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Sustainability of construction works — Additional environmental impact categories and indicators — Background information and possibilities — Evaluation of the possibility of adding environmental impact categories and related indicators and calculation methods for the assessment of the environmental performance of buildings

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This Published Document is the UK implementation of CEN/TR 17005:2016.

The UK participation in its preparation was entrusted to Technical Committee B/558, Sustainability of construction works.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2016

ISBN 978 0 580 90477 6
ICS 91.010.99

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 November 2016.

Amendments/corrigenda issued since publication

Date	Text affected

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TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 17005

October 2016

ICS 91.010.99

English Version

Sustainability of construction works - Additional environmental impact categories and indicators - Background information and possibilities - Evaluation of the possibility of adding environmental impact categories and related indicators and calculation methods for the assessment of the environmental performance of buildings

Indicateurs complémentaires pour la déclaration de la performance environnementale des produits de construction et pour l'évaluation de la performance environnementale des bâtiments

Nachhaltigkeit von Bauwerken - Hintergrundinformationen zu möglichen, zusätzlichen Wirkungskategorien und Indikatoren für die Erfassung der umweltbezogenen Qualität von Gebäuden

This Technical Report was approved by CEN on 26 August 2016. It has been drawn up by the Technical Committee CEN/TC 350.

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European foreword

This document (CEN/TR 17005:2016) has been prepared by Technical Committee CEN/TC 350 "Sustainability of construction works", the secretariat of which is held by AFNOR.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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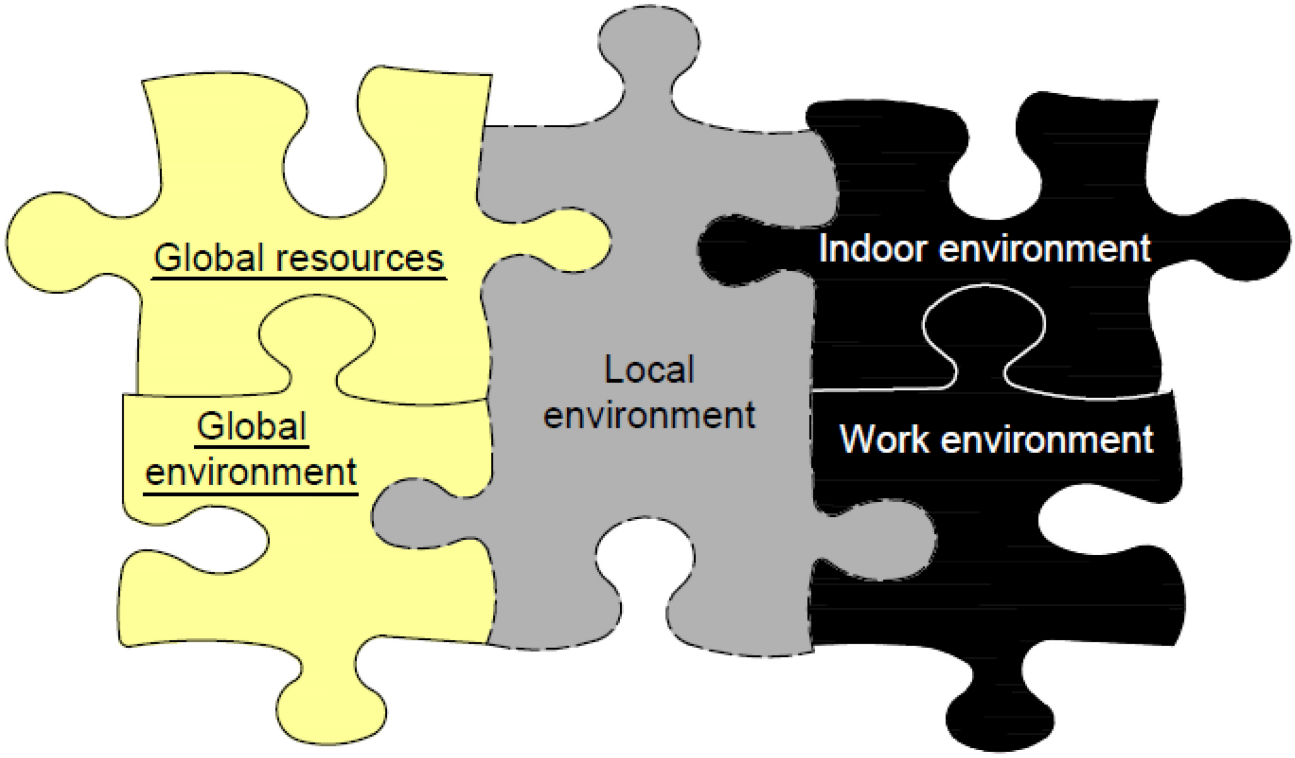


Figure 1 — Domain of LCA ([14], p. 33)

NOTE 1 One of the main drivers for using LCA, is the prevention of burden shifting.

NOTE 2 If in future, models become available that combine global environmental impacts with health impacts to the building users due to direct exposure, these might be considered in the context of the CEN/TC 350 framework in future.

Although the EN 15804 standard follows the LCA approach, it also states that additional information on release of dangerous substances to indoor air, soil and water during the use stage shall be provided (EN 15804:2012+A1:2013, 7.4). EN 15804:2012+A1:2013, 7.4.1 stipulates the requirements related to releases to indoor air, and EN 15804:2012+A1:2013, 7.4.2 stipulates the requirements related to releases to soil and water. Such releases are included in EN 15804 as these have a potential direct impact/risk for the inhabitants/users of the building.

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Both EN 15804 and EN 15978 contain seven life cycle environmental impact categories. Since their publication, however, a perceived need has arisen to include in these standards a broader set of environmental impacts categories due to the following:

— Additional environmental impact categories are currently part of European recommendations and of national legislation of several Member States.

— Additional environmental indicators are used in current practice (see EN 15643-2:2011, B.2 [3]).

— New research and developments in life cycle impact assessment (LCIA) methods and the characterization of environmental impacts.

This Technical Report (TR) has been developed to provide guidance to the working groups of CEN/TC 350 on the extension of the impact categories in EN 15804 and EN 15978. The TR provides a framework for the evaluation of environmental impact categories and evaluates the impact categories human toxicity and ecotoxicity, particulate matter, land use, biodiversity, water scarcity; and ionizing radiation by implementing the framework developed.

During the preparation of the TR a range of experts, such as developers of impact assessment models, LCA software developers and experts from the EC-JRC were consulted.

NOTE 3 Although this report is primarily referenced to buildings, the indicators and methods reviewed might have equal application in other construction works.

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Introduction

List of abbreviations:

CDV	Critical Dilution Volume
CF	Characterization Factor
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
ILCD	International Reference Life Cycle Data System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PCR	Product Category Rules
PEF	Product Environmental Footprint
RA	Risk Assessment
TR	Technical Report
TSP	Total Suspended Particles

The standards EN 15804 [1] and EN 15978 [2] provide a basis for the environmental assessment of buildings using a life cycle assessment approach.

The EN 15804 standard [1] provides core product category rules (PCR) for Type III environmental declarations of any construction product and services. An Environmental Product Declaration (EPD) is a verified document that reports environmental data of products based on life cycle assessment (LCA) and other relevant information and in accordance with the international standard ISO 14025 (*Type III Environmental Declarations*).

The EN 15978 standard [2] specifies the calculation method to assess the environmental performance of a building, based on LCA (i.e. using EPD for construction products and services) and other quantified environmental information (i.e. (1) indicators describing resource use based on input flows of the life cycle inventory (LCI) and (2) indicators describing waste categories and output flows derived from scenarios and LCI), and gives the means for the reporting and communication of the outcome of the assessment.

Life cycle Assessment (LCA) is defined as the "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*". (ISO 14040).

In LCA, the modelling is typically made at the global level, resulting in global characterization factors. Inherent to the modelling, the (current) environmental impact assessment models within LCA do not cover local impacts/risks due to direct exposure of some persons to a certain emission/hazardous substance. As it is acknowledged that the variation in population density influences the exposure rate and hence also the potential health damage, regional characterization factors (based on regional differences in population density) for some health related impact categories are being developed. The same is true for ecosystems related impact categories.

As is illustrated in Figure 1, LCA (in current practice) covers a great part of the total environmental perspective but is clearly restricted to regional and global impacts to the external environment (i.e. it does not include effects due to indoor exposure of the users of a building). Effects for which there is a low plausibility that they will occur (e.g. risks from nuclear waste) and local effects from the products

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on the manufacturers or users are disregarded. Recently, research has started to also address health effects due to indoor emissions on building users with similar approaches as used in LCA [13].

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1 Scope

This Technical Report (TR) has been developed by CEN/TC 350/WG 1 and WG 3 to provide a clear and structured view on the relevance, robustness and applicability of a predefined set of additional impact categories and related indicators for the assessment of the environmental performance of construction works, construction products and building materials.

The TR describes the evaluation criteria that are used to determine, for these impact categories, the suitability of indicators and calculation method(s) for inclusion in the standards EN 15978 and EN 15804 (or other CEN/TC 350 standards as appropriate) in terms of their:

a) relevance to:

   1) the environment,

   2) construction works,

   3) construction products, and

   4) EU policy;

b) scientific robustness and certainty; and

c) applicability of the impact assessment method(s).

The additional impact categories examined in the TR are:

— human toxicity and ecotoxicity;

— particulate matter;

— land use;

— biodiversity;

— water scarcity; and

— ionizing radiation.

Because EN 15978 and EN 15804 are founded on a life cycle approach, the impact categories, indicators and methods reviewed are predominantly based on their potential suitability for application in LCA. In relation to some of the areas of concern, however, where LCA methods might not be sufficiently robust or developed, some non-LCA based indicators and methods are also considered.

Due to the scope of LCA used in the EN 15804 and EN 15978, impacts to users of buildings due to direct exposure to harmful emissions fall outside the scope of this TR. This falls under the scope of CEN/TC 351. Important information related to this aspect found during the development of this TR, is however mentioned in the TR.

Uncertainty is an important issue in LCA. General assessment of the uncertainty related to impact assessment models is considered in the evaluation framework of this TR. However, the TR does not lay down a maximum uncertainty level to be considered acceptable in the context of the CEN standards EN 15804 and EN 15978, nor does it provide exact figures on uncertainties.

Annex A of the TR provides a description of options that may be considered for incorporating selected impact categories/indicator in the standards EN 15978 and EN 15804.

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The TR recognizes and takes account of:

— the work done by the European Commission, Joint Research Centre (EC-JRC), in the development of the International Reference Life Cycle Data System (ILCD) Handbook Recommendations,

— other reports and scientific studies into the methods and application of the indicators reviewed,

— findings of specific activities connected with this work such as of the CEN/TC 350 Workshop, held in Brussels on 24-25 June 2014.

2 The need for additional impact categories

2.1 Environmental relevance

It is widely recognized that the extraction and combustion of fossil fuels is a dominant cause of the environmental impact of a building across its life cycle ([23], 22], [24]). This is especially the case for existing European buildings that were constructed before national and European Energy regulations were introduced. The use of low efficiency gas and oil heating systems combined with a poorly insulated building envelop results in a high yearly combustion of fossil fuels and this combined with a relatively long lifespan of buildings, makes the operational energy use the dominant aspect in the environmental profile of many existing European buildings.

The extraction and combustion of fossil fuels is responsible for environmental impacts related to:

— **Global warming:** mainly CO_2 emissions related to the use, production and transport stages

— **Depletion of abiotic fossil fuels**: extraction of oil, gas and coal related to use, production and transport processes

— **Acidification**: SO_2 and NO_x emissions related to the combustion of fossil fuels related to the production or transport phases

— **Eutrophication:** nitrogen emissions related to the combustion of fossil fuels

— **Photochemical ozone creation:** emissions of nitrogen oxides related to the combustion of fossil fuels

— **Particulate matter formation:** emissions of nitrogen oxides, sulphur dioxides and small particulates

These impact categories except particulate matter formation are already integrated in the current version of the standards EN 15804 (2012+A1:2013) and EN 15978 (2011).

The increase in heating efficiencies and insulation level, and the growing use of renewable energy will result in a smaller influence of the operational energy of buildings on its overall environmental profile. With the 2019-2021 EPBD targets[1] in view, the environmental impacts of buildings of the near future will be less dependent on their operational energy use and increasingly influenced by the life cycle impacts of the constituent building products (cf. manufacturing, replacement and/or end-of-life) and other processes during the use phase, such as water consumption and transport of building users (e.g. commuting related to the dwelling location). [20], [22]

[1] The re-cast Energy Performance of Buildings Directive (EPBD) requires that from 2019 onwards 'all the new buildings occupied and owned by public authorities are nearly zero-energy buildings' (nZEB) and by the end of 2020 'all new buildings are nearly zero-energy buildings'.

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With this gradual shift in the relative environmental importance of a building's energy use, the need to consider other types of environmental impact, such as land occupation impacts of the building during its life cycle and land transformation impacts related to the provisioning of raw materials for building materials (e.g. sand, gravel, clay, ore and wood) [21] will become more apparent and increasingly important.

EXAMPLE For a single family dwelling representative for the Belgian building stock, which was upgraded from current common practice to the passive house standard, it was observed that there was a life cycle decrease in CO_2 emissions but at the same time there was a life cycle increase in SO_2 emissions (contributing to acidification impacts), $PM_{2,5}$ emissions (contributing to particulate matter) and ecotoxicity. [18]

In order to gain an insight into the potential relevance of the additional impact categories compared to the ones already included in the CEN standards, a comprehensive life cycle assessment was made of 16 residential buildings in Belgium, ranging in typology and construction period. For each home, an optimization of the life cycle environmental impact and financial cost was made. The optimization included both a differentiation in energy performance, heating and ventilation system, material choice, air tightness and overall design of the building. The outcome of the study is shown in Figure 2.

For the life cycle assessment a comprehensive set of impact categories was included (i.e. the impact categories included in Eco-indicator99) and an approach was developed to calculate a single score environmental impact (i.e. based on the calculation of external environmental cost through monetary valuation). By calculating this single score, it was possible to analyse the relative contribution of each of the impact categories to the overall environmental impact. This relative contribution can give a rough idea on the relevance of the impact categories.

The monetary valuation approach used within this study was based on the European project ExternE, in combination with other monetary valuation studies. For some harmful emissions monetary values were directly available, others required first an assessment at end point level, which were then translated into external environmental cost. For this end point impact assessment, Eco-Indicator99 was used.

NOTE The impact assessment method in this study was not in line with the ILCD recommendations (i.e. the ILCD handbook only recommends midpoint methods). As the impact assessment is partially based on Eco-Indicator99, there are some methodological limitations.

The results shown in Figure 2, are for one of the 16 residential buildings analysed. For this dwelling more than 2500 alternatives were analysed ranging in material choice (i.e. solid versus timber frame structures, different finishing materials at the outside and inside, different glazing and window frames), in insulation level, in heating system, in air tightness, in ventilation system, etc. For each of the 2500 alternatives, the total life cycle environmental impact (i.e. single score) was calculated and then the percentage contribution of each of the impact categories to this total score was calculated. The contribution of a particular impact category to the total environmental impact changed from one building alternative to another and, therefore, for each impact category the minimum and maximum contribution was determined; these values are presented in Figure 2. As the majority of the buildings had an energy performance which was far above the passive standard, the result (i.e. contribution of each impact category to the total environmental impact) is shown for the life cycle impact of the building together with the cradle-to-gate impact of the construction materials in the building.

The figure shows the minimum contribution to climate change was 31 % and the maximum contribution was 54 %. The dwellings with a climate change contribution of 31 % had a better energy performance than the dwellings with a climate change contribution of 54 %. The analysis revealed that the following impact categories are relevant (where a threshold of 10 % contribution has been defined as minimum value to be perceived as relevant), in order of importance:

— climate change;

— acidification;

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— eutrophication;

— particulate matter formation;

— ecotoxicity, land use; and

— fossil fuel depletion.

The indicators; particulate matter formation, ecotoxicity, and land use are not currently included in either EN 15804 or EN 15978.

Similar results were obtained in a more recent Belgian research project, the OVAM:MMG project. [16]

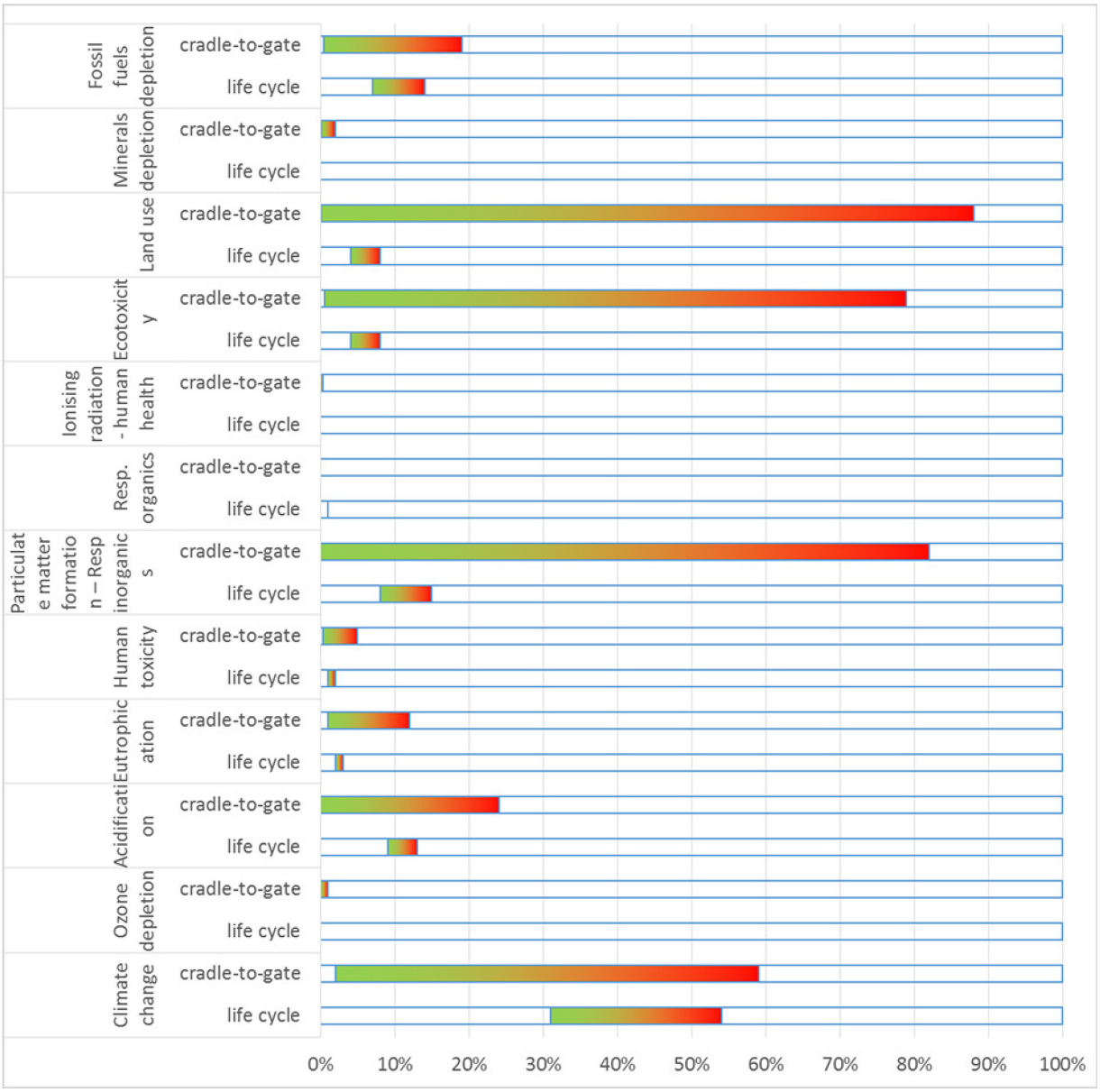


Figure 2 — Relevance of different impact categories on building level based on cradle-to-gate and cradle-to-grave assessment – impact assessment method = SuFiQuaD, based on [19]

Disclaimer: This figure shall be interpreted with caution due to methodological limitations of the impact assessment method used.

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2.2 Policy relevance

Several environmental impact categories and indicators that are additional to those used in current CEN/TC 350 standards are being advanced in European and national policies/regulations. Furthermore, as well as specific policies, there are other initiatives that also require additional indicators.

The lists below identify some of these policies and initiatives without describing them in detail.

NOTE Other policies and initiatives are identified in the review of each additional impact category (4.2.2.4, 4.3.2.4, 4.4.2.4, 4.5.2.4, 4.6.2.4 and 4.7.2.4).

a) EU level:

1) The Single Market for Green Products Initiative and Product Environmental Footprint (http://ec.europa.eu/environment/eussd/smgp/index.htm);

2) The 'Resource Efficient Buildings' study for the 'development of a common EU framework of indicators for the environmental performance of buildings' (http://ec.europa.eu/environment/eussd/buildings.htm); and

3) The construction products regulation BWR7 (http:// http://ec.europa.eu/growth/sectors/construction/product-regulation/)

These initiatives consider the use of one or more of following impact categories:

— climate change,

— ozone depletion,

— ecotoxicity for aquatic fresh water,

— human toxicity – cancer effects,

— human toxicity – non-cancer effects,

— particulate matter/respiratory inorganics,

— ionizing radiation – human health effects,

— human health effect model,

— photochemical ozone formation,

— acidification,

— eutrophication – terrestrial,

— eutrophication – aquatic,

— resource depletion – water,

— resource depletion – mineral, fossil, and

— land transformation.

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b) Member States:

1) Belgium: from 2017 the following additional impact categories and related indicators will be regulated providing there is a methodology in CEN/TC 350 or in the Product Environmental Footprint (PEF) method:

i) human toxicity (cancer),

ii) human toxicity (non-cancer),

iii) particulate matter,

iv) depletion of resources (water),

v) ecotoxicity (soil),

vi) ecotoxicity (marine), and

vii) land use (soil quality and biodiversity);

2) France: Pollution of air and water (method: XP P 01-064/CN); and

3) Netherlands: Human and ecotoxicity (method: CML).

2.3 Conclusions

Existing LCA studies of buildings highlight the environmental relevance of additional environmental impact categories which are not yet included in current versions of standards EN 15804 and EN 15978. The literature review revealed that this is particularly the case for energy-efficient buildings for which the environmental impact of the materials, water use, building location, etc. gain in relative importance in an environmental profile of a building as impacts shift away from mainly energy-related impact categories to others.

The literature review also identified that there is a need for a more in-depth study of these additional impact categories and the associated models and indicators in terms of scientific robustness, certainty, data availability, etc. Finally, the policy relevance of the additional environmental indicators was identified both at the EU level and the national level of several Member States.

3 Evaluation criteria for additional environmental impact categories for CEN/TC 350

3.1 Introduction

3.1.1 General

The selection of additional environmental impact categories and related assessment models and indicators for inclusion in the CEN/TC 350 standards shall be transparent and based upon clear and agreed criteria.

For this TR a framework has been developed for the evaluation of the environmental impact categories. This framework is based on a set of:

— general criteria related to standardization; and

— specific evaluation criteria related to the LCIA, which are based on the ILCD handbook criteria.

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3.1.2 Criteria related to standardization

It is widely accepted that for impact categories and their indicators to be considered appropriate in their application, and particularly for the purposes of standardization, the following criteria are important.

Impact categories and indicators should be:

— relevant for the environment and for buildings, construction products, policy;

— performance based;

— quantifiable;

— scientifically robust and sufficiently certain;

— based on stakeholder acceptance; and

— applicable.

For standardization, an additional consideration that might be taken into account is the presence of existing references to indicators/methods in national, European or International legislation or recommendations.

3.1.3 Criteria related to the LCIA models and indicators

The ILCD handbook was used as the foundation for the evaluation of the LCIA models and related indicators. The handbook includes a section on recommended impact assessment models and indicators with the overall aim of providing guidance on consistent and quality assured LCA data and studies. The evaluation criteria used in the ILCD handbook to formulate their recommendations are used for the evaluation of the impact categories in this TR. Further information on the background of the ILCD handbook is provided in Annex C.

The ILCD Handbook distinguishes five scientific criteria and one stakeholder acceptance criterion for classifying an LCIA method/model very similar to the criteria mentioned in Subclause 3.1.3:

a) completeness of the scope;

b) environmental relevance;

c) scientific robustness and certainty;

d) documentation, transparency and reproducibility;

e) applicability; and

f) degree of stakeholder acceptance and suitability for communication in a business and policy contexts.

The set of scientific criteria are further divided into:

1) general sub-criteria based on fundamental requirements for LCIA methods (both characterization models and factors) – which are the same for all impact categories; and

2) minor groups of specific sub-criteria for 'Environmental relevance' and 'Scientific robustness and certainty', which address the characteristic features of each individual impact category. General sub-criteria are given in Annex D. The specific sub-criteria are further outlined by the JRC [5].

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As can be seen, many of the criteria related to the JRC evaluation of LCIA models overlap with the standardization criteria (3.1.1). For the purposes of the evaluation in this TR, therefore, the criteria were combined to form an overall framework which is described in Subclause 3.2.

3.2 Evaluation framework for additional environmental impact categories for CEN/TC 350

3.2.1 General

The framework shown in Figure 3 and constituent criteria were developed for the evaluation of the predefined set of additional indicators. It is intended, however, that in future it could be used to evaluate impact categories and related assessment models and indicators other than those included in this TR.

Step 1: Identify the environmental relevance (see 3.2.2) of the effects and impact categories to be addressed at the building level

Step 2: Assess the likely relevance of the environmental impact; both at building and at product level (site specific vs embodied) relevance for buildings (see 3.2.3) and construction products (see 3.2.4).

Step 3: Assess the policy relevance: are the indicators already referenced in European legislation (see 3.2.5) or in other European standards?

standardization criteria

The first three steps used to establish relevance in relation to the CEN/TC 350 standards of the impact category and its possible indicators.

Step 4: Establish a list of possible performance based and quantifiable indicators (LCA-based) (see 3.2.6 and 3.2.7).

Step 5: Assess existing LCIA models based on the science based criteria developed by ILCD Handbook [5] (see 3.2.8).

Step 6: Evaluate existing LCIA models based on practice based criteria: availability of characterization factors and data, and applicability at EU level (see 3.2.9).

Step 7: Determine if there is any authoritative body in place and their recommendation if any (see Subclause 3.2.10).

ILCD criteria (slightly adapted for specific context of construction)

If the LCIA models have been identified as having significant drawbacks (i.e. not applicable, or a low level of scientific robustness), non-LCA methods may be searched for and described.

Figure 3 — Evaluation framework for additional environmental impact categories for CEN/TC 350

For each identified impact category/group of environmental effects identified in step 1 and found relevant in step 2 and/or step 3, a list of possible LCA-based assessment models and related indicators is established (step 4) and a table is developed to provide a clear overview of the outcome of evaluation from steps 5 and 6. In addition, the outcome of step 7 is described.

If both embodied impacts and site-specific impacts occur in a certain impact category, it seems preferable to use the same assessment model and indicator. If an impact assessment model, however, does not fulfil the evaluation criteria of the framework defined in this TR at both product and building level, it might be necessary to select two different models/indicators for assessing the embodied impact and the site-specific impact within one impact category. In this case both models might address slightly different environmental effects which should then be made clear in the standards.

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The selection criteria used to assess the relevance of an impact category in relation to standardization are described in Subclauses 3.2.2 - 3.2.8:

3.2.2 Environmental relevance – Standardization (step 1)

— What is the degree of pertinence of the indicator(s) for the addressed impact category?

— Is it documented clearly what the proposed additional impact category addresses?

— Is the impact category identified by the society as important?

— Is the building sector contributing to the impact category?

— Is it documented whether it is a midpoint or an endpoint indicator or whether it is a resource indicator?

3.2.3 Relevance for buildings (step 2a)

At the building level both site specific impacts and embodied impacts should be considered; the following criteria were used to determine the relevance for buildings:

— Does the impact category and related indicator affect the design of a building or building product?

— Is the impact and related indicator specific to the site (i.e. applicable only to the site of the works)?

— Is the impact and related indicator specific to the construction products used in the building, i.e. is it an embodied impact?

In the context of the CEN/TC 350 standards, the building level has precedence over the product level. This means that it is possible to have indicators at the building level which do not require data from the product level. Only if an indicator is found to be relevant at the building level data may be required from the product level.

3.2.4 Relevance for construction products (step 2b)

— Does the impact category and indicator affect the choice of materials and products incorporated in buildings?

It is recommended that the embodied impacts of the materials/products are compared to the impact of the works' construction process and of the use phase.

3.2.5 Policy relevance (step 3)

In respect of legislation, regulation and/or official recommendations, the following question is asked:

— Is the impact category/indicator referred to in any existing/notified national or European legislation?

3.2.6 Performance based (step 4a)

Indicators can be performance based or means based. For inclusion in standards indicators that are performance based are preferred as they focus on the result and leave freedom for the designer or manufacturer to determine how to achieve or influence the performance.

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3.2.7 Quantifiable (step 4b)

The LCA approach automatically provides quantifiable indicators and is widely recognized as technique to avoid burden shifting while addressing the whole life cycle (ISO 14040: pp. 6-7). The LCA approach makes it possible to aggregate the environmental impact from product level to building level.

Quantifiable non-LCA indicators are also considered. If non-LCA indicators are to be used, care should be taken to ensure these really reflect an environmental effect. The use of LCIA and non-LCA indicators covering the same environmental effects in the standards for assessing the environmental performance of buildings and products should only be done with care as this could lead to erroneous conclusions. To avoid double counting it is important that environmental indicators do not cover the same effect for the same environmental flow.

In some cases the only way to address an environmental impact might be via a qualitative indicator that still shall be descriptive of the environmental impact to be addressed. As stated in EN 15804[2] (Clause 5.1): "*an EPD according to this standard provides quantified environmental information for a construction product or service on a harmonized and scientific basis*", qualitative indicators are not covered by LCIA and are regarded as additional information (EN 15804[3] Subclauses 5.4 and 7.3) (this is further discussed in Annex A).

3.2.8 Scientific robustness and certainty (step 5)

Robustness is the stability of a method or indicator. The scientific robustness is evaluated based on several sub-criteria depending on the impact category. These include (for all impact categories):

— the characterization models, including the input data, have been peer reviewed (journal, panel, book, etc.);

— the characterization models reflect the current state of knowledge for the cause–effect chain (the critical links are covered);

— the characterization models are scientifically based.

The certainty covers following aspects:

— estimates of the uncertainty are provided for the indicators;

— uncertainties in the scenario(s) used and model are taken into account.

For the purposes of this report the approach and recommendations of the EC-JRC in their ILCD Handbook [4] are taken into account for the assessment of scientific robustness and certainty.

More specifically, the following criteria are considered within the scientific robustness and certainty evaluation:

a) Completeness of the scope

This criterion evaluates whether the LCIA model and indicator cover the majority of the impact mechanisms and relevant elementary flows.

[2] As impacted by EN 15804:2012+A1:2013

[3] As impacted by EN 15804:2012+A1:2013

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b) Environmental relevance – LCIA

The environmental relevance on the level of LCIA modelling is different to the environmental relevance for "standardization" (3.2.1). While the relevance for standardization is evaluated at the level of the impact category, the relevance here is evaluated at the level of the impact assessment modelling.

The general question addressed in this criterion is the following: "Are all critical parts of the environmental mechanism describing the cause–effect chain included with acceptable quality?"

For each impact category, specific questions are added to this general issue covering certain topics; for example:

1) Climate change: "Atmospheric fate and transport is considered"; "For damage to ecosystems, all relevant effects are considered"; "For damage to human health, all relevant effects are considered";

2) Particulate matter: "Secondary PM are considered"; "The model considers fate, exposure and effect in a quantitative way and fate factors, intake fraction, intake factor, uptake factor, dose-response information are given as intermediary results"; "Urban area is considered separately and resolution fine enough to capture significant differences in exposure".

For the full list of aspects addressed under this criterion by the ILCD handbook we refer to the handbook.

c) Scientific robustness and certainty

We refer to subclause 3.2.8 for the scientific robustness and certainty.

d) Documentation, transparency and reproducibility

This criterion evaluates whether:

— the model documentation is published and accessible;

— the characterization factors/models are published and accessible.

e) Applicability

This criterion evaluates:

— 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 characterization 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 industry.

NOTE The JRC review is currently being updated for expected publication at the end of 2016.

3.2.9 Applicability of the life cycle impact assessment method/model (step 6)

Although applicability is one of the criteria within the ILCD handbook (see Subclause 3.2.8), it is seen as a separate evaluation step within our framework. This is because the "applicability" within this evaluation framework slightly differs from the "applicability" as evaluated within the ILCD handbook.

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To assess applicability (i.e. the ability to apply) of a life cycle impact assessment method/model the following criteria are used:

a) Data (i.e. LCI and Characterization Factors) availability, taking into account:

   1) the availability of the LCI data:

      i) specific data can be made available by industry directly (e.g. data are already collected within the framework of existing legislation),

      ii) generic data for construction related processes is available;

   2) the availability of the characterization factors;

   3) the ease of updating the characterization factors;

   4) availability of regional data when needed (cf. site dependent);

   5) availability of regional characterization factors when needed;

b) experience – how widely used is the application/use of the impact assessment model;

c) availability of the model within existing, widely used LCA tools (i.e. support for the use of the indicator).

NOTE For this TR the assessment was limited to the three most widely used LCA tools: Simapro (Pre Consultants), GABI (Thinkstep) and openlca (GreenDelta).

3.2.10 Stakeholder acceptance of the impact assessment model (step 7)

It will be determined whether there is an authoritative body behind a model, e.g. such as the IPCC (consensus/international endorsement), and if such an authoritative body is in place whether they have made any recommendations regarding life cycle impact assessment model and related indicator.

NOTE The eventual inclusion of an indicator/method within the CEN/TC 350 standards will be subject to the normal process of stakeholder acceptance through the CEN procedures.

3.3 Compliance criteria of the ILCD handbook

The ILCD Handbook uses the following scores reflecting the compliance of the LCIA method/model with the criterion or sub-criterion requirements:

A: Full compliance

B: Compliance in all essential aspects

C: Compliance in some aspects

D: Little compliance

E: No compliance

In addition, due to the importance of some of the sub-criteria, an exclusion threshold is defined as a required minimum performance. This means that if an LCIA model comes below the exclusion threshold, the model will not be evaluated any further.

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3.4 Information sources regarding the additional impact categories

A primary source used for the preparation of this TR, has been the ILCD handbook of the EC-JRC, "*Recommendations for Life Cycle Impact Assessment in the European context*" (2011). The review of the LCIA methods and models in the ILCD handbook is, however, limited to the models and methods that were available in 2009. Since then, there have been a number of advances in the methods that are used. Other sources were, therefore, consulted in order to have a complete picture of the current state of the art. The information sources used were the following: scientific literature; impact assessment modelling reports, information acquired through the CEN workshop on additional environmental indicators held in Brussels on 24-25 June 2014; and expert consultation (i.e. impact assessment model developers, LCA software developers and the EC-JRC).

NOTE The EC-JRC has communicated that an update of the LCIA methods review is now in progress and is expected to be published in September 2016. The foreseen updates are mentioned in the TR.

4 The evaluation of additional impact categories

4.1 General

The evaluation framework has been used to assess the additional impact categories (assessment models and related indicators) previously identified as important [NWIP] and which are not included within the current versions of EN 15804 and EN 15978 standards. These are:

— human toxicity (cancer and non-cancer effects);

— ecotoxicity (terrestrial, freshwater and marine);

— particulate matter formation (or respiratory inorganics);

— ionizing radiation (human health and ecosystem health);

— land use (occupation and transformation) /biodiversity; and

— water depletion/scarcity.

The results of the evaluation are presented in the Subclauses 4.2– 4.7

4.2 Human toxicity: Cancer and non-cancer effects

4.2.1 Description

4.2.1.1 General

The impact category "human toxicity" accounts for the adverse health effects on human beings caused by the intake of toxic substances present in the environment. This can be through inhalation of air, food/water ingestion or penetration through the skin. They include both cancer and non-cancer health effects. [6] The effects of particulate matter/respiratory inorganics and ionizing radiation are not considered here, as separate impact categories have been developed for these impacts (see Subclauses 4.4 and 4.5).

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4.2.1.2 Mechanisms

Morten Birkved[4] (DTU), in his presentation at the CEN/TC 350 workshop on additional indicators[5], described how a number of chemical substances are capable of inducing toxicological effects in human beings (and other organisms). An emission of one of these chemicals sets off a chain reaction, starting with an increase in the concentration of the chemical in the environment. This is followed by an uptake/intake by organisms, causing an interaction between biological receptors and the chemical. This chain of events may eventually lead to changed behaviour, cancer, hereditary effects and, in extreme cases, death. The environmental mechanism for human toxicity, including fate, exposure and effect is shown in Figure 4.

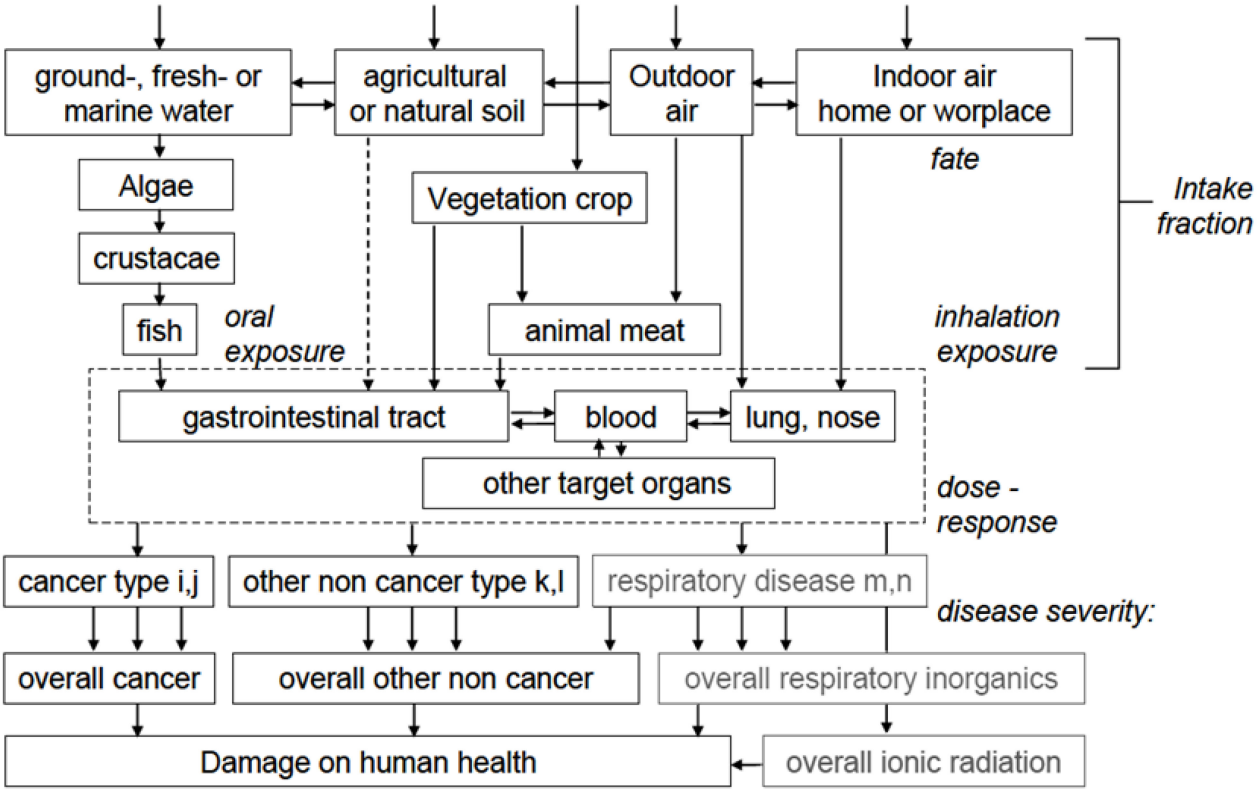


Figure 4 — Cause-effect chain for human toxicity effects (including mechanisms for ionizing radiation and respiratory effects associated with particulate matter, see 4.4 and 4.5). [5]

4.2.1.3 Health impact

Toxicological characterization factors for human health are calculated by taking into account the following parameters:

— the time integrated fate;

— the exposure of a unit mass of chemical released into the environment (in many cases including the size of the exposed population);

[4] Associate professor Morten Birkved, Section of Quantitative Sustainability Assessment (QSA), Department of Management Engineering, Technical University of Denmark

[5] CEN/TC 350 workshop on additional environmental indicators, 24 & 25 June 2014, Brussels, Belgium

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— the toxicological potency. This is a quantitative measure related to the dose–response of a chemical, such as the LOEL – the Lowest Observable Effect Level in a test;

— the toxicological severity (a measure or description, qualitative or quantitative, of the non-cancer effect incurred, such as skin irritation). [25]

The ILCD handbook [5] compares different frameworks for calculating characterization factors for human toxicity effects in LCA and concludes that the model for human toxicity shall account for the environmental fate (F), exposure (X), dose-response (R) of a chemical for midpoint factors and additionally severity (S) for endpoint factors:

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

in which:

- F: is the fate factor, which relates the emission flow to the change in mass in the environment;
- X: is the exposure factor, which links the change in mass in the environment to the change in intake rate;
- R: is the dose-response slope and is the likelihood of an additional effect per unit additional intake;
- S: is the severity and is the effect per case linked to mortality and morbidity.

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.

The ILCD handbook notes that these parameters could vary depending on location (e.g. habitat characteristics, local stressors, mixtures, background concentrations) and time (e.g. seasonal life stage sensitivity), although this is generally not accounted for in default models and factors.

The framework for calculating characterization factors for human toxicity effects is shown in Figure 5.

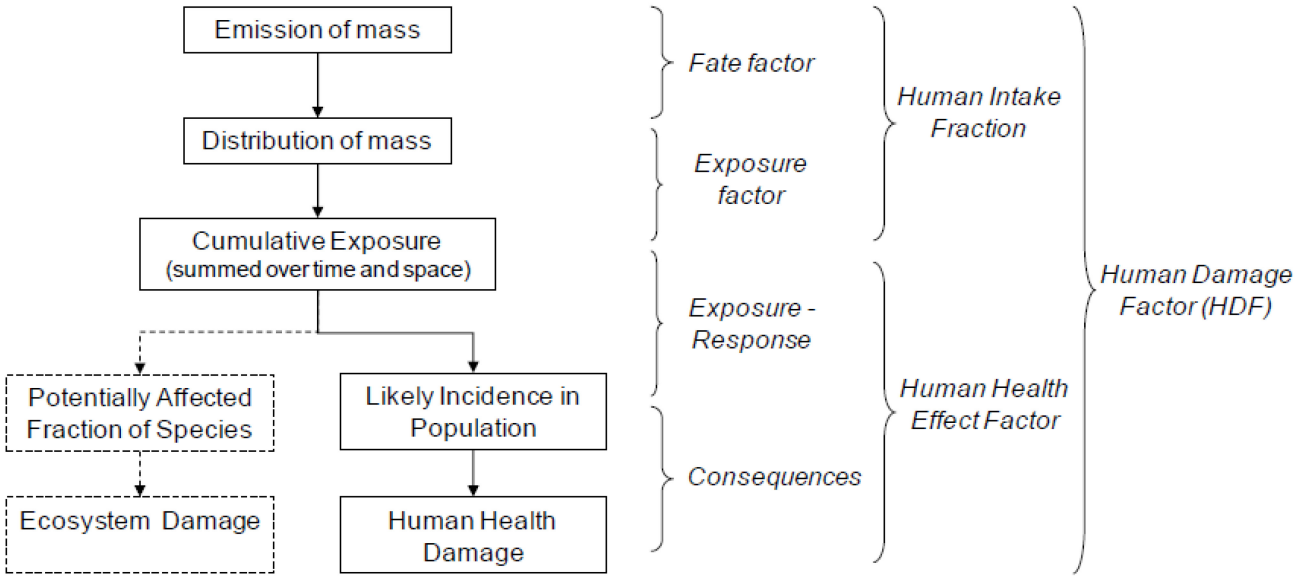


Figure 5 — Recommended framework for calculating characterization factors for human toxicity effects in LCA ([5], based on [27] and [28])

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Toxicological effects could be categorized into a large number of potential endpoints that involve various mechanisms, since each toxicological effect could contribute to one or more specific diseases. However, these effects are usually grouped in subcategories for practical reasons. Subcategories include [5]:

— cancer;

— respiratory diseases

— other non-cancer effects;

— impact of ionizing radiation.

The models used to characterize toxic impacts vary substantially in their scope, modelling principles, and in terms of the resulting characterization factors. Table 1 gives an overview of the most important factors that influence the performance of different models. A distinction is made between factors related to choice of parameter value and choice of algorithm. [29] The "parameter values" concern the values used to calculate fate, exposure, and effect parameters, "Algorithm choices" are referring to the choices related to the set of rules used in the model to approximate the events leading to toxicological effects.

Table 1 — Factors causing the different performance of the characterization models [29]

Model component	**Key factor**	**Parameter value (P) or algorithm choice (A)**
Fate	Advection as a loss mechanism in some models	A
	Inclusion of the intermittent character of rain	A
	Residence times of media, particularly marine water, differ greatly	P
	Different algorithms used for estimation of partition coefficients	A
	Modelling of soil compartment: (i) homogeneous versus vertically layered soil compartment and (ii) generic versus division between agricultural, industrial and natural soils	A
Human exposure	Urban air compartment nested within continental air compartment	A
	Difference in population density on the urban and rural scale	P
	Different algorithms used for estimation of bio-transfer and bio-concentration factors (fish, meat, milk, vegetation)	A
Human toxic effects	Some models extrapolate between intake routes (inhalation, ingestion, dermal)	A
	Models use different effect indicators (TD50, ADI, TD10)	P

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4.2.2 Relevance of human toxicity (step 1+2+3)

4.2.2.1 Environmental relevance (relevance for human health) (step 1)

The impact category human toxicity includes both carcinogenic (cancer-causing potential) effects and non-carcinogenic effects (e.g. on the central nervous system, on the immune system, on development/reproduction).

Many scientific studies provide evidence on the effects of a large number of toxic substances on human health.[6]

The World Health Organization (WHO) estimates that air pollution caused 7 million premature deaths worldwide in 2012. 3.7 million deaths were attributable to outdoor air pollution and 4.3 million deaths were due to household air pollution. Due to the overlap in indoor and outdoor exposure, mortality attributed to the two sources cannot simply be added together, hence the total estimate of around 7 million deaths. **This finding confirms that air pollution is now the world's largest single environmental health risk.** The researchers estimate that 80% of the outdoor air pollution-caused deaths were due to ischaemic heart disease[7] and strokes, while 14% of deaths were due to chronic obstructive pulmonary disease or acute lower respiratory infections and 6% of deaths were due to lung cancer. [32]

In the report "Air Pollution and Cancer" of the International Agency for Research on Cancer (IARC), a global overview is given on topics related to exposure characterization, atmospheric and engineering sciences, epidemiological studies on cancer, results of pertinent cancer bioassays, and data elucidating potential mechanisms of carcinogenicity of compounds related to air pollution. [33] In both indoor and outdoor locations there are sources that emit airborne carcinogens, like the combustion of fuels for heating, cooking, power generation, transport and industrial processes. Indoors, carcinogens may also be originating from tobacco smoking, building materials and furnishings, as well as the naturally occurring carcinogen radon.

Not only air pollution may cause health damage, also contaminants in food and water and toxic substances absorbed through the skin may have severe effects on human health, although global numbers are much more difficult to find as these effects are usually studied on a case by case basis.

4.2.2.2 Relevance for buildings (step 2a)

Buildings may contribute to human toxicity through the following pathways:

— direct emissions of chemicals from buildings during the construction and use phase, e.g. the leaching of components of impregnating agents (e.g. creosote or salts) from treated wood [34] and metals (e.g. copper and lead) from metal outdoor building products [35];

— emissions of chemical substances related to energy use during the use phase of the building;

— chemical substances released due to raw material extraction/manufacturing/transport/end-of-life (EoL) of products (embodied impact);

NOTE 1 Caution on direct (workers) exposure to toxic substances: People involved during the production/construction and end-of-life stage may be exposed to (local) toxic emissions. Local impacts due to direct exposure to toxic substances are not considered by the currently available LCIA models and are

[6] Different publications of the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) and the US Environmental Protection Agency (EPA); Wong et al., 2012; Chiu et al., 2013 ; Naujokas et al., 2013; Currie et al., 2014; Rengarajan et al., 2015; etc. [30], [31]

[7] disease characterized by reduced blood supply to the heart

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therefore not taken into account in this technical report. This does not imply any minimization of the importance of direct exposure of toxic substances.

— exposure to chemical substances released to indoor air during the use phase of a building;

NOTE 2 Caution on Indoor Air Exposure: Indoor, toxic chemicals may be present as the result of the infiltration of emissions from outdoors (through openings in the building) or due to building products emitting substances to the indoor air. Building materials like paints, varnishes and resin containing products, which may release volatile organic compounds, are a well-known example that may lead to toxic effects. ([34], [36], [40]) The World Health Organization (WHO) provides recommendations on the concentration of chemicals in indoor air. [41]

As indoor air exposure due to the emissions of indoor construction products is not considered by the currently available LCIA models[8], and are therefore not taken into account in this technical report. This does not imply any minimization of the importance of indoor air quality.

Due to specific conditions related to the location (e.g. high density population) and use of the building (e.g. ventilation), leaching (outdoors) and indoor emissions are often studied though risk assessment (RA) and not through LCA. Both these aspects are the subject of standardization in CEN/TC 351 "Assessment of release of dangerous substances from construction products". Risk assessment and LCA are complementary approaches. LCA toxicology impact categories aim to compare average potential impacts from emissions, while risk assessment is used to predict the effects of substance emissions individually in the environment. It focuses on ensuring exposure limits set through policy are not exceeded at any specific time and location. One of the core differences among the two types of approaches is the way regionalization is addressed. Risk assessment integrates the characteristics of one specific local receiving environment (e.g. background concentrations) to assess the impact of the substance on this local environment, while currently available LCIA models starts to consider local specificities but on a global scale and thus typically with less resolution (due to supply chains being global with their emissions occurring all over the planet). [42] Other differences between LCA and risk assessments include that RA uses worst-case, rather than median, data in the fate and exposure modelling, as well as the consideration of safety factors as an integral part of the toxicological effects data. [5] Risk assessment is thus applied to guarantee the intrinsic safety of products, while LCA can be used to compare the potential toxic effects of the lifecycle emissions from the two product options. In recent years, there have been significant efforts to integrate indoor exposure models into the environmental models commonly applied to LCA. [43] Indoor air exposure is outside the scope of this TR. Nevertheless, the indirect health impact caused by these emissions are included in the scope.

4.2.2.3 Relevance for construction products (step 2b)

Toxic effects associated with the life cycle of a construction product may be encountered:

— before manufacture of the construction product/extraction of raw materials;

For example; before manufacture, the raw materials needed for the production of some construction materials may involve mining, which could result in wastes containing harmful substances (e.g. heavy metals) which could contaminate soil and water.

— during manufacture of the construction product;

during manufacture it is possible that direct emissions of toxic substances may occur.

[8] In the final drafting stage of this Technical Report, USEtox v.2.0 was launched. As presented by the developers on the LCM Conference in Bordeaux on the 31st of August 2015, indoor air exposure is taken into account. However closer investigation is needed, especially how the modelling is done.

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— during its installation in a building;

— during its use phase;

in use emissions may occur as referred to in Subclause 4.2.2.2.

— waste disposal and recycling;

during the end of life treatment, emissions may occur.

Energy is needed during the different life cycle phases and may have associated toxic emissions. For example, when energy is derived from fossil fuels such as coal and lignite, the spoil generated during mining may contain harmful substances, such as heavy metals and arsenic, which can contaminate soil and water. Furthermore, all transport steps may contribute to toxicity, for example by the emission of trace elements in fuel and chemicals released due to abrasion of tyres and brake pads. [35]

Figure 6 shows the contribution of some typical construction materials and a transportation process to different impact categories concerning human health: particulate matter, photochemical ozone creation, human toxicity including cancer and non-cancer effects, ionizing radiation and ozone layer depletion. The cancer and non-cancer toxicological effects have a very high contribution to the potential damage to human health, expressed in Disability Adjusted Life Years (DALY, i.e. one lost year of "healthy" life).

However, the results of short- and long-term carcinogens and short-term non-carcinogens (i.e. human toxicity) should be carefully interpreted, as this impact category has an uncertainty of at least 2 to 3 orders of magnitude.

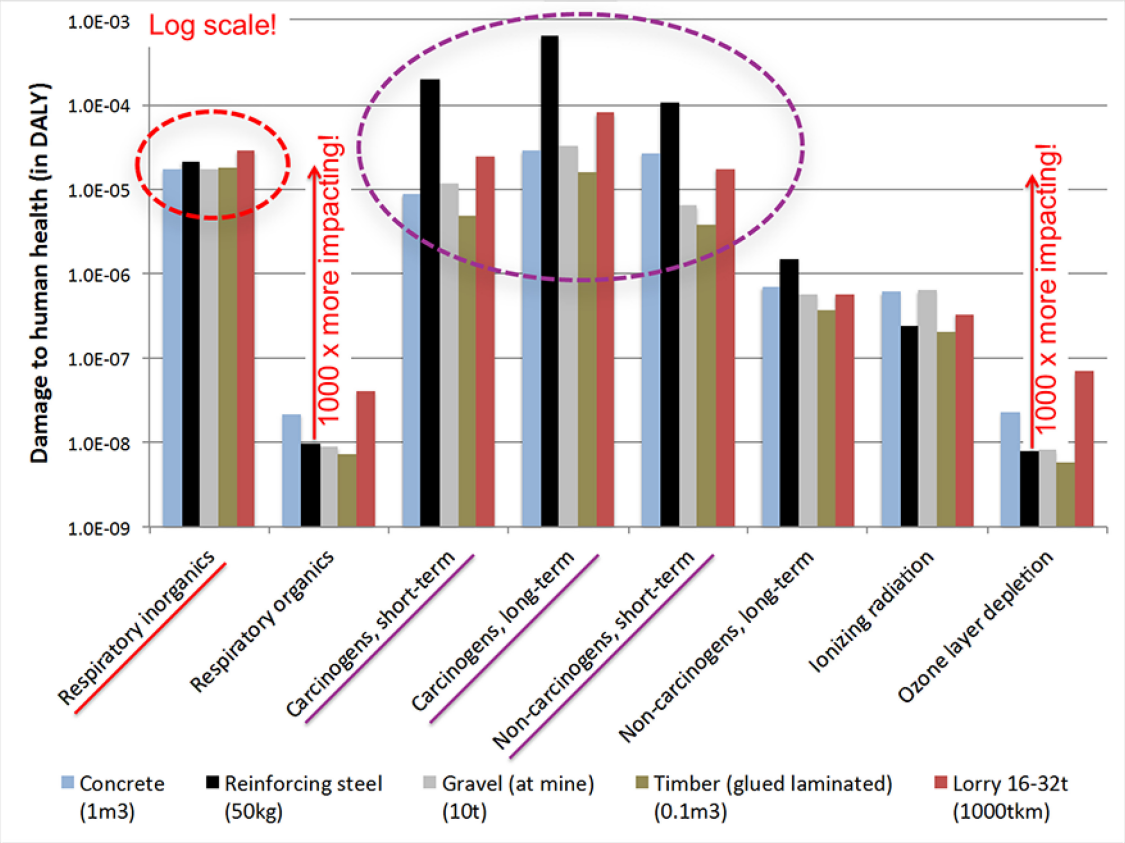


Figure 6 — Comparative damage to human health assessment of 8 impact categories, expressed in DALY in a log scale, adapted from Humbert (2014) [44]

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NOTE 1 The purpose of Figure 6 is to compare the different impact categories and their contribution to human health damage; it is NOT intended as an illustration of a comparison between the different building materials and transport processes.

NOTE 2 This TR does not consider the intrinsic toxicity of individual products.

4.2.2.4 Policy relevance (step 3)

European Union:

— The basic requirements for construction works in the framework of the Construction Products Regulation Basic Requirement for Construction Works 3 (BWR3) states "*The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, on the environmental quality or on the climate during their construction, use and demolition,...*" [45]; this demonstrates the growing importance of toxicity. Whereas in its predecessor, the Construction Products Directive [46], it was mainly local impacts during the use phase that were considered as most relevant, in the CPR global impacts over the life cycle are considered.

NOTE It is the responsibility of member states to determine the health and safety requirements under their national regulations.

— The European Commission has a department working on limiting the exposure of endocrine disrupters through the environment, for both men and nature.

— The Seventh Environment Action Programme (7EAP) aims to achieve levels of air quality that do not result in unacceptable impacts on, and risks to, human health and the environment. The EU acts at many levels to reduce exposure to air pollution: through legislation, through co-operation with sectors responsible for air pollution, through national, regional authorities and non-government organizations and through research. EU policies aim to reduce exposure to air pollution by reducing emissions and setting limits and target values for air quality.

— The 2005 Thematic Strategy on Air Pollution underpins the European Union's air pollution policy. It sets out ambitious but cost-effective objectives and measures for European air quality policy to 2020.

— At a Member State level, the existing National Emission Ceilings Directive (NEC Directive) imposes emission ceilings (or limits) for emissions of four key air pollutants (nitrogen oxides, sulphur dioxide, non-methane volatile organic compounds and ammonia) that harm human health and the environment.

— Other key EU legislation is targeted at reducing emissions of air pollutants from specific sources, for example: transport; stationary sources / industrial facilities; and paints and vehicle refinishing.

— New requirements with regard to the reporting and exchange of air quality information apply as from 1 January 2014, following the approval in 2011 of a Commission Decision on the reciprocal exchange of information and reporting.

— Regarding water quality the European Environmental Agency have stated:

We need clean, usable water every day: to drink, bathe in, cook, and produce many goods and services. Protecting water resources — and ensuring their ecological quality — is a cornerstone of EU environmental policy. Introduced in 2000, the Water Framework Directive (WFD) (2000/60/EC) was the first directive to take an integrated, 'ecosystem-based approach' to this task: protecting water ecosystems equally in terms of water quality, water quantity, and their role as habitats.

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However, it is likely that almost half of Europe's water bodies will miss the WFD target and still be in poor ecological status in 2015 (EEA report 08/2012). This is due to several causes.

Protecting Europe's common water resources and ecosystems from pollution, over-abstraction and structural changes requires concerted action at EU level.

— The WFD provides a framework for water protection and management in the European Community (Directive 2000/60/EC). Under its implementation, Member States shall first identify and analyse European waters, by individual river basin and district. They shall then adopt management plans and programmes of measures to protect water bodies in all European river basins. The adoption of the WFD was complemented by earlier EU water policies that are still in place, such as those concerning urban wastewater or bathing water.

— Other more specific legislation on chemicals:

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1907

International:

— The United Nations Economic Commission for Europe states that air pollution has significant impacts on our health, environment and economy. Pollutants in the air we breathe come from multiple sources, including sectors such as industry, transport and agriculture. Every day, air pollution causes respiratory and cardiovascular diseases. It also damages vulnerable ecosystems and biodiversity and leads to a decrease in agricultural crop and commercial forest yields. It is therefore paramount that we take action together - across sectors and national boundaries.

Their focus is to improve air quality on the local, national and regional levels, UNECE member States have been working successfully to gradually reduce and prevent air pollution in the region. One of the vehicles through which this has been achieved is the Convention on Long-range Transboundary Air Pollution, which was signed in 1979. Over the years, this Convention has been extended by eight protocols that identify specific measures to be taken by Parties to cut their emissions of air pollutants. Fifty-one UNECE member States are Parties to the Convention. Member States also formulate air pollution policies in the framework of the Committee on Environmental Policy (cf. the Air convention [47]).

— The issue of air pollution emissions is also being addressed by the UNECE Convention on Long-range Transboundary Air Pollution (the LRTAP Convention) and its protocols. The Gothenburg 'multi-pollutant' protocol under the LRTAP Convention contains national emission ceilings that, for the EU Member States, are either equal to or less ambitious than those in the EU NEC Directive. The Protocol was amended in 2012 to include national emission reduction commitments to be achieved in 2020 and beyond, including fine particulate matter.

— The EU's air quality directives (the 2008 Directive on Ambient Air Quality and Cleaner Air for Europe and the 2004 Directive on heavy metals and polycyclic aromatic hydrocarbons in ambient air) address air pollution under the Thematic Strategy on Air Pollution. Both describe the basic principles concerning the assessment and management of air quality and set pollutant concentrations thresholds that shall not be exceeded. In case of exceedances, authorities shall develop and implement air quality management plans.

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EU Member States:

The Netherlands are developing a policy to calculate the environmental impact of buildings based on LCA. Additional to the CEN/TC 350 indicators, in the Netherlands, human toxicity needs to be included in EPDs of construction products, the CML v2010 method shall be used for calculations. [48]

Member States shall also implement policies regarding air quality and monitor them.

4.2.2.5 Conclusion from evaluation of the relevance criteria in relation to CEN/TC 350 standards

	Environment	Building	Construction products	Policy
Relevance	**Yes**	**Yes**	**Yes**	**Yes**

Human toxicity is demonstrated to be relevant to the environment (human health), buildings and construction products, and is referenced in a wide range European, International and EU Member State polices, (directives and regulations) and other initiatives.

People involved during the production/construction/use and end-of-life stage may be exposed to (local) toxic emissions. Local impacts due to direct exposure to toxic substances are not considered by the currently available LCIA models and are therefore not taken into account in this technical report. This does not imply any minimization of the importance of direct exposure of toxic substances.

As indoor air exposure due to the emissions of indoor construction products is not considered by the currently available LCIA models, and are therefore not taken into account in this technical report. This does not imply any minimization of the importance of indoor air quality.

Based on this conclusion that the impact category human toxicity has relevance for the TC350 standards, the available LCIA methods were analysed; the results are presented in the Subclauses 4.2.3 - 4.2.7.

4.2.3 List of available LCIA methods (step 4)

The LCIA models/methods that were evaluated and a description of the effects that each method covers are given in Table 2.

Table 2 — List of available LCIA models/methods and effects each of the methods is covering, based on the ILCD Handbook (JRC, 2011)

Method	Effects covered by method
USEtox version 1.01 (midpoint)	USEtox v.1.01 includes all essential model elements in a scientifically sound way, except for metals and direct impact of pesticides (less relevant for building applications). For buildings, also the exclusion of indoor air pollutants could be a limitation. USEtox is sufficiently documented and has the largest substance coverage. Uncertainty may require further attention.
ReCiPe (mid- and end point)	ReCiPe addresses human toxicity and includes all essential model elements in a scientifically sound way, except for metals and direct application of pesticides (less relevant for building applications). General information is available, background calculations are hard to find.
IMPACT 2002+ (mid- and end point)	IMPACT2002+ addresses human toxicity and includes all essential model elements in a scientifically sound way, except for metals (less relevant for building applications). General information is available, background calculations are hard to find.
TRACI version 2.1 (midpoint)	All toxicity impact categories are directly taken from the USEtox v.1.01 method, so the same effects are covered.

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Method	Effects covered by method
EDIP2003 (midpoint)	EDIP addresses human toxicity and includes the effect part in a scientifically sound way, except for metals and direct application of pesticides. It is well documented. The fate assessment is, however, very simplified and no information is available on the uncertainties involved in the model results.
CML-IA (midpoint)	CML-IA is an update of the CML 2 baseline 2000. It is not clear which effects are covered. Although the method is available, no recent publications are found on human toxicity. Characterization factors seem to be calculated with USES-LCA 1.0, but new factors also seem to be added based on the USEtox v.1.01 model.
MEEuP (midpoint)	The method is not meant as a toxicity indicator. A set of weighting factors based on emission limit values (ELVs) in the various Ambient Air Quality Directives. There is no compliance with science-based criteria for the evaluation of human toxicity impacts. Political emission targets are used in the indicator development.
EPS2000 (end point)	Coverage limited in number of substances and impact pathways. Estimates 'Willingness to pay' (WTP) to restore changes in the safe guard subjects.

4.2.4 Scientific substantiation of available LCIA methods (step 5)

The ILCD Handbook (2011) evaluated eight LCIA methods on human toxicity. Since then, most of these methods have been updated, and a major revision of the TRACI and the CML method has taken place. Table 3 shows the methods that are available in LCA software at the moment. Table 3 shows that the overall scores of the methods are B or C, except the E for MEEuP.[49], demonstrating that the majority of the LCIA methods studied are of high to medium scientific value.

Table 3 — Overview of the evaluation of available LCIA methods/models regarding human toxicity, adapted from the ILCD Handbook ([4] 2011)

	Completeness of scope	Environmental relevance	Scientific robustness and certainty	Documentation transparency and reproducibility	Applicability	SCIENCE BASED CRITERIA OVERALL EVALUATION
USEtox version 1.01 (midpoint)	*A/B*	*B*	*B*	*A*	*A*	***B***
ReCiPe (mid- and endpoint)	*B*	*B*	*B*	*A/B*	*A/B*	***B***
IMPACT 2002+ (mid- and endpoint)	*A*	*B*	*B*	*A/B*	*A/B*	***B***
TRACI version	*A/B*	*B*	*B*	*A*	*A*	***B***

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	Completeness of scope	Environmental relevance	Scientific robustness and certainty	Documentation transparency and reproducibility	Applicability	SCIENCE BASED CRITERIA OVERALL EVALUATION
2.1 [9] **(midpoint)**						
EDIP2003 (midpoint)	*B/C*	*C*	*C*	*A*	*B*	***C***
CML-IA [10] **(midpoint)**	*A/B*	*B?*	*B?*	*C*	*A/B?*	***C***
MEEuP (midpoint)	*E*	*D/E*	not further evaluated	not further evaluated	not further evaluated	***E***
EPS2000 (endpoint)	*C*	*D*	*C*	*B*	*C*	***C***

Several exposure conditions are not considered by most LCIA models:

— residues of pesticides in food;

— indoor air pollution;

— dermal exposure;

— direct exposure to a substance for the factory / construction / demolition worker and building user.

According to Birkved appropriate models to quantify chemical emissions and impacts are available for the following phases related to the building (product) life cycle[11]:

— extraction of raw materials;

— production of material;

— waste disposal and recycling.

Further development of inventory approaches and impact assessment methods on toxicity will lead to coverage of more chemical emissions. As many of the chemicals that are not covered yet are biologically active chemicals, their future inclusion is likely to enable further differentiation between the toxicological impact categories and other (more conventional) impact categories and hence provide additional support to decision-making.

[9] All toxicity impact categories of the new TRACI method are directly taken from the USEtox v.1.01 method (instead of CalTOX), therefore the same scores are given to both methods.

[10] CML-IA is an update of the CML 2 baseline 2000, released in April 2013. No publications on the update of human toxicity were found; therefore a score "C" is given on documentation, transparency and reproducibility.

[11] CEN/TC 350 workshop on additional environmental indicators, 24 & 25 June 2014, Brussels, Belgium.

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NOTE There have been recent developments in toxicity related methods:

a) USEtox v.2.0 (based on the official launch of USEtox v.2.0, presented on 31st of August 2015, at the LCM conference in Bordeaux)[12]:

   1) includes characterization of impacts from indoor air exposure;

   2) modelling of ionizing organic substances is improved by adding environmental fate factors;

   3) regionalized values at continental and sub-continental scale have been added;

   4) modelling of pesticide exposure via food is possible;

   5) calculations on end point level in DALY have been made possible;[13]

   6) 400–500 new substances are currently been reviewed and will be added shortly;

b) IMPACT World+ (BETA version available, final version about to be released):

   1) joint major update to IMPACT 2002+, EDIP, and LUCAS;

   2) no detailed information on human toxicity methods available yet;

c) LC-Impact (toxicity impacts will become available in 2015):

   1) new dynamic plant uptake model for pesticides applied to food crops.

It was not possible to evaluate these updates to methods prior to the publication of this report.

4.2.5 Applicability (step 6)

4.2.5.1 General

The ILCD Handbook (2011) recommends using USEtox v.1.01 as default midpoint LCIA method for human toxicity for as well cancer as non-cancer effects. The Joint Research Centre (JRC) recommends the separate characterization of cancer and non-cancer effects. The USEtox model is the result of a joint initiative between UNEP and SETAC and has been adopted by the LCA community and several national and international organizations. It provides characterization factors for human toxicity (and ecotoxicity) applicable on a worldwide basis and for a large number of substances. This model is the result of several years of collaborative work between LCA and Risk Assessment experts. It constitutes a consensus model to compare chemical pressure on ecosystem and on humans. USEtox is thus not a scientific state-of-the-art model, but a stable interface between the most advanced science in the field and the day-to-day application in LCA practice. Once a modelling practice has reached scientific consensus, it will be validated and integrated in USEtox (updates are foreseen every 2-5 years for model

[12] Due to time limitations the listed developments were not checked and are only based on presented information by the developers.

[13] The endpoint level has been introduced in order to be able to compare impacts of carcinogenic and non-carcinogenic toxicity. At midpoint level these two types of human toxicity impacts have different units, i.e. CTUh-cancer and CTUh non-cancer respectively.

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and databases). Characterization factors cover 1031 substances for cancer effect and 437 for non-cancer[14].

At the endpoint level, PROSUITE [50] (recommends the use of LC-IMPACT PSHT for health impacts of pesticides applied to food crops; however, this is less important for the built environment.

The "Apeldoorn declaration" [51] and the "Leuven Workshop", in which the shortcomings related to metals of the currently available ecotoxicity-based LCIA methods were discussed, is also relevant for human toxicity. It is further described in paragraph 4.3.5 of the impact category ecotoxicity.

Whether indoor exposure should be taken into in LCA account is still a point of discussion. According to Hellweg et al. [43], indoor exposure should be considered within LCA as the intake per unit of indoor emission may be several orders of magnitude higher than for outdoor emissions. The reasons for this are that indoor emissions are diluted in smaller volumes of air and that people spend a lot of time indoors. The authors develop a general methodological framework that allows for the assessment of indoor emissions and human exposure in combination with commonly used outdoor fate and exposure models in LCA. The indoor exposure model is nested into the USEtox model, and is included in the new USEtox version 2.0[15]. The importance of the impact of indoor emissions in LCA is confirmed by other authors, such as Collinge et al. [52] In their case study concerning a green university building, building-specific indoor cancer toxicity impacts were greater than external impacts by an order of magnitude, although this was not the case for non-cancer toxicity impacts and respiratory effects. Also Skaar and Jørgensen [53] indicate that the impact on human health from indoor emissions can be of significance, when compared to the impact on human health from total outdoor emissions. The authors develop a method that, based on a set of measured emission rates, calculates the impact on human health during the use stage of products that are used indoors and that emit volatile organic compounds (VOCs).They recommend that when performing an LCA of products that emit VOCs, the indoor use stage is included in the life cycle impact assessment. In recent years, there have been significant efforts to integrate indoor exposure models into the environmental models commonly applied to LCA. [43] Therefore, indoor air quality has been included in this TR to the extent it has been considered by LCIA methods, although it is the subject of standardization in CEN/TC 351.

4.2.5.2 Applicability: Data availability (LCI quality, characterization factors)

Life cycle inventory:

Concern exists on the availability and quality of LCI data (both foreground and background) in view of the ambitions of the toxicity impact assessment methods. One example is that the airborne emissions that are measured in a specific country or region depend on national legislation. At the moment, the focus is on "traditional" air pollutants; this includes also "sum parameters" like TVOC and PAH which are not useful for the assessment of toxicity. In order to obtain comparable results, all toxic emissions relevant to the process and the selected method need to be included. It also needs to be checked whether the toxic emissions in the background data are of acceptable quality compared to the requirements of the LCIA method. Further improvements on LCI data availability and quality are thus needed in order to be able to assess toxicity in a robust way.

It may be difficult to collect data on toxic emissions taking place during the construction and use phase, e.g. related to the use of solvents or other chemical products, as specific data may not be readily available (relevant information on safety datasheets can be very limited).

[14] Executive summary of 'Current and future implementability of USEtox' PEF meeting, Modeling Human and Ecosystem Exposure and Impacts for Life Cycle Assessment: The USEtox Model: by Professor M. Hauschild (MH), on behalf of the USEtox team.

[15] based on presentation of the launch of USEtox 2.0 at the LCM Conference in Bordeaux and further communication with the developers. See also http://www.usetox.org/forum/other-questions/indoor-air-model

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Characterization factors:

USEtox v.1.01 characterization factors are widely available and can be easily applied.

In the USEtox v.1.01 method, a distinction is made between recommended and interim characterization factors, reflecting the level of reliability of the calculations. Characterization factors for 'metals', 'dissociating substances' and 'amphiphilics' (e.g. detergents) were all classified by USEtox as interim due to the relatively high uncertainty of addressing fate and human exposure for all chemicals within these substance groups. These factors have been classified as level III "recommended, but to be applied with caution" by ICLD. The other included chemicals have been classification as level II "recommended but in need of some improvements" by ILCD. The USEtox team advises to use the interim USEtox characterization factors always together with the recommended factors, as otherwise the substances concerned would be characterized with zero impact as no characterization factor is applied to their emissions. In this document, the recommended and interim characterization factors are both considered.

According to Professor M. Hauschild USEtox should be used to identify the 10-20 chemicals out of thousand present in a life cycle inventory that may require further investigation[16]. In the workshop on Environmental and Human Toxicity of metals in LCA [42], it has been proposed to compare the relative values of human health results in log normal between substances to account for the typically two to three orders of magnitude uncertainty compared to 12 orders of magnitude variations between substances.

NOTE The precision of the characterization factors of USEtox v.1.01 was estimated to be within a factor of 100–1 000 for human health. This uncertainty range is due to variation between the models and does not include parameter uncertainties attached to the input data. Although it seems high, such a precision of two to three orders of magnitude is significantly lower than the roughly 12 orders of magnitude variation between the characterization factors of the different chemicals. These aspects need to be taken into account when interpreting the human toxicity results of an assessment. [54]

Human toxicity characterization factors on many chemicals are missing. The (further) use of risk assessment data may help to fill in data gaps. According to Pennington et al. [27], characterization factors in LCA should reflect the risk integrated over time and space that is associated with the release of a quantity of chemical into the environment. While LCA intends to consider the cumulative risk, regulatory approaches focus more on peak exposures compared to acceptable thresholds. Nevertheless, Pennington et al. [26] demonstrate that regulatory-based hazard equivalents can provide a useful basis for indicators in LCA, although uncertainties can be high, especially for non-cancer human health effects.

4.2.5.3 Applicability: Experience

The USEtox v1.01 method has been available since 2010 and is integrated in several LCA tools. The number of papers on LCA studies applying USEtox is growing each year.

[16] Executive summary of 'Current and future implementability of USEtox' PEF meeting, Modeling Human and Ecosystem Exposure and Impacts for Life Cycle Assessment: The USEtox Model: by Professor M. Hauschild (MH), on behalf of the USEtox team.

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4.2.5.4 Applicability: availability within widely used tools

	Simapro	Gabi	openlca
USEtox version 1.01	✓	✓	✓
ReCiPe	✓	✓	✓
IMPACT 2002+	✓	✓	✓
TRACI version 2.1	✓	✓	✓
EDIP2003	✓	✓	✓
CML-IA	✓	✓	✓
MEEuP	0	0	0
EPS2000	✓	0	✓

There are still some issues being tackled by the developers of the tools, such as the harmonization of the nomenclature of the toxic emissions, the inclusion of regionalized values at smaller scale etc.

4.2.6 Stakeholder acceptance (step 7)

USEtox is based on scientific consensus; however, not all stakeholders agree it is ready for implementation. In the context of the Product Environmental Footprint (PEF) pilots, a meeting to discuss the current and future implementability of USEtox v.1.01 method took place on 15 January 2015. The main conclusions from this meeting were [25]:

— The experience of using the USEtox model by PEF pilots present in the meeting was rather negative. The model was not criticized as such but the input/output data were seen as doubtful.

— The underlying data (physico-chemical and toxicity) seems to be a source for significant differences, controversies and criticisms. For many substances, especially fate and effect data may not be suitable as currently used in USEtox.

— The most contributing chemicals identified by USEtox as pressure indicator in LCA are not necessarily the ones known for having the highest actual impact on the environment from other tools, e.g. ERA (Environmental Risk Assessment) or based on CLP (Classification, Labelling and Packaging of substances and mixtures (European Regulation (EC) No 1272/2008)).

— Lack of transparency regarding input data as well as complexity of using the model to calculate new Characterization Factors were seen as a limitation for use especially by SMEs.

— Most pilots recommended not using the model, especially not for comparisons and benchmarking, before an agreement is reached on the selection of input data.

— For metals, the result of the UNEP-SETAC and Metal industry workshop shall be implemented before characterization factors are calculated and used for PEF. Furthermore, the concept of "essentiality of metals" was pointed out as an important modelling issue/gap to be addressed.

— Alignment between data used to run USEtox and data used for risk assessment purpose should be achieved. Using REACH data only may be a way forward.

— Work needs to be undertaken to address the issues of input data (all physico-chemical and toxicity data shall be verified and validated or come from a source used for regulatory purposes like REACH) as well as some important modelling specificities for metals.

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— Results of metals and other chemicals could be separately reported, as the level of robustness of the assessment is different and, in many case, metals are driving the overall impact

— In the context of the current activity of the PEF, USEtox shall still be used for the screening and supportive studies, but it may not be used for benchmarking and communication purposes, until the outcome is more robust.

4.2.7 Conclusions on methodology

4.2.7.1 Strengths

Both the ILCD Handbook and PROSUITE recommend the use of LCIA to describe human toxicity impacts, and indicate that USEtox is the preferred method for this purpose. The USEtox v1.01 method includes all vital model elements in a scientifically sound way, except for metals and direct impact of pesticides. It is sufficiently documented and has the largest substance coverage of all methods evaluated (i.e. more than 1250 human toxicological characterization factors).

The USEtox method was composed through an international model comparison/consensus process, in order to cope with the large variations in available methods.

The USEtox method reflects the latest consensus amongst LCIA modellers and is being updated regularly.

NOTE The USEtox method is being updated in order to take into account characterization of impacts from indoor air pollutants, improve the model for metals and ionizing organics, pesticide exposure via food and regionalized values at continental and sub-continental scale. A new version, USEtox v.2.0, was released 31 August 2015. The advances in the characterization modelling of metals regarding Human Toxicity in the new version of USEtox relative to the Apeldoorn recommendations are summarized in Table 4.

Table 4 — Advances in the characterization modelling of metals in USEtox ("-" = not considered, "✓" = considered, "%" = partially considered, "+" = research needed "n.a." = not applicable) [42]

Recommendations from Apeldoorn declaration (2004)	**USEtox v.1.01 (2008) = Status at WS**	**USEtox v.2.0 (2015) = Expectations at WS 2014[a]**	**USEtox v.2.0 (2015) = Release August 2015[b]**
	Human toxicity	Human toxicity	Human toxicity
Speciation determines bioavailability and toxicity and is a highly desirable extension of LCIA, both in fate and effect modelling	-	-	%
Persistence Infinite time horizons in steady state effect models could only be appropriate if bio- availability is properly considered	-	100 years horizon also available	100 years horizon is **NOT yet** available
Essentiality Within the essentiality window of essential metals the LCA general principle of "less is better" does not apply and the possibility of adverse biological effects should be set at zero	**+**	**+**	**+**

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Recommendations from Apeldoorn declaration (2004)	USEtox v.1.01 (2008) = Status at WS	USEtox v.2.0 (2015) = Expectations at WS 2014[a]	USEtox v.2.0 (2015) = Release August 2015[b]
	Human toxicity	Human toxicity	Human toxicity
Bioavailability The Biotic Ligand Model (BLM) should be used preferentially, with the Free-Ion Activity Model (FIAM) used in cases where the BLM has not been fully developed.	n.a.	n.a.	%
Characterization The characterization factor should be chosen at the HC50 (geometric mean of EC50) level rather than the HC5 or the NOEC level.	n.a.	n.a.	n.a.
Compartments in the multimedia model If effects are negligible in a given compartment, there is no need to consider effects. This may well be the case for essential metals in the ocean.	✓	✓	✓
Spatial aspects The consequences of regional differences in bioavailability, background concentrations, and therefore toxicity need to be further elaborated	%	%	%

[a] Based on expectations at Brussels workshop 2014, before future release.

[b] Based on the presentation of launch USEtox v.2.0 and communication with developers at the LCM Conference in Bordeaux (on August 31st). Due to time limitations the listed developments were not checked.

4.2.7.2 Weaknesses

Some features of the USEtox v.1.01 method for human toxicity still need to be improved:

— spatial variability needs to increase;

— modelling of the impact of metals and ionizing organics;

— pesticide exposure via food is missing;

— more chemicals need to be included.

For all methods, including USEtox v.1.01, supplementary life cycle inventory data is needed, especially for metals and inorganic substances. Furthermore, the methods need to be improved in order to take into account speciation and bioavailability of metals and make the methods applicable and relevant for all substances emitted.

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It needs to be taken into account that the uncertainty related to human toxicity impact calculation is large. Therefore, when declaring toxicity, the uncertainty and completeness of the used data needs to be considered and should be documented transparently.

4.2.8 Overall conclusions on human toxicity

1) Human toxicity is found to be relevant both at building and at product level and is part of EU and international policies.

2) Human toxicity is found to be relevant for the environment.

3) The USEtox model seems to be the preferred indicator for human toxicity, as it is a consensus model that is updated regularly.

4) Concern exists on the availability and quality of LCI data (both foreground and background) in view of the ambitions of the toxicity impact assessment methods. Further improvements on LCI data availability and quality are needed in order to be able to assess toxicity in a robust way.

5) There remain concerns raised by stakeholders (**4.2.6**) over the application of the method to certain product groups, particularly metals and other inorganic materials. Some of these concerns may be partially addressed by recent updates to the USEtox method; the evaluation of these updates has not been possible for this report.

6) Toxicity assessment of construction products using current methodologies should not be communicated without interpretation due to inherent uncertainties. EN 15804 does not supply any standardized method for interpretation of LCIA results.

4.3 Ecotoxicity: Terrestrial, freshwater and marine

4.3.1 Description of impact category

4.3.1.1 General

The impact category “ecotoxicity” addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms, caused by the release of substances with a direct effect on the health of the ecosystem. [6]

4.3.1.2 Mechanisms

Morten Birkved[17] (DTU), in his presentation at the CEN/TC 350 workshop on additional indicators[18], described how a number of chemical substances are capable of inducing toxicological effects in different organisms. An emission of one of these chemicals sets off a chain reaction, starting with an increase of the concentration of the chemical in the environment. This is followed by an uptake/intake by organisms causing an interaction between biological receptors and the chemical. This chain of events may lead to changed behaviour, hereditary effects, reduced growth, reduced reproduction rate and death. This damage on individual level may cause the disappearance of species from the ecosystem. The environmental mechanism for ecotoxicity, including fate, exposure and effect is shown in Figure 7.

[17] Associate professor Morten Birkved, Section of Quantitative Sustainability Assessment (QSA), Department of Management Engineering, Technical University of Denmark

[18] CEN/TC 350 workshop on additional environmental indicators, 24 & 25 June 2014, Brussels, Belgium

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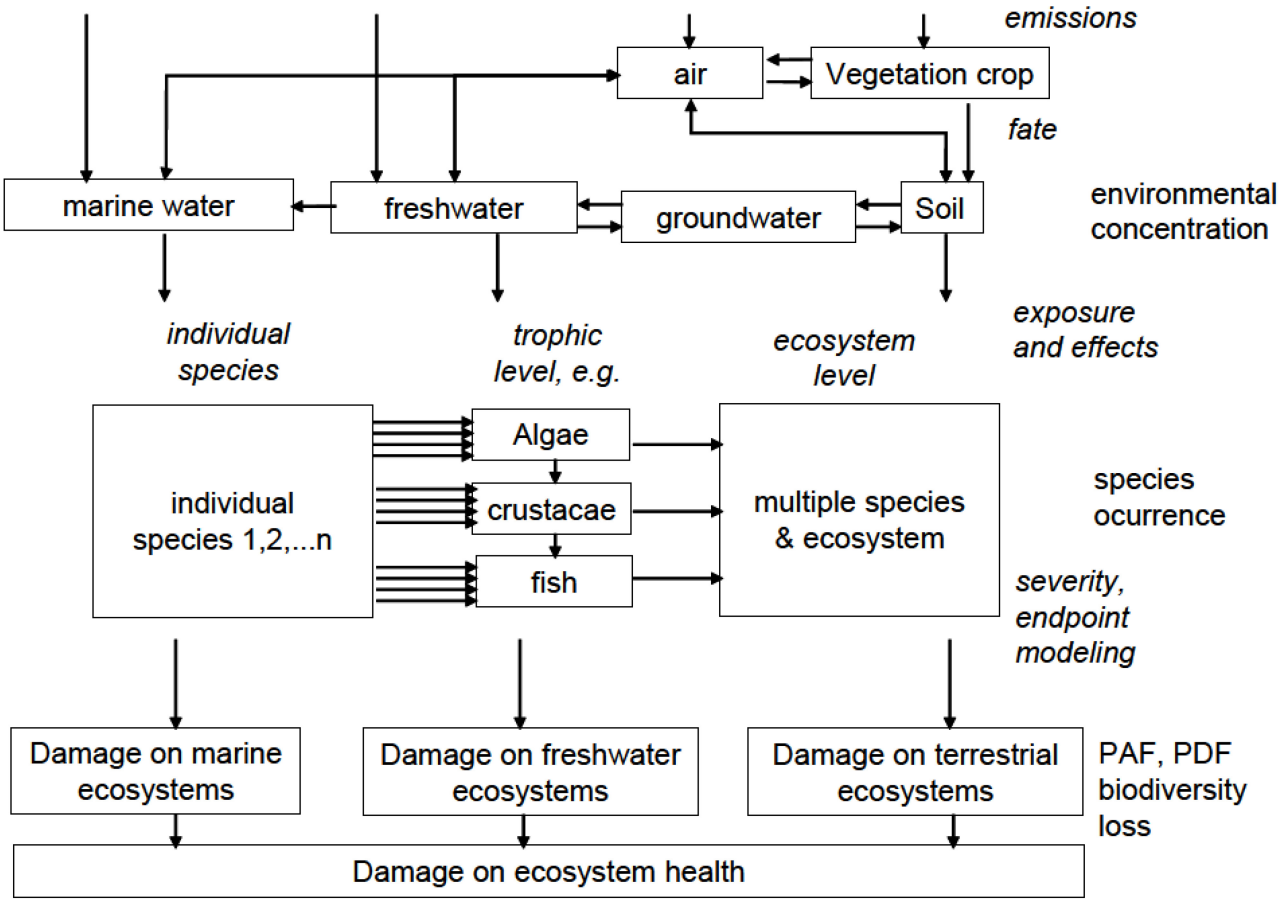


Figure 7 — Cause-effect chain for ecotoxicity effects [5]

4.3.1.3 Quality of ecosystems

The characterization factors of ecotoxicity account for the environmental persistence (fate), species exposure of a unit mass of chemical released into the environment), and toxicological response (likelihood of effects and severity) of a chemical. Ecotoxicity covers a number of effects such as acute and chronic toxicity on different species in soil (i.e. terrestrial ecotoxicity) and water (i.e. freshwater and marine ecotoxicity). The area of protection is the natural environment, i.e. species diversity (and not on the damage to ecosystem services).

The ILCD handbook compares different frameworks for calculating characterization factors (CF) for ecotoxicity effects in LCA and concludes that the model for ecotoxicity shall account for the environmental persistence/ fate (F) and ecotoxicity/ effect (E) of a chemical:

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

in which:

- $CF_{j,i,x}$: is the ecotoxicological characterization factor of chemical x emitted to compartment i and transported to environment j;

- $F_{j,i,x}$: is the fate factor relates the emission flow to the change in mass in the environment and can be calculated by means of fate and exposure models. The fate factor accounts for bioaccumulation/magnification;

- $E_{j,x}$: is the effect factor E can be derived from toxicity data based on laboratory experiments.

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In the ecotoxicity methods, different emission compartments are distinguished, such as urban and rural air, freshwater and sea water, and agricultural and industrial soils. Equally, different endpoints are considered, representing the terrestrial, freshwater and marine environments for example.

The framework for calculating characterization factors for ecotoxicity effects is shown in Figure 8.

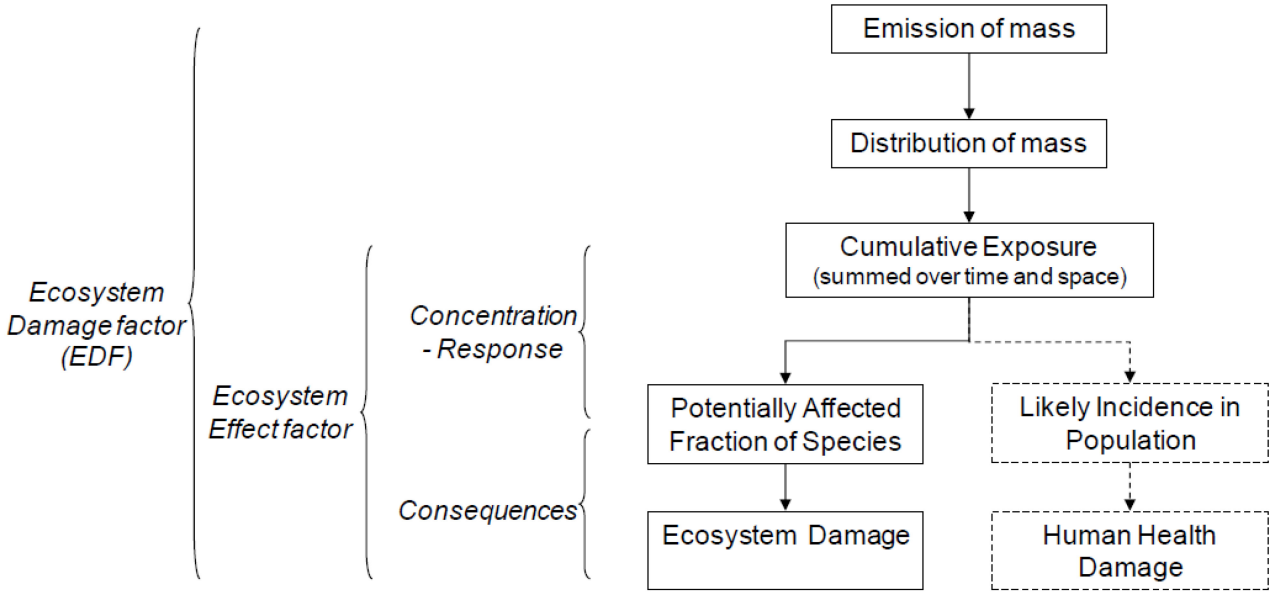


Figure 8 — Recommended framework for calculating characterization factors for ecotoxicity effects in LCA ([5], based on [27] and [28])

The models used to characterize toxic impacts vary substantially in their scope, modelling principles, and in terms of the resulting characterization factors. Furthermore, the number of substances included is limited and, therefore (among other reasons), many LCA practitioners exclude the toxicity-related impacts from their LCIA. Table 5 gives an overview of the most important factors that influence the performance of different models. A distinction is made between factors related to choice of parameter value and choice of algorithm. [29]

Table 5 — Factors causing the different performance of the characterization models [29]

Model component	Key factor	Parameter value (P) or algorithm choice (A)
Fate	Advection as a loss mechanism in some models	A
	Inclusion of the intermittent character of rain	A
	Residence times of media, particularly marine water, differ greatly	P
	Different algorithms used for estimation of partition coefficients	A
	Modelling of soil compartment: (i) homogeneous versus vertically layered soil compartment and (ii) generic versus division between agricultural, industrial and natural soils	A

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Exposure	Different algorithms used for estimation of bio-transfer and bio-concentration factors	A
Ecosystem effects	Models use different effect indicators (PNEC, HC50)	P
	Ocean modelled as a sink only (no effects considered)	A
	Some models use acute ecotoxicity indicator	P

Work is ongoing to solve some of the problems related to the toxicity impact indicators, such as the modelling of metal toxicity, spatial differentiation and inclusion of a larger number of substances. For example, the new version of the USEtox method (v.2.0), which is released in August 2015, will contain an improved model for metals and ionizing organics and regionalized values at continental and sub-continental scale.

4.3.2 Relevance of ecotoxicity – standardization (step 1+2+3)

4.3.2.1 Environmental relevance (step 1)

Several studies highlight the impact of toxic substances on several types of ecosystems. An example is the report "European waters - assessment of status and pressures" [56], which indicates that the continuing presence of a range of pollutants in some of Europe's waters threatens aquatic ecosystems. These pollutants arise from a range of sources including agriculture (e.g. pesticides), industry (e.g. heavy metals and some industrial chemicals), households (e.g. pharmaceuticals and cleaning agents) and the transport sector. In parts of Europe, mining (including abandoned mines) exerts a localized but significant pressure upon the chemical and ecological quality of water, particularly with respect to the discharge of heavy metals. Once released into freshwater, pollutants can be transported downstream and ultimately be discharged to coastal waters, together with direct discharges from cities, industrial discharges and atmospheric deposition polluting coastal waters. Also shipping, harbour and port activities, offshore oil exploration and aquaculture emit a variety of pollutants. All these factors contribute to the "less than good" ecological status of more than half of the surface water bodies in Europe, they will need mitigation and/or restoration measures to meet the Water Framework Directive objective. [57]

4.3.2.2 Relevance for buildings (step 2a)

Ecotoxical effects associated with the life cycle of a construction product may be encountered:

— before manufacture of the construction product/extraction of raw materials;

  For example; before manufacture, the raw materials needed for the production of some construction materials may involve mining, which could result in wastes containing harmful substances (e.g. heavy metals) which could contaminate soil and water.

— during manufacture of the construction product;

  during manufacture it is possible that direct emissions of toxic substances may occur.

— during its installation in a building and during its use phase;

  in use emissions may occur as referred to in 4.2.2.2.

— waste disposal and recycling;

  during the end of life treatment, emissions may occur.

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Some examples of potential toxicity related to buildings are the leaching of components of impregnating agents (e.g. creosote or salts) from treated wood [34] and of metals (e.g. copper and lead) from metal outdoor building products [35]. Ecosystems may be exposed to outdoor toxic emissions through contaminated water or soil.

Energy is needed during the different life cycle phases and may have associated toxic emissions. For example, when energy is derived from fossil fuels such as coal and lignite, the spoil generated during mining may contain harmful substances, such as heavy metals and arsenic, which can contaminate soil and water. Furthermore, all transport steps may contribute to toxicity, for example by the emission of trace elements in fuel and chemicals released due to abrasion of tyres and brake pads. [35]

4.3.2.3 Relevance for construction products (step 2b)

Same as for human toxicity (see Subclause 4.2.2.3).

4.3.2.4 Policy relevance (step 3)

EU and international:

The European and international regulations, polices and initiatives that are relevant to the impact category Human Toxicity (see Subclause 4.2.2.4) are also relevant for the impact category ecotoxicity.

In addition:

— In the EU Ecolabel model, the freshwater ecotoxicological impact of a chemical *i* is represented by the Critical Dilution Volume (CDV). The CDV [L/g] is the volume of water necessary to dilute a chemical to a safe concentration and is calculated as the ration of a degradability factor (DF) and an ecotoxicity factor (TF) [39]. The EU Ecolabel detergent ingredient database (DID-list) is used as main data source. The DID-list is a reference list, which contains agreed and verified fate and ecotoxicity data for a group of toxic substances. [38]

EU Member States:

According to the French law the declaration of an LCA is mandatory for construction products with an environmental claim on the packaging. The LCA shall be in line with EN 15804, yet a national supplement to EN 15804 has been published in which specifications on the calculation of air and water ecotoxicity impacts for EPDs of construction products are given. It contains requirements related to water pollution and air pollution environmental impact assessment, based on the calculation of CDV. Although the USEtox model has a larger scope – i.e. also the soil and air compartments are included – the use of CDV is preferred to USEtox within the French supplement of EN 15804 due to consistency reasons related to the well-established EU Ecolabel and the French national standard NF P01-010 [37], published for the first time in 2000, when USEtox was not available yet. Furthermore, based on a comparative assessment 69 chemicals common in USEtox v 1.01 and CDV models, Saouter et al. [38] conclude that there is a significant number of chemicals ranked differently. According to Saouter et al. [38] the main reasons lays in the different sources of physico-chemical, fate and ecotoxicity data within the two model databases and the different way they are used for the ranking parameter calculation. The CDV model is criticized, because this method is based on threshold defined on BAT within the framework of the IPPC directive.

See also 4.2.2.4 (EU Member States).

4.3.2.5 Conclusion from evaluation of the relevance criteria in relation to CEN/TC 350 standards

	Environment	Building	Construction products	Policy
Relevance	**Yes**	**Yes**	**Yes**	**Yes**

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The impact category Ecotoxicity is demonstrated to be relevant to the environment, construction works and construction products, and is referenced in a wide range European, International and EU Member State polices, (directives and regulations) and other initiatives.

Based on this conclusion that the impact category ecotoxicity has relevance for the CEN/TC 350 standards, the available LCIA methods were analysed; the results are presented in the Sublauses 4.3.3 - 4.3.7.

4.3.3 List of available LCIA methods (step 4)

The LCIA models/methods that were evaluated and a description of the effects that each method covers are given in Table 6.

Table 6 — List of available LCIA models/methods and effects each of the methods is covering, based on the ILCD Handbook [4]

Method	Effects covered by method
USEtox version 1.01 (midpoint)	For the freshwater environment, USEtox v.1.01 includes all essential model elements in a scientifically sound way, except for metals. Marine and terrestrial ecotoxicity are excluded. USEtox is sufficiently documented. Uncertainty may require further attention.
ReCiPe (midpoint)	ReCiPe addresses the freshwater, marine and terrestrial environments, and includes all essential model elements in a scientifically sound way, except for metals. General information is available, background calculations are hard to find.
IMPACT 2002+ (midpoint)	The model addresses the freshwater, marine and terrestrial environments, and includes all essential model elements in a scientifically sound way, except for metals. General information is available, background calculations are hard to find.
TRACI version 2.1 (midpoint)	All toxicity impact categories are directly taken from the USEtox v.1.01 method, so the same effects are covered.
EDIP2003 (midpoint)	EDIP addresses the freshwater and terrestrial environments, and includes the effect part in a scientifically sound way, except for metals. It is well documented. The fate assessment is, however, very simplified and no information is available on the uncertainties involved in the model results.
ReCiPe (endpoint)	Environmental relevance for endpoint assessment of effects on ecosystem biodiversity is rather low. Principles of the model are relatively easy to understand, but the endpoint part of the model is not endorsed by an authoritative body.
IMPACT 2002+ (endpoint)	Environmental relevance for endpoint assessment of effects on ecosystem biodiversity is rather low. Principles of the model are relatively easy to understand, but the endpoint part of the model is not endorsed by an authoritative body.
EPS2000 (endpoint)	No compliance with science-based criteria for the evaluation of ecotoxicological impacts. Cause-effect chain of individual chemicals not included. Estimates 'Willingness to pay' (WTP) to restore changes in the safe guard subjects.
Swiss Ecoscarcity (midpoint)	No compliance with science-based criteria for the evaluation of ecotoxicological impacts. Political emission targets are used in the indicator development

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Method	Effects covered by method
MEEuP (midpoint)	The method is not meant as a toxicity indicator. A set of weighting factors is based on emission limit values (ELVs) in the various Ambient Air Quality Directives. There is no compliance with science-based criteria for the evaluation of ecotoxicity impacts. Political emission targets are used in the indicator development.

4.3.4 Scientific substantiation of available LCIA methods (step 5)

The ILCD Handbook [4] evaluated ten LCIA methods on ecotoxicity. Since its publication, most of these methods have been updated, and a major revision of the TRACI method took place. Table 7 shows the methods that are available in LCA software at the moment. Some methods that will be implemented soon are described in this subclause but not included in the analysis yet. As shown in Table 7, the scientific value of the studied methods varies from high to low (B to E). It is striking that the endpoint methods (EPS2000, ReCiPe endpoint and IMPACT2002+ endpoint) have little or no compliance with the scientific criteria.

Table 7 — Overview of the evaluation of available LCIA methods/models regarding ecotoxicity, adapted from the ILCD Handbook [4]

	Completeness of scope	Environmental relevance	Scientific robustness & certainty	Documentation transparency & reproducibility	Applicability	SCIENCE BASED CRITERIA OVERALL EVALUATION
IMPACT 2002+ (midpoint)	*A/B*	*A/B*	*B*	*A*	*A/B*	***B***
USEtox version 1.01 (midpoint)	*A*	*B/C*	*B*	*A*	*B/C*	*B*
ReCiPe (midpoint)	*A/B*	*B*	*B*	*A*	*A*	*B*
EDIP2003 (midpoint)	*A/B*	*B/C*	*C/D*	*A*	*B*	*C*
ReCiPe (endpoint)	*A/B*	*C*	*D*	*A*	*A*	*D*
IMPACT 2002+ (endpoint)	*A/B*	*C*	*E*	*A*	*A/B*	*D*
EPS2000 (endpoint)	*A*	*E*	not further evaluated	not further evaluated	not further evaluated	*E*
Swiss Ecoscarcity (midpoint)	*E*	*E*	not further evaluated	not further evaluated	not further evaluated	*E*

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	Completeness of scope	Environmental relevance	Scientific robustness & certainty	Documentation transparency & reproducibility	Applicability	SCIENCE BASED CRITERIA OVERALL EVALUATION
MEEuP (midpoint)	*E*	*E*	not further evaluated	not further evaluated	not further evaluated	*E*
TRACI version 2.1* [19] (midpoint)	*A*	*B*/*C*	*B*	*A*	*B*/*C*	*B*

According to Birkved appropriate models to quantify chemical emissions and impacts are available for the following phases related to the building (product) life cycle[20]:

— extraction of raw materials,

— production of material,

— waste disposal and recycling.

Current LCIA models/methods still do not cover every part of the use phase of a building. Toxicity impacts related to indoor and outdoor emission within a building's use phase are often excluded in characterization models due to the difficulty of determining effects at the building level.

Further development of inventory approaches and impact assessment methods on toxicity will lead to coverage of more chemical emissions. As many of the chemicals that are not covered yet are biologically active chemicals, their future inclusion is likely to enable further differentiation between the toxicological impact categories and other (more conventional) impact categories and hence provide additional support to decision-making.

NOTE There have been some recent developments of toxicity related methods:

a) USEtox v.2.0 (based on the official launch of USEtox v.2.0, presented on 31st of August 2015, at the LCM conference in Bordeaux)[21]:

   1) modelling of freshwater ecotoxicity for only cationic metals is improved;

   2) modelling of ionizing organic substances is improved by adding environmental fate factors;

   3) regionalized values at continental and sub-continental scale have been added;

   4) calculations on end point level in PAF.m^3.yr - and in PDF.m^2.yr through use of a conversion factor - have been made possible;

   5) 400–500 new substances are currently been reviewed and will be added shortly

[19] All toxicity impact categories of the new TRACI method are directly taken from the USEtox v.1.01 method (instead of CalTOX), therefore the same scores are given to both methods.

[20] CEN/TC 350 workshop on additional environmental indicators, 24 & 25 June 2014, Brussels, Belgium.

[21] Due to time limitations the listed developments were not checked and are only based on presented information by the developers.

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b) IMPACT World+ (BETA version available, final version about to be released):

   1) joint major update to IMPACT 2002+, EDIP, and LUCAS;

   2) no detailed information on human ecotoxicity methods available yet;

c) LC-Impact (toxicity impacts will become available in 2015):

   1) improved characterization of ecotoxic impacts from metals in terrestrial ecosystems;

   2) characterization factors for ecotoxicological impacts of organic chemicals on warm-blooded predators at the end of freshwater food chains.

It was not possible to evaluate these updates to methods prior to the publication of this report.

4.3.5 Applicability (step 6)

4.3.5.1 General

The ILCD Handbook and PROSUITE recommend USEtox version 1.01 for characterizing impacts related to freshwater ecotoxicity at midpoint. It is applicable to different geographical levels and is consistent with the model recommended for human toxicity (see also remarks 'human toxicity' in Subclause 0). On terrestrial and marine ecotoxicity none of methods reviewed are recommended by ILCD. The USEtox model is the result of a joint initiative between UNEP and SETAC and has been adopted by the LCA community and several national and international organizations. It provides characterization factors for ecotoxicity (and human toxicity) applicable on a worldwide basis and for a large number of substances. This model is the result of several years of collaborative work between LCA and Risk Assessment experts. It constitutes a consensus model to compare chemical pressure on ecosystem and on humans. USEtox is thus not a scientific state-of-the-art model, but a stable interface between the most advanced science in the field and the day-to-day application in LCA practice. Once a modelling practice has reached scientific consensus, it will be validated and integrated in USEtox (updates are foreseen every 2-5 years for model and databases). Characterization factors cover 2519 substances for ecotoxicity. [64]

PROSUITE [55] recommends the use of Gandhi et al. ([58], [59], [60]) and Owsianiak et al. [61] to determine characterization factors for freshwater ecotoxicity of metals and soil, in addition of USEtox for other chemicals.

In 2004, a workshop on the inclusion of state of the art expertise and current expert knowledge on risk assessment of non-ferro metals in LCIA was organized by CML and TNO. During this workshop a TNO-report [62] on LCA practice for metals was discussed. This report investigates the scientific issues encountered when developing or using characterization factors in Life Cycle Impact Assessment. Furthermore, it identifies a number of directions for improvement. A result of the workshop is the so-called "Apeldoorn declaration" [51], which briefly summarizes the shortcomings of the current LCIA methods for metals, and advises that the methods be used with caution since current ecotoxicity LCIA methods can often produce an overemphasis on the impact of metals. Methods available in 2004, therefore, should not be used for business or policy decisions regarding metals without further discussion. Agreement was reached that the following seven aspects are of major relevance for a correct understanding of the fate and toxicity of essential elements and need further elaboration [51]:

— Speciation. This feature of metals, which determines their bioavailability and toxicity, was regarded as a highly desirable extension of LCIA, both in fate and effect modelling. The present focus on total metals concentrations in LCA and LCIA could be overly conservative.

— Persistence. Although metals may remain in a certain compartment of a model or ecosystem for a long time, they are usually not present in their bio-available form, but are rather converted to other species and/or adsorbed to particulate matter (e.g. soils, sediments, suspended matter). Infinite time horizons in steady state effect models could only be appropriate if bio-availability is properly considered.

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— Essentiality. Within the essentiality window of essential metals, the possibility of adverse biological effects should be set at zero. Adverse effects may occur above or below that window. Below and within that window the LCA general principle of "less is better" does not apply.

— Bioavailability. As noted above, metals speciation determines bioavailability, which also needs to be included in LCIA. For this purpose the Biotic Ligand Model (BLM) should be used preferentially, with the Free-Ion Activity Model (FIAM) used in cases where the BLM has not been fully developed.

— Characterization. Because LCA is used for comparative rather than predictive purposes or determinations of absolute risk, it is appropriate to use robust measures of toxicity rather than the lowest measures of toxicity, which are generally interpolated rather than directly measured. On this basis, the characterization factor should be chosen at the HC_{50} (geometric mean of EC_{50}[22]) level rather than the HC5 or the NOEC level, based on the most representative, not the most sensitive species.

— Compartments in the multimedia model. A distinction should be made between compartments in the fate model (which should be as inclusive as possible) and in the effect model. If effects are negligible in a given effect compartment, there is no need to consider effects. This may well be the case for essential metals in the ocean.

— Spatial aspects. The consequences of regional differences in bioavailability, background concentrations, and therefore toxicity need to be further elaborated.

One of the suggestions of the workshop was to improve the LCIA models to provide a more meaningful result in ecotoxicity assessment by critically adopting and adapting advanced knowledge and models from risk assessment.

In 2014, a workshop on environmental and human toxicity of metals in LCA was held in Leuven [42], in which the status and appropriateness of USEtox for assessing the toxicity of metals was addressed. It was attended by more than 40 invited participants composed of metal industry experts as well as USEtox developers and users. In this workshop Delbeke and Rosenbaum indicate that, since the Apeldoorn declaration, researchers have (partially) addressed some of the above issues, proposing a way forward to improve the metal characterization factors. Speciation (partially), compartment sections, spatial aspects (partially), HC_{50}-based effect characterization and bioavailability (partially) were addressed. Some issues still require further consideration regarding their actual importance:

— Persistence: The residence time of freshwater in USEtox is <100 days and a few years in coastal water. This essentially leads to metal accumulation in the ocean compartment, which does not result in freshwater (or coastal marine water) ecotoxicity impacts attributable to the influence of the choice of time horizon. The latter is hence only of importance in the context of terrestrial and deep-ocean ecotoxicity, both not yet mature enough and thus not implemented in USEtox.

— Essentiality/Compartments in the multimedia model: While its relevance for freshwater ecosystems remains to be studied, this is important to consider for terrestrial and marine ecotoxicity (both not yet mature enough/implemented in USEtox).

A comparison between the status in 2004 (Apeldoorn) and 2014 (Leuven) can be found in Table 7.

Consideration of long-term (thousands of years) emissions and impacts from landfills and mine tailings is an ongoing discussion and research subject in the LCA community, thus the importance to differentiate effect within e.g. 100 years from longer term potential effects.

[22] EC_{50} is the half maximal effective concentration

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