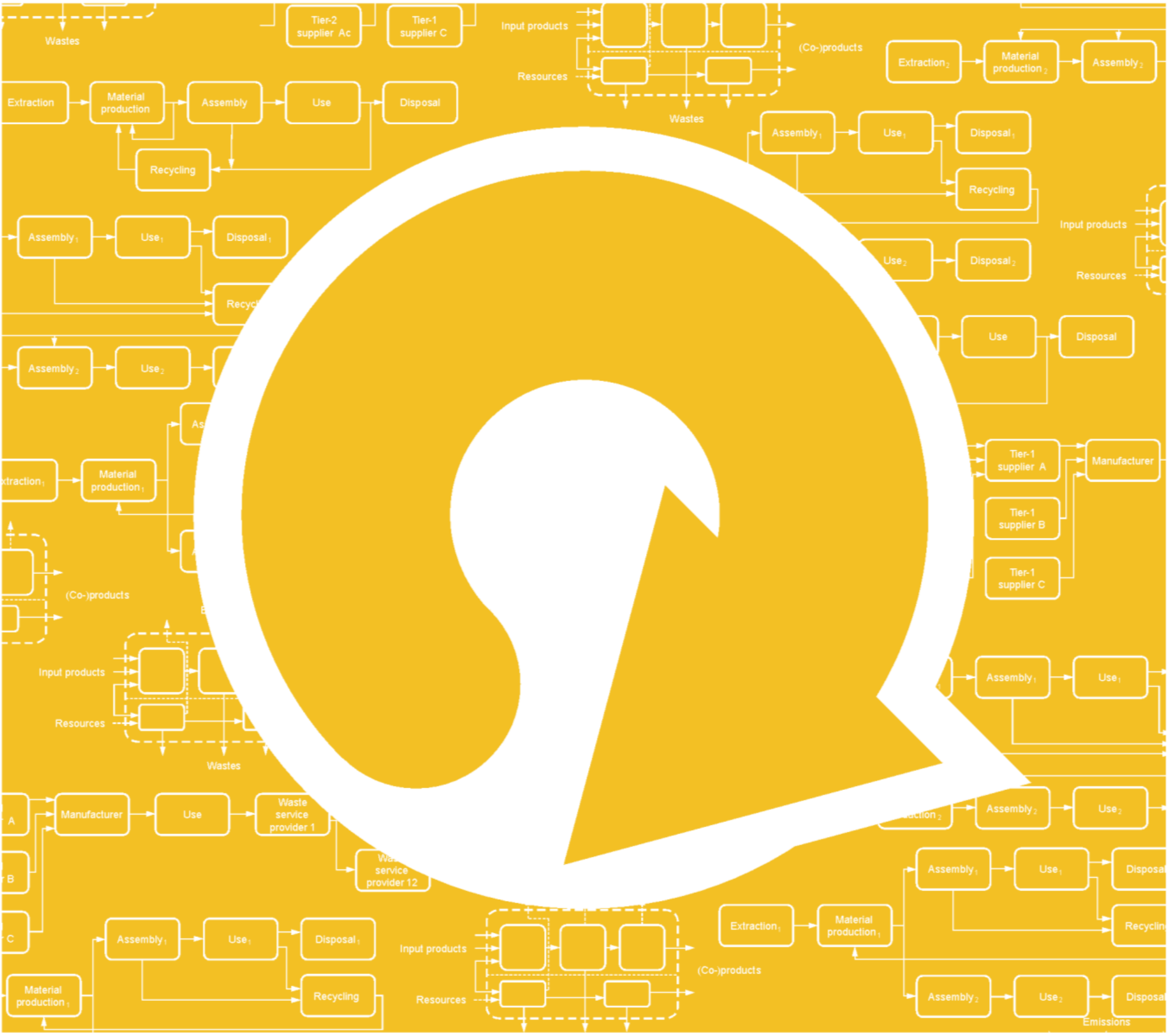
ILCD handbook

International Reference Life Cycle Data System



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Framework and requirements for Life Cycle Impact Assessment models and indicators

First edition

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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 guidance document provides a framework and requirements for the models that are used to analyse the emissions into air, water and soil, as well as the resources consumed in terms of their contributions to different impacts on human health, natural environment, and natural resources. It supports the calculation of indicators for different impact categories such as climate change or acid rain in a Life Cycle Assessment.

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 guidance document provides a framework and requirements for the models that are used to analyse the emissions into air, water and soil, as well as the resources consumed in terms of their contributions to different impacts on human health, natural environment, and natural resources.

About Life Cycle Impact Assessment (LCIA)

In a Life Cycle Assessment, the emissions and resources consumed that are linked to a specific product are compiled and documented in a Life Cycle Inventory (LCI). 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. Emissions and resources consumed, as well as different product options, can then be cross-compared in terms of the indicators.

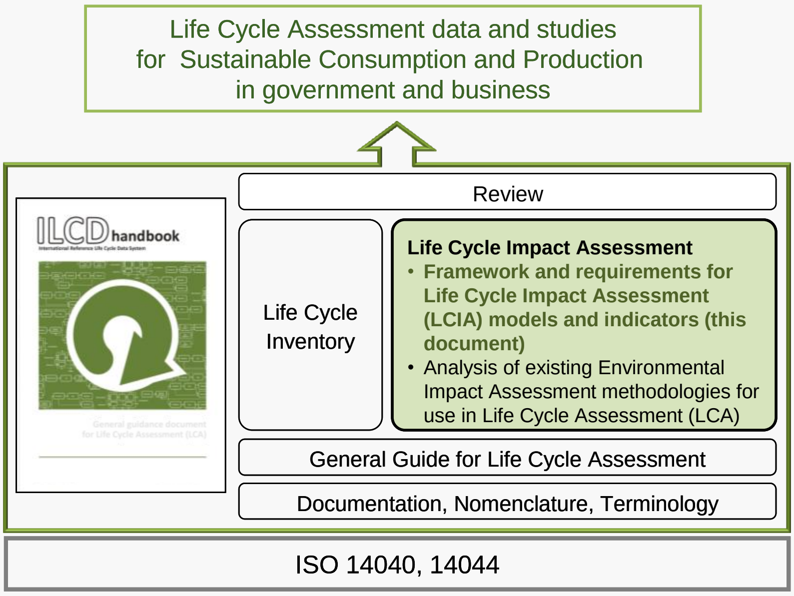
About the International Reference Life Cycle Data System (ILCD)

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, ISO 14040/44, that 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 guidance document provides a framework and requirements for the models that are used to analyse the emissions into air, water and soil, as well as the resources consumed in terms of their contributions to different impacts on human health, natural environment, and natural resources. It supports the calculation of indicators for different impact categories such as climate change or acid rain in a Life Cycle Assessment.



Approach and key issues addressed in this document

Several methodologies have been developed for LCIA and some efforts have been made towards harmonisation. The ISO standards brought some clarity on basic principles, but a comprehensive set of requirements for LCIA methods is currently lacking. Therefore, this guidance document provides:

- sets of criteria and recommendations against which models and indicators for use in LCIA should be evaluated, such as the required scientific qualities (completeness of scope; environmental relevance; scientific robustness and certainty; documentation, transparency and reproducibility; applicability), and the aspects that influence their acceptability to stakeholders;
- recommendations for the overall impact assessment framework for considering a broad range of environmental impacts under the three Areas of Protection of human health, natural environment, and natural resources.
- a description of the environmental mechanism (“cause-effect chain”) for each impact category to provide a common understanding of what needs to be modelled;
- a set of model requirements for the specific environmental impact categories that are commonly addressed in an LCA.

CONTENTS

FIGURES

TABLES

1 Introduction

The concept of Life Cycle Thinking (LCT) and its associated quantitative tool Life Cycle Assessment (LCA) are increasingly – and globally - used in the development, implementation, and monitoring of environmental and industrial policies within both public and private sectors. Most importantly, Life Cycle Thinking and Assessment help to avoid resolving one environmental problem while creating another, the so-called "shifting of burdens".

Life Cycle Assessment is a structured, internationally standardised method[1] 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, production, use and recycling to the disposal of the remaining waste.

Life Cycle Assessment (LCA) consists of 4 phases *(ISO 14044*):

1. Goal and Scope definition.
2. Life Cycle Inventory (LCI).
3. Life Cycle Impact Assessment (LCIA).
4. Interpretation.

In a Life Cycle Impact Assessment (LCIA), inventories of emissions and resources consumed are assessed in terms of impacts. This is achieved using indicators for 'Human Health', 'Natural Environment', and 'Natural Resources'. Since the early 1990s, numerous LCIA methodologies[2] have been developed. The existence of several different methodologies has sometimes created unnecessary confusion partly due to differing results, depending on the methodology chosen.

Although the ISO guidelines on Life Cycle Assessment brought some standardization to a general framework, they did not provide a technically-detailed standardisation. The UNEP-SETAC Life Cycle Initiative, aided further developments towards consensus and a recommended best practice, and this work has since been complemented by the activities of many other organisations, such as the United States Environmental Protection Agency (US EPA) and the European Commission. This brought LCIA closer to rigorous standardisation and resulted in landmark recommendations on the best approaches and underlying principles to follow (see Udo de Haes *et al*. 2002). The key results of these developments include:

- a consensus on the need to merge the so-called models for calculating midpoint indicators, such as CO_2 equivalents, and associated endpoint indicators, such as ecosystem impacts for climate change, in one consistent, integrated framework to combine the advantages of both midpoints and endpoints (Bare *et al., 1999,* Bare *et al., 2000*);
- a generic set of 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., 2008*); and

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[1] See *ISO 14040, 14044*

[2] Throughout this document an "LCIA methodology" refers to a collection of individual characterisation "models" or characterisation "methods" that 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.

- a growing global consensus among model developers based on current practice, for example for toxicological effects. (Udo de Haes *et al.,* 2002*,* Hauschild *et al.,* 2007, Rosenbaum *et al.,* 2007).

This is the setting in which the International Reference Life Cycle Data System (ILCD), provides this Guidance Document. It is intended to support a robust and consistent framework and methods for Life Cycle Impact Assessment. It is also acknowledged that most product systems include activities at a global level, hence the recommendations must have a global scope, irrespective of the ultimate user or commissioner of an assessment.

The present Guidance Document provides the LCIA framework, and the general recommendations for Areas of Protection and single impact categories. This includes:

- general and specific criteria for the evaluation of existing characterisation models, and
- Data ('characterisation factors') for calculating indicators.

1.1 Environmental Impact Assessment in LCA

The ISO 14044 standard defines Life Cycle Impact Assessment (LCIA) as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system" (ISO 14044*,* 2006). The purpose of the impact assessment phase is thus to interpret the life cycle emissions and resource consumption inventory in terms of indicators for the Areas of Protection (AoPs), i.e. to evaluate the impact on the entities that we want to protect. The Areas of Protection considered in this Guidance Document are 'Human Health', 'Natural Environment' and 'Natural Resources'.

1.1.1 The four steps of the LCIA

According to ISO 14044, Life Cycle Impact Assessment proceeds through four steps[3] :

1. **Selection of impact categories and classification *(mandatory)***

   In this step, the environmental impacts relevant to the study are defined. The elementary flows from the life cycle inventory (e.g. resource consumption, emissions into air, etc.) are then assigned to impact categories according to the substances' ability to contribute to different environmental problems. Figure 1-1 shows the environmental impact categories covered by this document.

2. **Characterisation *(mandatory)***

   The impact of each emission or resource consumption is modelled quantitatively, according to the environmental mechanism (see Figure 1-2). The result is expressed as an impact score in a unit common to all contributions within the impact category by applying the so-called "characterisation factors" (e.g.). For example, kg of CO_2-equivalents for greenhouse gases contributing to the impact category 'Climate Change'. Here, the characterisation factor of CO_2 for climate change is 1, whilst methane has a characterisation factor of more than 20, reflecting its higher climate change potential.

3. **Normalisation *(optional)***

   The characterised impact scores are associated with a common reference, such as the impacts caused by one person during one year in a stated geographic context. This facilitates comparisons across impact categories and/or Areas of Protection.

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[3] Steps 1 and 2 are mandatory, while steps 3 and 4 are optional.

4. **Weighting *(optional)***

   The different environmental impact categories and/or Areas of Protection are ranked according to their relative importance. Weighting may be necessary when trade-off situations occur in LCAs which are being used for comparing alternative products.

The ILCD Handbook focuses on the two mandatory steps of ‘Classification’ and ‘Characterisation’. The two optional steps of ‘Normalisation’ and ‘Weighting’ are not the focus of this Guidance Document.

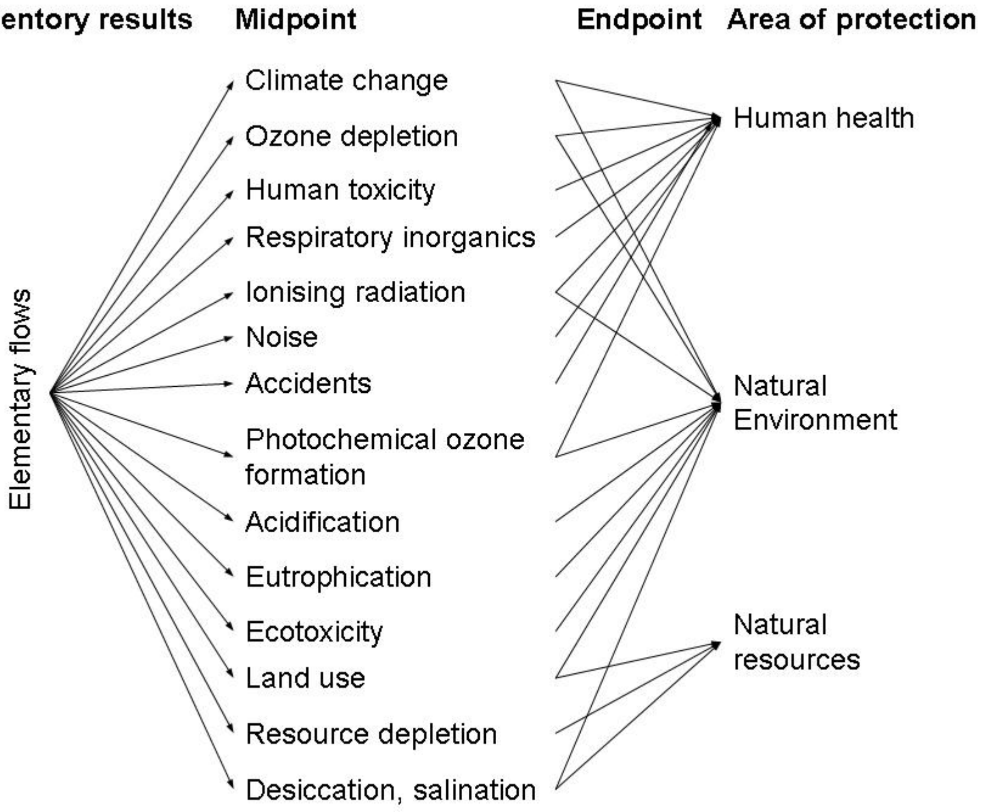

Figure 1-1 Framework of impact categories for characterisation modelling at midpoint and endpoint (Area of Protection) levels.

1.1.2 Framework for LCIA modelling

Impacts on the Areas of Protection are modelled by applying knowledge about the relevant impact pathways or environmental mechanisms as illustrated in Figure 1-2.

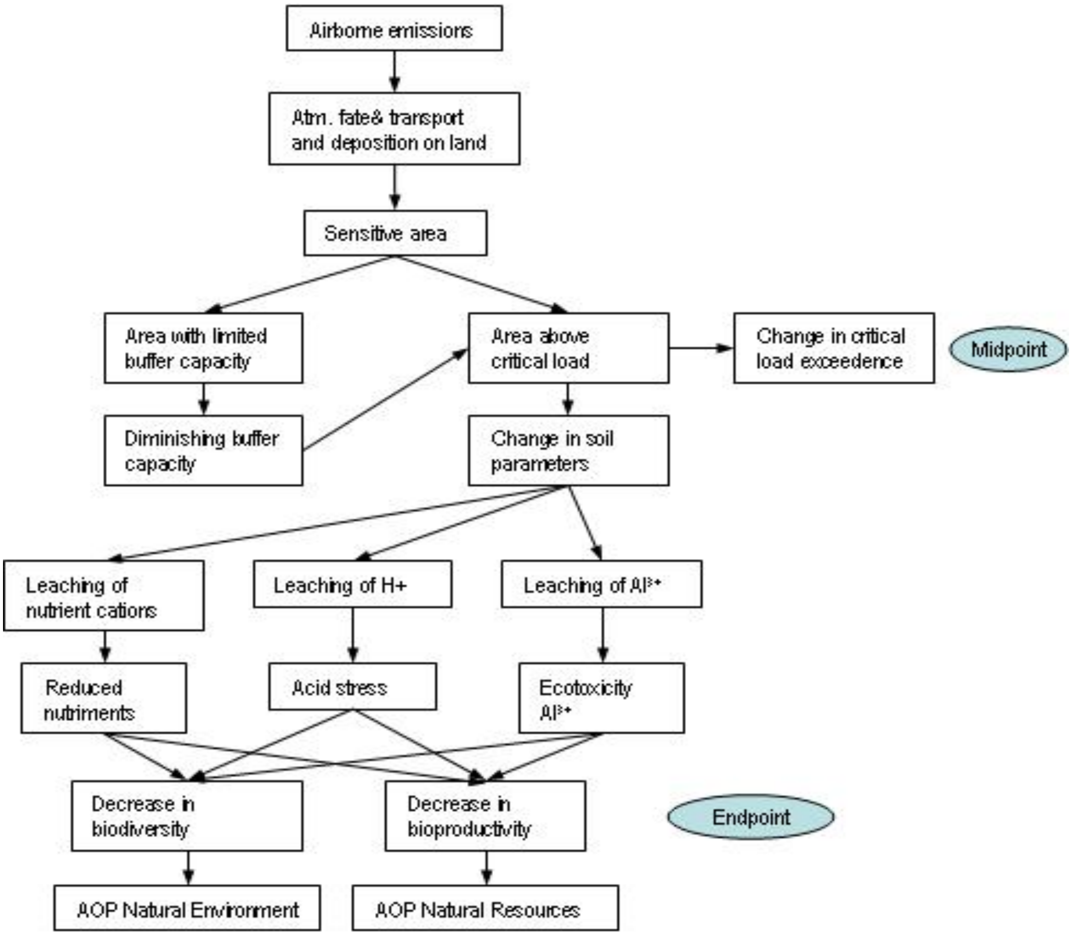

Figure 1-2 Impact pathway for the impact category acidification with indicated location of chosen midpoint and endpoint indicator

According to ISO 14044, the indicator of an impact category can be chosen anywhere along the impact pathway, which links inventory data to impacts on the AoPs. Characterisation at midpoint level models the impact using an indicator located somewhere along (but before the end of) the mechanism.

Characterisation at the endpoint level requires modelling all the way to the impact on the entities described by the AoPs i.e. on Human Health, on the Natural Environment and on Natural Resources. This then allows for cross-comparison of different impact categories within AoPs on a natural or social science basis, and where possible taking into account all substance-specific differences.

Impact categories at the midpoint level are defined at the place where a common mechanism for a variety of substances within that specific impact category exists. For example, 'Global Warming' impacts involve a series of steps, starting with the release of greenhouse gases, and ending with impacts on humans and ecosystems. There is a point where the greenhouse gases have an effect on the radiative forcing. Greenhouse gas emissions have a pathway that is different before that point, but identical beyond that point. Therefore, the radiative forcing provides a suitable indicator for the midpoint impact category of 'Global Warming'.

Most of the other impact categories, such as 'Human Toxicity' and 'Ecotoxicity Effects' are more heterogeneous. In these impact categories there is no real midpoint. The midpoint applied is in fact as close as practicable to the area of protection. The endpoint modelling then consists only of additionally characterising the severity or consequences. Therefore, in practice, a trade-off is often reached. On the one hand there are uncertainties associated with incomplete modelling and providing midpoint indicators, and on the other hand uncertainties associated with modelling further to the endpoint.

Figure 1-1 shows the relationship between the midpoint impact categories and the three Areas of Protection which are addressed in this Guidance Document.

2 Development and Application of the Criteria for Evaluation

The development of criteria and a procedure for the evaluation of characterisation models addressing midpoint and endpoint levels (Areas of Protection, AoP) is described in this section. The criteria and procedure serve to analyse existing characterisation models and factors across the most common impact categories, at both midpoint and endpoint levels. The aim of this analysis is to identify the best practice among existing characterisation models for each impact category.

The development of criteria builds on the work of the SETAC working groups (Udo de Haes *et al.,* 2002) and the Life Cycle Impact Assessment programme of the UNEP-SETAC Life Cycle Initiative on the LCIA selection criteria and their application to the acidification impact category (Margni *et al*., 2008). This work has been modified and extended. While it integrates criteria regarding policy relevance and applicability to LCI data sets, it also covers all emission-related midpoint categories, resources and land use, and the damage characterisation models for all Areas of Protection for damage assessment.

Consultation process for development of criteria

The development of criteria and their application in evaluating the methods from the different impact categories has been aided by a consultation process involving domain experts, the international cooperation of partners on good practice on LCA, including:

- National LCA project in Brazil, China, Japan, Malaysia, and Thailand,
- European Commission and EU Member-States representatives,
- UNEP,
- European Platform on LCA Advisory Groups, including Industry Associations and LCA research/consultancy organisations, and
- a public stakeholder consultation.

2.1 Criteria for the evaluation of characterisation models

The analysis of the different characterisation models relies on a set of general criteria based on fundamental requirements for LCIA methods (both characterisation models and factors), which are the same for all impact categories. These consist of 5 scientific criteria and 1 stakeholder acceptance criterion.

Scientific criteria:

- Completeness of scope
- Environmental relevance
- Scientific robustness and certainty
- Documentation, transparency and reproducibility
- Applicability

Stakeholder acceptance criterion:

- Degree of stakeholder acceptance and suitability for communication in a business and policy context.

Each criterion is specified through a number of sub criteria as listed in Table 2-1.

Table 2-1 General criteria and sub-criteria for the analysis of characterisation models

Name of impact category		Sub-criteria	Threshold[1] (Minimum score)	Impor-tance [2] (H-N)	Method score[3]
Introduction		• Timeframe, discounting, etc.			
		• Marginal (M) or Average (A) defined, if not described (ND)			
		• Total number of individual substances covered by specific provided characterisation factors			
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health			
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment			
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources			
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain			
		• The characterisation model is adaptable to spatial and temporal explicit evaluation			
		• Global geographical validity preferable, separate validity for Europe beneficial			
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)			
		• When empirical data is used, double counting is avoided			
	Overall evaluation				
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality given current scientific understanding --> provide a list of specific criteria per impact category			
	Overall evaluation				
Scientific robustness & Certainty	Scientific robustness	• The critical part of the model including the parameters used in the model have been peer reviewed (journal, panel, book, etc.)			
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered) --> provide a list of specific criteria for each impact category			

Name of impact category		Sub-criteria	Threshold[1] (Minimum score)	Impor-tance [2] (H-N)	Method score[3]
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation			
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available			
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms			
		• Scenario and model uncertainty as well as substance data and parameter uncertainty are taken into account			
	Overall evaluation	• The category indicator and characterisation models are science based			
Documentation & Transparency & Reproducibility		• The model documentation is published and accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)? This must support the development of new, consistent factors by third parties.			
		• The set of characterisation factors/models is published and accessible			
		• The input data are published and accessible			
		• The characterisation model is published and accessible			
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation			
		• Value choices are explicitly stated			
	Overall evaluation				
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)			
		• Ease to update to conform e.g. with the ILCD nomenclature and units			
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools			
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be directly made available by the relevant actor such as the producing industry			
	Overall evaluation				
Overall evaluation of science based criteria					
Stakeholder acceptance criteria		• The indicator is easily understood and interpretable			

Name of impact category		Sub-criteria	Threshold[1] (Minimum score)	Importance [2] (H-N)	Method score[3]
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)			
		• The principles of the model are easily understood by non-LCIA experts			
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products			
		• The indicator is relevant with current policy indicators of the European Commission or similar authoritative bodies			
Overall evaluation of stakeholders acceptance criteria					
Final recommendation					

1: Define an acceptable threshold per sub criteria, if relevant
2: Importance of the sub criterion: H – high, N - normal
3: Scores for characterisation models:
    A: Full compliance
    B: Compliance in all essential aspects
    C: Compliance in some aspects (``so-so``)
    D: Little compliance
    E: No compliance

2.2 Evaluation procedure for the application of the criteria

A hierarchical procedure has been developed for the application of the relevant criteria to a given impact category. A similar procedure was previously developed and successfully applied to several impact categories under the UNEP-SETAC Life Cycle Initiative[4] . Both the category indicators and characterisation models/data can be evaluated. The procedure for the application of the criteria and for the evaluation of a characterisation model aims to bring together science and pragmatism in order to identify those practices that are scientifically defendable, relevant to the decision endpoints, and important, practical and acceptable for stakeholders.

The application of the criteria to evaluate a characterisation model involves the stages detailed in the following sections.

2.2.1 Description of the cause-effect chain

Prior to applying the evaluation criteria, the characterisation method has to be described with a diagram of the general impact mechanism that includes all the relevant pathways and flows which may be part of a characterisation model (see example in Figure 4.1). The thickness of the arrows in the diagram describes the importance of the pathway in the overall mechanism, while the colour describes the specificity of the step:

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[4] See Margni *et al.*, 2008, Hauschild *et al.*, 2007, Rosenbaum *et al*., 2007

- **Green arrows:** region-specific factors,
- **Red arrows:** substance-specific factors,
- **Blue arrows:** compartment-specific factors,
- **Black arrows:** no specific factors.

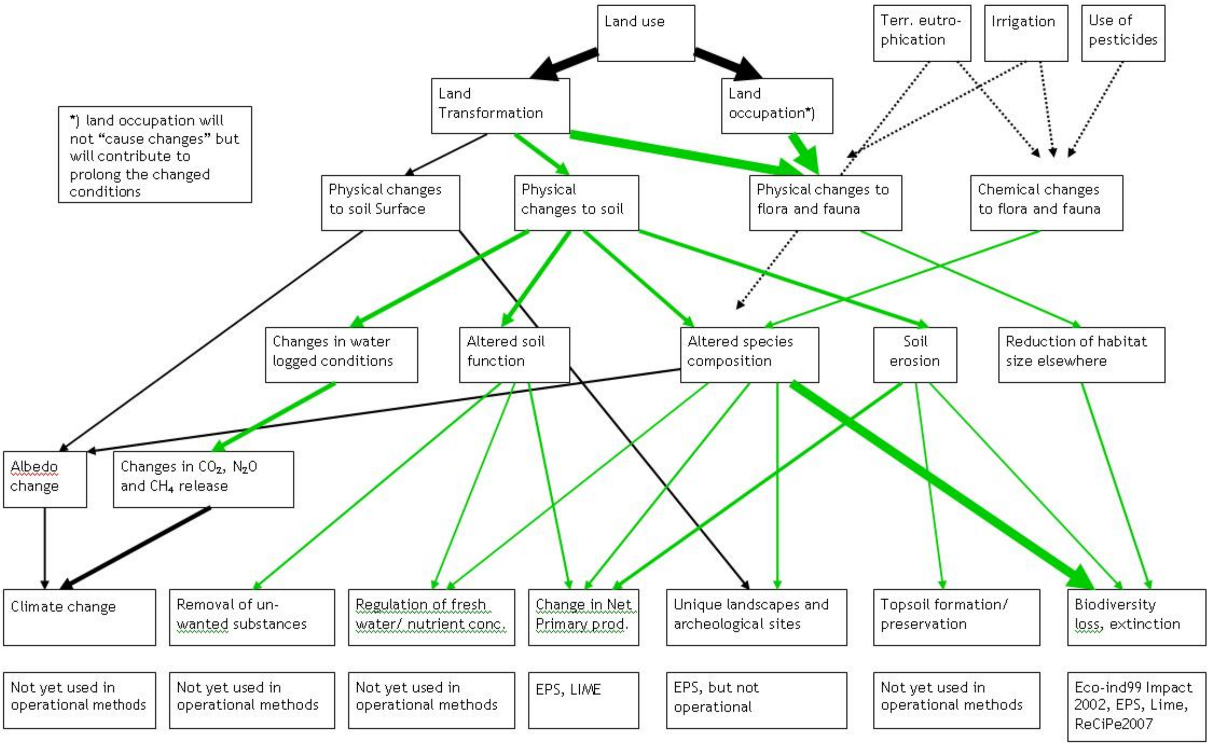

Figure 2-1 Example of diagram of the general impact mechanism for the impact category land use (based on Weidema and Lindeijer, 2001).

This step is necessary to improve transparency, and to make model choices explicit. A quantitative analysis is made wherever possible, through a method-performance comparison, enabling the identification of the key differences and aspects that are important in the impact category.

2.2.2 Development of criteria specific to each impact category

Based on the model analysis and supported by the diagram, a limited number of additional category-specific sub-criteria are developed under the two criteria: 'Environmental relevance' and 'Scientific robustness and certainty' (see Table 2-1). This is to supplement the general criteria and adapt them to the specificities of the impact category. Chapter 2 describes the general recommendations and specific criteria that have been defined for each impact category.

2.2.3 Methods evaluation and comparison – identification of key differences

The existing characterisation models are evaluated against the total set of criteria and sub-criteria (general plus category-specific). A scoring procedure is proposed to evaluate the characterisation model's compliance with each of the criteria:

A – Full compliance
B – Compliance in all essential aspects
C – Compliance in some aspects (or acceptable agreement made)
D – Little compliance
E – No compliance.

For the overall evaluation of the characterisation model, the importance of each criterion and sub-criterion is assessed for the impact category in question. A differentiation between normal (N) and high (H) importance is applied. Criteria of high importance are criteria which significantly differentiate the different models from each other and which address key aspects for the resulting characterisation factors.

For some of the sub-criteria, it is relevant to define an exclusion threshold as a required minimum performance. Whenever a characterisation model fails to pass such an exclusion threshold, the subsequent analysis of that characterisation model is not performed.

2.2.4 Development of criteria for the evaluation of endpoint models

Discussions on midpoint *vs.* endpoint modelling started under the umbrella of the US EPA and UNEP and continued within the Life Cycle Initiative[5], a joint project between UNEP and SETAC, where a comprehensive LCA framework has been proposed to combine midpoint-oriented and damage-oriented approaches in a common and consistent framework. The present chapter focuses on the assessment of midpoint and endpoint categories for a set of LCIA impact categories, building on the latest outcomes of the Life Cycle Initiative on this issue[6].

The general criteria in Chapter 2 also apply for the evaluation of characterisation models linking midpoint impacts to impacts on the Areas of Protection (endpoint characterisation models). In addition, to ensure environmental relevance across the different midpoint impact indicators and a consistent and common approach to midpoint-damage modelling, the following guidelines specific to midpoint-damage modelling shall be considered in the development of specific criteria for endpoints (compare with Margni *et al.*, 2008):

- The goal of damage modelling is to aid in understanding and interpreting midpoints. It aims to make results in different midpoint categories cross-comparable within Areas of Protection using, as far as possible, natural science approaches, and not necessarily to arrive at a single score. It can then replace or support weighting practices in the midpoint approaches. In some cases, a scientific approach for midpoint factors which are truly cross-comparable even within an impact category, does not exist. In such cases, endpoint approaches will be necessary, which should avoid implicit value judgements.
- All modelling (midpoint and endpoint) should ideally be properly documented on uncertainty and reliability. The choice to go to the damage/endpoint level is to be maintained, as is to eventually come to different recommendations depending on the context/application and to increase transparency. In this sense the framework should enable both (midpoint and damage) in a consistent way.

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[5] See Bare *et al.* 1999, 2000 and Jolliet *et al*., 2004
[6] See Margni *et al*., 2008

- Value choices in midpoint and damage modelling should be made explicit and properly documented. It is necessary to make a clear distinction between data uncertainties, modelling assumptions/uncertainties and value choices, in order to be transparent about the different and specific sources of uncertainty. decrease the overall uncertainty. Midpoint approaches also contain value choices, often relying on implicit ones. There is no unique universal set of "values"[7].
- Care must be taken to ensure comprehensiveness, avoiding considering only partial information on damages (e.g. effect of Climate Change on malaria), excluding other potentially more important parameters and effects (e.g. effects on biodiversity). Hence, it is useful to retain both midpoint and endpoint insights, particularly for impact categories such as ‘Climate Change’ where the consequences cannot be fully modelled at this time, bearing in mind additional uncertainties arising on the way from midpoint to endpoint.

2.2.5 Additional sub-criteria for endpoint models

- Do all category indicators and characterisation models linking midpoint to damage fulfil the requirements of being science based?
- How complete is the coverage of the impacts in the modelling from midpoint to endpoint, in terms of current scientific knowledge?
- Is duplication avoided? If not, it should be identified and/or removed or accounted for in other ways, where possible.

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[7] In this sense, Years of Life Lost and Years of Life Disabled should be considered first separately for impacts on Human Health. Disability weighting for non fatal effects could then be explicitly considered if desired to group diseases together to arrive to DALY. The value choice of assuming equal severity for different diseases is often implicitly made when performing human toxicity characterisation modelling based on toxicological effect data alone at midpoint level.

3 Requirements for Areas of Protection

Table 3-1 summarizes the Areas of Protection (AoPs) and associated damages, as well as example indicators for Human Health, Natural Environment and Natural Resources. The following sub-sections present the general description and recommendations for each AoP in the LCIA framework.

Table 3-1 Damage categories and possible damage indicators (modified from Margni *et al.*, 2008)

Subject considered	**Damages related to intrinsic values**	**Damages related to functional values**	**Damage measured**	**Damage indicators**
Human life	Human health (intrinsic)		Both mortality and morbidity over time and space	Number and age of death; number, type and duration of diseases, YLL, YLD, DALY
		Human health (labour and productivity)	Loss in productivity	Usually not considered, related to indicators for intrinsic damages on Human Health
Biotic environment	Biotic natural environment and ecosystem stability (biodiversity)		Loss or disappearance of species over time and space	PDF·m^2·yr
		Biotic productivity: biotic natural resources (e.g. tuna) and man-made biotic environment	Biotic productivity loss	Net Primary Production expressed in monetary units of productivity losses
	Abiotic natural environment (e.g. rapids)			
Abiotic environment		Abiotic natural resources (e.g. water, minerals)	Intermediary towards damages on biodiversity and human welfare	MJ surplus energy
	Man-made abiotic environment, cultural objects	Man-made abiotic environment (e.g. houses)	Physical destruction or impairment of objects	Cost for repair or loss in monetary units

Abbrevations: YLL: Years of Life Lost; YLD: Years of Life Disabled; DALY: Disability-Adjusted Life Years; PDF: Potentially Disappeared Fraction; MJ: megajoule

3.1 Human Health

3.1.1 Recommendations

For impacts on Human Health caused by various types of environmental stressors, the aim is to quantify the changes in both mortality and morbidity that are associated with goods or services in an integrated way. For human endpoint indicators, the focus is on the integration of various stressors towards a common endpoint for Human Health[8]. In this context, aggregated Human Health indices are of particular importance.

The DALY-concept (Disability Adjusted Life Years) combines information on quality of life and life expectancy in one indicator, deriving the (potential) number of healthy life years lost due to premature mortality or morbidity. Morbidity is weighted for the severity of the disorder (Murray and Lopez, 1996). The QALY concept (Quality Adjusted Life Years) can be considered similar to the DALY.

As the focus of the LCIA method recommendations is on Human Health impacts due only to stressors, the DALY is selected as the most appropriate metric for the Area of Protection Human Health. The use of the DALY-concept is recommended including years of life lost for mortality and years of life disabled for morbidity, without age weighting and discounting.

3.1.2 Background and Discussion

For Human Health, the aim is to provide indicators, in terms of both mortality and morbidity, for the effects caused by various types of stressors. Aggregate Human Health indicators are of particular relevance. As indicated by McAlearney *et al.* (1999) and Gold *et al.* (2002), well-known concepts are Quality Adjusted Life Years (QALY) and Disability Adjusted Life Years (DALY).

The QALY-concept combines both the quality and quantity elements associated with Human Health in one indicator to express the total health benefits of various healthcare programs in common units (Weinstein and Stason, 1977). The DALY-concept was first introduced by Murray and Lopez (1996) as part of the Global Burden of Disease study. The DALY-concept similarly combines information on quality and quantity of life in one indicator, deriving the (potential) number of healthy life years lost due to premature mortality or morbidity. In fact, as argued by Weidema (2006, 2008), the change in measurement unit QALY can be considered identical to the change in DALY, except for a reversal of signs (ΔQALY=$-\Delta$DALY).

Morbidity is weighted in terms of the severity of the disorder. For example, if a person gets lung cancer at the age 62 and consequently suffers for 5 years before dying, an estimation of both the severity of her suffering from lung cancer and information on the life expectancy in the absence of the cancer is required.

As the focus of LCIA is on Human Health **impacts** and not Human Health **benefits**, the DALY is selected as the most appropriate indicator. Its use and associated assumptions are discussed in more detail in the following sub-sections.

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[8] The following midpoint impacts are considered to contribute to damages on Human Health, although the contribution has not been modelled completely by all the recommended methods: climate change, ozone depletion, human toxicity, respiratory organics, ionising radiation and photochemical ozone formation

3.1.3 Disability-Adjusted Life Years (DALYs)

3.1.3.1 Concept

After studying the work of Murray and Lopez (1996) for the World Health Organisation (WHO), Hofstetter proposed in 1998 the DALY-concept as a health endpoint for use in Life Cycle Assessment. Since that time, Human Health impacts due to environmental stressors in LCA have been commonly assessed using DALY.

Murray and Lopez (1996) derived the Disability-Adjusted Life Years of a disease using world-wide Human Health statistics. DALYs have been reported for a wide range of diseases, including various cancer types, vector-borne diseases and non-communicable diseases (Frischknecht *et al.* 2000; Goedkoop and Spriensma, 1999; Murray and Lopez, 1996).

Applying equal weightings to the importance of 1 year of life lost for all ages and not discounting for future damages, the DALY is the sum of years of life lost (YLL) and years of life disabled (YLD):

$$\mathrm{DALY} = \mathrm{YLL} + \mathrm{YLD}$$

In turn, the YLD is equal to:

$$\mathrm{YLD} = w \cdot D$$

where w is the disability weight between 0 (complete health) and 1 (dead), and D is the duration of the disease. Thus, DALY is a Human Health indicator that is measured with the unit of one year.

3.1.3.2 Discussion

Although the concept of DALYs has proven to be useful in the assessment of Human Health impacts in Life Cycle Assessment (Hofstetter 1998), the actual calculation depends on a number of uncertainties, choices and assumptions.

1. First, in most LCIA methodologies DALYs are calculated without applying age-specific weighting and without discounting future health damages. These two starting points, however, are a matter for debate (Hofstetter and Hammitt, 2002; Hellweg *et al*., 2005). For example, using non-uniform age weights and a future discount rate of 0.03, as proposed by Murray and Lopez (1996), DALY estimates typically decrease by a factor of 2.

From a practical point of view, however, time discounting is considered problematic in LCA as the life cycle inventory is commonly ill-suited to provide the relevant time information that would be needed to consider discounting, and this factor of 2 may be negligible. Furthermore, age-weighting changes the DALY-estimates only if a significant loss of children’s health has a high contribution to the DALY of a specific disease. Usually, only a very small part of health burden in LCA is due to loss of children’s health. Therefore, the practical relevance of future discounting and age-weighting is considered limited.

Equally, from a sustainability point of view, it is argued that it is preferable to leave out discounting and age weighting in standard DALY calculations for LCA purposes. LCA does not treat Human Health as a functional value but takes the intrinsic value of human well-being as a starting point. With the intrinsic value of human well-being as a starting point, there is no specific reason to value a future DALY less than a present DALY since we are not proposing to determine costs related to disability adjusted life years. The same line of reasoning holds for age weighting, as LCA is not looking at human productivity *per se*. This argument against distinctions may be extended to the geographic location of a population that is potentially affected by a stressor, as discussed below.

2. The use of years of life disabled (YLD) includes judgement of the weighting of health disabilities by medical experts and/or other stakeholders, such as the general public (Krewitt *et al.* 2002). For cancer diseases, DALYs are almost fully determined by years of life lost, indicating that the inclusion of years of life disabled does not have a large influence on the DALY outcomes and is therefore not associated with such subjective judgements (Crettaz *et al.*, 2002; Huijbregts *et al.*, 2005). The situation is different, however, for a number of non-cancer diseases, such as for musculoskeletal, neuropsychiatric, sense-organ diseases, vector-borne diseases, and frequent - but mild – diseases, such as sleep disturbance. For these disease types, the years of life disabled can have a dominant contribution to the DALY estimates (Murray and Lopez, 1996*).* Although health-preference measurements tend to be fairly stable across groups of individuals and regions of the world (Hofstetter and Hammitt 2002), it is expected, however, that the influence of subjective judgment about years-of-life-disabled estimates on the DALY outcomes as a function of stakeholder group or geographic location will be small.
3. DALYs refer to a specified region and time frame, such as the world in 1990 (Murray and Lopez, 1996). Applying world average DALY-estimates in the calculation of characterisation factors, implies that it is assumed that Human Health damages associated with emissions can be represented by world averaged disease data from 1990. However, for LCA case studies that focus on Human Health impacts occurring in a specific region, these DALY estimates may need to be used with care.

   Results can change when another region in the world is taken as a starting point for the DALY calculation. As an example, for established market economies in 1990, DALYs are up to a factor of 2 lower for cancer diseases and up to a factor of 5 lower for non-cancer diseases when compared with average world DALYs (derived from Murray and Lopez, 1996). This can be explained by much more advanced medical healthcare in the established market economies when compared with the world average. For the same reason, differences in medical health care in 1990 compared with those in the future may result in differences in DALYs. This may be particularly important for emissions occurring now, but which cause impact in the future, such as emissions of greenhouse gases, ozone-depleting chemicals and carcinogenic substances (with long latency periods between release and exposure or disease). Again, in practice, the importance of this variation may be negligible from a scientific perspective.
4. In burden-of-disease assessments, DALY estimates refer to expected health damages, taking into account the situation of health care services in different parts of the world (see Murray and Lopez, 1996). This implies that Human Health damages depend on external boundary conditions. For example, the Human Health damage due to exposure to carcinogenic chemicals can be lower than predicted, because medical treatment in many parts of the world prevents the disease from running its natural course. Currently, however, the extra damage that may somewhat offset this, which is caused by the life cycle of the medical treatment itself (such as hospital construction, surgery waste and drug production) is neglected.
5. The actual implementation of the DALY concept on the level of individual substances in LCA is not free from practical problems. The concept of DALYs as used by the LCA community can require even more assumptions and data limitations than the DALY based on disease statistics, as implemented by Murray and Lopez (1996).

To obtain endpoint characterisation factors, information on the critical effect of a substance is required. For ozone depleting substances, radioactive emissions, greenhouse gases, photochemical oxidants and particulate matter/respiratory inorganics, important critical effects are generally specified[9] (. For chemicals causing non-cancer toxicological effects, information on critical effects relevant for humans is commonly lacking. However, this is not identified as a significant problem for carcinogens.

In the case of lacking critical effect data for carcinogens the average cancer DALY can be used instead. This is considered a suitable practical approach, because the variation in cancer-specific DALYs per incidence is relatively low when compared with the uncertainty reported for the toxic potencies of the majority of carcinogenic substances (Crettaz *et al.* 2002, Huijbregts *et al.*, 2005).

For non-cancer effects caused by chemical exposure, the situation is more problematic. Standard toxicological-response variables in test species, such as decrease in body weight, are, in most cases, not specific for disease genesis in humans and, therefore, cannot be properly translated to real-life conditions (De Hollander *et al.* 1999; Owens, 2002). Furthermore, DALYs are currently not available for all relevant non-caner health effects potentially caused by chemical exposure.

3.2 Natural Environment

3.2.1 Recommendation

The Area of Protection subject ‘Natural Environment’ encompasses the natural ecosystems around the world in terms of their function and structure. The resource aspect of ecosystems are addressed under the AoP subject ‘Natural Resources’ and not included here. For Natural Environment, the aim is thus to quantify the negative effects on the function and structure of natural ecosystems as a consequence of exposure to chemicals or physical interventions[10]. The recommendation is to use the Potentially Disappeared Fraction of species (PDF) concept as an endpoint indicator for the AoP Natural Environment. However, it is acknowledged that there is a need to further investigate the factors which are applied for deriving PDFs for the ecotoxic impacts.

The complexity of the natural ecosystems with their multiple interactions between different populations at the same or different trophic levels, and the physical and chemical surroundings makes it a challenging task to assess changes in their structure and various functions. It is recommended to follow the structure-based approach typically taken in ecotoxicology, focusing on biodiversity, for example. the occurrence of different species in the ecosystem.

Biodiversity can be viewed at different levels: ecological diversity (ecosystems),,population diversity (species); and genetic diversity (genes). All levels are addressed by different approaches, but only the approach addressing the population diversity level seems sufficiently mature for application in LCIA. It is hence recommended to focus the quantification of damage to the AoP ‘Natural Environment’ on the loss of biodiversity and for this to apply the Potentially Disappeared Fraction of species (PDF)

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[9] see e.g. Slaper et al., 1996; Frischknecht et al. 1999; Patz and Campbell-Lendru, 2005; Anderson et al. 2004; Kunzli et al 2000

[10] The following midpoint impacts are considered to contribute to damages on Natural Environment include, although the contribution has not been modelled completely by all the recommended methods:climate change, ozone depletion, ionising radiation, photochemical ozone formation, acidification, eutrophication, ecotoxicity, land use, erosion, desiccation and salination

concept. For biodiversity, the species-diversity oriented PDF-concept is seen as the only really operational concept among those investigated, integrating the potentially lost fraction of natural species over area and time.

3.2.2 Background and Discussion

The Area of Protection 'Natural Environment' (or Ecosystem Health), encompasses the natural ecosystems globally, in terms of their function and structure. It ought to be noted that the resource aspect of ecosystems (biological renewable resources, and managed, man-made ecosystems like plantations or agricultural fields) is addressed under the AoP 'Natural Resources' and not included here. For Natural Environment, the aim is to quantify the negative[11] effects on the function and structure of natural ecosystems as a consequence of exposure to chemicals or physical interventions[12].

The complexity of the natural ecosystems with their multiple interactions between different populations at the same or different trophic levels, and the physical and chemical surroundings makes it a challenging task to assess effects on their structure and functions. In ecotoxicology, this task has typically been addressed by focusing on the occurrence of different species in the ecosystem, i.e. the biodiversity.

"Biodiversity can be defined at different levels: ecological diversity (ecosystems), population diversity (species) and genetic diversity (genes). This grouping is reflected in the Rio Convention's definition of biodiversity as "*the variability among all living organisms from all sources, including* inter alia*, terrestrial, marine and other aquatic ecosystems and ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"* (EEA, 1997).

*"Biodiversity, which is an indicator of the ecosystem structure, does not automatically reflect the natural environment (*Forbes and Forbes 1993; Tillman 2001*). This is due to the fact that the integrity of ecosystems depends not only on species richness (and other structure related properties, e.g. number of trophic levels) but also on the protection of the function of the ecosystem (e.g. biomass production and nutrient cycling). If for example a chemical stress is targeted at a single species but this species is a keystone species on which the function of the ecosystem heavily relies, the function of the ecosystem may undergo major changes,"*[13] whereas other species may exert functions which are easily taken over by other species, should this species disappear (*Mooney et al., 1995*).

When modelling damage to natural ecosystems, biodiversity is thus not the only possible endpoint. Function-related parameters like biomass production or mineralisation might represent better the functional performance of the ecosystem and, in some cases, might be a more relevant endpoint indicator, depending on which properties of the AoP are deemed worthy of protection[14]. Recreative value may thus be better represented by a biodiversity indicator, whereas production value and life support functions may be better represented by

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[11] All impacts on the environment are considered as negative in the sense of being undesirable. To the extent that the product system, which is the object of the LCA, has positive impacts on the environment (e.g. wastewater treatment), this is quantified in the inventory analysis.

[12] The following midpoint impacts are considered to contribute to damages on Natural Environment, although the contribution has not for all of them been modelled by recommended methods: climate change, ozone depletion, photochemical ozone formation, ionising radiation, acidification, eutrophication, ecotoxicity, land use, desiccation and salination.

[13] From J. Payet & H.F. Larsen, *Damage modelling for Life Cycle Impact Assessment on Ecosystems*; Report- Swiss National Fund and Ecole Polytechnique Fédérale de Lausanne; November 2002 (13p.).

[14] The health of Earth ecosystems and the role of ecosystem function for quality of human life is investigated and extensively discussed in the Millenium Ecosystem Assessment – see http://www.millenniumassessment.org/en/index.aspx

a functional measure like biomass production or energy transfer through the food web. “*However, there are good indications that ecosystem biodiversity is at least as sensitive to stress as function-related properties like decomposition or photosynthesis” (*Selck *et al.*, 2002*)*.[8]

Given that, in the present context, the productivity of ecosystems is addressed under the AoP Natural Resources, it is proposed to focus endpoint modelling for the AoP Natural Environment on the biodiversity of the exposed ecosystems and, more specifically, on the diversity within the ecosystem based on population diversity (i.e. diversity among species). This is a positively correlated proxy of ecosystem function and structure, which is fundamentally what we want to protect.

3.2.3 Measuring biodiversity loss

Different approaches have been developed to quantify losses in biodiversity as a consequence of environmental stress.

3.2.4 PDF and PAF

In Life Cycle Impact Assessment (LCIA), endpoint indicators for Natural Environment due to environmental stressors are sometimes expressed in terms of Potentially Disappeared Fraction of species (PDF). The PDF can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavourable conditions. The PDF is related to the Probability Of Occurrence (POO), as used in Alkemade *et al.* (1996) to model the effects of acidification and eutrophication. The PDF is in fact represented by 1 POO. This means the fraction of species that does not occur is interpreted as the fraction of the species that has disappeared.

Eco-toxic effects from chemicals are estimated based on results from laboratory tests of the chemicals on organisms of different species. Based on the test results for individual species, statistical distribution curves can be plotted for the sensitivities of a selection of species, considering them as representative of the ecosystem. Such species sensitivity distribution curves (SSD curves) support estimation of the fraction of the species in the ecosystem that is exposed above the level which affects them (the Potentially Affected Fraction of species, PAF) or above the threshold level where the species will disappear (PDF) (Hamers *et al.*, 1996, Kleppers and van de Meent, 1997) – see Figure 3-1).

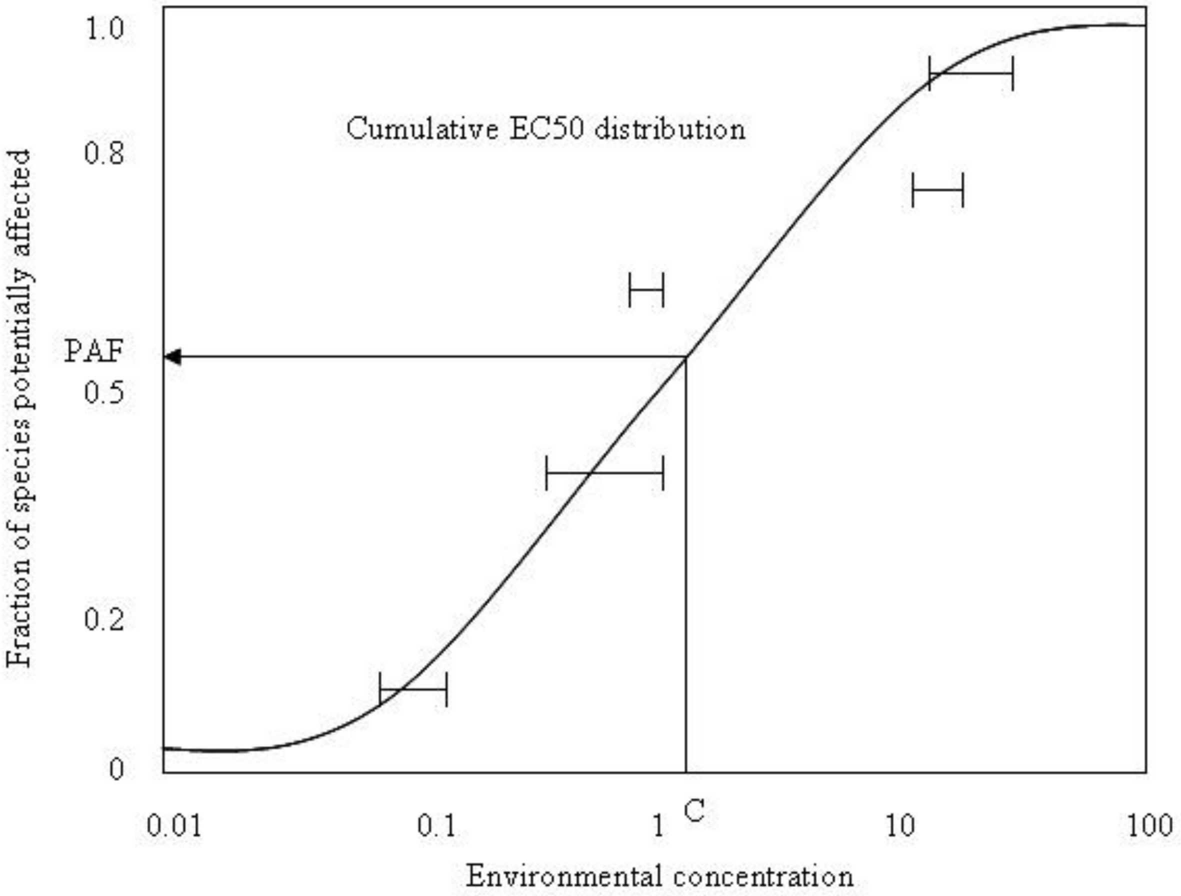

Figure 3-1 Example of Species Sensitivity Distribution Curve. Individual Species effect concentrations (EC50) shown as intervals.

The translation between the affected fraction (PAF) and the potentially 'disappeared' fraction (PDF) "*is based on the assumption that the quality of the media (e.g. water) has a direct link with the biodiversity, i.e. that a species disappears when the chemical concentration in the ecosystem reaches a certain level, and reappears when the concentration, due to for example degradation, comes below that level again"*[15]. The model also assumes "*that the time span of disappearance and time span of reappearance of species are equal*".

Examples of PAF and PDF approaches in LCA include early use by Goedkoop and Spriensma, 2000, while the concept is widely discussed in this context by several authors (see e.g. Udo de Haes *et al.* 2002, Pennington *et al.* 2006).

3.2.4.1 Mean Extinction Time (MET)

The Mean Extinction Time (MET) model was developed based on stochastic population approaches in order to quantify the expected survival of species exposed to a habitat-size reduction or to an environmental pollutant (Lande 1998).

The impacts stressing an exposed ecosystem will normally not lead to "*immediate extinction of a population but may shorten the expected time to extinction*" (Hakoyama and

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[15] As shown by Posthuma, when acute EC50 is used as toxicity metric, the extent to which species are affected comes close to disappearance. Therefore, PDF can be found as the acute EC50-based PAF.

Iwasa 2000)[16], meaning that the population disappears from the ecosystem before it would have if the ecosystem had not been exposed to the stress, "*due to a reduction of the growth rate of the population. The estimated decrease in growth rate can be translated into an extinction risk, corresponding to the reduction of the MET (Hakoyama and Iwasa 2000) called MET risk (Tanaka and Nakanishi 2000). The MET model requires knowledge of the life history of the considered species, in order to assess the growth rate of the population. The population life-history data needed for estimation of the MET is the ecosystem's carrying capacity for the population, an intrinsic growth rate for the population and its variance. Hakoyama and Iwasa demonstrate that estimation of values for these three needed population life history parameters requires a time series of population fluctuation including at least 10 data points*."[17]

This data requirement is not generally considered realistic in an LCIA context. Nevertheless, the MET approach has now been applied to LCIA in the Japanese LIME methodology [17] as a basis for deriving endpoint indicators for ecotoxicity effects - the EINES indicator (Expected Increase in Number of Extinction Species). Further study into the related simplifications and robustness of this approach is justified.

3.2.4.2 Changes in genetic diversity

Both approaches to the assessment of biodiversity loss described above suffer from "*a conceptual divergence from the earlier quoted Rio Convention's definition of biodiversity*"[17], quoted as including the diversity within a species reflecting the genetic variation within the population. Instead of using biodiversity as a basis for the endpoint modelling, use of "*genetic diversity could be a good alternative in solving some of the problems*"[17] related to the divergence of concepts focusing on diversity within species, versus concepts focusing on diversity between species. This also considers the problem with vulnerability of species after repeated exposure to contaminants.

"With the development of new genetic techniques, it has become possible to quantify the number of genes of some species or some loci*. Genetics of ecotoxicology has become an important field of research (van Straalen and Timmermans, 2002; Belfiore and Anderson 1998; Bickham et al. 2000). This approach is based on the principle that genetic changes in a population are resulting from mutations, migration, genetic drift, and natural selection. The possession of one or more alleles by individuals will confer it a better "fitness", compared to other individuals. The increase in reproductive effort of this individual compared to others will change the frequency of the same allele in the population.*"[17] This is, however, still a field of research, and to the extent that models exist (e.g. Norberg *et al.*, 2001) the data are not yet available to run such models for the combinations of species and chemicals required in applications like LCA.

3.3 Natural Resources

3.3.1 Recommendation

No recommendation is made here at the endpoint level for the Area of Protection of 'Natural Resources'. Recommendations for specific indicators can be based on current practice, while these are unlikely to address all options. For example, the characterisation models used in current LCIA practice for resources are based on quantifying the effort

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[16] See Hakoyama and Iwasa, 2000

[17] See Itsubo *et al*., 2003; Itsubo and Inaba, 2003; Narita *et al*., 2004

needed to safeguard the availability of resources that can be used, including land, with a focus on the use-value for humans.

3.3.2 Background and Discussion

A clear distinction between this Area of Protection and the AoPs of 'Human Health' and 'Natural Environment' does not exist. They are intrinsically linked. The extraction of resources, such as mineral deposits, fossil energy carriers, fish, trees, and water has many repercussions on the environment. The extracting activity in itself – e.g. mining, forestry, fishery – releases toxic emissions, creates noise, damages the landscape, etc., which are dealt with under other AoPs,

Complementarily, this AoP is concerned with, the removal of resources from the environment (and their use) which results in a decrease in the availability of the total resource stock[18], as non-renewable (usually abiotic) resources are finite. Conversely, the availability of renewable resources (usually biotic) depends entirely on the time they take to regenerate relative to the time we take in consuming them. As resources dwindle, the economic system upon which human welfare depends may be damaged. Resource scarcity is therefore the rationale for this AoP.

The extraction of biotic resources through, e.g., intensive land use can impact on both ecosystems and human welfare. For example, fish populations may decline, and thereby resulting in less food for both human and non-human species; the food chain of an ecosystem may breakdown; or forests may collapse, resulting in the disappearance of forest-dwelling species.

The extraction of water could lead to smaller reserves of potable water.

The extraction of non-renewable resources may mean (depending on its recycling potential) that we limit – or even eliminate - the future possibility to use that resource. For example, if all coal mines are exhausted, then there is no coal left to run the equipment that relies on that particular resource.

Similarly, when the dodo became extinct, it was permanently eliminated, a prospect which some species (e.g. fish) are subject to. The exhaustion of these global biotic and abiotic stocks may, therefore, be irreversible.

The characterisation models used in LCIA for the category indicators for Natural Resources (based on quantifying the effort needed to safeguard the availability of resources), have an anthropocentric approach as they focus on the use value for humans, largely excluding its non-use and intrinsic value[19]. Resources serve many functions for humans. De Groot (1992) presented a list of the functions of ecosystems, and these are presented solely with an anthropocentric perspective (*see Figure 3-2*).

Udo de Haes *et al.* (1999) similarly adopt an anthropocentric perspective and define natural resources as "*those elements that are extracted for human use. They comprise both abiotic resources, such as fossil fuels and mineral ores, and biotic resources, such as wood and fish. They have predominantly a functional value for society.*"

The absence of fish as a human food resource would, in theory, affect humans, especially since many societies live and depend on coastal zones. Concomitantly, the abundance or absence of fish also affects other species: micro-organisms, other fish, birds, and other predators along the food chain. As a result, the distinction between the AoP 'Natural

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[18] At least of those stocks that are in a form that can be easily extractable with current technology

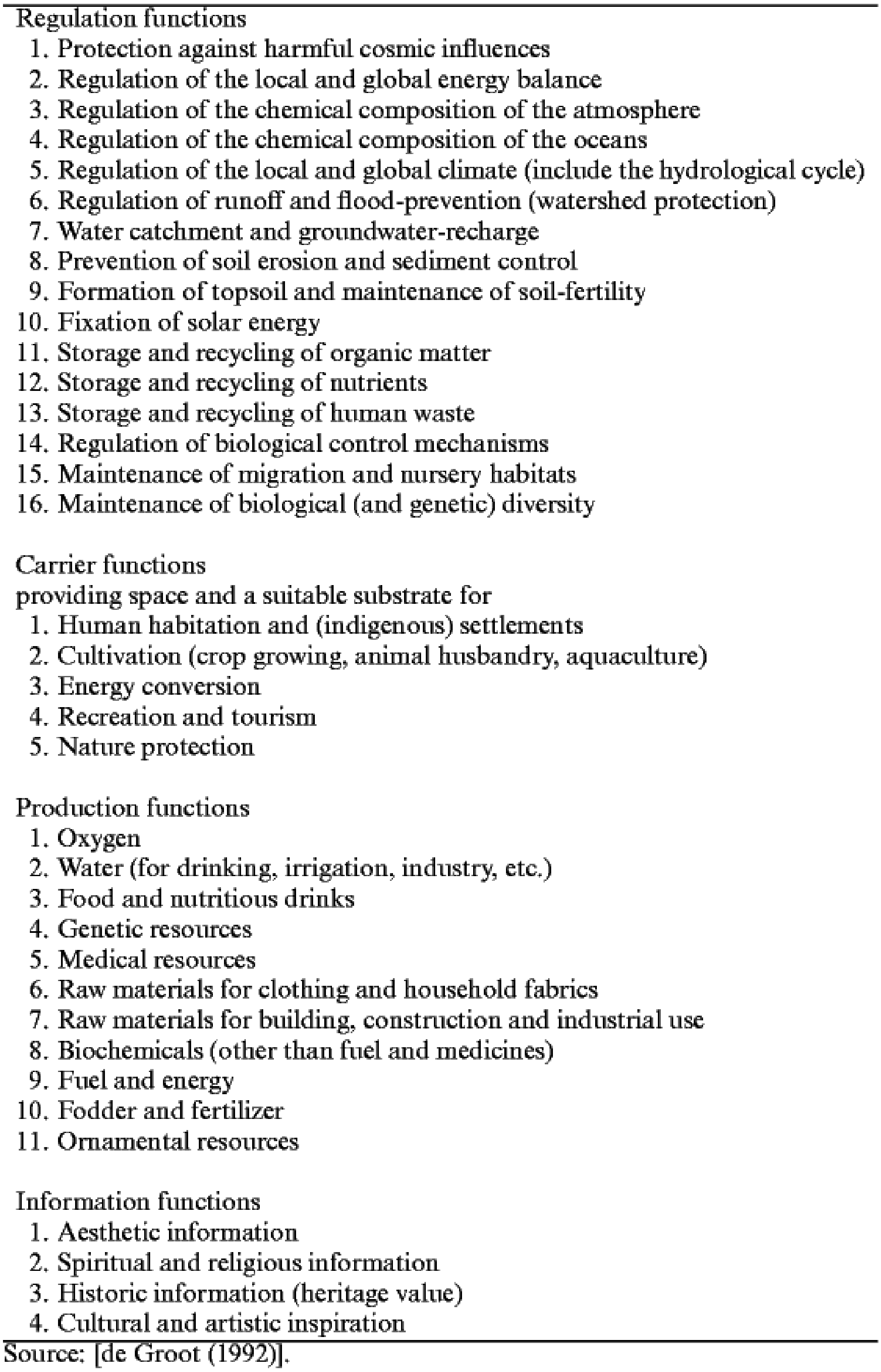
[19] See also the ILCD background document: "Analysis of Existing Environmental Impact Assessment Methodologies and Indicators for Use in Life Cycle Assessment"

Resources' and the AoP 'Natural Environment' is not always clear. However, although resources provide functions for species other than humans, the concern for the AoP term 'Natural Resources' is to capture the availability and use potential of resources used and valued by humans only. It should also be noted that through the extraction and use of one resource, humans can also affect (both posititvely and negatively) the availability of other resources. For example, if the stock of fish A has been depleted by humans, the availability of fish B - who depended on fish A – also decreases. If fish B is a human resource, its decrease as a resource is also accounted for in this AoP; if it is not a resource valued by humans, then it is only accounted for in AoP 'Natural Environment'. The AoP 'Natural Resources' also considers the corresponding impacts on the material quality of life: the idea that the ability of humans to meet their requirements in terms of material welfare is, or will be, impacted upon.

The overview above demonstrates that there are many possibilities in defining the AoP of 'Natural Resources', and that a clear discussion is needed on the appropriate definition. Elements to consider include:

- Is the AoP for 'Natural Resources' restricted to the role of resources for humans, or does it also include the role for ecosystems or parts of ecosystems. For instance, while humans could live without trees in some regions, squirrels and other mammals and insects cannot survive without the existence of trees.
- Is the role of natural resources for humans restricted to its present uses, or should we also address future needs? For instance, will we have to take into account that the importance of indium may increase in the next hundred years, and that the importance of copper may decrease?
- Are the resources we distinguish for human needs focused on essential functions (such as nourishment), or does it also include luxury items (such as using ivory for pianos)?
- To what extent do we need to address developments in population growth and affluence in the future? For instance, in assessing the future role of iron ore, what population size do we take into account, and do we assume that e.g. Africa's needs are similar to Europe's on a per capita basis?

Only after considering these points can principles for defining midpoint and endpoint indicators be made. This includes the choice of the categories themselves, from one aggregate resource depletion indicator on the one extreme side, to a broad range of resource depletion indicators (e.g., for metals, fossils, water, fish, wood, land, etc.) on the other extreme side. Subsequently, it is possible to choose or develop a characterisation method.



Regulation functions

1. Protection against harmful cosmic influences
2. Regulation of the local and global energy balance
3. Regulation of the chemical composition of the atmosphere
4. Regulation of the chemical composition of the oceans
5. Regulation of the local and global climate (include the hydrological cycle)
6. Regulation of runoff and flood-prevention (watershed protection)
7. Water catchment and groundwater-recharge
8. Prevention of soil erosion and sediment control
9. Formation of topsoil and maintenance of soil-fertility
10. Fixation of solar energy
11. Storage and recycling of organic matter
12. Storage and recycling of nutrients
13. Storage and recycling of human waste
14. Regulation of biological control mechanisms
15. Maintenance of migration and nursery habitats
16. Maintenance of biological (and genetic) diversity

Carrier functions
providing space and a suitable substrate for

1. Human habitation and (indigenous) settlements
2. Cultivation (crop growing, animal husbandry, aquaculture)
3. Energy conversion
4. Recreation and tourism
5. Nature protection

Production functions

1. Oxygen
2. Water (for drinking, irrigation, industry, etc.)
3. Food and nutritious drinks
4. Genetic resources
5. Medical resources
6. Raw materials for clothing and household fabrics
7. Raw materials for building, construction and industrial use
8. Biochemicals (other than fuel and medicines)
9. Fuel and energy
10. Fodder and fertilizer
11. Ornamental resources

Information functions

1. Aesthetic information
2. Spiritual and religious information
3. Historic information (heritage value)
4. Cultural and artistic inspiration

Source: [de Groot (1992)].

Figure 3-2 Functions of the natural environment, according to De Groot (1992), reproduced from Gustafson (1998).

Dewulf *et al.* (2007) distinguishes more categories within the resources section of the AoP 'Natural Resources'. These include:

- atmospheric resources,
- land,
- water,
- minerals,
- metal ores,
- nuclear energy,
- fossil fuels
- renewables.

This is just one categorization. Other categorizations split resources differently. For example, Finnveden (1998) splits resources into deposits, funds and fows, whereas Guinée *et al.*, 2002 splits resources into biotic and abiotic resources.

A clear advantage of distinguishing several resource-related impact categories is that it becomes possible to include different issues of concern in the different resource classes. For example, metal ores become dispersed through their use, fossil resources are consumed, and water is only temporarily removed from circulation. Such differences in the underlying mechanism may require different models and separate metrics, just as acidifying and toxic substances are treated in separate indicators, using different models. However, since the context of the impact categories is given, and since most impact assessment methods use just one indicator for resource depletion, such a separation of mechanisms and indicators has not been carried out. Only impacts related to land use have been addressed separately; the focus of this treatment is then on ecological impacts, such as loss of biodiversity or habitat destruction. The scarcity of land itself (i.e. land competition, the restriction that one human user exerts on the possibilities of another human user) can be addressed in LCA by existing land use concepts.

In analysing the use value of a resource, many issues arise. Some use values are essential (such as nutrition), others are desirable (such as luxury products), and others even have an aspect that many people dislike (such as military purposes).

It is difficult to decide which functions to preserve, especially as needs in the future are either unknown or not yet recognized. For example, it would have been impossible to predict that germanium and other semiconductors would become an essential resource in the second half of the 20th century; or that wood as a construction material would become less dominant. Besides, there is an important issue here that relates to rebound and other behavioural aspects. When resources become scarce, prices rise. This leads to multiple effects. The demand for the resource declines. This may stimulate the development of substitute resources, and the development of new technologies and recycling techniques. It may also lead to further exploration and the discovery of new reserves. Finally, it will make non-economic reserves more profitable, perhaps with more intense environmental repercussions due to higher requirements on drilling, mining, and refining.

Technology and prices also dictate the quantity of the reserve. Geologists distinguish between proven reserves, probable reserves, possible reserves, and so on, as determined by technical and financial feasibility.

Also the conservation-potential nature of materials is important: copper does not become depleted when it is used, it can only become dispersed over the world in low concentrations. In principle, given enough energy and money, recollection is possible but not feasible in today’s practice. For energy carriers, the situation is different: the energy carrier is not conserved, although the energy is. What is lost is the quality or potential to use that energy. Exergy is an important way to measure this. In fact, exergy as a measure of resource depletion is slowly growing in popularity, mainly because it combines aspects of quantity and quality.

Finally, it is necessary to assess how it is possible to maintain our current needs and habits at the same quality as we have come to expect, and what extra efforts are required to ensure that. This may turn out to be the appropriate question in the context of sustainable use of resources, and exergy may well provide a key to this.

We can see, that given a basic level of technology and enough stimulus through increased need or reduced availability, humans will be able to find new resources, develop more advanced technologies, seek out substitutes, and apply sustainability principles. Indeed this challenge is “potentially the biggest business opportunity since the industrial revolution” (David Middleton WBCSD, UK).

4 Requirements for specific impact categories

This chapter provides an overview of the requirements for each impact category for the:

- Framework and Scope – outlining the context and general approach for the impact assessment for the categories.
- Environmental Mechanism (or cause-effect chain) – outlining which pathways are generally considered when modelling between the emissions/resources to the Area of Protection. Recommendations for the Midpoint and Endpoint indicators are highlighted.
- Criteria for Model Evaluation.

4.1 Climate change

4.1.1 Framework and scope

Climate change involves a number of environmental mechanisms that affect both the AoPs 'Human Health' and 'Natural Environment'. Climate change models are, in general, developed to assess the future impact on climate resulting from different policy scenarios. The environmental mechanisms used for this impact category have a somewhat different structure, compared to the fate, effect and damage steps applied to many of the other impact categories. Man-made climate change is caused by the emission of greenhouse gases (and by other activities influencing their atmospheric concentration). Greenhouse gases are substances with the ability to absorb infrared radiation from the earth (radiative forcing).

When modelling the radiative forcing of an emission, the change in concentration and radiative forcing is determined, taking into account the residence time of the substance. A globally-recognised model (the Bern model) has been developed by the Intergovernmental Panel on Climate Change (IPCC) that calculates the radiative forcing of all greenhouse gases and branded them Global Warming Potentials (GWP).

The IPCC's 'GWPs' are recommended for use at midpoint.

- Firstly, at midpoint the GWPs are used directly as characterisation factors.
- Secondly, these factors are used to express a combined fate and effect (in terms of radiative forcing), which is then coupled to a modelling of a resulting temperature increase, using the residence time and the radiative forcing of the greenhouse gas.
- Thirdly, the temperature rise results in damage to Human Health and ecosystems, and here several effects are considered, such as an increase in malaria and malnutrition (for Human Health) or disappearance of a species and change in biomass[20] (for ecosystems).

4.1.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-1 presents the cause-effect chain for climate change from emission to damage, illustrating the most important pathways (*see bold arrows*).

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[20] The change in biomass refers to change in crop productivity (e.g food and wood). This effect can be considered by both the area of protection 'Natural Environment' and 'Natural resources'. In this document, this type of effect was considered to be part of effects on ecosystems (AoP Natural Environment).

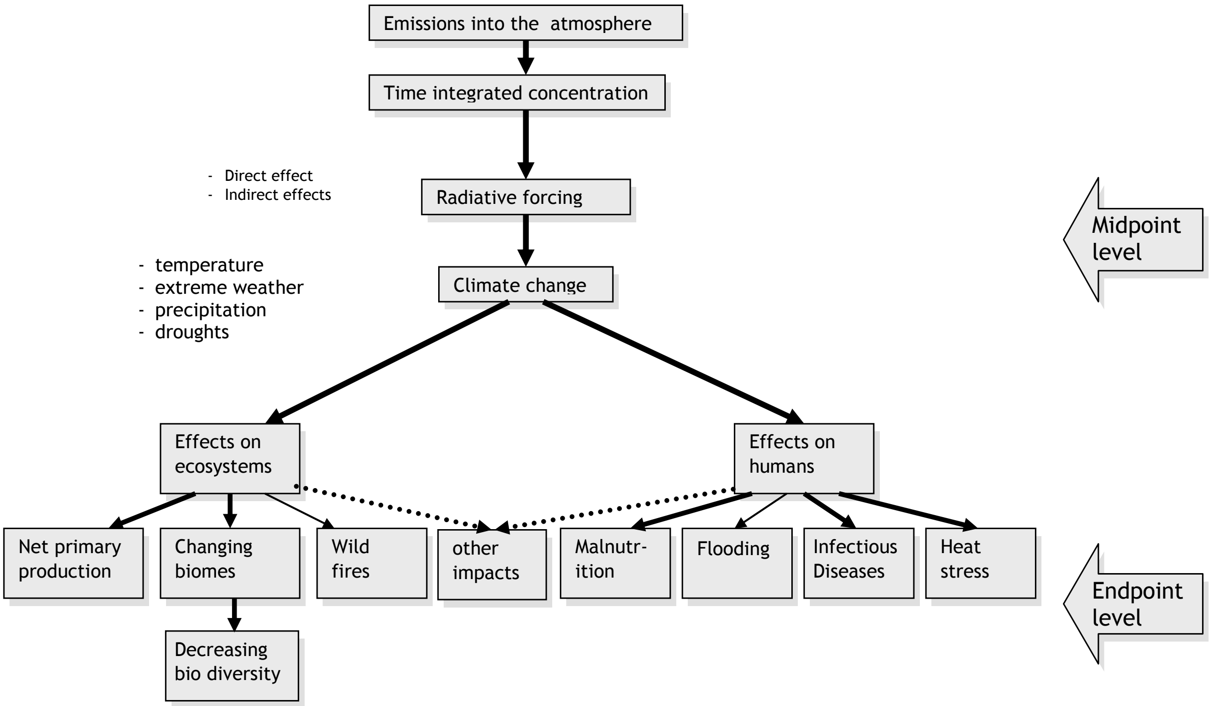

Figure 4-1 Flow diagram for climate change.

The thickness of the arrows in the diagram illustrates how important the pathway is in the overall mechanism. Radiative forcing is caused by direct and indirect effects. The box “other impacts” is added, as there are several other impacts, which have not been adequately described to warrant inclusion.

4.1.2 Criteria for Evaluation of this impact category

After the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘scientific robustness’ have been specified by ten sub-criteria in order to outline the modelling of climate change in more detail. These sub-criteria, based on the cause-effect chain illustrated in Figure 4-1, are:

- Atmospheric fate and transport is considered.
- For damages on ecosystems, all relevant effects are considered.
- For damages on Human Health, all relevant effects are considered.
- All category indicators and characterisation models linking midpoint to endpoint fulfil the science-based requirements.
- The coverage of the impacts in modelling from midpoint to endpoint is complete.
- The fate and transport model reflects the latest stage of knowledge.
- The human damage model is scientifically robust.
- The ecosystem damage model with loss of species is scientifically robust.
- The ecosystem damage model on primary production is scientifically robust.
- The model including the underlying data has potential for being consistently improved and further developed regarding geographic and temporal differentiation.

The table below shows the general and specific criteria for climate change identifying the minimum score (threshold value) to be met and the most relevant criteria for the impact category (importance).

Table 4-1 General and specific criteria for climate change with threshold value and importance.

CLIMATE CHANGE		**Check the following:**	**Threshold** (Minimum score)	**Impor-tance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of substances covered by the provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health		H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment?		H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen at the right point in the cause-effect chain, where all LCI are aggregated as early as possible in the cause effect chain		
		• The characterization model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)	B	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality	C	H
		• Atmospheric fate and transport is considered	C	
		• For damages on ecosystems, all relevant effects are considered		
		• For damages on Human Health, all relevant effects are considered		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)		H
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered)		
		• All category indicators and characterisation models linking midpoint to damage are science based		
		• The coverage of the impacts in the modelling from midpoint to endpoint is complete		
		• The fate and transport model reflects the latest stage of knowledge		
		• The human damage model is scientific robust		
		• The ecosystem damage model with loss of species is scientific robust		
		• The ecosystem damage model on primary production is scientific robust		

CLIMATE CHANGE		**Check the following:**	**Threshold** (Minimum score)	**Impor-tance** (H-N)
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
		• The category indicator and characterisation models are science based		
	Overall evaluation			
Documentation & Transparency & Reproducibility		• The model documentation is published and accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)	C	H
		• The set of characterization factors/models is published and accessible	B	H
		• The input data are published and accessible		
		• The characterization model is published and accessible		H
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation		H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)		
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools		
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly made available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The unit is easily understood		
		• There is an authoritative body behind the model principles like the IPCC model (consensus/international endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.2 Ozone Depletion

4.2.1 Framework and scope

The “hole in the ozone layer” was detected over Antarctica in 1985. Ozone is continuously formed and destroyed by sunlight and chemical reactions in the stratosphere. Ozone depletion occurs if the rate of ozone destruction is increased due to fugitive losses of anthropogenic substances which persist in the atmosphere. Stratospheric ozone, which is 90% of the total ozone in the atmosphere, is vital for life because it hinders harmful solar ultraviolet UV-B radiation from penetrating the lower levels of the atmosphere. If not absorbed, UV-B radiation below 300 nanometres will reach the troposphere and the surface of the earth, where it can increase the human risk of skin cancer and cataract when appropriate precautions are not taken. It may also cause premature aging and suppression of the immune system. In addition to the increased risk to ‘Human Health’ the UV-B radiation can also damage terrestrial plant life and aquatic ecosystems.

The characterization factor for ozone depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). These are persistent chemicals that contain chlorine or bromine atoms. Because of their long atmospheric lifetime Cl and Br are able to reach the stratosphere. Chlorine atoms in chlorofluorocarbons (CFC) and bromine atoms in halons are effective in degrading ozone due to heterogeneous catalysis, which leads to a slow depletion of stratospheric ozone around the globe. The chlorine and bromine atoms that are released from these reactions have the ability to destroy a large quantity of ozone molecules in the stratosphere because they act as free radical catalysts in a sequence of degradation reactions, in which they react with ozone to split it into molecular and atomic oxygen without being consumed (WMO, 2003) as shown:

$Cl + O_3 \rightarrow ClO + O_2$

$Br + O_3 \rightarrow BrO + O_2$

$ClO + O \rightarrow Cl + O_2$

$ClO + BrO \rightarrow Cl + Br + O_2$

Ozone depletion potentials

The ozone depletion potential (ODP) of a substance is a relative measure for the potency to form EESC (Equivalent Effective Stratospheric Chlorine). The ODPs are equivalency factors that encompass the atmospheric residence time of ozone depleting substances, the formation of EESC and the resulting stratospheric ozone depletion.

ODP steady state

Steady-state ODPs represent the cumulative effects on ozone over an infinite time scale:

$$ODP_x(\infty) = \frac{\partial [O_3]_x}{\partial [O_3]_{CFC-11}}$$

where $\delta[O_3]_x$ and $\delta[O_3]_{CFC-11}$ denote the total changes in the stratospheric ozone in the equilibrium state due to annual emissions of halocarbon species x and CFC-11, respectively.

The most recent steady-state ODPs were published by the World Meteorological Organization in 1999 and are the equivalency factors for the impact category of ‘Ozone Depletion’. This model is recommended to be used both in midpoint and endpoint methods.

For the calculation of endpoint (damage) factors, it is recommended to use the WMO 2003 scenario A1, which predicts that the Equivalent Effective Stratospheric Chlorine (EESC) concentration will drop in 2044 to below a threshold value (EESC0), when UV damage to Human Health will equal the natural background. Any ODS emitted after 2040 can be considered as not contributing to any additional damage.

4.2.1.1 Environmental Mechanism (cause-effect chain)

The picture below illustrates the cause-effect chain used by most models. It is similar to that of the climate model. The link to cataract is becoming more disputed (de Gruijl 2002 and Sasaki 1999) and the link to immune suppression has not been implemented. *NB: this link is not completely clear*.

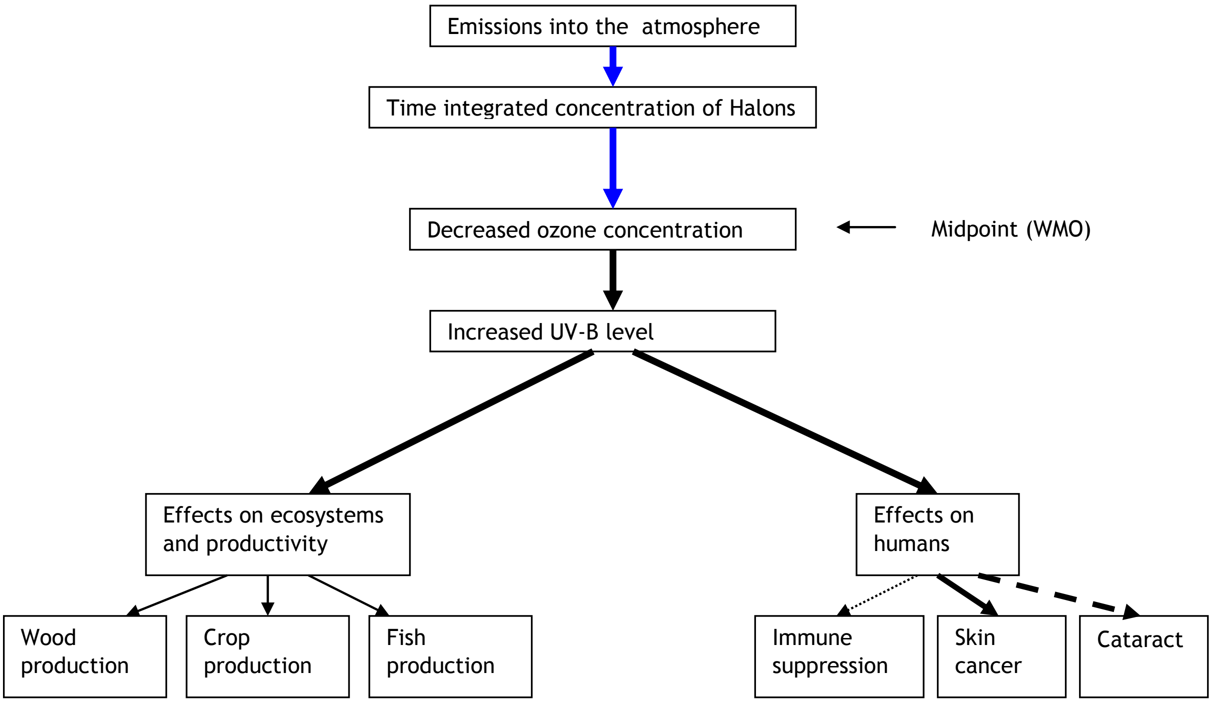

Figure 4-2 Causality chain of the model to assess impacts of ODS. The link to ecosystems is generally not modelled in terms of biodiversity losses.

4.2.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘Scientific robustness’ have been specified by the following sub criteria:

- Atmospheric fate and transport is considered.
- For damages on ecosystems, all relevant effects are considered.
- For damages on Human Health, all relevant effects are considered.
- All category indicators and characterisation models linking midpoint to damage fulfil the science-based requirements.
- The coverage of the impacts in the modelling from midpoint to endpoint is complete.
- The fate and transport model reflects the latest state of knowledge.
- The human damage model is scientifically robust.
- The ecosystem damage model with loss of species is scientifically robust.

- The ecosystem damage model on primary production is scientifically robust.
- The model including the underlying data have a good potential for being consistently improved and further developed including geographical/emission situation and temporal differentiation.

The table below presents the general and specific criteria for ozone depletion identifying the minimum score (threshold value) to be met and the most relevant criteria for the impact category (importance).

Table 4-2 General and specific criteria for ozone depletion with threshold value and importance.

OZONE DEPLETION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of substances covered by the provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen at the right point in the cause-effect chain, where all LCI are aggregated as early as possible in the cause effect chain		
		• The characterization model is adaptable to spatial explicit evaluation		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)		H
		• When empirical data is used, double counting is avoided		
		•The model is representative for a generic global scale	B	H
		• There is consistency between the different endpoint indicators		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality	C	H
		• Atmospheric fate and transport is considered		
		• For damages on ecosystems, all relevant effects are considered		
		• For damages on Human Health, all relevant effects are considered		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)		H
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered)		
		• All category indicators and characterisation models linking midpoint to damage are science based		
		• The coverage of the impacts in the modelling from midpoint to endpoint is complete		

OZONE DEPLETION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• The fate and transport model reflects the latest stage of knowledge		
		• The ecosystem damage model with loss of species is scientific robust		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
	Overall evaluation			
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible	C	H
		• The set of characterization factors/models is published and easily accessible	B	H
		• The input data are published and easily accessible		
		• The characterization model is published and easily accessible	B	H
		• Ability for third parties to freely generate additional, consistent factors and to further develop models, e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	B	H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)		
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools		
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The unit is easily understood		
		• There is an authoritative body behind the model like the IPCC model (endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.3 Human toxicity

4.3.1 Framework and scope

Models and factors for toxicological effects in LCA must be based on the relative risk and associated consequences of chemicals that are released into the environment. These must build on the principles of comparative risk assessment, while providing indicators linked to the Area of Protection ‘Human Health’ (see Chapter 2).

LCA characterisation models and factors for toxic effects must rely on models that account for a chemical’s fate in the environment, human exposure, and differences in toxicological response (both likelihood of effects and severity).

The scope and methodology of an LCA differs from that of many approaches adopted for toxicological assessments in a regulatory context. Regulatory assessments of chemical emissions usually have the objective of evaluating whether there will be an unacceptable risk of a toxicological effect to an individual or subpopulation.

The focus in regulatory assessments is generally on ensuring that policy-based limits are not surpassed by exposures at any location or point in time. For example, the maximum likely exposure in the region of an emission may be compared to a tolerable threshold. If this exposure is less than the agreed threshold then no further action is likely to be necessary from a regulatory perspective. It should be noted that these regulatory limits, for example for cancer effects, do not necessarily reflect an absence of an effect and neither are they generally suitable for use in comparative risk assessments where one emission has to be compared against another.

Nevertheless, the underlying mass balance models and basic dose-response information used to determine comparative estimates for LCA are often the same as for regulatory approaches. A key difference is that LCIA takes into account all releases of all substances with a toxicity potential due to the evaluated product over the entire life cycle, regardless of where and when they are released. However, in LCIA all emissions not related to the evaluated product are deliberately excluded from the assessment, e.g. emission of the same chemicals from other products or from sites unrelated to the product. Thus, site specific regulatory assessments, chemical related regulatory assessments and toxicity aspects in LCIA are to be seen complementary in their nature.

Life cycle assessments provide insights for products that are complementary to those of many regulatory risk assessments. In LCA it is desirable to account for the full extent of the likelihood of an effect (recommended midpoint indicator basis) and differences in severity (recommended endpoint indicator basis).

The basis of comparative risk in LCA is the entire global population, using best-estimates complemented with uncertainty insights. The factors must reflect the likelihood of a toxicological impact integrated over time and space that is associated with the release of a quantity of chemical into the environment. This is a fundamental difference from many regulatory approaches, which focus more on realistic peak exposures for individuals compared to acceptable thresholds. Nevertheless, this basis is consistent with the principles already adopted for the assessment of substances such as radionuclides, for other impact categories in LCA such as climate change, as well as in approaches necessary to support cost-benefit analyses.

Contributions of emissions to short-term/acute and local scale effects are presently not addressed in the recommendation. This includes those associated with indoor exposures, direct exposure to products during their use stage, and to exposures in the work place. The focus here is on the contribution of emissions to the risk of toxicological impacts and associated consequences considering the entire human population and dispersed emissions.

4.3.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-3 presents the environmental mechanism for human toxicity effects and corresponds to the model framework of fate, exposure and effect assessment, as described in the next section.

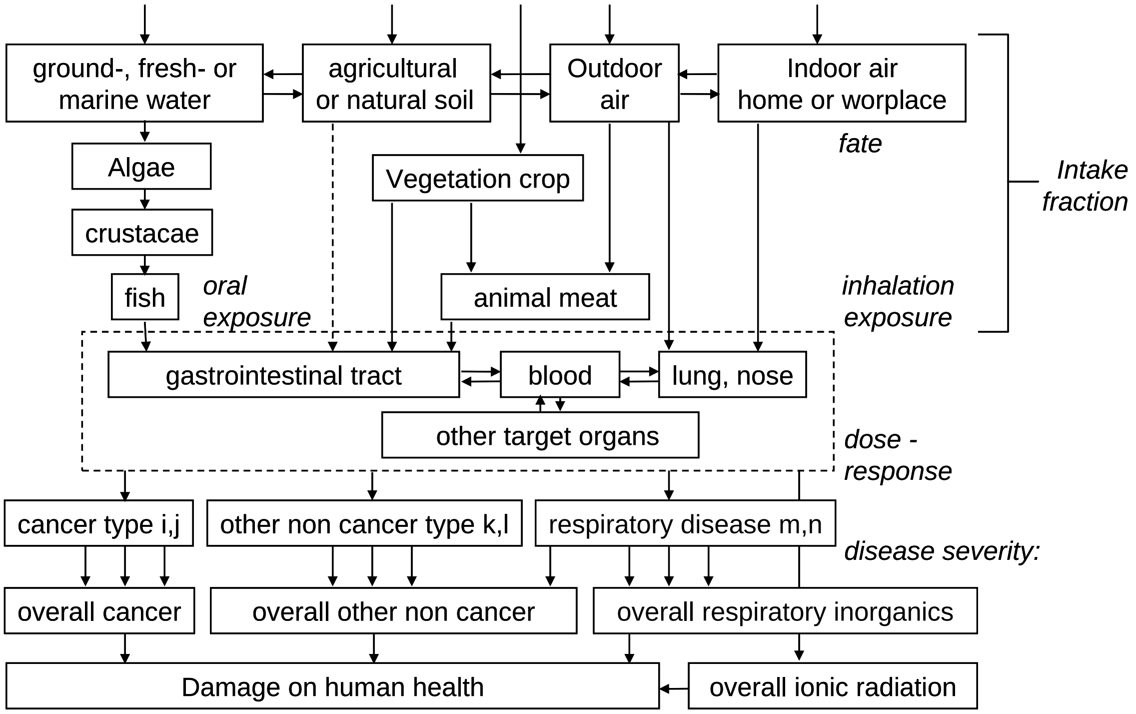

Figure 4-3 Environmental mechanism for the human toxicity effects (including mechanisms for ionising radiation and respiratory effects associated with particulate matter, *see Chapters 4.4 and 4.5*).

4.3.1.2 Framework for analysing the characterisation models

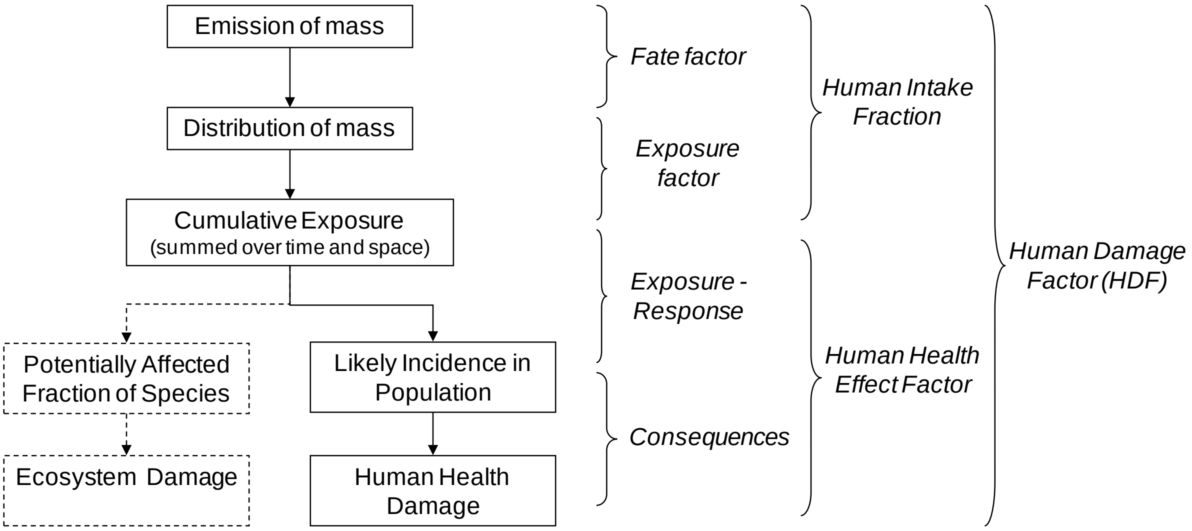

Figure 4-4 Recommended framework for calculating characterisation factors for human toxicity effects in LCA. (based on Pennington *et al.* 2006, Jolliet *et al.* 2006)

From Figure 4-4, it is clear that the model for human toxicity effects must account for the environmental fate (F), exposure (X), dose-response (R) of a chemical for midpoint factors and additionally severity (S) for endpoint factors (Udo de Haes *et al.* 2002, Pennington *et al.* 2006, Jolliet *et al.* 2006):

$$CF = S \cdot R \cdot X \cdot F = S \cdot R \cdot iF$$

The fate factor above relates the emission flow to the change in mass in the environment. The exposure factor links the change in mass in the environment to the change in intake rate. The dose-response slope is the likelihood of an additional effect per unit additional intake and the severity is the effect per case linked to mortality and morbidity.

In reality, these parameters vary depending on location (e.g. habitat characteristics, local stressors, mixtures, background concentrations) and time (e.g. seasonal life stage sensitivity). The implications of many of these assumptions in comparative applications such as LCA, as well as in regulatory contexts, are only now beginning to be quantified. These variations are therefore generally not adopted in default models and factors.

The fate and exposure factors can be combined into an Intake Fraction (iF). This characterizes the fraction of the emission that is taken in by the overall population (Bennet *et al.* 2002).

In estimating the comparative risk of a chemical in LCA, dose-response extrapolations are based on toxicological benchmarks. Dose-response benchmarks can be estimated from toxicity data on e.g. laboratory experiments, assuming a variety of models (e.g. Crettaz *et al.*, 2002)

Benchmarks are exposure measures associated with a consistent change in response, such as the 10% or even the 50% effect level. Regulatory-based measures do not necessarily provide a consistent risk basis for comparison, as they were often not developed for use in such a comparative context or to facilitate low dose-response extrapolation. Other differences in data use in LCA and regulatory/based risk assessments include the preferred use of median, rather than extreme, data in the fate and exposure modelling, as well as the consideration of safety factors only as part of the uncertainty assessment, and not as an integral part of the toxicological effects data.

Due to the large number of potential endpoints that involve various mechanisms, there is no true midpoint for toxicological effects where comparisons can be made on a purely natural science basis. The midpoint indicator is therefore based on the likelihood of an effect associated with an emission of a quantity of a chemical.

Though each toxicological effect could be treated as a separate endpoint, these effects are usually grouped for practical reasons in subcategories. Subcategories include:

- Cancer.
- Respiratory diseases.
- Other non cancer effects.
- Impact of ionizing radiation.

The severity factor to account for differences in the effects can be estimated by implicitly assuming equal weighting within these categories or by using explicit metrics such as Years of Life Lost (YLL) and Years of Life Disabled (YLD) as discussed in Chapter 3 for Human Health.

4.3.2 Criteria for Evaluation of this impact category

In addition to the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘scientific robustness’ are further specified by the following sub criteria:

For environmental relevance, criteria have been defined to assess the quality and adequacy of the assessment framework:

- The model considers fate, exposure and effects in a quantitative way. Fate factors, intake fraction and dose-response information can be given as intermediary results.
- Urban area is considered separately. Advection out of a region or from a continent, for example, is not considered a final loss.
- Influential fate processes are taken into account as appropriate (e.g. –degradation, chemical reaction, volatilization, deposition, intermittent rain, direct deposition of pesticides on plants, colloid matter, sedimentation).
- Main impact pathways are covered as being relevant (inhalation, ingestion of meat, dairy products, fish, eggs, etc).
- Regarding dose-response, the Effect Dose 10% (ED10) or 50% (ED50) is used as a benchmark for the point of departure, avoiding safety factors. If not available extrapolation from NOAEL to LOAEL (No or Lowest Observable Adverse Effect Levels) is performed. Human data are preferably used when test sample sizes are sufficient and a causal relationship is proven.
- Chemicals that test negative in cancer tests are differentiated from chemicals without available data.
- Route to route extrapolation (e.g. oral to inhalation) methods are available for chemicals with partial data.
- Regarding severity and aggregation, value judgments are transparent and intermediary results are kept separate.

For scientific robustness, the following criteria have been identified to assess the quality and adequacy of the models and data used:

- Intermedia transfer and loss processes reflect latest scientific research that can be applied in a practical form.
- Bioaccumulation/magnification is included, and related correlations comply with mass balance principles.
- Model algorithms are valid for special classes of chemicals such as metals and application of pesticides.
- Slope of the effect factors accounts for up to date research.
- Best available knowledge is used for the severity factors.

Table 4-3 below presents the general and specific criteria for human toxicity identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-3 General and specific criteria for human toxicity with threshold value and importance.

HUMAN TOXICITY EFFECTS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		Total number of substances covered by the provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterisation model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors / precautionary principle)	B	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality --> provide a list of specific criteria per impact category		
	Overall structure	• The model considers fate, exposure and effect in a quantitative way and fate factors, intake fraction, dose-response information are given as intermediary results	C	H

HUMAN TOXICITY EFFECTS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
	Fate	• Urban area is considered separately and advection out of a region or of a continent is not considered a final loss.	C	H
		• Influential fate processes are considered (classic - volatilization, chemical reaction, deposition, colloid matter, sedimentation, intermittent rain, direct deposition of pesticides on plants)		
	Exposure	• Main impact pathways are covered (inhalation, ingestion of meat, dairy products, fish, eggs, dermal uptake)	C	H
	Dose-response	• Regarding dose-response Effect Dose 10% (ED10) or 50% (ED50) are used as a point of departure, avoiding safety factors, if not available extrapolation from NOAEL to LOAEL is performed, human data are preferably used	C	H
		Negative carcinogenic chemical are accounted for differently from non available data and route to route extrapolation is included		
	Severity	Regarding severity and aggregation, value judgments are transparent and intermediary results are kept separate	C (only for endpoint methods)	N
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	C	H
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered) --> provide a list of specific criteria for each impact category		
		• Intermedia transfer and loss processes reflects latest state of knowledge		
		• Biomagnification is included, carry over rates do comply with mass balance principles even at high Kow	C	H
		• Model valid for metals and direct application of pesticides before harvest		
		• Slope of the effect factors accounts for latest state of knowledge		
		• Best available knowledge is used for the severity factors, latest data used on WHO factor		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty as well as substance data and parameter uncertainty are taken into account		
	Overall evaluation	• The category indicator and characterisation models are science based		

HUMAN TOXICITY EFFECTS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Documentation & Transparency & Reproducibility		• The model documentation is published and accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)	C	N
		• The set of characterisation factors/models is published and accessible	B	H
		• The input data are published and accessible		
		• The characterisation model is published and accessible		
		• Ability for third parties to freely generate additional, consistent factors and to further develop models, e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	B	H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)	C	H
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools	A	N
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.4 Respiratory Inorganics / Particulate Matter

4.4.1 Framework and scope

Ambient concentrations of particulate matter (PM) are elevated by emissions of primary and secondary particulates. The mechanism for the creation of secondary emissions involves emissions of SO_2 and NO_x that create sulphate and nitrate aerosols. Particulate matter is measured in a variety of ways: total suspended particulates (TSP), particulate matter less than 10 microns in diameter (PM_{10}), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) or particulate matter less than 0.1 microns in diameter ($PM_{0.1}$).

The characterisation factor (*CF*) for particulate matter/respiratory inorganics accounts for the environmental fate (F), exposure (X), dose-response (R) of a pollutant for midpoint factors, and of severity (S) for endpoint factors (Humbert *et al.*, 2008a). See below:

$CF = S \cdot R \cdot X \cdot F = EF \cdot iF$

The pollutant can be a single chemical (e.g. CO) or group of agents (e.g. $PM_{2.5}$). The fate factor relates the emission flow to the mass in the air. The exposure factor determines the change in intake rate per change in mass in the environment. The dose-response slope relates the change in intake with the marginal change in morbidity and mortality cases and the severity is the change in damage per morbidity and mortality case.

The fate and exposure can be combined into an intake fraction (iF) (Bennett *et al.*, 2002). The dose-response and the severity can be combined into the effect factor (EF, in $DALY/kg_{inhaled}$).

The intake fraction describes the fraction of the emission that is taken in by the overall population. Intake fractions can be calculated using fate and exposure models. For the case of particles, it is possible to characterize the fate and exposure further in the cause-effect chain by an intake factor (van Zelm *et al.*, 2008) or even an uptake factor (Humbert and Horvath, 2008) because:

1. The exposing particle can be different from the emitted particle (e.g., secondary PM from precursors);
2. The influence of the changing particle size distribution (PSD) throughout time through phenomena like coagulation and nucleation can render the metric of the intake fraction, only a partial representation of exposure.

. However, since these two metrics are not yet widespread and not used for other toxic impacts, the metric of the intake fraction is recommended to be used.

Several studies suggest that no thresholds for PM_{10} should be assumed in the effect calculations (World Health Organization, 2004). Thus it is recommended to derive dose-response from epidemiological studies assuming linear slopes. However, while the influence of this assumption is unclear based on analogous insights for toxicity effects (e.g. Crettaz *et al.*), it is necessary to stress that the linear dose-response assumption is not well accepted for the high concentrations found in developing countries.

For respiratory inorganics, all available methods are de facto endpoint methods. It is advised to report both the number of cases of different diseases as well as the related Years of Life Lost, Years of Life Disabled and DALYs.

4.4.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-5 presents the cause-effect chain of respiratory impacts caused by inorganics and corresponds to the framework of fate, exposure, and effect assessment.

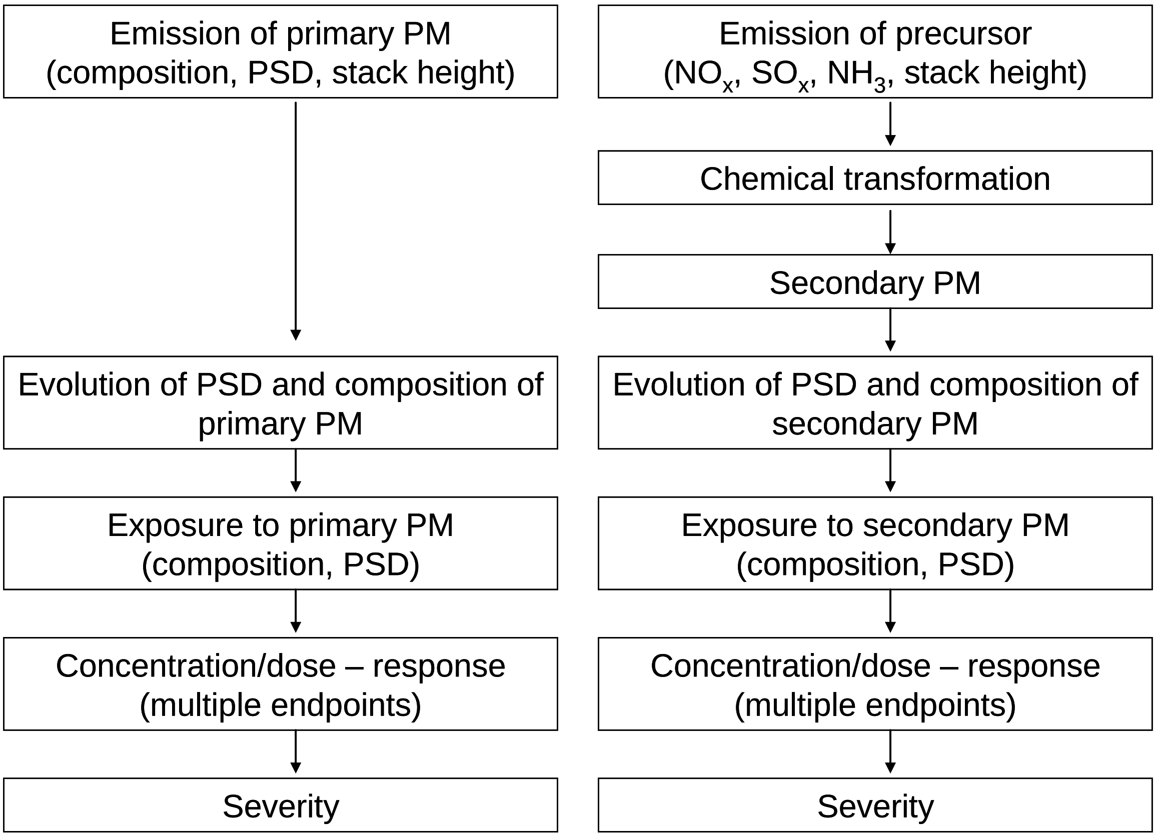

Figure 4-5 Flow diagram for the respiratory inorganics impact category (derived from Humbert 2008)

4.4.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘Scientific robustness’ have been specified by 9 additional criteria to describe the impacts of primary and secondary particulates in more detail.

For environmental relevance:

- Secondary PM is considered.
- Inter continental transport is considered.
- Advection out of a region or of a continent is not considered a final loss.
- Urban area is considered separately and resolution fine enough to capture significant differences in exposure (to account for the findings of Greco *et al.* 2007[21]).
- Influential fate processes are considered (coagulation, nucleation, diffusion, dispersion, deposition, intermittent rain).
- Influence of emission/stack height is considered.
- Influence of source composition and particle size distribution on fate and exposure are considered.
- Intake fraction, intake factor as well as uptake fraction is considered.

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[21] We conclude that long-range dispersion models with coarse geographic resolution are appropriate for risk assessments of secondary PM2.5 or primary PM2.5 emitted from mobile sources in rural areas, but that more resolved dispersion models are warranted for primary PM2.5 in urban areas due to the substantial contribution of near-source populations. (Greco et al. 2007).

- Dose-response slopes consider the influence of the size (e.g. mass based, surface base, number based).
- Dose-response slopes consider the influence of the particle composition.
- All the main types of adverse health effects are considered (various morbidity as well as mortality).
- Regarding severity and aggregation, value judgments are transparent and intermediary results are kept separate.

For scientific validity:

- Best available and most recent knowledge ion typical particle size distribution is used to determine default factors.
- Best available and most recent knowledge ior transformation from precursor to secondary PM is considered.
- Slope of the effect factors based on epidemiological data account for best available and most recent knowledge
- Best available and most recent knowledge is used for the severity factors.

The table below presents the general and specific criteria for respiratory inorganics identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-4 General and specific criteria for respiratory inorganics with threshold value and importance.

RESPIRATORY INORGANICS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND) *(i.e., is effect a marginal effect (additional impact per kg additional PM at present working point) or estimated as the overall effect divided by the overall emissions).*		
		• Total number of substances covered by the provided characterisation factors.		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain.		
		• The characterisation model is adaptable to spatial and temporal explicit evaluation.		
		• Global geographical validity preferable, separate validity for Europe beneficial.		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle).	B	H

RESPIRATORY INORGANICS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• When empirical data is used, double counting is avoided.		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality.		
	Structure and scope	• The model considers fate, exposure and effect in a quantitative way and fate factors, intake fraction, intake factor, uptake factor, and dose-response information are given as intermediary results.		
		• Secondary PM are considered.	B	H
	Fate	• Inter continental transports are considered.		
		• Advection out of a region or of a continent is not considered a final loss.		
		• Urban area is considered separately and resolution fine enough to capture significant differences in exposure.	B	H
		• Influential fate processes are considered (coagulation, nucleation, diffusion, dispersion, deposition, intermittent rain).	C	N
		• Influence of emission/stack height is considered.		
		• Influence of source composition and particle size distribution on fate and exposure are considered.		
	Exposure	• Intake fraction, intake factor as well as uptake fraction are considered.		
	Dose-response	• Dose-response slopes consider the influence of the size: --> i.e., mass based, surface base, number based?		
		• Dose-response slopes consider the influence of the particle composition.		
		• All the main types of adverse health effects are considered (various morbidity as well as mortality).		
	Severity	• Regarding severity and aggregation, value judgments are transparent and intermediary results are kept separate.		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	B	H
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered).	C	N
		• Best knowledge on typical particle size distribution is used to determine default factors.		
		• Best knowledge is used for transformation from precursor to secondary PM is considered.	C	N
		• Slope of the effect factors are base on epidemiological data accounts for latest state of knowledge.	B	H
		• Best available knowledge is used for the severity factors, latest 2002 data used on WHO factor.		

RESPIRATORY INORGANICS		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation.		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available.		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms.		
		• Scenario and model uncertainty as well as substance data and parameter uncertainty are taken into account.		
	Overall evaluation	• The category indicator and characterisation models are science based.		
Documentation & Transparency & Reproducibility		• The model documentation is published and accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?	C	N
		• The set of characterisation factors/models is published and accessible.	B	H
		• The input data are published and accessible.		
		• The characterisation model is published and accessible.	C	N
		• Ability for third parties to freely generate additional, consistent factors and to further develop models, e.g. incorporating further geographical/emission situation, temporal and speciation differentiation.	C	N
		• Value choices are explicitly stated.		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007) (NOx as NO2, NOx, PM2.5, PM10, PMtot, SO2).		
		• Ease to update to conform e.g. with the ILCD nomenclature and units.		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools.	B	H
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry.		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood.		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement).		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public.		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products.		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies.		
Overall evaluation of stakeholders acceptance criteria				

RESPIRATORY INORGANICS	**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Final recommendation			

4.5 Ionizing Radiation

4.5.1 Framework and scope

The same framework for human toxicity and ecotoxicity applies for ionizing radiation: the modelling starts with releases at the point of emission, expressed as Becquerel (Bq), and calculates the radiative fate and exposure, based on detailed nuclear physics knowledge.

For human toxicity, the exposure analysis calculates the dose that a human actually absorbs, given the radiation levels that are calculated in the fate analysis. The measure for the effective dose is the Sievert (Sv), based on human body equivalence factors for the different ionising radiation types ($\alpha-$, $\beta-$, γ-radiation, neutrons: 1 Sv = 1 J/kg body weight).

Data expressed in Sievert include physical data on energy doses and biological data on the sensitivities of different body tissues. Man Sievert (Man-Sv) is the collective dose, calculated by multiplying the average individual dose representative of the population, by the number of people affected and integrating it over a specified time horizon. An intermediate stage in the calculations of doses is often expressed as Gray (Gy). This is the measure of absorbed dose without considering the different reaction types of body tissues.

For ecosystem impacts, the ecotoxicity framework is based on Hazardous Concentration affecting 50% of species (HC_{50}) at their 50% effect (EC_{50}) and on the concept of the change in the potentially affected fraction (*PAF*), adapted to radioactive substances. The ecotoxicological effect factor is calculated by converting the dose rates into the corresponding medium concentration (i.e. water and sediment for freshwaters). For a given radionuclide r, this conversion from dose rate endpoint (HDR_{50} in µGy/h) to corresponding medium concentration (HC_{50r}) needs to implement:

- A transfer sub-model to take on board all potential exposure pathways (external and internal irradiation);
- A dosimetric sub-model to calculate the energy absorbed by the organism from each radionuclide source, including water, sediment and the organism itself.

The relationship between the activity concentration of an organism or media, and internal or external absorbed dose rates is described by the dose conversion coefficient (DCC):

µGy/h per Bq/kg fresh weight that is organism (o) and radionuclide (r) specific as described by Beaugelin *et al.* (2006). Therefore:

$HC_{50r,o} = HDR_{50} \ / DDC_{r,o}$.

4.5.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-6 describes the framework for human toxicity while Figure 4-7 describes the framework for ecotoxicity.

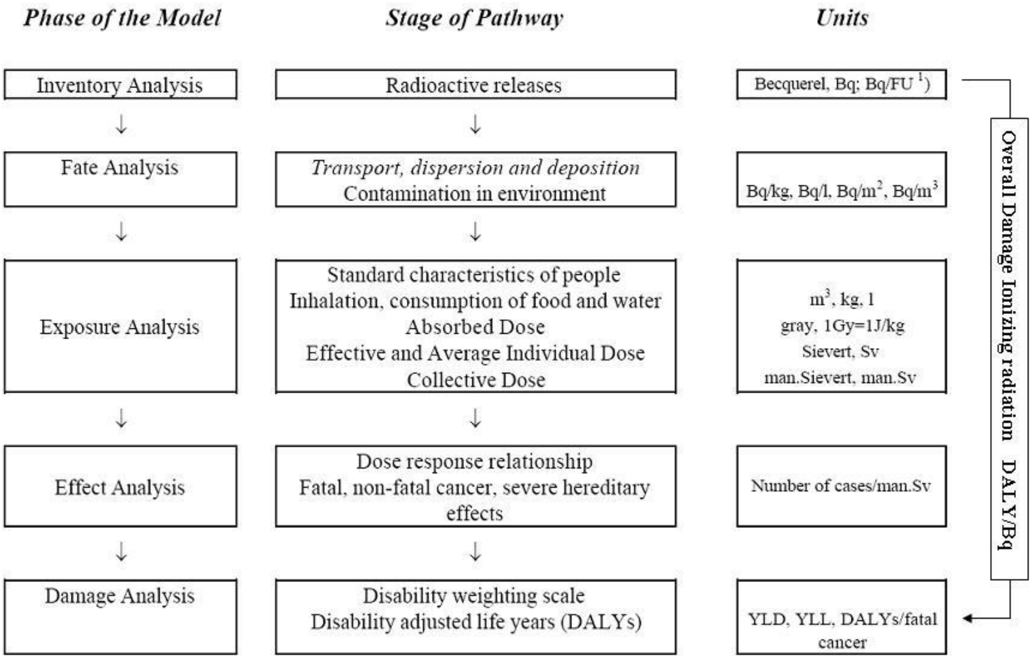

Figure 4-6 Overview of impact pathway stages of radioactive releases for Human Health (adapted from Frischknecht *et al.*, 2000).

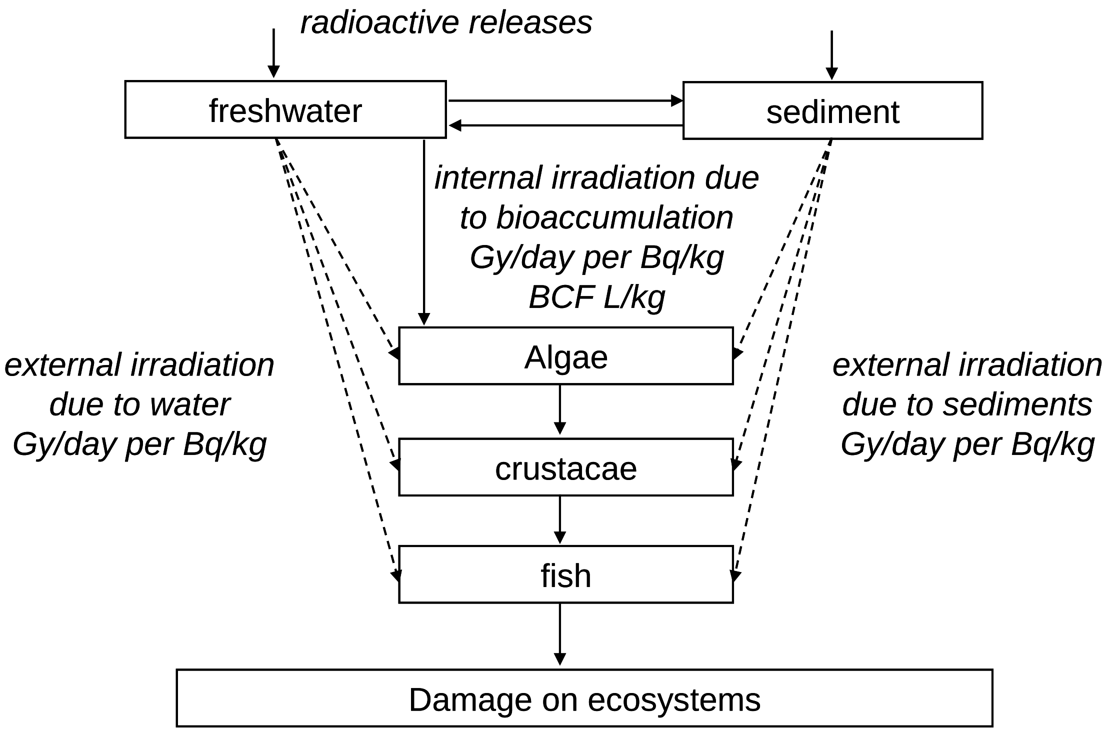

Figure 4-7 Overview of impact pathway on ecosystem for radioactive releases to freshwater. Solid lines refer to physical transfers of radioactive substances, whereas dotted lines correspond to exposures of radioactive radiation.

4.5.2 Criteria for Evaluation of this impact category

Since currently only a single method is presently considered relevant for each of the ionizing radiation subcategories, no detailed criteria-based comparison is planned as with the other impact categories. Hence no specific criteria have been developed for this impact category. Instead the evaluation is focused on the level of quality reached by the available methods within each main criterion.

4.6 Photochemical ozone formation

4.6.1 Framework and scope

The negative impacts from the photochemically generated pollutants are due to their reactive nature which enables them to oxidise organic molecules on the surfaces they expose. Impacts on humans arise when the ozone and other reactive oxygen compounds are inhaled and come into contact with the surface of the respiratory tract, where they damage tissue and cause respiratory diseases. Impacts on vegetation arise when the reactive compounds attack the surfaces of the plants or enter the stomata of the plant leaves, and cause oxidative damage on photosynthetic organelles. Impacts on man-made materials are caused by oxidation and damage to many types of organic materials which are exposed to ambient air. *NB: the man-made environment is not considered in the recommendations, and therefore the effects on man-made materials will not be considered further.*

The reaction scheme underlying the impact pathway is highly complex and depends on the formula of the concrete VOC, but it can be summarised as:

1. VOCs or CO react with hydroxyl radical OH• in the troposphere and form peroxy radicals, ROO•.
2. The peroxy radicals oxidize NO to NO_2.
3. NO_2 is split by sunlight with formation of NO and release of oxygen atoms.
4. Oxygen atoms react with molecular oxygen, O_2, to form ozone.

Both VOCs and nitrogen oxides are therefore needed for the photochemical ozone formation and should be covered by the characterisation models. The heterogeneous spatial distribution of VOC and NO_x sources across Europe, and the hundreds of chemical species involved, makes the photochemical formation of ozone on a regional scale highly non-linear and dynamic. It is influenced by meteorological conditions and interaction between the different VOCs – both from anthropogenic and natural sources, such as forests.

The complexity and the number of individual substances for which characterisation factors must be calculated leads to a need for simplification which is obtained in two different ways in the available characterisation models.

1. The non-linear and dynamic behaviour is ignored in a model which represents one or more typical situations in terms of meteorology, atmospheric chemistry and concomitant emissions of other air pollutants.
2. The variation between individual VOCs is (largely) ignored and only a few substance-specific characterisation factors are calculated.

The first approach is adopted in the models based on the POCP (Photochemical Ozone Creation Potential) or MIR (Maximum Incremental Reactivity) concept. Here individual characterisation factors are provided for many different VOCs. The second approach is adopted in regionally differentiated models which attempt to capture the non-linear nature of the ozone formation with its spatially and temporally determined differences.

Due to the complexity of the underlying chemical reaction schemes and the number of different substances which contribute to photochemical ozone formation, a trade off exists between the degree of detail which can be applied in the fate modelling (including the support of spatially explicit modelling) and the degree of detail applied in the distinction of differences in substance characteristics for the individual VOCs.

The variation in photochemical ozone formation between substances is rather modest, except for halogenated hydrocarbons, CH_4 and CO, which all have relatively low ozone formation potentials. This is revealed by the POCP or MIR values applied for substance differentiation in several methods. The variation caused by spatial differentiation in the modelling of fate and exposure within Europe is considerably higher (Hauschild *et al.* 2006). Various studies including those by Andersson-Skjöld in the 1990s seemed to point at a weakness in the calculations of Photochemical Ozone Creating Potential (POCPs) performed in the 1990s using highly detailed chemical mechanisms. The POCPs were generally obtained using very simplified Lagrangian transport models, using linear trajectories, and the results were thus strongly linked to the chemical regimes that the air parcels were passing in the performed scenario calculations. Although the study of Derwent *et al.* (1998) was performed using a highly detailed chemical mechanism, these new studies indicated that very different results might have been obtained for a different air parcel. It is thus considered preferable to simplify the model on the substance side rather than on the modelling of the dynamic and non-linear nature of the impact pathway.

To ensure consistency with several other impact categories, the ideal midpoint indicator would be the time- and area-integrated concentration increase for ozone in the troposphere. This midpoint would cover impacts later in the environmental mechanism on the areas of protection (AoP) ‘Human Health’ and ‘Natural Environment’ (vegetation).

4.6.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-8 shows the cause-effect chain for photochemical ozone formation from airborne emissions of volatile organic compounds, carbon monoxide or nitrogen oxides with the most important pathways highlighted (bold arrows).

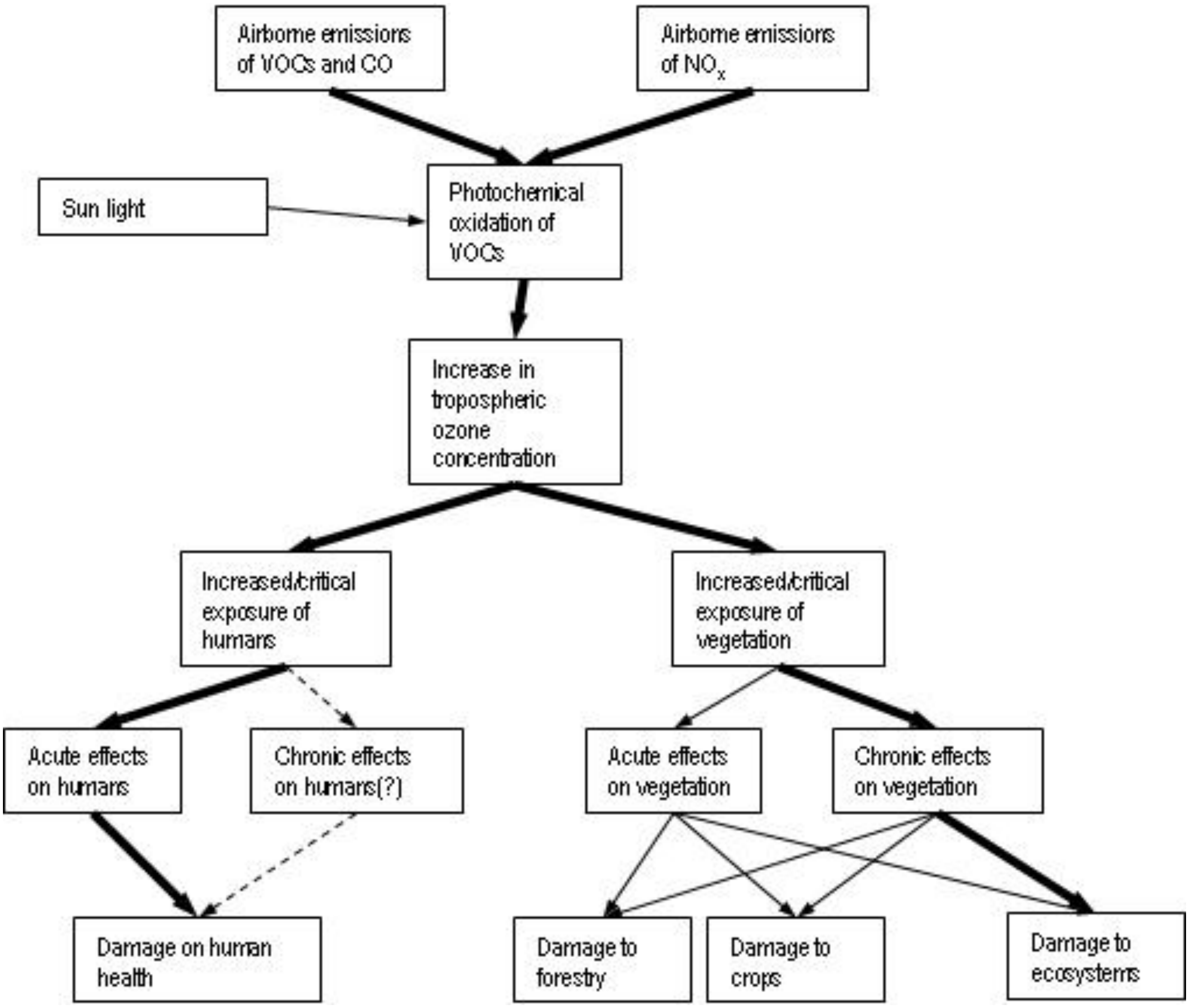

Figure 4-8 Flow diagram for photochemical ozone formation

4.6.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria 'Environmental relevance' and 'Scientific robustness' have been specified by the following sub criteria:

- Atmospheric fate and transport is considered.
- For damages on vegetation, a fate sensitivity factor discriminating between sensitive and insensitive areas is included.
- For damages on Human Health, a fate sensitivity factor discriminating between sensitive and insensitive areas is included.
- Magnitude of exceedance for exposure above critical level is considered.
- Covers both VOCs and inorganic pollutants.
- Distinction of individual VOCs.

- Potency or dose-response is included.
- The model reflects the latest knowledge for the cause-effect chain (the critical links are covered)
  - Atmospheric fate and transport model
  - Exposure model
  - Potency or dose-response model
- All category indicators and characterisation models linking midpoint to damage fulfil the requirements of being science based.
- The coverage of the impacts in the modelling from midpoint to endpoint is complete.

The table below presents the general and specific criteria for photochemical ozone formation identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Figure 4-9 General and specific criteria for photochemical ozone formation with threshold value and importance.

Photochemical ozone formation		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of individual substances covered by specific provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterisation model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)	B	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		Atmospheric fate and transport is considered	B	H
		For damages on vegetation, a fate sensitivity factor discriminating between sensitive and insensitive areas is included		H

Photochemical ozone formation		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		For damages on Human Health, a fate sensitivity factor discriminating between sensitive and insensitive areas is included		H
		Magnitude of exceedance for exposure above critical level is considered		
		Covers both VOCs and inorganic pollutants	B	H
		Distinction of individual VOCs		
		Potency or dose-response is included	C	H
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	C	H
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered); Atmospheric fate and transport model		
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered); Exposure model		
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered); Potency or dose-response model		
		• All category indicators and characterisation models linking midpoint to damage are science based	C	
		• The coverage of the impacts in the modelling from midpoint to endpoint is complete		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
	Overall evaluation	• The category indicator and characterisation models are science based		
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?	C	
		• The set of characterization factors/models is published and easily accessible	B	H
		• The input data are published and easily accessible		
		• The characterization model is published and easily accessible		H
		• Ability for third parties to freely generate additional, consistent factors and to further develop models, e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	C	H

Photochemical ozone formation		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)		
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools	A	H
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		H
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.7 Acidification

4.7.1 Framework and scope

This impact category addresses the impacts from acidification generated by the emission of airborne acidifying chemicals. Acidification refers literally to processes that increase the acidity of water and soil systems by hydrogen ion concentration. It is caused by atmospheric deposition of acidifying substances generated largely from emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3), the latter contributing to acidification after it is nitrified (in the soil).

The model framework for the acidification characterization factor is expressed as a fate factor, FF multiplied by an effect factor, EF as per the equation below:

$$CF_{i,ar} = FF \cdot EF = f_{i,ar} \cdot \theta_{i,r\ \text{sensitivity}} \cdot \beta_{\text{dose-response}}$$

$$\underbrace{\qquad\qquad\qquad}_{FF}\quad\underbrace{\qquad\qquad}_{EF}$$

where:

- $f_{i,ar}$ represents the fate factor representing the transport of substance (i) in air (a) and the transfer to receptor-environment (r). [dimensionless (kg/kg)].
- $\theta_{i,r\ sensitivity}$ is the fate sensitivity factor of the receptor-environment. It models for example the change in soil parameters such as acidity potential (or base saturation) due to change in acid deposition. It can be calculated as the number of mol H^+ released per kg of deposited pollutant [mol H^+/kg], which depends on the intrinsic property of the chemical and the soil sensitivity. This framework is also valid for the base saturation approach of van Zelm and colleagues (2007) with some adaptations.
- $\beta_{dose\text{-}response}$ expresses the effect factor, i.e. the response of the ecosystem to the change in cation capacity (or base saturation) e.g. [Impact/mol H^+] or [-].

4.7.1.1 Environmental Mechanism (cause-effect chain)

The figure below shows the cause-effect chain for airborne acidifying emissions with the most important pathways highlighted (bold arrows).

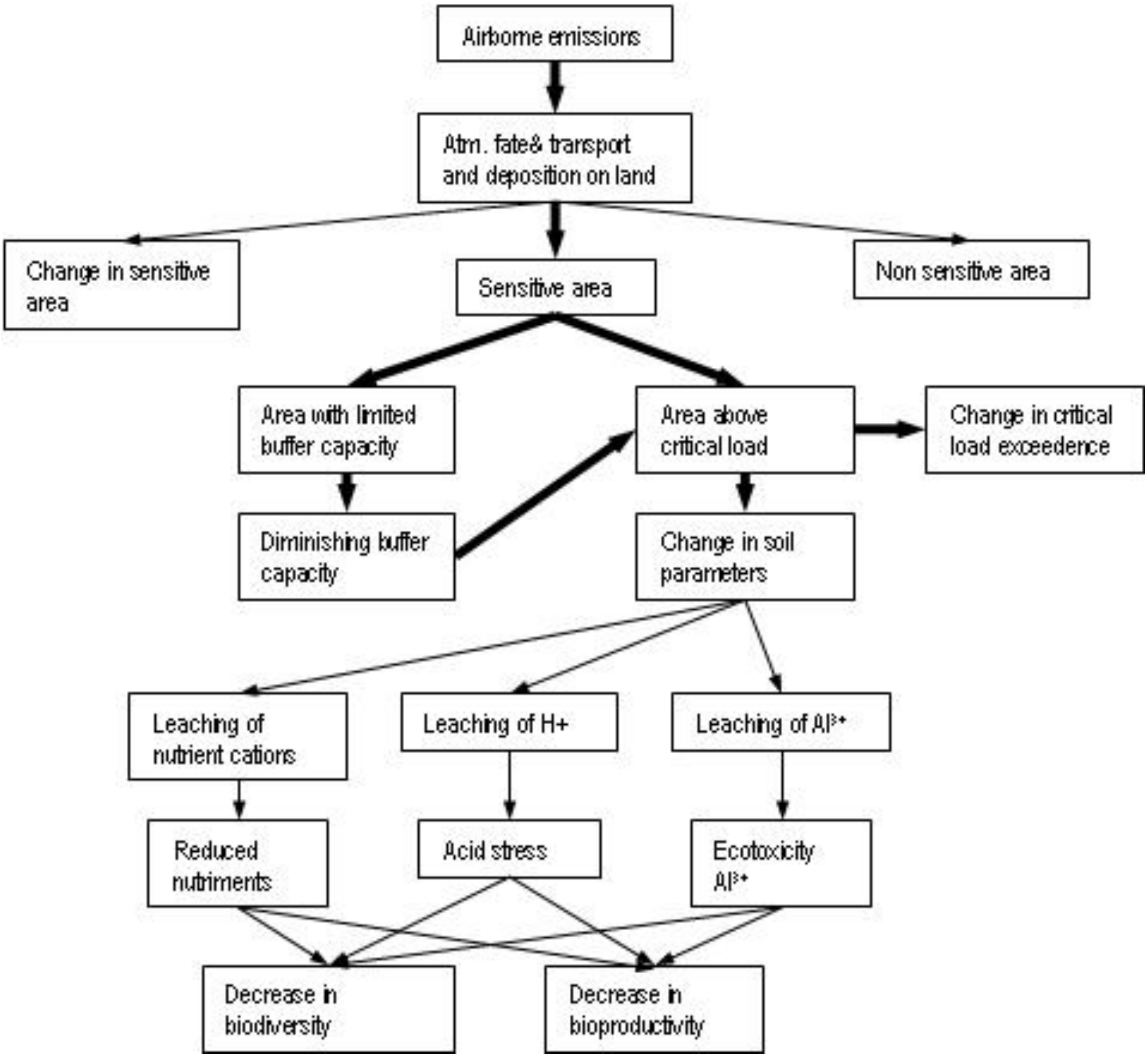

Figure 4-10 Flow diagram for acidification impact category.

4.7.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘scientific robustness’, have been specified by 9 sub criteria:

- Atmospheric fate and transport is considered.
- Only deposition of acidifying chemicals on land is considered, while ocean is disregarded.
- For damages on biodiversity/bioproductivity, a fate sensitivity factor discriminating between sensitive and insensitive areas is considered.
- Sensitive areas include areas with limited buffer capacity, in addition to the areas at critical load (insensitive ones do not contribute).
- Sensitive areas consider areas above critical load, i.e. the magnitude of the deposition above critical load is considered.
- Acidification potential is considered at midpoint.
- Dose response model for biodiversity/bioproductivity is considered at endpoint.
- The model uses the latest data on (changes in) current emission levels.
- The model addresses temporal changes for future emissions.

The table below presents the general and specific criteria for acidification identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-5 General and specific criteria for acidification with threshold value and importance.

ACIDIFICATION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of individual substances covered by specific provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterization model is adaptable to spatial and temporal explicit evaluation		

ACIDIFICATION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)	C	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		Atmospheric fate and transport is considered	B	H
		Only deposition of acidifying chemicals on land is considered, ocean is disregarded	B	H
		For damages on biodiversity/bioproductivity, a fate sensitivity factor discriminating between sensitive and insensitive areas is considered.	B	H
		Sensitive areas include areas with limited buffer capacity in addition to the areas at critical load	B	H
		Sensitive areas consider areas above critical load, i.e. the magnitude of the deposition above critical load is considered	B	H
		Acidification potential is considered at midpoint	B	H
		Dose response model for biodiversity/bioproductivity is considered at endpoint		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	B	H
		The model uses the latest data on (changes in) current emission levels		
		The model addresses temporal changes for future emissions		
		Atmospheric fate and transport model		
		Soil fate sensitivity model		
		Dose-response model		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		

ACIDIFICATION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
	Overall evaluation	• The category indicator and characterisation models are science based		
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?	B	H
		• The set of characterization factors/models is published and easily accessible	B	H
		• The input data are published and easily accessible		
		• The characterization model is published and easily accessible	C	H
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	C	H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)		
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools	A	H
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly made available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The unit is easily understood (like a footprint)		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		H
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		

ACIDIFICATION	**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Overall evaluation of stakeholders acceptance criteria			
Final recommendation			

4.8 Eutrophication

4.8.1 Framework and scope

The impact category appears under different names like eutrophication, nutriphication or nutrient enrichment. It addresses the impacts from the macro-nutrients nitrogen and phosphorus in bio-available forms on aquatic and terrestrial ecosystems.

In natural terrestrial systems, the addition of nutrients may change the species composition of the vegetation by favouring those species which benefit from higher levels of nutrients to grow faster than more nutrient efficient plants. This therefore changes the plant community from nutrient-poor (e.g. heath lands, dunes and raised bogs) to nutrient rich and more commonly, due to the widespread dispersion of nutrients,, plant communities. The primary impact on the plant community leads to secondary impacts on other species in the terrestrial ecosystem. Terrestrial eutrophication is caused by deposition of airborne emissions of nitrogen compounds like nitrogen oxides (NO_x = NO and NO_2) from combustion processes and ammonia, NH_3 from agriculture. Airborne spreading of phosphorus is not prevalent, and terrestrial eutrophication is therefore mainly associated with nitrogen compounds.

In aquatic systems, the addition of nutrients has a similar primary impact by fertilising the plants (algae or macrophytes) with a number of consequences for the ecosystem:

- Species composition of the plant community changes to more nutrient-demanding species;
- Algal blooms create shadowing, filtering the light penetrating into the water mass, changing life conditions from the macrophytes, which need the light for photosynthesis, and for predatory fish which need the light to see and catch their prey;
- Oxygen depletion near the bottom of the water body where dead algae deposit and degrade.

All these consequences lead to a change in the species composition and of the function of the exposed aquatic ecosystem.

In aquatic systems it is often one of the macronutrients which limits the growth of algae. Addition of the limiting nutrient will lead to increased primary production, while addition of the nutrient which is not limiting will have no effect on the primary production, and this should be reflected in the life cycle impact assessment. There may be seasonal variations in the pattern of limiting nutrients, but as a general rule, P is the limiting nutrient in freshwater systems while N is limiting nutrient in marine systems.

Freshwater and marine aquatic systems are exposed to water-borne emissions (nitrate, other nitrogen compounds expressed as total N, phosphate and other phosphorus-containing compounds expressed as total P). Marine aquatic systems and very large lakes are also substantially exposed by airborne emissions (NO_x).

One of the consequences of eutrophication is oxygen depletion near the bottom of the exposed systems. Emissions of biological material may also contribute to oxygen depletion when it degrades in the water. This is why some characterisation models provide characterisation factors for waterborne emissions of organic material, expressed as:

- BOD: Biological Oxygen Demand when degraded biologically in water, typically over 5 or 7 days.

or

- COD: Chemical Oxygen Demand when degraded by chemical oxidation.

The inclusion of COD and BOD emissions is not consistent with the impact pathway at midpoint level, but they do contribute to some of the same damages, as emission of nutrients (*see Figure 4-11*).

The model framework for the eutrophication characterization factor is expressed as a fate factor: FF multiplied by an effect factor: EF as per equation below:

$$CF_{i,m,r} = FF \cdot EF = f_{i,mr} \cdot \beta_{dose\text{-}response}$$

where:

- $f_{i,m,r\ is}$ the fate factor representing the transport of substance (i) in the media air or water (m) and the transfer to receiving environment (r). [dimensionless (kg/kg)].
- $\beta_{dose\text{-}response}$ is the effect factor expressing the response of the ecosystem to the change in nutrient status e.g. [Impact/kg N or P] or [-].

4.8.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-11 shows the cause-effect chain for eutrophication of the aquatic and terrestrial environment from air and waterborne emissions of nutrients (N and P) and biological material (COD or BOD) with the most important pathways highlighted (bold arrows).

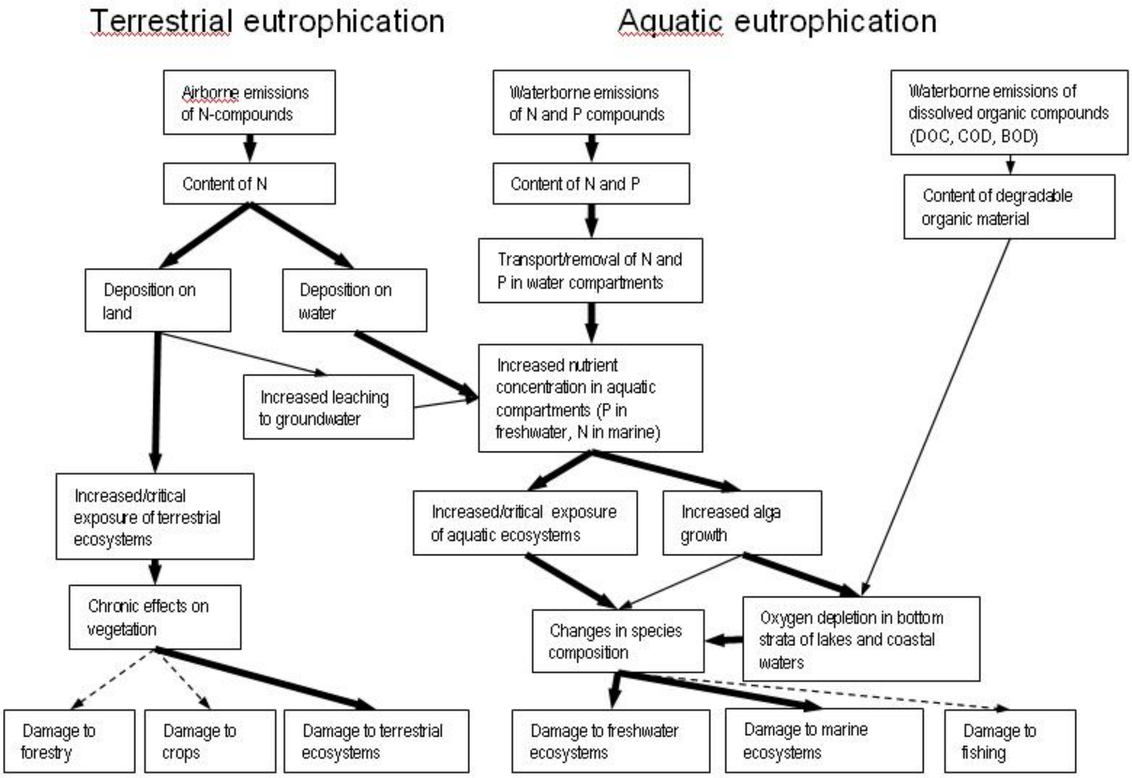

Figure 4-11 Flow diagram for eutrophication

4.8.2 Criteria for Evaluation of this impact category

Following the general criteria described in Chapter 2, the main criteria 'Environmental relevance' and 'scientific robustness' have been specified by the following sub criteria:

- Fate and transport is considered.
- Advection out of a region is not considered a final loss.
- Influential fate processes are considered:
  - For aquatic systems: denitrification, precipitation and sedimentation of P
  - For terrestrial systems: oxidation, deposition.
- For damages on ecosystems, a fate sensitivity factor discriminating between sensitive and insensitive recipients is included:
  - For aquatic systems according to their sensitivity to eutrophication and oxygen depletion and limiting nutrient (N for marine, P for freshwater).
  - For terrestrial systems according to the sensitivity to eutrophication (critical load, N).
- Magnitude of exceedance for exposure above critical level is considered.
- Potency or dose-response is included.
- Distinction of individual N- and P-compounds.
- The model reflects the latest knowledge for the cause-effect chain (the critical links are covered)
  - Atmospheric fate and transport model

  - Exposure model
  - Potency or dose-response model.
- Coverage of the impacts in the modelling from midpoint to endpoint is complete.

The table below presents the general and specific criteria for eutrophication, identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-6 General and specific criteria for eutrophication with threshold value and importance.

Eutrophication		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of individual substances covered by specific provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterisation model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)	B	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		• Fate and transport is considered	B	H
		• Advection out of a region is not considered a final loss		
		• Influential fate processes are considered For aquatic systems: denitrification, precipitation and sedimentation of P For terrestrial systems: oxidation, deposition		

Eutrophication		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• For damages on ecosystems, a fate sensitivity factor discriminating between sensitive and insensitive recipients is included • For aquatic systems according to their sensitivity to eutrophication and oxygen depletion and limiting nutrient (N for marine, P for freshwater) • For terrestrial systems according to the sensitivity to eutrophication (critical load, N)		H
		• Magnitude of exceedance for exposure above critical level is considered		
		• Potency or dose-response is included		
		• Distinction of individual N- and P-compounds	C	H
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	C	H
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered) Fate and transport model		
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered) Exposure model		
		• The model reflects the latest knowledge for the cause-effect chain (the critical links are covered) Potency or dose-response model		
		• The coverage of the impacts in the modelling from midpoint to endpoint is complete		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
	Overall evaluation	• The category indicator and characterisation models are science based		
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?	C	
		• The set of characterization factors/models is published and easily accessible	B	H
		• The input data are published and easily accessible		
		• The characterization model is published and easily accessible		H

Eutrophication		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	C	H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD core database (version October 2007)		
		• Ease to update to conform e.g. with the ELCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools	A	H
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		H
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.9 Ecotoxicity

4.9.1 Framework and scope

Models and factors for toxicity effects in LCA must be based on the relative risk and associated consequences of chemicals that are released into the environment. These must build on the principles of comparative risk assessment, while providing indicators linked to the Area of Protection 'Natural Environment' (see Chapter 3.2).

LCA characterisation models and factors for toxicity effects must be based on models that account for a chemical's fate in the environment, species exposure, and differences in toxicological response (likelihood of effects and severity).

The scope and methodology of an LCA differs from that of many approaches adopted for toxicological assessments in a regulatory context. In LCA it is desirable to account for the full extent of the likelihood of an effect (recommended midpoint indicator basis) and differences in severity (recommended endpoint indicator basis).

The basis of comparative risk in LCA accounting for the entire global population of species is recommended. This must be based on best-estimates complemented with uncertainty insights. The factors must reflect the likelihood of a toxicological effect integrated over time and space that is associated with the release of a quantity of chemical into the environment. This may be zero.

Contributions of emissions to short-term/acute and local scale effects are not typically addressed in LCAs. The focus here is on the contribution of emissions to the long-term risk of ecotoxicological effects and associated consequences considering all species habitats and disperse emissions.

4.9.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-12 shows the cause-effect chain of ecotoxicological impacts and corresponds to the framework of fate and ecotoxicity effect assessment, as described in the next section.

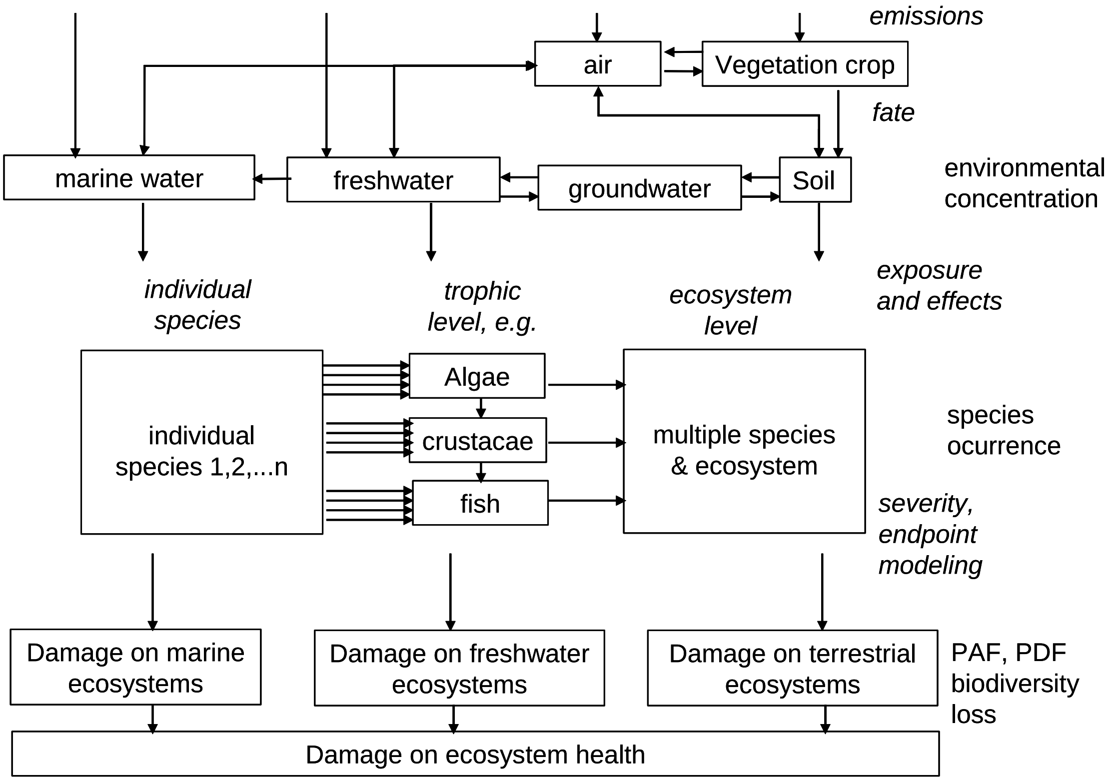

Figure 4-12 Flow diagram for ecotoxicity impacts

4.9.1.2 Framework for analysing the characterisation models

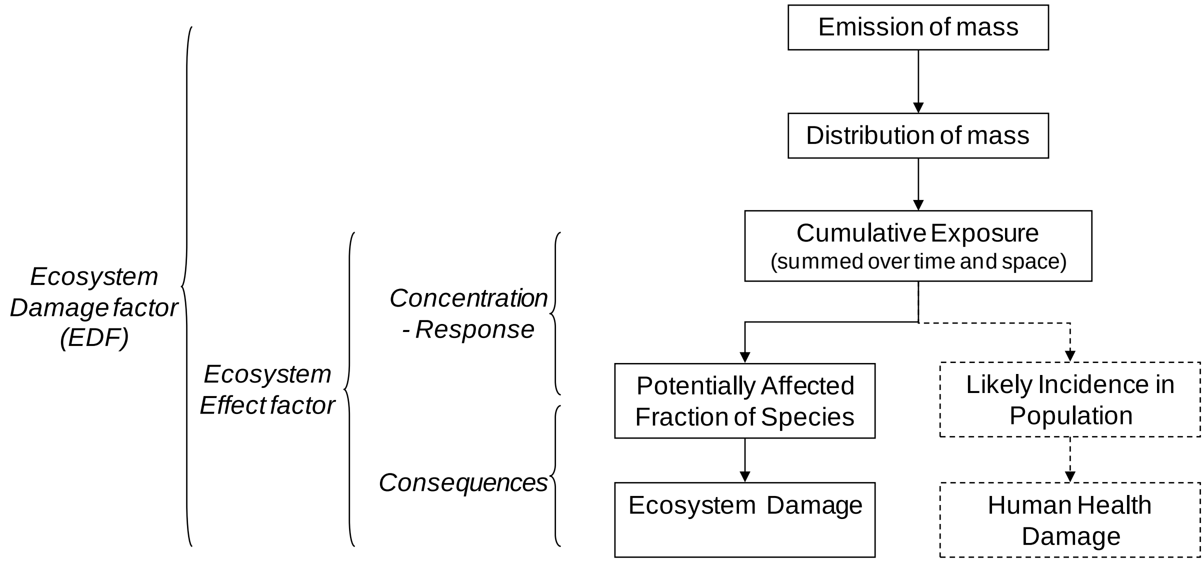

Figure 4-13 Framework for calculating risk-based characterisation factors for ecotoxic impacts in LCA. (based on Pennington *et al.* 2006, Jolliet *et al.* 2006)

Figure 4-13 presents the framework which is used for analysing the characterisation models for ecotoxicity effects. This is analogous to Figure 4-3 for toxicity effects on Human Health.

The Life Cycle Impact Assessment (LCIA) characterisation factor for ecotoxic effects accounts for the environmental persistence (fate - F) and ecotoxicity (effect - E) of a chemical:

$$CF_{j,i,x} = F_{j,i,x} \cdot E_{j,x}$$

where $CF_{j,i,x}$ is the ecotoxicological characterisation factor of chemical x emitted to compartment i and transported to environment j. Fate factors F can be calculated by means of fate and exposure models, while effect factors E can be derived from toxicity data based on laboratory experiments. The fate factor accounts for bioaccumulation/magnification.

The requirements must consider the extent to which the method distinguishes the emission compartments such as urban and rural air, freshwater versus sea water, and agricultural versus industrial soils. It must equally distinguish endpoints representing the terrestrial, freshwater and marine environments for example.

Note that the framework specifically focuses on damage to the Natural Environment, i.e. species diversity, and not on the damage to ecosystem services. *NB: Ecosystem services are defined as the products of ecosystem functions or processes that directly or indirectly contribute to human well-being or have the potential to do so in the future* (see e.g. Costanza *et al.*, 1997; Boyd and Banzhaf, 2007).

As ecosystem services are defined in terms of contribution to human well-being, this aspect is of high interest for the Area of Protection ‘Human Health’, but not as a starting point to address ecotoxicological impacts on ecosystems.

4.9.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria ‘Environmental relevance’ and ‘scientific robustness’ have been specified by the following sub criteria:

Environmental relevance: The following critical parts of the environmental mechanism describing the cause-effect chain, are included with acceptable quality:

- Advection out of a region or continent , for example, is not considered a final loss.
- Influential fate processes are considered (e.g. degradation, volatilization, deposition/sedimentation, intermittent rain).
- Effect factors are available for all environmental compartments.
- Marine environment and coastal zones are differentiated for aquatic ecotoxicological effects.
- The effect factors are derived from the average toxicity over all species instead of the most sensitive species.
- Direct effects on species diversity are included in the endpoint assessment.
- Indirect effects on species diversity via food web changes are included in the endpoint assessment.
- Chronic toxicity data are preferable to acute data as a basis for toxicity effect factors.
- EC_{50}[22] data are preferable to LOEC/NOEC[23] data as a basis for toxicity effect factor

Scientific robustness: The model reflects the latest research for the cause-effect chain and the following critical links are covered:

- Fate
- Bioavailability

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[22] EC50 = Concentration at which 50% of the exposed population is affected

[23] L/NOEC = Low/No Observed Effect Concentration

- Toxicity
- Bioaccumulation/magnification
- Effects on biodiversity

Table 4-7 presents the general and specific criteria for eco-toxicity, identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-7 General and specific criteria for eco-toxicity with threshold value and importance.

ECOTOXICITY		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		Total number of substances covered by the provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment?	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterisation model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors / precautionary principle)	B	H
		• When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		The following critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality:		
		• Advection out of a region or of a continent is not considered a final loss.	C	H
		• Marine environment and coastal zone are differentiated		
		• Influential fate processes are considered (classic - volatilization, deposition/sedimentation, intermittent rain)	C	H
		• The effect factors are derived from the average toxicity over all species instead of the most sensitive species	C	H
		• Direct effects on species diversity of toxicants are considered		

ECOTOXICITY		Check the following:	Threshold (Minimum score)	Importance (H-N)
		• Indirect effects on species diversity of toxicants via food web changes are included in the endpoint assessment		
		• Chronic toxicity data are considered preferable to acute data as a basis for toxicity effect factors		
		• EC50 data are considered preferable to NOEC data as a basis for toxicity effect factors		
		• Effect factors are available for all environmental compartments		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)	B	H
		The model reflects the latest stage of knowledge for the cause-effect chain, i.e. the following critical links are covered:		
		• Fate	C	N
		• Bioavailability		
		• Toxicity	C	N
		• Effects on biodiversity		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
	Overall evaluation			
Documentation & Transparency & Reproducibility		• The model documentation is published and accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?	C	N
		• The set of characterisation factors/models is published and accessible	B	H
		• The input data are published and accessible		
		• The characterisation model is published and accessible	B	H
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation	B	H
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)	C	H
		• Ease to update to conform e.g. with the ILCD nomenclature and units		

ECOTOXICITY		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools	A	N
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.10 Land use

4.10.1 Framework and scope

The impact category Land Use reflects the damage to ecosystems due to the effects of occupation and transformation of land. Examples of land use are agricultural production, mineral extraction and human settlement. Occupation of land can be defined as the maintenance of an area in a particular state over a particular time period. Transformation is the conversion of land from one state to another state, e.g. from its original state to an altered state or from an altered state to another altered state. Often transformation is followed by occupation, or occupation takes place in an area that has previously been transformed. The question of whether and how to take into account Indirect Land Use Changes (ILUC) is dealt with in the general ILCD Guidance Document on LCA.

Weidema and Lindeijer (2001) propose the following mathematical framework:

The occupation impact (I_{occ}) can be calculated from the formula[24]:

$I_{occ}=A*t_i*(Q_{pot}-Q_{act})/S_i$

where A is the area occupied, t_i the time of occupation, Q_{pot} the quality indicator for the reference situation, Q_{act} the quality indicator for present occupation and S_i the slope factor that reflects the duration of restoration.

The transformation impact (I_{trans}) can be calculated from the formula[25]:

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[24] There are variations to this formula, see e.g. Baitz 2002, Mila I Canals 2007a-c

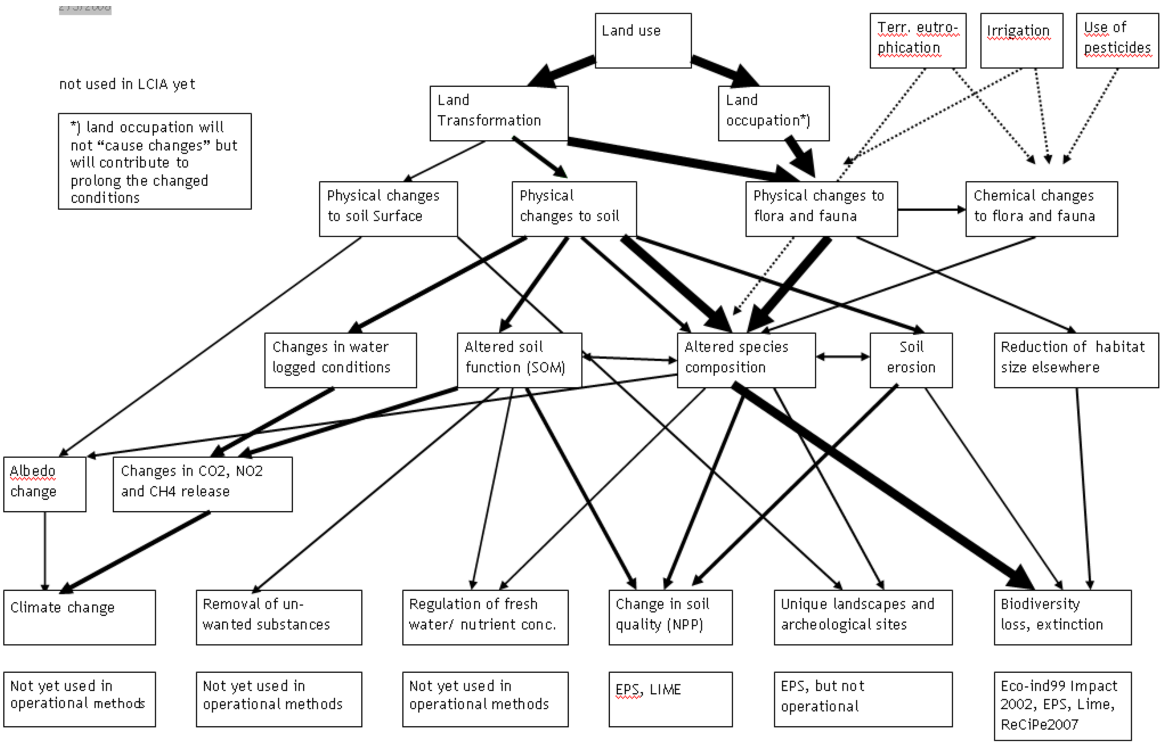
$I_{trans}=A*t_r*(Q_{pot}-Q_{act})/S_i$

where t_r is the time of restoration.

In order to quantify the quality of a certain state (land use type) an appropriate indicator must be chosen along a relevant environmental pathway. Milà i Canals *et al.*, (2007a) identifies the following impact pathways as relevant : biotic production potential, biodiversity and ecological soil quality. The impacts can be described, on midpoint or endpoint level, by different quality indicators, such as species loss, primary production, soil organic matter content and soil loss.

4.10.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-14 visualises the cause-effect chain of land use impacts[26].



Source: Physical impacts of land use in product life cycle assessment by Bo P. Weidema with contributions from Erwin Lindeijer (2001). Subject report of the EURENVIRON-LCAGAPS sub-project on land use.

Figure 4-14 Impact assessment model of land use (NPP=Nett Primary Production; SOM= Soil Organic Matter).

4.10.2 Criteria for Evaluation of this impact category

Following the general criteria described in Chapter 2, eleven sub-criteria have been developed within the main criteria 'Environmental relevance' and 'Scientific robustness':

- A specific underlying model is used.
- Land transformation is well considered.
- Land occupation is well considered.

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[25] There are variations to this formula, see e.g. Baitz 2002, Mila I Canals 2007a-c

[26] The presented aspects of the cause-effect chain provide a comprehensive picture of the complexity involved but it will not necessarily be possible to address all of them today, e.g. albedo change.

- Duration of physical changes is considered.
- Quantitative changes to fauna and flora are considered, e.g. altered species composition, reduction of habitat size elsewhere.
- Physical changes to soil are considered, e.g. altered soil function, changes in water conditions or soil erosion.
- Physical changes to soil surface that cause damage to unique landscapes or cultural heritage are considered.
- Effects on climate change are considered, due to albedo change or changes in CO_2, N_2O or CH_4 balances.
- Effects on Net Primary Production are considered, due to altered soil function or species composition.
- Biodiversity loss due to altered species composition is considered.
- Biodiversity loss due to reduction of habitat size elsewhere[27] (indirect land use changes) is considered.

Damages to landscapes have not been included in these criteria.

The table below presents the general and specific criteria for land use identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-8 General and specific criteria for land use with threshold value and importance[28].

LAND USE		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Introduction		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of individual substances covered by specific provided characterisation factors[29]		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment	B	H
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen at the right point in the cause-effect chain, where all LCI are aggregated as early as possible in the cause effect chain		

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[27] This is due to Indirect Land Use Changes (ILUC), a relevant aspect for consequential LCA modelling.

[28] Criteria not relevant for land use impacts are marked in grey.

[29] This criterion is applied in a way to reflect the inclusion of different land use types in a model.

LAND USE		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• The characterization model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors / precautionary principle)	B	H
		When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality.		
		A specific underlying model is used		
		Land transformation is considered		
		Land occupation is considered	C	H
		Duration of physical changes is considered	C	N
		Physical changes to fauna and flora are considered, e.g. altered species composition, reduction of habitat size elsewhere		
		Physical changes to soil are considered, e.g. altered soil function, changes in water conditions or soil erosion		
		Physical changes to soil surface what creates unique landscapes are considered		
		Effects on climate change are considered, due to albedo change or changes in CO2, NO2 or CH4 releases.		
		Effects on changes in Net Primary Production are considered, due to altered soil function or species composition.		
		Biodiversity loss due to altered species composition is considered		
		Biodiversity loss due to reduction of habitat size elsewhere is considered		
	Overall evaluation			
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)		
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered)		
		• All category indicators and characterisation models linking midpoint to damage fulfil the requirements of science based		
		• The coverage of the impacts in the modelling from midpoint to endpoint is complete		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty are taken into account		
		• The category indicator and characterisation models are science based		

LAND USE		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
	Overall evaluation			
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)		
		• The set of characterization factors/models is published and accessible		
		• The input data are published and accessible		
		• The characterization model is published and accessible		
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation		
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD database (version October 2007)		
		• Ease to update to conform e.g. with the ILCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools		
		• Life cycle inventory data can be made directly available by producing industry		
	Overall evaluation			
Overall evaluation of science based criteria				
Stakeholder acceptance		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

4.11 Resource depletion

4.11.1 Framework and scope

The earth contains a finite amount of non-renewable resources, such as metals and fuels. Van Oers *et al.* (2002) describe the depletion of resources as follows: "*abiotic resource depletion is the decrease of availability of the total reserve of potential functions of resources, due to the use beyond their rate of replacement*". This impact category considers the effect on both renewable and non-renewable resources. Depletion of minerals and fossil fuels falls within the category non-renewable resources, while extraction of water, wind (abiotic) and wood (biotic) falls within renewable resources.

Despite Resource depletion often being considered a single impact category in LCA, this does not reflect the wide range of issues related to resource depletion. In fact, many methods combine several issues and use several mechanisms within a single impact category. This has resulted in a relatively unclear situation. The following pragmatic approach is recommended:

- Focus on the impacts of direct exploitation of resources (renewable or non-renewable). Indirect damages to resources, especially damages on crops (for instance due to climate, ozone etc.), are often found in other endpoint impact categories, but these are not considered in the resource depletion category.
- Harvesting crops or wood can be seen as a land-use issue, although the extraction of "funds", like the decrease of the available amount of standing trees, would be a resource issue. It is not always easy to distinguish which impact category this impact should be characterized as. The depletion of biotic resources is considered in the impact category 'Resource Depletion'.
- Water is treated as a separate issue, as it has many unique properties that make the problem of water availability very different from such factors as, for example, mineral resources.

For the impact of renewable resource use, such as wood and fish, two main approaches are used:

- One based only on the amount of renewable resource used (expressed as weight, volume or exergy), and
- another based on the amount of renewable resource used, considering the regeneration rate.

The methods used to assess the impact of non-renewable resource use can be categorised into four main approaches (Lindeijer *et al.*, 2002, Stewart and Weidema, 2005). The effects of the extraction of a certain amount of a resource can be modelled, based on:

- energy or mass,
- exergy or entropy,
- future consequences of resource extraction (scarcity or extra need for energy for extraction), and
- use of stock.

The endpoint characterisation factor for Resource Depletion is assessed as the future consequences of resource extraction. The basic idea behind it is that extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. This results in the need for additional efforts which can be translated into higher energy or costs, and thus leads to an increased impact on the environment and economy (Müller-Wenk, 1998b; Steen, 2006). The endpoint indicator can, for example, be calculated as ‘willingness to pay’, expressed as the future payment for extracting a resource; or the ‘surplus energy’, expressed as the additional energy requirement for further extractions of the resource in the future.

Following the impact pathway in Figure 4-15, resource depletion impacts are suggested to be divided into four categories reflecting the lack of consensus on what is the main issue for this impact category *(see also discussion on the Area of Protection Natural Resources*).

Category 1 methods are at the first step of the impact pathway. They use an inherent property of the material as a basis for characterisation. The environmental relevance is low in terms of expressing resource depletion, but the characterisation factors are relatively robust. As described in the AoP for ‘Natural Resources’, those methods that do not include the concept of resource scarcity are not considered. Therefore, this category is considered incompatible with the AoP ‘Natural Resources’ (irrespective of the quality of the method).

Category 2 methods address the scarcity of the resource by basing the characterisation factor on the ratio between what is extracted, and what is left. They have a higher environmental relevance, and potentially a higher uncertainty.

Category 3 methods focus on water and are treated as a separate category due to the regional dependence of this resource issue, which the characterisation model needs to consider.

Category 4 describes the endpoint methods. These aim to cover the entire environmental mechanism.

4.11.1.1 Environmental Mechanism (cause-effect chain)

Figure 4-15 illustrates the cause-effect chain of the impacts due to resource depletion.

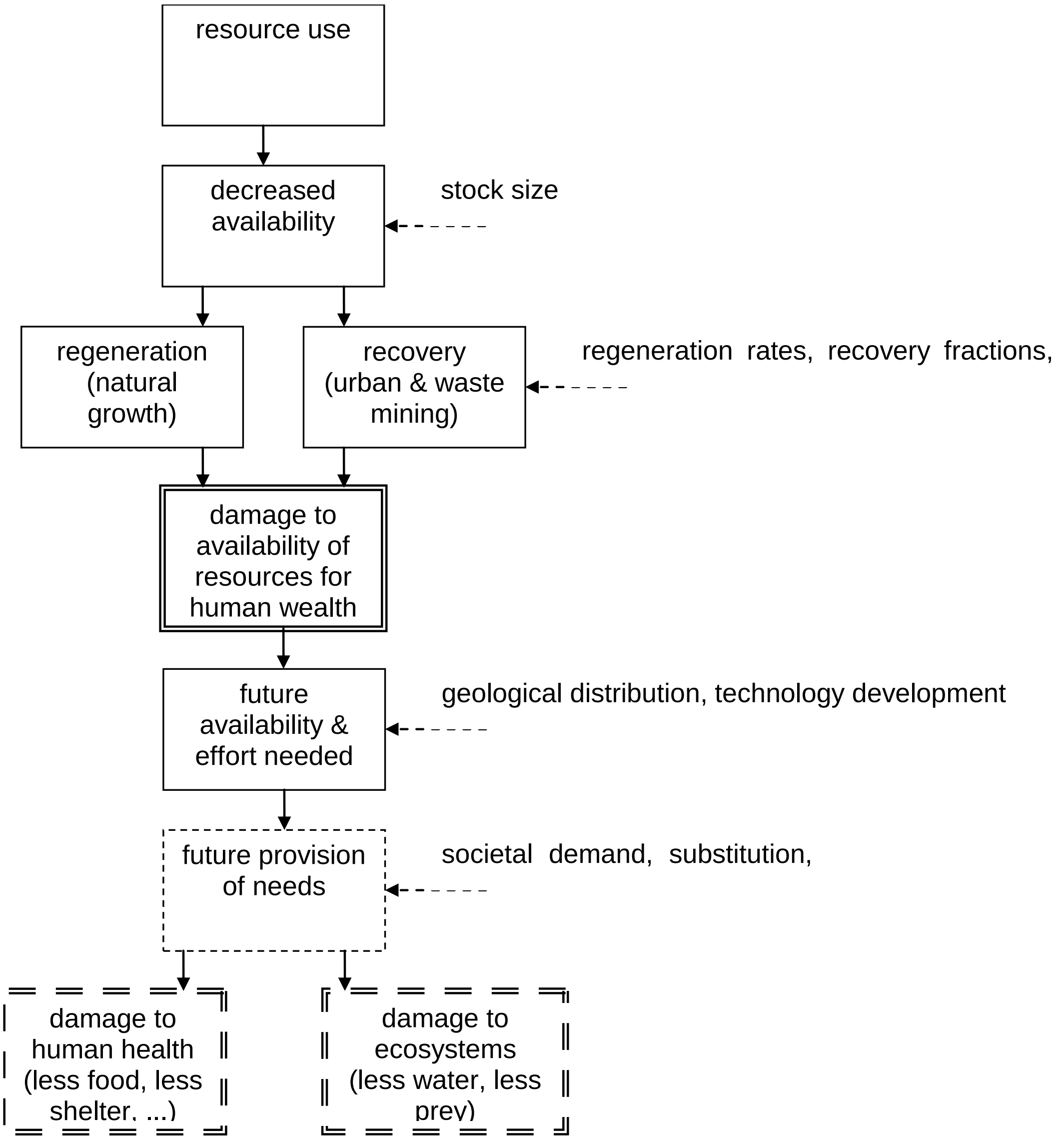

Figure 4-15 Flow diagram for resource depletion

4.11.2 Criteria for Evaluation of this impact category

Next to the general criteria described in Chapter 2, the main criteria 'Environmental relevance' and 'Scientific robustness' have been specified by the following sub-criteria:

- Biotic resources (such as wood, fish stock, meat stock or land use)
- Solar, wind and water energy
- Water
- Size of stock/reserves
- Regeneration and/or recovery
- Technology

In addition to the criteria, it is important to mention that the recommended method should be applied to the irreversibly dissipated fraction of the material produced from the inventoried resources, rather than to the full extracted quantity. This is one of the recommendations from the UNEP-SETAC Life Cycle Initiative Task force on Natural Resources and Land Use.

The table below presents the general and specific criteria for resource depletion identifying the minimum score to be met (threshold value) and the most relevant criteria for the impact category (importance).

Table 4-9 General and specific criteria for resource depletion with threshold value and importance.

RESOURCE DEPLETION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
		• Timeframe, discounting, etc.		
		• Marginal (M) or Average (A) defined, if not described (ND)		
		• Total number of individual substances covered by specific provided characterisation factors		
Completeness of scope		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Human Health		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Environment		
		• The impact indicator covers the majority of impact mechanisms and relevant elementary flows for the AoP Natural Resources		
		• The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause effect chain		
		• The characterization model is adaptable to spatial and temporal explicit evaluation		
		• Global geographical validity preferable, separate validity for Europe beneficial		
		• The method is compatible with, or developed specifically for, the comparative assessment scope of LCA (e.g. factors do not include security factors/precautionary principle)		
		When empirical data is used, double counting is avoided		
	Overall evaluation			
Environmental relevance		• All critical parts of the environmental mechanism describing the cause-effect chain are included with acceptable quality.		
		• Biotic resources are included		
		• Water is included		
		• Stock/reserve size is included		
		• Regeneration and/or recovery is included		
		• Technology is included		
	Overall evaluation			

RESOURCE DEPLETION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Scientific robustness & Certainty	**Scientific robustness**	• The critical part of the model including the input data have been peer reviewed (journal, panel, book, etc.)		
		• The model reflects the latest stage of knowledge for the cause-effect chain (the critical links are covered)		
		• The model including the underlying data have a good potential for being consistently improved and further developed including regarding geographical/emission situation and temporal differentiation		
	Certainty	• Indicators can be confirmed and verified against monitoring data, if available		
		• Uncertainty estimates of the indicators are provided, justified and reported in statistical terms		
		• Scenario and model uncertainty as well as substance data and parameter uncertainty are taken into account		
		• The category indicator and characterisation models are science based		
	Overall evaluation			
Documentation & Transparency & Reproducibility		• The model documentation is published and easily accessible (incl. description of the mechanism, the model, temporal and spatial scale, etc.)?		
		• The set of characterization factors/models is published and easily accessible		
		• The input data are published and easily accessible		
		• The characterization model is published and accessible		
		• Ability for third parties to freely generate additional, consistent factors and to further develop models e.g. incorporating further geographical/emission situation, temporal and speciation differentiation		
		• Value choices are explicitly stated		
	Overall evaluation			
Applicability		• Coverage of impacting single substance/resource elementary flows of the ELCD core database (version October 2007)		
		• Easy to update to conform e.g. with the ELCD nomenclature and units		
		• The characterisation factors are straightforward to apply for general LCA practitioners and in most market-relevant LCA software tools		
		• Life cycle inventory figures for the distinguished emission compartments or resource types can be directly made available by producing industry		
	Overall evaluation			

RESOURCE DEPLETION		**Check the following:**	**Threshold** (Minimum score)	**Importance** (H-N)
Overall evaluation of science based criteria				
Stakeholder acceptance criteria		• The indicator is easily understood		
		• There is an authoritative body behind the general model principles like the IPCC model (consensus/international endorsement)		
		• The principles of the model are easily understood by non-LCIA experts and preferably also by the general public		
		• The covered elementary flows and impact models do not inappropriately favour or disfavour specific industries, processes, or products		
		• The indicator is relevant with current policy indicators of the European Commission or similar international authoritative bodies		
Overall evaluation of stakeholders acceptance criteria				
Final recommendation				

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6 Annex A: 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.

Disclaimer: Involvement in the development or consultation process does not imply an agreement with or endorsement of this document.

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)
- European Copper Institute
- European Confederation of woodworking industries (CEI-Bois)

Disclaimer: Involvement in the development or consultation process does not imply an agreement with or endorsement of this document.

- European Federation of Corrugated Board Manufacturers (FEFCO)
- Industrial Minerals Association Europe (IMA Europe)
- Lead Development Association International (LDAI), global
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Abstract
Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are the scientific approaches behind modern environmental policies and business decision support related to 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 and studies. Such data and studies support coherent SCP instruments, such as Ecolabelling, Ecodesign, Carbon footprinting, and Green Public Procurement. This guidance document provides a framework and requirements for the models that are used to analyse the emissions into air, water and soil, as well as the resources consumed in terms of their contributions to different impacts on human health, natural environment, and natural resources. The principle target audience for this document is the Life Cycle Impact Assessment (LCIA) expert but also the experienced LCA practitioner and decision makers that are interested in the Impact Assessment models and indicators used in LCA. This document builds upon to related topics and conforms to the ISO 14040 and 14044 standards on LCA.

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