LCA 2.0 for toxic pollutants (metals and organics) extended with generic slope factor based on non-linear species sensitivity distributions. SSDs are based on EC50-data	Critical flow for toxics (heavy metals), partly derived from maximal admissible concentration;			

LCIA METHODOLOGY	RECIPE	SWISS ECO SCARCITY	TRACI	MEEuP	USEtox
Land use to NE	Based on species-area relationship ($s=cA^z$), with variable z-factors and c-factors depending on the land use type. Three types of land use intensiveness are considered.				
Natural resources	Two endpoints contribute to resource depletion, expressed as surplus costs [USD]: (1)Depletion of minerals (1)Depletion of fossil fuels	Fossil oil, fossil coal, fossil natural gas, uranium, water			
Energy to NR	Surplus costs [USD]	Based on political objectives, a sanctioned critical flow for primary energy consumption from fossil, nuclear and hydro power sources may be derived: • Fossil energy resources: set equal to the current flow in 1990 (614'000 TJ). • A critical flow of primary hydro and nuclear energy of 398'000 TJ results. • A critical flow of utilization of primary energy from fossil and nuclear energy resources and primary energy from hydro power of 1'012'000 TJ.			
Minerals to NR	Surplus costs [USD]. Based on deposits and commodities.				
Water to NR	not included	New factors for water in the 2007 Swiss Ecoscarcity method			

7 Annex 2: Development of this document

Based on and considering the following documents

The background document has been drafted taking into account amongst others the following existing sources:

- Harmonised ISO standards
  - ISO 14040: 2006 Environmental management - Life cycle assessment – Principles and framework
  - ISO 14044: 2006 Environmental management - Life cycle assessment - Requirements and guidelines
- Guidance documents in the field of Life Cycle Impact Assessment (LCIA)

The analysis background document to the ILCD Handbook builds on existing integrated methods and achievements made in the scientific communities that primarily support LCA. This includes the voluntary achievements of the Society of Environmental Toxicology and Chemistry (SETAC) and more recently the joint Life Cycle Initiative of the United Nations Environment Programme (UNEP) with SETAC. We equally acknowledge the US Environmental Protection Agency (US EPA) for providing workshop documentation and other documents related to the scope and framework of LCIA.

A wealth of information and publications on the LCIA framework, methodologies and methods has been taken into account as referenced in the document.

Drafting

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Invited stakeholder consultations

An earlier draft version of this document has been distributed to more than 60 organisations and groups, covering EU Member States, European Commission (EC) Services, National Life Cycle Database Initiatives outside the European Union, business associations as members of the Business Advisory Group, Life Cycle Assessment software and database developers and Life Cycle Impact Assessment method developers as members of the respective Advisory Groups, as well as other relevant institutions.

Public consultation

A public consultation was carried out on the advance draft guidance document from June 10, 2009 to August 31, 2009. This included a public consultation workshop, which took place from June 29 to July 2, 2009, in Brussels.

Overview of involved or consulted organisations and individuals

The following organisations and individuals have been consulted or provided comments, inputs and feedback during the invited or public consultations in the development of this document:

Invited consultation

Internal EU steering committee

- European Commission services (EC),
- European Environment Agency (EEA),
- European Committee for Standardization (CEN),
- IPP representatives of the 27 EU Member States

National LCA database projects and international organisations:

- United Nations Environment Programme, DTIE Department (UNEP-DTIE)
- World Business Council for Sustainable Development (WBCSD)
- Brazilian Institute for Informatics in Science and Technology (IBICT)
- University of Brasilia (UnB)
- China National Institute for Standardization (CNIS)
- Sichuan University, Chengdu, China
- Japan Environmental Management Association for Industry (JEMAI)
- Research Center for Life Cycle Assessment (AIST), Japan
- SIRIM-Berhad, Malaysia
- National Metal and Material Technology Center (MTEC), Focus Center on Life Cycle Assessment and EcoProduct Development, Thailand

Advisory group members

Business advisory group

- Alliance for Beverage Cartons and the Environment (ACE), Europe
- Association of Plastics Manufacturers (PlasticsEurope)
- Confederation of European Waste-to-Energy plants (CEWEP)
- European Aluminium Association
- European Automobile Manufacturers' Association (ACEA)
- European Cement Association (CEMBUREAU)
- European Confederation of Iron and Steel Industries (EUROFER)

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- European Copper Institute
- European Confederation of woodworking industries (CEI-Bois)
- European Federation of Corrugated Board Manufacturers (FEFCO)
- Industrial Minerals Association Europe (IMA Europe)
- Lead Development Association International (LDAI), global
- Sustainable Landfill Foundation (SLF), Europe
- The Voice of the European Gypsum Industry (EUROGYPSUM)
- Tiles and Bricks of Europe (TBE)
- Technical Association of the European Natural Gas Industry (Marcogaz)

LCA database and tool developers advisory group

- BRE Building Research Establishment Ltd - Watford (United Kingdom)
- CML Institute of Environmental Science, University of Leiden (The Netherlands)
- CODDE Conception, Developement Durable, Environnement – Paris (France)
- ecoinvent centre – (Switzerland)
- ENEA – Bologna (Italy)
- Forschungszentrum Karlsruhe GmbH - Eggenstein-Leopoldshafen (Germany)
- Green Delta TC GmbH – Berlin (Germany)
- Ifu Institut für Umweltinformatik GmbH – Hamburg (Germany)
- IVL Swedish Environmental Research Institute – Stockholm (Sweden)
- KCL Oy Keskuslaboratorio-Centrallaboratorium Ab – Espoo (Finland)
- LBP, University Stuttgart (Germany)
- LCA Center Denmark c/o FORCE Technology – Lyngby (Denmark)
- LEGEP Software GmbH - Dachau (Germany)
- PE International GmbH – Leinfelden-Echterdingen (Germany)
- PRé Consultants – Amersfoort (The Netherlands)
- Wuppertal Institut für Klima, Umwelt, Energie GmbH – Wuppertal (Germany)

Life Cycle Impact Assessment method developers advisory group

- CIRAIG – Montreal (Canada)
- CML Institute of Environmental Science, University of Leiden (The Netherlands)
- Ecointesys Life Cycle Systems - Lausanne (Switzerland)
- IVL Swedish Environmental Research Institute – Stockholm (Sweden)

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- PRé Consultants – Amersfoort (The Netherlands)
- LCA Center Denmark – Lyngby (Denmark)
- Musashi Institute of Technology
- Research Center for Life Cycle Assessment (AIST) (Japan)

Public consultation

Contributors providing written feedback in the public consultation

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- Alexander Voronov (Russia)
- Stahlinstitut VDEh (Germany)

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