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Environmental management — Life cycle impact assessment — Examples of application of ISO 14042

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TECHNICAL REPORT

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Environmental management — Life cycle impact assessment — Examples of application of ISO 14042

Management environnemental — Évaluation de l'impact du cycle de vie — Exemples d'application de l'ISO 14042

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Foreword

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In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 14047 was prepared by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*.

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Introduction

The heightened awareness of the importance of environmental protection, and the possible environmental significance of a product system[1)], has increased the interest in development of methods to better understand this significance. One of the techniques being developed for this purpose is Life Cycle Assessment (LCA).

Life cycle impact assessment (LCIA) is the third phase of life cycle assessment, and its purpose is to assess a product system's life cycle inventory analysis (LCI) results to better understand its environmental significance. It models selected environmental issues called impact categories and, through the use of category indicators which help condense and explain the LCI results, portrays the aggregate emissions or resources used for each impact category to reflect their potential environment impacts.

This Technical Report provides examples to illustrate the application of ISO 14042, *Environmental management – Life cycle assessment — Life cycle impact assessment*. It uses several examples concerning key areas of ISO 14042 in order to enhance the understanding of its requirements.

1) In this Technical Report the term “product system” also includes service systems.

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Environmental management — Life cycle impact assessment — Examples of application of ISO 14042

1 Scope

This Technical Report provides examples to illustrate current practice in carrying out a life cycle impact assessment in accordance with ISO 14042. These are only examples of the total possible “ways” to satisfy the provisions of ISO 14042. They reflect the key elements of the life cycle impact assessment (LCIA) phase of the LCA.

NOTE The examples presented in this Technical Report are not exclusive; other examples exist to illustrate the methodological issues described.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 14040:1997, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14042:2000, *Environmental management — Life cycle assessment — Life cycle impact assessment*

3 Abbreviated terms

The following is a non-exhaustive list of abbreviated terms found in this Technical Report.

ADI allowable dose intake

AP acidification potential

CFC chlorofluorocarbon

CML Centre of Environmental Science, Leiden University

COD chemical oxygen demand

DALY disability-affected life years

DLY disability life years

E exponent

EBIR equal benefit incremental reactivity

EDIP environmental design of industrial products

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EL	environmental load
ELU	environmental load unit
EPS	environmental priorities strategy
ETP	eco-toxicity potential
FU	functional unit
GWP	global warming potential
IIASA	International Institute for Applied Systems Analysis
IPPC	integrated pollution prevention and control
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
MDF	medium density fibreroad
MIR	maximum incremental reactivity
MOIR	maximum ozone incremental reactivity
NP	nutrification potential
ODP	ozone depletion potential
OSB	oriented standard board
PAH	polycyclic aromatic hydrocarbon
PDF	potentially disappeared fraction
PEC	predicted environmental concentration
PNEC	predicted no-effect concentration
POCP	photochemical ozone creation potential
RIVM	National Institute of Public Heath and the Environment
SE	sensitive ecosystem category indicator
USES	uniform system for the evaluation of substances
VOC	volatile organic compound
WMO	World Meteorological Organization
YLL	years of life lost

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4 Organization of examples in ISO/TR 14047

4.1 Mandatory and optional elements

The general framework of the LCIA phase is composed of several mandatory elements that convert Life Cycle Inventory (LCI) results to indicator results. In addition, there are optional elements for normalizing, grouping or weighting of the indicator results and data quality analysis techniques for assisting in the interpretation of the results.

4.2 Scope of examples

The examples provided within this Technical Report illustrate and support the methodology specified in Clauses 5, 6, 7 and 10 of ISO 14042:2000. The coverage is indicated in Table 1.

Table 1 — Elements or clauses of ISO 14042:2000 illustrated with examples

ISO 14042:2000 reference	IS0 14042 clause	Example coverage in this Technical Report
Clauses 1 to 4	Foreword, Scope, Normative references, Terms and definitions, General description of LCIA	Examples of impact categories
Clause 5	Mandatory elements	Example 1, Example 2, Example 3, Example 4, Example 5
5.1	General	
5.2	Concept of category indicators	
5.3	Selection of impact categories, category indicators and characterization models	
5.4	Assignment of LCI results (classification)	
5.5	Calculation of category indicator results (characterization)	
Clause 6	Optional elements	
6.1	General	
6.2	Calculating the magnitude of the category indicator results relative to reference information (normalization)	Example 1, Example 2, Example 6, Example 7
6.3	Grouping	Example 1
6.4	Weighting	Stem example, Example 5, Example 8
Clause 7	Data quality analysis	Stem example, Example 5
Clause 8	Limitations of LCIA	Not covered in ISO/TR 14047
Clause 9	Comparative assertions disclosed to the public	
Clause 10	Reporting and critical review	Example 1

In some key areas, more than one example is provided to illustrate the different ways in which it may be possible to apply ISO 14042. It is important to stress this point. In many LCIA studies, more than one approach or practice may be used which will still allow conformance with the methodology specified in ISO 14042. There is currently no unique approach. This Technical Report may be thought of as illustrating a number of ways that may be used in the LCIA phase as specified in ISO 14042. Table 2 gives the title of the example and the purpose of the illustration.

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Table 2 — Example titles and the purpose of the illustrations

Example No.	Example title	Purpose of illustration	ISO 14042:2000 subclause reference
1	Use of two different materials for gas pipelines	Full procedure of LCIA	5.2 to 5.5, 6.2 to 6.4, Clause 7 and (reference to Clause 10)
2	Two acidification impact category indicators	Consequences of using general or site-dependent models	5.3 to 5.5, Clause 6
3	Impacts of greenhouse gas (GHG) emissions and carbon sinks on forestry activities	GHG emissions and carbon sinks	5.2 to 5.5
4	Endpoint category indicators assessment	Transforming ionizing radiation inventory results into impact category indicator (YLL)	5.2 to 5.5
5	Choice of material for a wind spoiler in car design study	Impact modelling at endpoint level and weighting	5.2 to 5.5, 6.4, Clause 7
6	Normalization of LCIA indicator results for the use of different refrigerator gases	Normalization using different types of reference information	6.2
7	Normalization in a waste management study	Use of normalization in the communication processes	6.2 and (reference to Clause 10)
8	A technique for the determination of weighting factors	The use of a panel of experts in such a study	6.4

4.3 Organization of document and route map

This Technical Report is organized along the lines of a process “plant”. First, Clause 5 begins with a “General description of LCIA” and introduces the examples. A central “stem” example, Example 1, runs through the document illustrating the key areas between Clauses 5 to 10 of ISO 14042:2000. This uses one set of LCI data and processes it through the LCIA stages. Examples illustrating the different paths possible within the ISO 14042 methodology run in parallel to Example 1. These examples use different source data from Example 1. Figure 1 presents the process in a flow diagram.

NOTE Following Clause 5 the examples are organized as follows:

Examples in Clause 6 are mandatory elements running consecutively, i.e. Example 1, Illustration of 5.2 to 5.5 of ISO 14042:2000, followed by Example 2, followed by Example 3, and so on.

Examples in Clause 7 are organized on a “topic” basis, e.g. with all examples on Illustration of 6.2 of ISO 14042:2000 on normalization, followed by examples on Illustration of 6.3 of ISO 14042:2000 on Grouping, and so on.

The reader may adopt a number of alternative ways of using this Technical Report. These are broadly as follows:

— follow Example 1 from start to finish;

— select an alternative example and follow the process flow;

— select a topic and read all the alternative approaches on that particular topic.

Each example is preceded by an overview to describe the key area of ISO 14042 which will be illustrated. The body of the example follows the overview. Where an example continues through the document, it generally has not been necessary to precede each clause with an overview.

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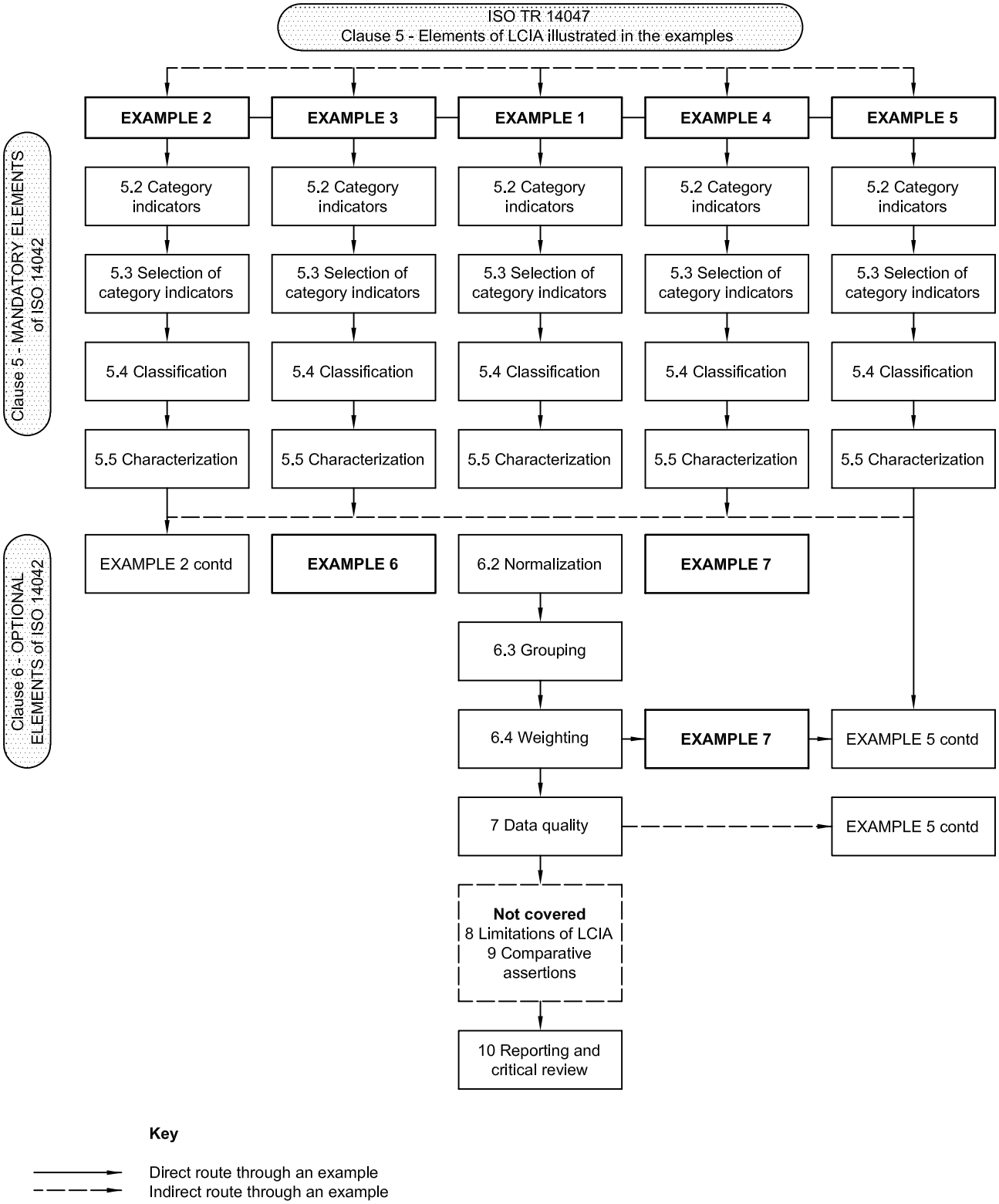

Figure 1 — Organization and route map for this Technical Report

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5 Elements of LCIA as illustrated in the examples

5.1 General

This clause gives a general description of LCIA, explaining key elements of the procedure, and places the examples in the context of ISO 14042:2000. The LCIA process elements are shown in Figure 2.

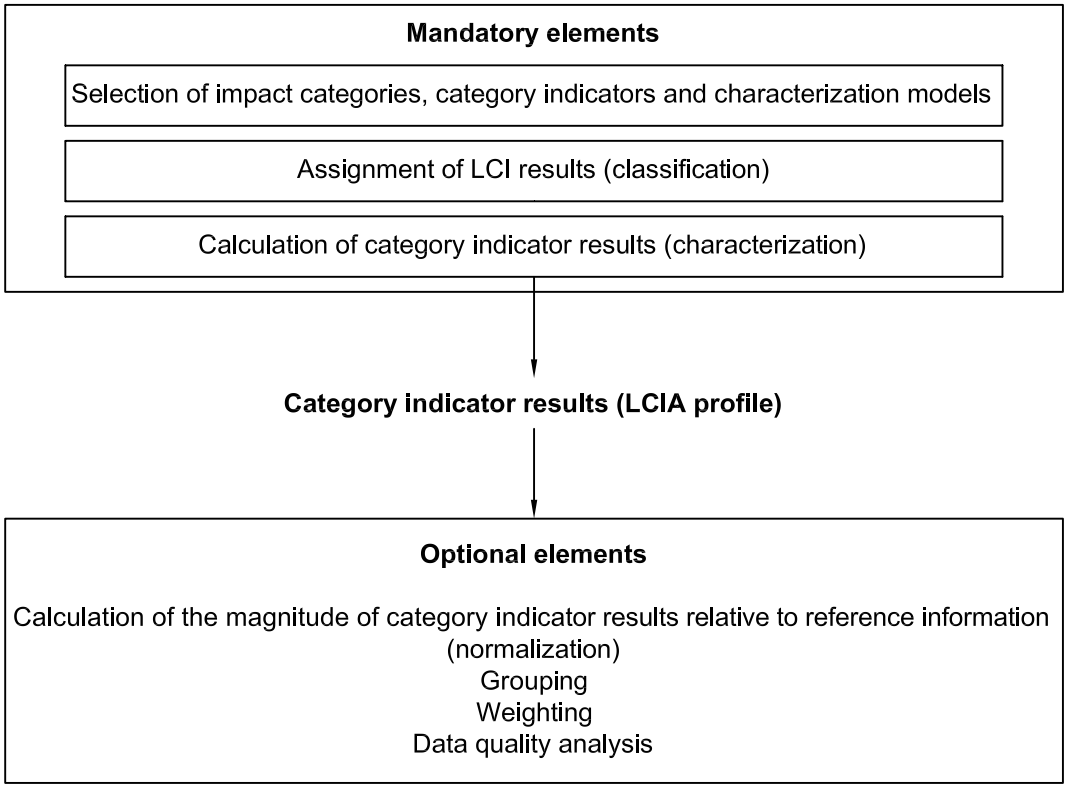

Figure 2 — Elements of the LCIA phase (ISO 14042:2000)

5.2 Mandatory elements

5.2.1 General

According to ISO 14042, the mandatory elements of LCIA are:

— selection of impact categories, category indicators and characterization models;

— assignment of LCI results (classification) to the impact categories;

— calculation of category indicator results (characterization).

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5.2.2 Selection of impact categories, category indicators and characterization models

5.2.2.1 General

For each impact category, a distinction can be made between LCI results, including extractions (inputs) and emissions (outputs), category endpoints and intermediate variables in the environmental mechanism between these two groups (sometimes called "midpoints"). This is illustrated in Figure 3.

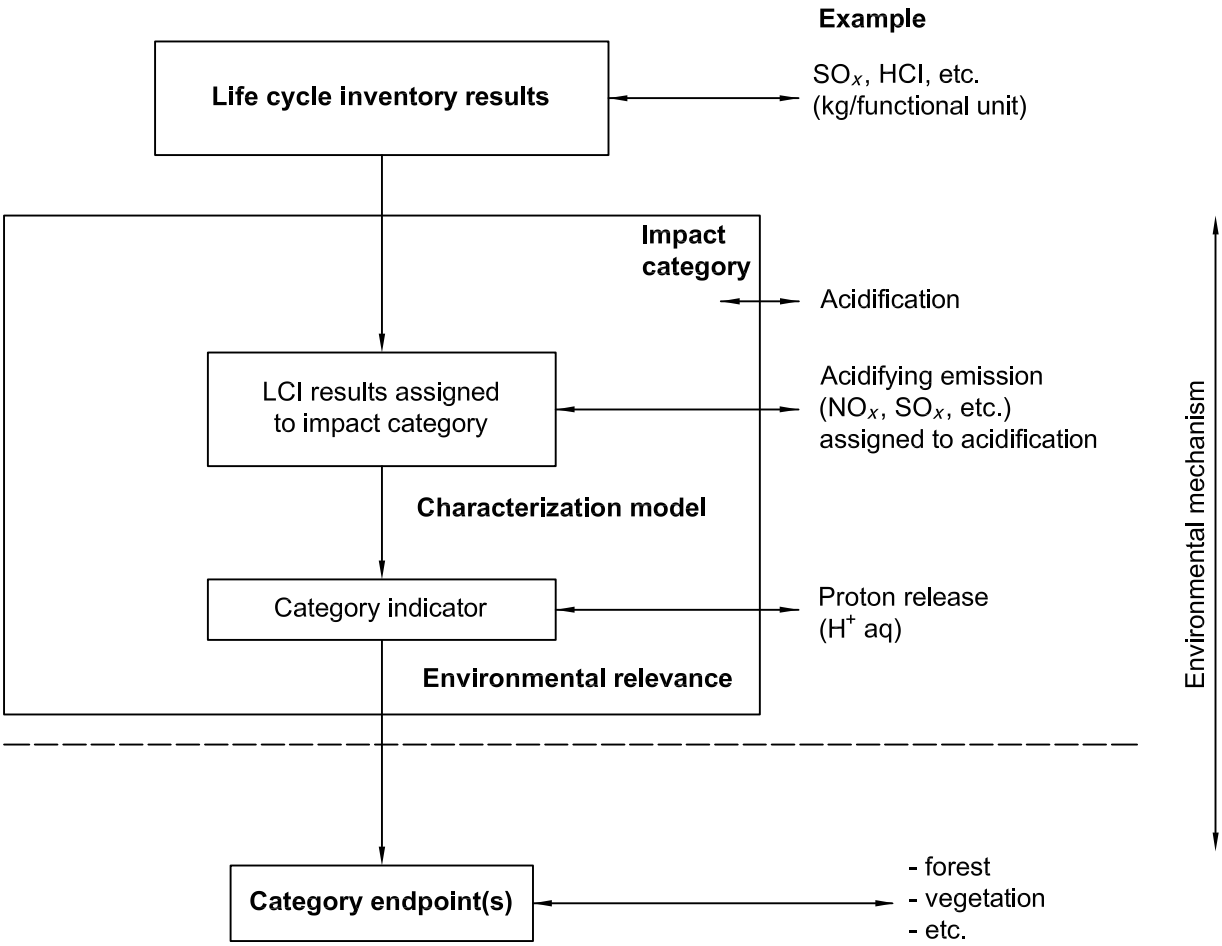

Figure 3 — Concept of category indicators (Figure 2 from ISO 14042:2000)

When defining the impact categories, an indicator must be chosen somewhere in the environmental mechanism. Often indicators are chosen at an intermediate level somewhere along that mechanism; sometimes they are chosen at endpoint level. Table 3 shows examples of relevant intermediate variables and relevant category endpoints for a number of impact categories.

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Table 3 — Examples of intermediate variables and category endpoints for a number of impact categories

Impact category	Choices of indicator level	
	Examples of intermediate variables	Examples of category endpoints
Climate change	Infrared radiation, temperature, sea-level	Human life expectancy, coral reefs, natural vegetation, forests, crops, buildings
Stratospheric ozone depletion	UV-B radiation	Human skin, ocean biodiversity, crops
Acidification	Proton release, pH, base-cation level, Al/Ca ratio	Biodiversity of forests, wood production, fish populations, materials
Nutrification	Concentration of macronutrients (nitrogen, phosphorus)	Biodiversity of terrestrial and aquatic ecosystems
Human toxicity	Concentration of toxic substances in environment, human exposure	Aspects of human health (organ functioning, human life expectancy, number of illness days)
Ecotoxicity	Concentration or bio-availability of toxic substances in environment	Plant and animal species populations

In Tables 4, 5 and 6, LCI results and indicator results are expressed using the same functional unit (the one selected in the LCI phase, Scope).

In Table 4, examples of terms used for defining an impact category and describing the chosen characterization model are given for six different impact categories to further illustrate the principles of Table 1 from ISO 14042:2000. Impact Categories 1 and 2 are input-related; Impact Categories 3 to 6 are output-related.

Table 4 — Examples of definitions and description of six impact categories

Term	Impact Category 1	Impact Category 2
Impact category	Depletion of fossil energy resources	Depletion of mineral resources, (excluding energy resources)
LCI results	Extraction of resources of different fossil fuels	Extraction of resources, expressed as useful material
Characterization model	Cumulated energy demands	Static scarcity model
Category indicator	Energy content of energy resources	Extraction of material in the ore as a function of estimated supply horizon of the reserve base
Characterization factor	Low calorific value per mass unit	Present extraction of the material in the ore divided by estimated supply horizon of the reserve base
Indicator result	Total low calorific value (megajoules)	Total mass of used material in the ore divided by estimated supply horizon of the reserve base
Category endpoints	Heating, mobility	Availability of resources
Environmental relevance	Diverse problems known from energy crises	Diverse problems from mineral resources

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Table 4 (*continued*)

Term	Impact Category 3	Impact Category 4
Impact category	Climate change	Stratospheric ozone depletion
LCI results	Emissions of greenhouse gases	Emissions of ozone-depleting gases
Category indicator	Increase of infrared radiative forcing (W/m^2)	Increase of stratospheric ozone breakdown
Characterization model	The model as developed by the IPCC defining the global warming potential of different greenhouse gases [6], [7]	Table 5 — The model as developed by the WMO defining the ozone depletion potential for different ozone-depleting gases [8], [9]
Characterization factor	Global Warming Potential for time horizon of 100 years (GWP100) for each greenhouse gas emission (kg CO_2 eq./kg emission)	Ozone Depletion Potential in the steady state ($ODP_{steady\ state}$) for each emission (kg CFC-11-eq./kg emission)
Indicator result	Kilograms of CO_2-equivalents	Kilograms of CFC-11-equivalents
Category endpoints	Years of life lost (YLL), coral reefs, crops, buildings	Illness days, marine productivity, crops
Environmental relevance	Infrared radiative forcing is a proxy for eventual effects on the climate, depending on the integrated atmospheric heat absorption caused by emissions and the distribution over time of the heat absorption	Empirical and experimental linkage between UV-B radiation levels and damage
Term	**Impact Category 5**	**Impact Category 6**
Impact category	Nutrification	Ecotoxicity
LCI results	Emissions of nutrients	Emissions of organic substances to air, water and soil
Category indicator	Deposition increase divided by N/P equivalents in biomass	Predicted Environmental Concentration increase divided by Predicted No-Effect Concentration (PNEC)
Characterization model	The stoichiometric procedure as described by [10], which identifies the equivalence between N and P for both terrestrial and aquatic systems.	USES 2.0 model developed at RIVM, describing fate, exposure and effects of toxic substances, adapted to LCA by [11]
Characterization factor	Nutrification Potential (NP) for each eutrophicating emission to air, water and soil (kg PO_4^{3-}- eq./kg emission)	Ecotoxicity Potential (ETP) for each emission of a toxic substance to air, water and soil (kg 1,4-dichlorobenzene eq./kg emission)
Indicator result	Kilograms of PO_4^{3-} equivalents	Kilograms of 1,4-dichlorobenzene equivalents
Category endpoints	Biodiversity, natural vegetation, algal bloom	Biodiversity
Environmental relevance	The nutrification indicator represents a clear causal factor in the mechanism of nutrification for different types of ecosystems; it is defined at a global level	The PNEC represents a threshold for a possible effect of the substance on the species composition of an ecosystem; no spatial differentiation is considered

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In Table 4, all six examples use the category indicator at the level of intermediate parameters in the environmental mechanism. In order to illustrate the number of possible options when defining an impact category and choosing a characterization model, Table 5 gives examples of different category models and category indicators within the environmental mechanism of one impact category – photochemical ozone formation. The examples given are not the only alternatives. A similar table could be prepared for each of the impact categories in Table 4. Five of the alternatives presented in Table 5 focus on the same category indicator chosen early in the environmental mechanism, but compare five different characterizations models. For the sixth alternative, the indicator is chosen close to the endpoint. The main distinguishing features are presented in **boldface type**.

Table 5 — Example of terms and different characterization models for the impact category photo-oxidant formation

Term	Alternative 1	Alternative 2	Alternative 3
Impact category	Photo-oxidant formation	Photo-oxidant formation	Photo-oxidant formation
LCI results	Emissions of substances (VOC, CO) to air	Emissions of substances (VOC, CO) to air	Emissions of substances (VOC, CO) to air
Characterization model	**UNECE** **Trajectory model** **[12], [13]**	**Trajectory model** **[14]**	**Maximum Incremental Reactivity (MIR) scenario; Single-cell model [15], [16]**
Category indicator	Quantity of tropospheric ozone formed	Quantity of tropospheric ozone formed	Quantity of tropospheric ozone formed
Characterization factor	**Photochemical Ozone Creation Potential (POCP) for each emission of VOC or CO to air** **(kg ethylene eq./kg emission)**	**Photochemical Ozone Creation Potential (POCP) for each emission of VOC or CO to air** **(kg ethylene eq./kg emission)**	**Kg ozone formed for each emission of VOC or CO to air** **(kg ozone/kg emission)**
Indicator result	Kg ethylene equivalents	Kg ethylene equivalents	Kg ozone
Category endpoints	Illness days, crops	Illness days, crops	Illness days, crops
Environmental relevance	Ozone formation estimated with relatively high background NO_x	Ozone formation estimated with low background NO_x	Highest rise in ozone levels per added amount of standard VOC mixture, very high NO_x concentration, high concentration is inhibiting ozone creation

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Table 5 (*continued*)

Term	Alternative 4	Alternative 5	Alternative 6
Impact category	Photo-oxidant formation	Photo-oxidant formation	Photo-oxidant formation, impacts on vegetation
LCI results	Emissions of substances (VOC, CO) to air	Emissions of substances (VOC, CO) to air	Emissions of substances (NO_x, VOC, CO) to air
Characterization model	**Maximum Ozone Incremental Reactivity (MOIR) scenario; Single-cell model** **[15], [16]**	**Equal Benefit Incremental Reactivity (EBIR) scenario; Single-cell model** **[15], [16]**	**RAINS adapted to LCA Option for spatial differentiation within Europe** **[17]**
Category indicator	Quantity of tropospheric ozone formed	Quantity of tropospheric ozone formed	Area of ecosystem times duration and extent of exposure above critical level for plants
Characterization factor	**Kg ozone formed for each emission of VOC or CO to air** **(kg ozone/kg emission)**	**Kg ozone formed for each emission of VOC or CO to air** **(kg ozone/kg emission)**	**Extent of exposure above critical level for each emission of NO_x, VOC or CO to air** **(m^2 × ppm × hours/kg emission)**
Indicator result	Kg ozone	Kg ozone	m^2 × ppm × hours
Category endpoints	Illness days, crops	Illness days, crops	Crops, natural vegetation
Environmental relevance	Highest ozone concentration per added amount of standard VOC mixture, relatively high NO_x concentration, realistic for peak situations	NO_x and VOC contribute equally to ozone production, relatively low NO_x concentration, lower concentrations of NO_x and VOC both reduce ozone creation	Includes the contribution from NO_x together with VOC and CO, permits spatial differentiation to take regional differences in reactivity and ecosystem sensitivity into account. Models close to endpoint

5.2.2.2 Identification of possible indicators

The task of LCIA is to establish a relation between the inputs, e.g. fossil fuels or minerals, and outputs of the Life Cycle Inventory phase with the impacts on the environment. For this reason, for every impact category an indicator shall be chosen in the environmental mechanism, which as far as possible represents the totality of all impacts in the impact category. This indicator can in principle be located at any position in the mechanism, from the LCI results down to the category indicators. In Table 6 this aspect is illustrated for an impact category dealing with acidification. Here three different characterization models are compared, each of them focusing on a distinct category indicator. The three models, and connected indicators, differ in their degree of sophistication. The first category indicator is the simplest, and is defined at the level closest to the emissions. The second category indicator is defined at the level of an intermediate variable close to the endpoint; while the third indicator is defined at endpoint level, also known as damage approach. Again, the major distinguishing cells are presented in **boldface type**.

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Table 6 — Indicators and underlying models chosen at different places in the environmental mechanism

Term	Alternative examples for the category indicator for acidification		
Impact category	Acidification	Acidification	Acidification
LCI results	Emissions of acidifying substances to air and water	Emissions of acidifying substances to air	Emissions of acidifying substances to air
Characterization model	CML-method **[10]**; EDIP-model **[17]**	RAINS, adapted to LCA **[11] and (Example 2 [6])**	Ecoindicator-99 **[18],** using the model Nature Planner **[19]**; Fate modelling by SMART **[20]**; damage modelling by MOVE **[16]**
Category indicator	**Maximum release of protons (H^+)**	**Deposition / Acidification Critical Load**	**Increase in $PDF_{vegetation}$ (Potentially Disappeared Fraction) of plant species in natural areas**
Characterization factor	Acidification Potential (AP) for each acidifying emission to air and water (kg SO_2-eq./kg emission)	Acidification Potential (AP) for each acidifying emission to air (kg SO_2-eq./kg emission)	Potentially Disappeared Fraction (PDF) for each acidifying emission to air (PDF·m^2·yr/kg emission)
Indicator result	Kilograms SO_2 equivalents	Kilograms SO_2 equivalents	PDF·m^2·yr
Category endpoints	Biodiversity, natural vegetation, wood, fish, monuments	Biodiversity, natural vegetation, wood, fish, monuments	Biodiversity, natural vegetation, wood, fish, monuments
Environmental relevance	Maximum potential effect; fate is not included; no spatial differentiation	Fate is included; risk of effects are spatially differentiated	Fate and effects on natural vegetation are included; effects in the Netherlands are a proxy for effects in Europe

Requirements for the selection of category indicators are described in 5.3 of ISO 14042:2000. These requirements are addressed for the following indicators of the acidification impact category:

— maximum proton release indicator: very crude indicator, far removed from endpoints (i.e. little environmental relevance), but easy to handle (pertains to all units mentioned);

— critical load indicator: spatially differentiated, relatively certain in the modelling, but closer to endpoints (moderate environmental relevance in ISO terms);

— endpoint indicators: spatially differentiated, high environmental relevance in ISO terms, because at endpoint level, but involving large uncertainties in the modelling up to the chosen endpoints.

5.2.2.3 Environmental relevance

The link between the LCI results (extractions, emissions and types of land use), and the category indicator is normally given by clear modelling algorithms. The term environmental relevance refers to how much bearing the category indicator has on the category endpoint it attempts to reflect in a general and qualitative way. This helps understand the attributes and relevance of the impact category (see Figure 2). Typically, the environmental relevance is higher for indicators chosen later in the environmental mechanism (see ISO 14042:2000, 5.3.5).

For the example of acidification in Table 6, the following could be stated for the environmental relevance of the indicator representing maximum proton release:

— ecosystems with their flora and fauna in temperate and subpolar zones are threatened by acidic deposition;

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— the intensity of the impact is closely related to the buffering capacity of the receiving soils and water bodies. Low base-cation regions in Northern Europe and North America show a high intensity of impacts due to acidification;

— acidification has a regional distribution with short-range and long-range impacts. Short range is related to higher acid concentrations in air and part of the forest-decline effects, while the long-range impacts lead to the breakdown of soil buffers and to the acidification of lakes and subsequent fish die-back;

— the duration of acidified environmental compartments is long, since only the weathering of base-cation-containing rocks counteracts the effect;

— the reversibility of the impact depends on the category endpoint. By application of calcium carbonate or lime to acidified soils, some vitality effects can be treated immediately while a reversibility for the loss of natural species, for instance due to acidified lakes, is not given;

— a large number of research activities have been conducted and the mechanisms are quite well understood.

In the majority of examples given throughout this Technical Report, the category indicator is chosen at the level of an intermediate parameter in the environmental mechanism. Exceptions are Examples 4 and 5 where indicators are chosen near the endpoint level for all impact categories. Example 2 illustrates the potential importance of the location of the chosen indicator for the impact category acidification, comparing approaches along the lines of the first two alternatives of Table 6.

5.2.2.4 Choice of impact categories

A list of commonly used impact categories is presented in Table 7.

Table 7 — Commonly used impact categories [22]

Output-related categories:
— Climate change
— Stratospheric ozone depletion
— Photo-oxidant formation
— Acidification
— Nitrification
— Human toxicity
— Ecotoxicity
Input-related categories:
— Depletion of abiotic resources (e.g. fossil fuels, minerals)
— Depletion of biotic resources (e.g. wood, fish)

This list cannot be regarded as complete. Other categories may for instance focus on radiation, noise and odour, working environmental impacts or land use, but for these categories as yet no widely accepted characterization methods are available. In reference [22] to the table, land use was also included in the list of commonly used impact categories.

The selection also depends on the definition of the system boundaries. For instance, solid waste can be selected as a category. However, if the LCI results are specified in terms of the emission of single substances, the waste flows are to be regarded as part of the product system and these flows have to be translated into emissions related to other categories, as specified above. The same holds true for a possible “energy” category.

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Often, the characterization model is chosen among existing models; this is the case for the majority of examples. Example 3 documents the development of a new impact category covering the sequestration of carbon in a forestry-based product system, and Example 4 presents the principles behind impact categories defined with indicators at endpoint level.

5.2.3 Assignment of LCI results (classification)

Assignment of LCI results to impact categories shows which results have an impact on which categories. Often this information is provided by a table of characterization factors which come from the model chosen for the impact category. A main distinction in ISO 14042 concerns the difference between serial and parallel processes. The characteristic to remember in parallel processes is that one substance that has an impact on different categories may have to be divided over these categories because one part of the emission leads to effects in one category, and another part to effects in another category. For example, the emission of SO_2 contributes to three categories: acidification, climate change (counteracting) and human toxicity (see Figure 4).

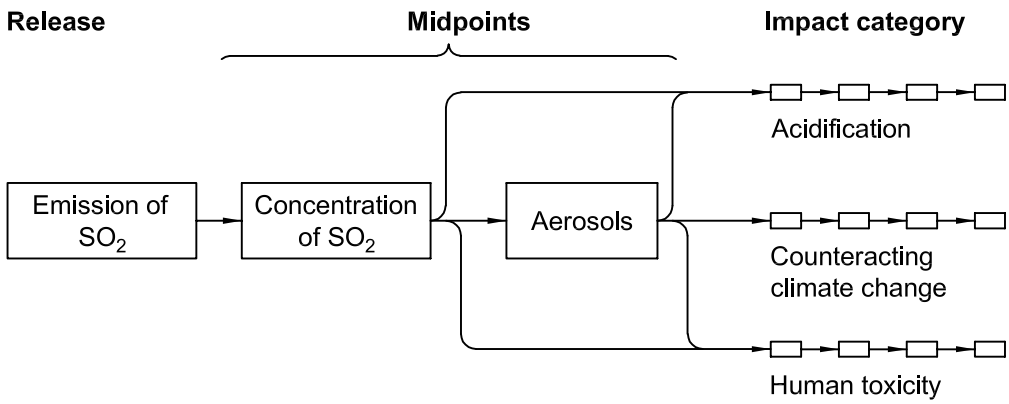

Figure 4 — Example of parallel processes

Serial processes are illustrated for CFC emissions. The characteristic to remember in serial processes is that a substance may consecutively contribute to different impact categories, again necessitating a choice concerning the contribution to these consecutive categories. The emission of CFCs contributes to the following two impact categories: first to climate change at tropospheric level, then to stratospheric ozone depletion (see Figure 5).

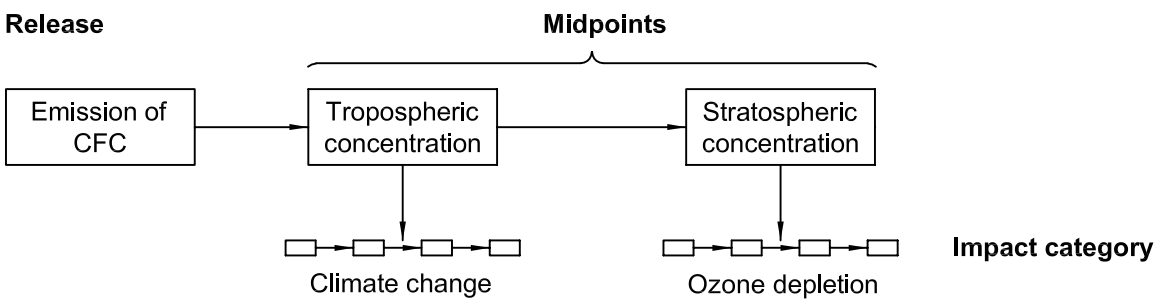

Figure 5 — Example of a serial process

As stated above, for parallel processes the emissions should in principle be divided between the different processes; for serial processes the same substance can in principle be attributed in its full amount to the different types of impact, one after the other. It should be noted, however, that if characterization is based on multimedia modelling, this attribution is taken into account automatically. Then classification is not an element in itself.

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In Example 1, the handling of parallel and serial impacts is discussed in the illustration of 5.4 of ISO 14042:2000.

5.2.4 Calculation of category indicator results (characterization)

Following the identification of impact categories, the choice of indicators and selection or development of characterization model, and the assignment of LCI results to impact categories, indicator values are then calculated for each impact category using characterization factors. The procedure is illustrated in Examples 1, 2, 3, 4 and 5. Examples 1 and 3 illustrate characterization for impact categories defined early or at an intermediate level in the environmental mechanism. Example 2 illustrates the use of spatially differentiated characterization factors, while Examples 4 and 5 demonstrate characterization performed at endpoint level.

5.3 Optional elements (related to ISO 14042:2000, Clause 6)

5.3.1 General

Following the mandatory elements described above, there are a number of optional elements that may be used to help explain the results of the LCA according to the goal definition of the study.

In ISO 14042, the optional elements are

— calculating the magnitude of category indicator results relative to reference information (normalization),

— grouping: sorting and possibly ranking of the impact categories,

— weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value choices,

— data quality analysis: better understanding the reliability of the collection of indicator results, i.e. the LCIA profile.

5.3.2 Calculating the magnitude of category indicator results relative to reference information (normalization)

ISO 14042 states:

“The aim of the normalization of indicator results is to better understand the relative magnitude of each indicator result of the product system under study. Calculating the magnitude of indicator results relative to reference information (often referred to as normalization) is an optional element, which may be helpful in, for example

— checking for inconsistencies,

— providing and communicating information on the relative significance of the indicator results, and

— preparing for additional procedures, such as grouping, weighting or life cycle interpretation.”

Examples 1, 2, 6 and 7 show how normalization can be used to assist the interpretation of the environmental profile and illustrate the significance of different choices of a normalization reference.

5.3.3 Grouping: sorting and ranking of the impact categories

Following normalization, grouping may be performed on the indicator results. Two types of grouping can be carried out: sorting (which is descriptive) and ranking (which is normative). In general, both types of grouping of the indicator results lead to better possibilities for interpretation of these results.

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Sorting of the indicator scores may for example be done according to the

— spatial scale of the impact category (global, regional local),

— area of protection for the impact category (human health, natural environment, resources),

— degree that the impact category model is science- or value-choice-based.

Ranking of the indicator scores might apply criteria such as

— the degree of reversibility of the impacts,

— the degree of certainty of the impacts,

— policy priorities regarding the types of impact.

Example 1 illustrates sorting and ranking.

5.3.4 Weighting

For certain applications, a weighting process may be performed. This is understood as the conversion of category indicator results by using numerical factors based on value choices. In contrast to ranking, not only classes of priorities are used but also numerical factors, i.e. the weighting factors, which are multiplied by the (normalized) indicator results. Since weighting may include aggregation of the weighted indicator results, the outcome of this step can be one number. This score, or index, represents the environmental performance of the product system(s) under study. It should be noted that according to ISO 14040 there is no scientific way to reduce LCA results to a single overall score or number, hence it cannot be used for comparative assertions.

In general, weighting across impact categories tries to achieve surveyable results that are simple to handle. Weighting can particularly be useful for routine decisions in product design, and for decisions that imply many different types of information, e.g. environmental, economic, legal and social information. This may also lead to a need for data reduction.

In general, three types of weighting method can be distinguished:

a) monetary weighting, based on willingness-to-pay or on revealed preference approaches;

b) distance-to-target weighting, using policy standards;

c) social panel weighting, using the judgement of experts or of stakeholders in the decision process.

Examples 1, 5 and 8 illustrate weighting. Example 1 uses weighting factors based on a social panel process. Example 5 uses weighting factors based on costing of the different impacts. Example 8 describes the development of weighting factors applying a panel process in a two-step procedure, first relating indicator scores to endpoints, and second, weighting the endpoints relative to each other.

5.3.5 Data quality analysis

The data quality tools mentioned in ISO 14042 comprise: gravity analysis, sensitivity analysis and uncertainty analysis. They can be applied at different levels of the impact assessment process, i.e:

— assigned LCI results;

— indicator results;

— normalization results;

— weighting results.

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Gravity analysis reveals the main contributors to parameters such as indicator scores. It is typically carried out to provide an overview of the contribution of different unit processes to the indicator results, and the contribution of the individual LCI results to the indicator results.

Uncertainty analysis shows how uncertainties in LCI data and/or characterization factors propagate in the indicator results, while sensitivity analysis can be used to measure the change in the indicator results for induced changes in LCI results or in the different types of factors. Typically, a sensitivity analysis regarding the indicator results can be carried out for unit process data (LCI results) and for characterization factors, normalization factors and weighting factors.

In Examples 1, 5 and 6, the different analyses are performed at various stages of the life cycle impact assessment process.

6 Examples of the mandatory elements of LCIA

6.1 General

Figure 1 above highlights the number of examples within the mandatory elements section. Readers may commence their journey through this clause either at Example 1, and then through each of the other examples in turn, or may select whichever example is of particular interest.

6.2 Example 1 — Use of two different materials for gas pipelines

6.2.1 ISO 14042:2000, 5.1 General — Overview

This example, which acts as the “stem” element, is used to illustrate the whole LCIA process within the ISO 14042 document. At different points alternative examples will be presented.

First, a short description is given of the example. Although it is directly derived from practice, it is presented stressing the importance of the general methodological aspects, and not the specific results.

In the example, a comparison is made between Materials A and B in the production and use of gas pipelines in country X in the year Y. The functional unit is the supply of 20 $\times 10^6$ m^3 of natural gas during one year by the distribution network, from the feeder system to 10 000 service connection points. The unit processes to be considered are: extraction of resources, production of materials, components and the gas pipeline system in total, the use of the gas pipeline system, waste management, electricity production along the life cycle, and transportation along the life cycle.

6.2.2 ISO 14042:2000, 5.2 Concept of category indicators — LCI results

The example analyses only emissions to air and water connected with the two product systems. Table 8 shows the types and quantities of emissions considered in Example 1.

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Table 8 — LCI results of Example 1

Substance	LCI results			
	Material A		Material B	
	Air emissions kg	Water emissions kg	Air emissions kg	Water emissions kg
Carbon dioxide	4,22E+04		4,81E+03	
Bromotrifluoro-methane	1,55E–03		4,30E–04	
Tetrachloromethane			4,90E–04	
Methane	6,73E+03		6,75E+03	
Ethane	1,94E+02		1,98E+02	
Propane	2,97E+01		2,99E+01	
Sulfur dioxide	3,06E+02		1,83E+01	
Nitrogen dioxide	1,11E+02		1,64E+01	
Ammonia	8,76E–02	5,44E–01	8,01E–03	1,23E–01
Phosphorus		1,22E+00		5,41E–02
Nitrogen		4,05E–01		1,80E–01
Phenol	9,40E–05	1,15E–01	9,00E–06	1,54E–02
Arsenic	2,47E–02-	4,14E–02	1,92E–04	1,90E–03
Nickel	1,57E–01	1,05E–01	6,40E–03	6,77E–03
Vanadium	5,72E–01	1,03E–01	2,51E–02	5,36E–03
Cadmium	1,64E–02	1,56E–03	1,75E–04	1,47E–04
Lead	4,72E–01	1,16E–01	3,62E–03	4,93E–02
Chromium	3,23E–02	2,08E–01	3,54E–04	1,02E–02
Copper	3,54E–02	1,04E–01	1,27E–03	

6.2.3 ISO 14042:2000, 5.3 Selection of impact categories, category indicators and characterization models

6.2.3.1 Selection of impact categories

For illustrative purposes, a broad list of impact categories has been selected for the air and water emissions in the example. The following impact categories have been taken into account:

— climate change;

— stratospheric ozone depletion;

— photo-oxidant formation;

— acidification;

— eutrophication;

— human toxicity;

— ecotoxicity.

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6.2.3.2 Selection of the indicator(s)

The following category indicators have been selected for the various categories taken into account:

— climate change: infrared radiative forcing for a time horizon of 100 years [6], [7];

— stratospheric ozone depletion: stratospheric ozone breakdown [8], [9];

— photo-oxidant formation: tropospheric ozone production [12], [13];

— acidification: acidification critical load [11];

— eutrophication: eutrophication critical load [10];

— human toxicity: PEC/ADI [11];

— ecotoxicity: PEC/PNEC [11].

The choice in the example for category indicators earlier in the environmental mechanism level, instead of at endpoint level, is primarily based on the relatively high certainty connected with modelling up to indicators early in the environmental mechanism and their high coverage of environmental pathways. Examples are the prediction of sea-level rise and impacts on ocean currents and their consequences due to climate change, and the prediction of impacts on wood production due to acidification.

The above category indicators, with the related characterization models, are science-based, with the exception of the indicator for human toxicity. The results of this model are not fully science-based due to the inclusion of ADI-values as a measure of the no-effect level.

6.2.3.3 Selection of characterization models

For the impact categories that are selected, the following characterization models are used:

— for climate change, the characterization models of the IPCC are selected. The IPCC provides characterization factors, Global Warming Potentials (GWPs), for three different time horizons: 20, 100 and 500 years [6], [7]. The GWP100 is selected in the present example;

— for stratospheric ozone depletion, the characterization model of the WMO is selected [8], [9]. This model provides stratospheric ozone depletion potentials (ODPs) for a steady state in terms of CFC-11 equivalents;

— for photo-oxidant formation, the UNECE Trajectory model is selected [12], [13];

— for acidification, the RAINS model of IIASA is selected, adapted for LCA [11]. For this category a marginal approach is chosen, taking into account spatially differentiated background levels. Spatial differences in sensitivity of regions are taken into account. The information is aggregated up to European characterization factors;

— for eutrophication, the stoichiometric approach, establishing equivalency of macronutrients on the basis of their occurrence in biomass, is selected [10];

— for human toxicity, the model USES 2.0 of RIVM is selected, adapted for LCA [11]. In this model both fate and effect of the substances is included. It is a steady state model at world level, without background levels. It is repeated here, that the model is not fully science based, due to the inclusion of ADI-values;

— for ecotoxicity, the model USES 2.0 of RIVM is selected, adapted for LCA [11]. In this model, both fate and effect of the substances is included. It is a steady state model at world level, without background levels. Aquatic ecotoxicity potentials are used as proxies for the ecotoxicity potentials. The characterization factors are presented in the references given.

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6.2.3.4 Identification of characterization factors

In Table 9, the characterization factors are given for the emitted substances, as these are derived from the characterization models for the different impact categories.

6.2.4 ISO 14042:2000, 5.4 Assignment of LCI results (classification)

SO_2 has a number of parallel impacts, as described earlier in 5.2.3. To avoid double-counting, these should be divided among the impact categories concerned. However, at present only a simplified procedure is possible:

— acidification: all emissions of SO_2 to be assigned to acidification (including aerosols);

— climate change: only SO_2 aerosols to be assigned to climate change, although at present this type of impact is not yet quantified in terms of a negative GWP value (see Note to Table 9);

— human toxicity: for human exposure, a distinction is to be made between the direct toxic effect of SO_2 and the PM10-impact of aerosols. As these exposures do not affect the amount available for the other two categories in a significant way, no correction is made.

CFCs exert serial impacts, as described earlier in 5.2. These substances first have an impact on climate change due to their concentration in the troposphere; after that they contribute to ozone depletion, once they have been distributed to the stratosphere.

6.2.5 ISO 14042:2000, 5.5 Calculation of category indicator results (characterization)

In this subclause the characterization results are calculated. The functional unit and the unit processes are given earlier in 5.2. There also, the emissions are given for the two materials considered. The impact categories considered are selected as shown in point 1) in the illustration of ISO 14042:2000, 5.3. The category indicators are selected as shown in point 2) in the illustration of ISO 14042:2000, 5.3. The characterization models and characterization factors will be used according to point 3) of the illustration of 5.3 of ISO 14042:2000. The characterization results are presented in Tables 10 and 11 for the two materials under consideration. The characterization algorithm implies that, for each impact category, the emissions in that category are multiplied by the characterization factors concerned and subsequently added up.

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Table 9 — Characterization factors for Example 1

Impact category	Substance	Characterization factors								
		Climate change kg CO_2 eq./kg	Stratosph. ozone depletion kg CFC-11 eq./kg	Photo-oxidant formation kg ethylene eq./kg	Acidification kg SO_2^- eq./kg	Eutrophication kg PO_4^- eq./kg		Human toxicity kg 1,4-DCB/kg	Ecotoxicity kg 1,4-DCB/kg	
		Air emissions	Air emissions	Air emissions	Air emissions	Air emissions	Water emissions	Air emissions	Air emissions	Water emissions
Climate change	Carbon dioxide	1								
	Bromotrifluoro-methane	5 600								
	Methane	21								
Stratospheric ozone depletion	Bromotrifluoro-methane		12							
	Tetrachloro-methane		1,2							
Photo-oxidant formation	Methane			0,006						
	Ethane			0,123						
	Propane			0,176						
Acidification	Sulfur dioxide	a			1					
	Ammonia				1,3					
	Nitrogen dioxide				0,41					
Nutrification	Ammonia					0,35	0,33			
	Nitrogen dioxide					0,13				
	Phosphorus						3,1			
	Nitrogen						0,42			
Human toxicity	Sulfur dioxide							0,096		
	Nitrogen dioxide							1,3		
	Arsenic							347 699,7		
	Lead							466,52		
	Nickel							35 032,84		
	Vanadium							6 240,35		
	Chlorinated organic trace pollutants								b	b
Ecotoxicity	Phenol								1,5	237
	Cadmium								289	1 523
	Lead								2,4	9,615 719
	Chromium								1,9	6,9
	Copper								221,653 8	1 157,307
	Chlorinated organic trace pollutants								b	b

NOTE The uncertainty for human toxicity and ecotoxicity characterization factors is much larger than for the other factors. For this reason, the impact categories are represented throughout the report as two groups: one with relatively high and one with relatively low certainty. In the tables, the two groups are separated with an additional line. Also see Example 1, **7.3 Sensitivity analysis**.

a It is recognized that the emission of SO_2 diminishes climate change, however, it is not yet possible to quantify this type of impact.

b No quantitative characterization factors could be obtained for the toxic effects of chlorinated organic trace pollutants which are emitted in very small quantities with Material B.

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