TECHNICAL REPORT

ISO/TR 14047

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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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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*.

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.

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

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

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.

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.

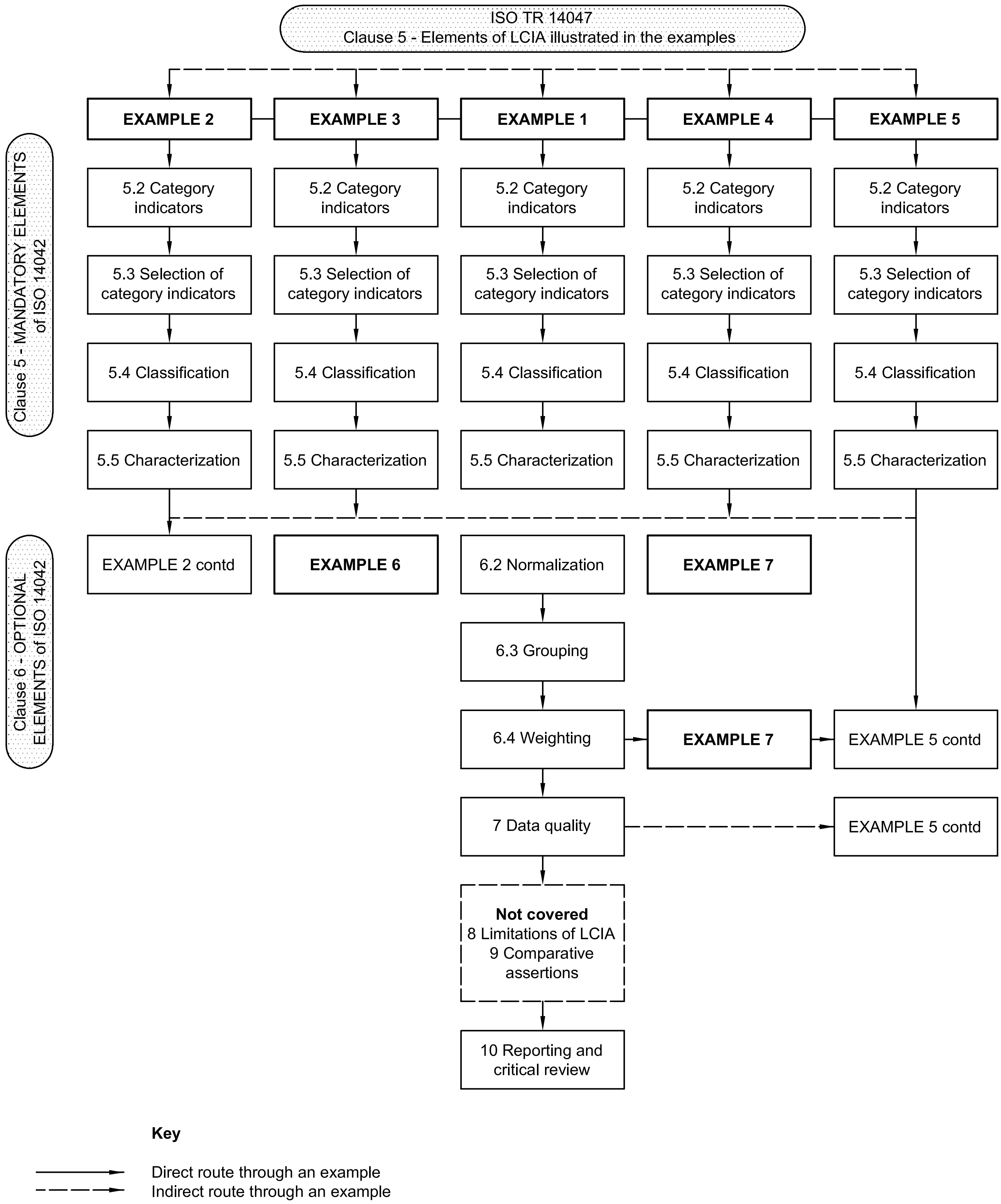


Figure 1 — Organization and route map for this Technical Report

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.

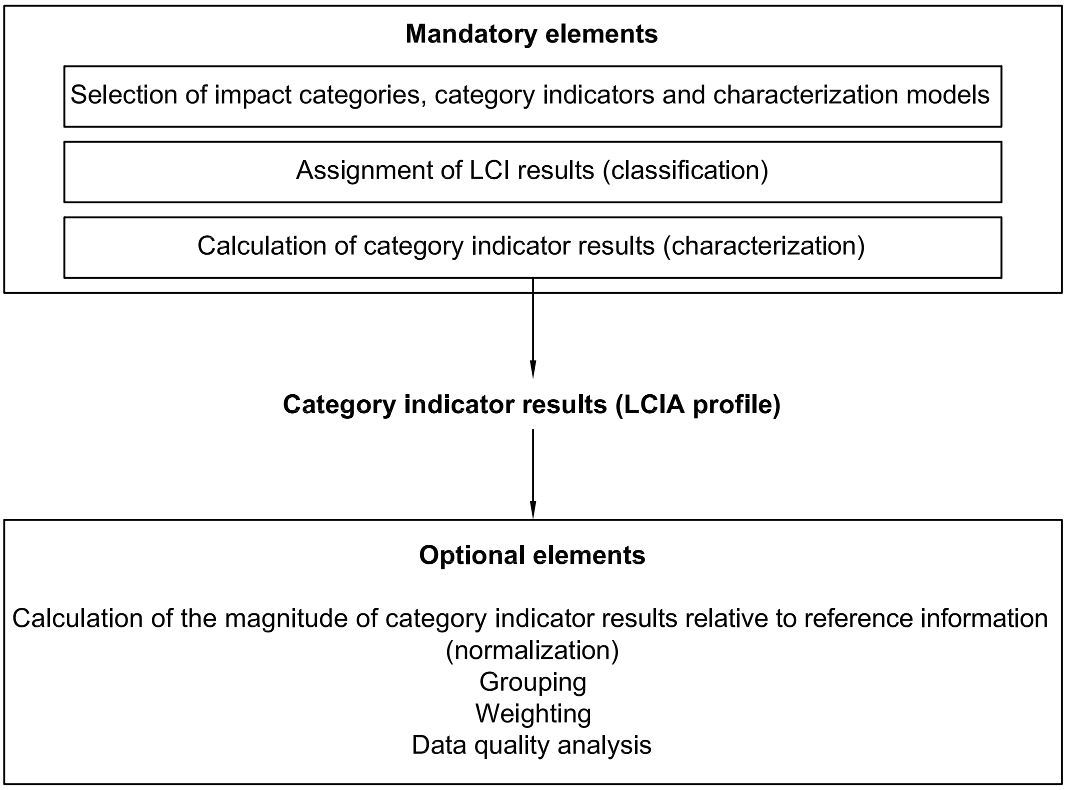


Figure 2 — Elements of the LCIA phase (ISO 14042:2000)

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).

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.

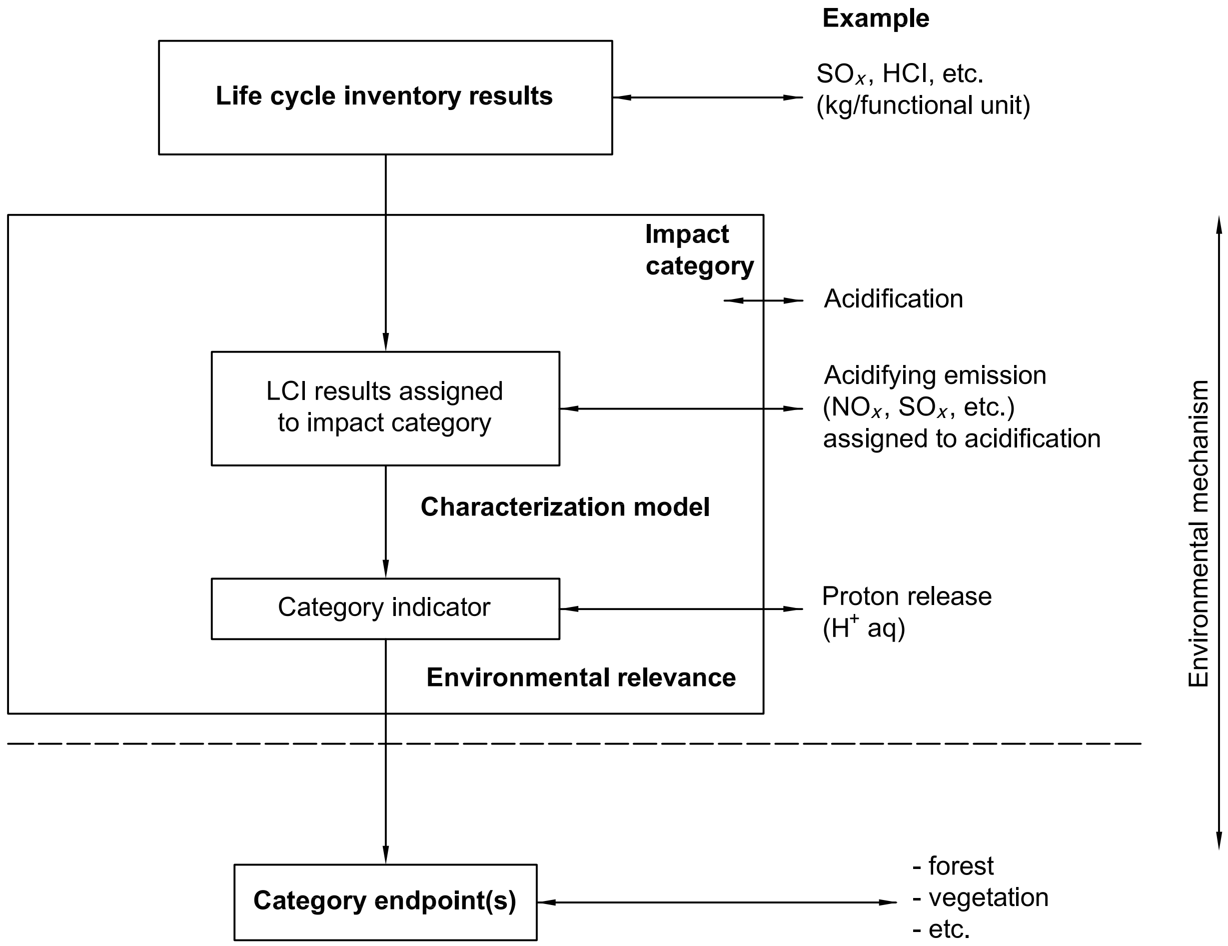


Figure 3 — Concept of category indicators (Figure 2 from ISO 14042:2000)

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.

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

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

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

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** **($m^2 \times$ ppm $\times$ hours/kg emission)**
Indicator result	Kg ozone	Kg ozone	$m^2 \times$ ppm $\times$ 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**.

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;

- 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.

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).

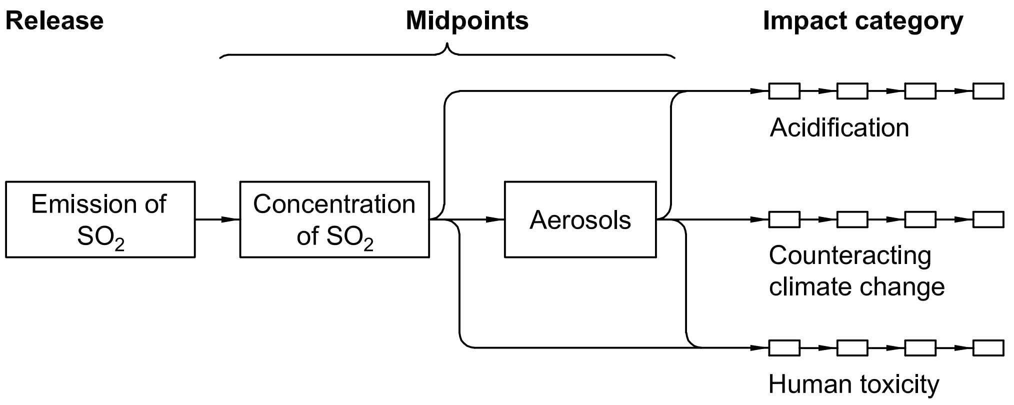


Figure 4 — Example of parallel processes

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).

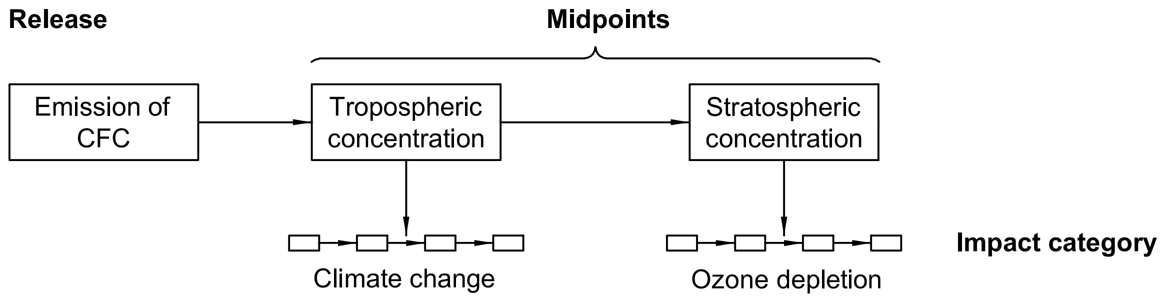


Figure 5 — Example of a serial process

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.

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.

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.

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 20×10^6 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.

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.

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.

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.

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.

Table 10 — Calculation of indicator results of stem example — Material A

Impact category	Substance	Assigned LCI results		Characterization factors		Converted LCI results		Indicator results
		Air emission	Water emission	Air emission	Water emission	Air emission	Water emission	(LCIA profile)
		kg	kg	kg…eq./kg	kg…eq./kg	kg…eq.	kg…eq.	kg eq.
Climate change	Carbon dioxide	4,22E+04		1,00E+00		4,22E+04		1,84E+05
	Bromotrifluoro-methane	1,55E–03		5,60E+03		8,66E+00		
	Methane	6,73E+03		2,10E+01		1,41E+05		
Stratospheric ozone depletion	Bromotrifluoro-methane	1,55E–03		1,20E+01		1,86E–02		1,86E–02
	Tetrachloro-methane			1,20E+00				
Photo-oxidant formation	Methane	6,73E+03		6,00E–03		4,04E+01		6,95E+01
	Ethane	1,94E+02		1,23E–01		2,39E+01		
	Propane	2,97E+01		1,76E–01		5,23E+00		
Acidification	Sulfur dioxide	3,06E+02		1,00E+00		3,06E+02		3,51E+02
	Ammonia	8,76E–02	5,44E–01	1,30E+00		1,14E±01		
	Nitrogen dioxide	1,11E+02		4,10E–01		4,53E+01		
Eutrophication	Ammonia	8,76E–02	5,44E–01	3,50E–01	3,30E–01	3,07E–02	1,79E–01	1,85E+01
	Nitrogen dioxide	1,11E+02		1,30E–01		1,44E+01		
	Phosphorus		1,22E+00		3,10E+00		3,79E+00	
	Nitrogen		4,05E–01		4,20E–01		1,70E–01	
Human toxicity	Sulfur dioxide	3,06E+02		9,60E–02		2,94E+01		1,81E+04
	Nitrogen dioxide	1,11E+02		1,30E+00		1,44E+02		
	Arsenic	2,47E–02	4,14E–02	3,48E+05		8,58E+03		
	Lead	4,72E–01	1,16E–01	4,67E+02		2,20E+02		
	Nickel	1,57E–01	1,05E–01	3,50E+04		5,51E+03		
	Vanadium	5,72E–01	1,03E–01	6,24E+03		3,57E+03		
Ecotoxicity	Phenol	9,40E–05	1,15E–01	1,50E+00	2,37E+02	1,41E–04	2,73E+01	1,66E+02
	Cadmium	1,64E–02	1,56E–03	2,89E+02	1,52E+03	4,73E+00	2,38E+00	
	Lead	4,72E–01	1,16E–01	2,40E+00	9,62E+00	1,13E+00	1,11E+00	
	Chromium	3,23E–02	2,08E–01	1,90E+00	6,90E+00	6,14E–02	1,43E+00	
	Copper	3,54E–02	1,04E–01	2,22E+02	1,16E+03	7,84E+00	1,20E+02	
NOTE E plus following number indicates exponent (power of 10).								

Table 11 — Calculation of indicator results of stem example — Material B

Impact category	Substance	Assigned LCI results		Characterization factors		Converted LCI results		Indicator results
		Air emission	Water emission	Air emission	Water emission	Air emission	Water emission	(LCIA profile)
		kg	kg	kg…eq./kg	kg…eq./kg	kg…eq.	kg…eq.	kg eq.
Climate change	Carbon dioxide	4,81E+03		1,00E+00		4,81E+03		1,46E+05
	Bromotrifluoro-methane	4,30E–04		5,60E+03		2,41E+00		
	Methane	6,75E+03		2,10E+01		1,42E+05		
Stratospheric ozone depletion	Bromotrifluoro-methane	4,30E–04		1,20E+01		5,16E–03		5,75E–03
	Tetrachloro-methane	4,90E–04		1,20E+00		5,88E–04		
Photo-oxidant formation	Methane	6,75E+03		6,00E–03		4,05E+01		7,01E+01
	Ethane	1,98E+02		1,23E–01		2,44E+01		
	Propane	2,99E+01		1,76E–01		5,26E+00		
Acidification	Sulfur dioxide	1,83E+01		1,00E+00		1,83E+01		2,50E+01
	Ammonia	8,01E–03	1,23E–01	1,30E+00		1,04E–02		
	Nitrogen dioxide	1,64E+01		4,10E–01		6,72E+00		
Eutrophication	Ammonia	8,01E–03	1,23E–01	3,50E–01	3,30E–01	2,80E–03	4,04E–02	2,42E+00
	Nitrogen dioxide	1,64E+01		1,30E–01		2,13E+00		
	Phosphorus		5,41E–02		3,10E+00		1,68E–01	
	Nitrogen		1,80E–01		4,20E–01		7,54E–02	
Human toxicity	Sulfur dioxide	1,83E+01		9,60E–02		1,76E+00		4,73E+02
	Nitrogen dioxide	1,64E+01		1,30E+00		2,13E+01		
	Arsenic	1,92E–04	1,90E–03	3,48E+05		6,68E+01		
	Lead	3,62E–03	4,93E–02	4,67E+02		1,69E+00		
	Nickel	6,40E–03	6,77E–03	3,50E+04		2,24E+02		
	Vanadium	2,51E–02	5,36E–03	6,24E+03		1,57E+02		
Ecotoxicity	Phenol	9,00E–06	1,54E–02	1,50E+00	2,37E+02	1,35E–05	3,65E+00	4,76E+00
	Cadmium	1,75E–04	1,47E–04	2,89E+02	1,52E+03	5,06E–02	2,24E–01	
	Lead	3,62E–03	4,93E–02	2,40E+00	9,62E+00	8,70E–03	4,74E–01	
	Chromium	3,54E–04	1,02E–02	1,90E+00	6,90E+00	6,73E–04	7,04E–02	
	Copper	1,27E–03		2,22E+02	1,16E+03	2,81E–01		

NOTE E plus following number indicates exponent (power of 10).

From these results it can be concluded that pipes of Material A yield a higher environmental impact for most of the selected impact categories than do pipes of Material B; only for photo-oxidant formation do they yield about the same result. However, it should be noted that chlorinated organic trace pollutants are not taken into account quantitatively (see Note in Table 9).

The above results are not presented in graphical form on purpose, as this is completely dependent on the units chosen. Such a representation only provides meaningful results after normalization, when the results are converted into common units.

6.3 Example 2 – Two acidification impact category indicators

6.3.1 ISO 14042:2000, 5.1 General — Overview — Examples illustrating the effect of selecting different acidification impact category indicators

The example illustrates the importance of ISO 14042 recommendations and the criteria for environmental relevance by comparing two very different indicators (see Table 12). There are very significant differences between the indicator results, e.g. over 700-fold difference between sites (Table 13) even when the same inventory results are used. Such differences are important to consider during the goal and scope definition, in order to fulfil the purpose of the study and to understand the inventory data that need to be collected.

6.3.2 ISO 14042:2000, 5.2 Concept of category indicators

Due to the focus on a single impact category, an illustration of 5.2 of ISO 14042:2000 is omitted. For guidance, see the other examples and the text of ISO 14042.

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

6.3.3.1 Describing the environmental mechanism for an impact category

Two choices for acidification are used. The first alternative is an impact category for the total emission burden or load of acids and acid precursors to the environment. The single impact category combines, through its category indicators, several separate effects using value choices, e.g. aquatic impacts, terrestrial impacts, and deterioration of materials in buildings and other structures. The category indicator in Example 2 reflects the system environmental burden, in this case the total flow of possible acid emissions crossing the system boundary. The indicator provides only the total emissions or inventory outputs crossing the product system boundary as proton equivalents; it provides no information on the environment itself, e.g. condition, intensity of impact, reversibility, etc.

The second alternative uses the area where the critical capacity of the environment is exceeded, which is linked to possible effects on terrestrial plants. The characterization model is intended to provide environmentally relevant information and:

- uses the spatial location of inventory emissions in the environment;
- characterizes the degree and rate of conversion of each emission to acid in the environment;
- characterizes each acid’s spatial transport to different receiving locations in the environment, and
- characterizes the area of sensitive ecosystems at each receiving location where the critical neutralizing capacity is exceeded by the deposited acid.

A simplified environmental mechanism for acidification is shown in Figure 6, depicting the flow of emissions across the product system boundary, their conversion to different acids, their dispersion to remote spatial locations, their deposition as acids in spatially remote locations by several paths, and, if the critical capacity of the soil to neutralize acids is exceeded, the effects on terrestrial plants.

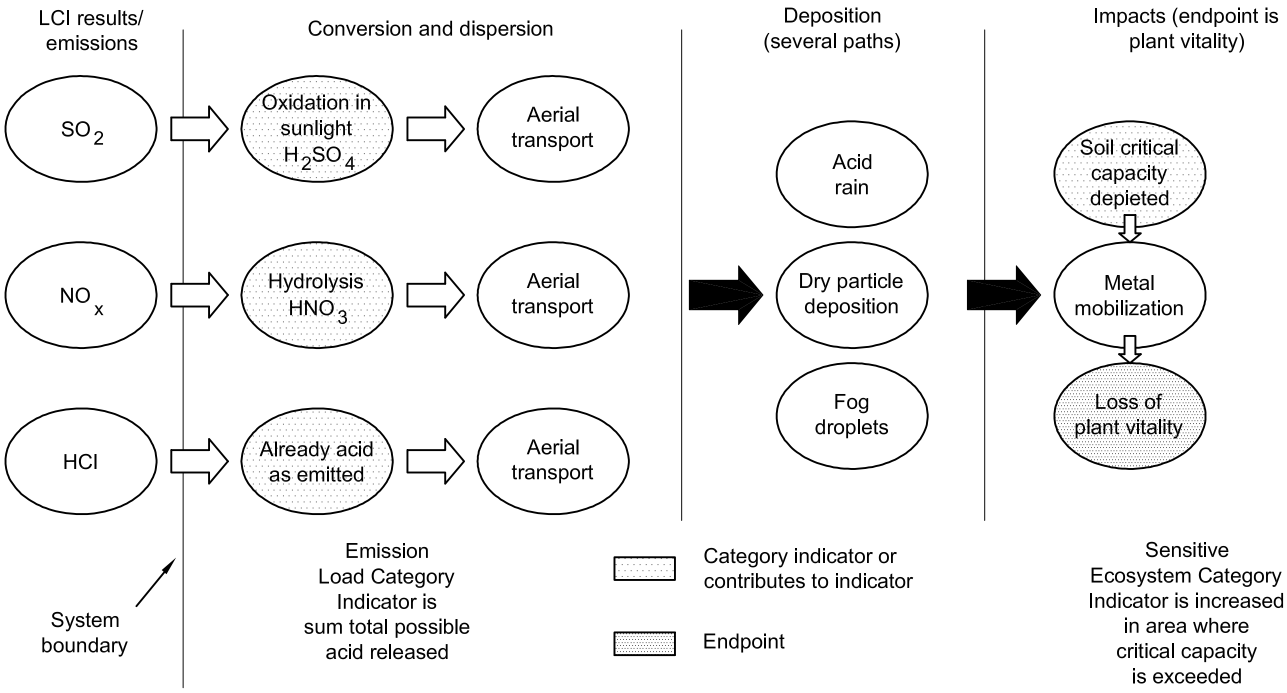


Figure 6 — Simplified environmental mechanism for acidification

Table 12 — Comparison of 14042 recommendations and criteria for EL and SE indicators

ISO 14042 Notes	EL Indicator	SE Indicator
LCI Results – Both indicators use the same LCI parameters, but spatial detail needed for SE indicator		
ISO 14042:2000, 5.3.4		
Spatial and temporal differentiation of the characterization model relating the LCI results to the category indicator should be considered	No spatial or temporal differentiation	The geographical location of releases from the inventory and the location of sensitive receiving locations are both utilized.
Fate and transport of the substances should be part of the characterization model	Assumes only 100 % conversion to acid	Calculates the conversion, transport and deposition from each source location to each of the many different receiving areas.
ISO 14042:2000, 5.3.5		
Reflect the consequences of the LCI results on the category endpoint(s), at least qualitatively	Strictly the amounts emitted	The ability to relate the acid load in each receiving area to critical neutralizing capacities in the receiving areas and whether the critical capacity is exceeded. This is the area where negative consequences are likely.
Condition of the category endpoint(s)	No information provided	In the area where the critical capacity to neutralize acids is exceeded, negative conditions are implied.
Spatial aspects, such as the area and scale	As noted above, no spatial or temporal differentiation	The ability to calculate the marginal increase in the area where the critical capacity is exceeded. This relates to the damage to which a system may be contributing.

Table 13 — Characterization factors for several substances and countries according to the SE model

Country	AF(SO_2)		AF(NO_x)		AF(NH_3)		AF(HCl)	
	ha/tonne	m^2/g	ha/tonne	m^2/g	ha/tonne	m^2/g	ha/tonne	m^2/g
Albania	0,02	0,0002	0,00	0,0000	0,01	0,0001	0,00	0,0000
Belgium	1,28	0,0128	0,82	0,0082	1,10	0,0110	0,02	0,0002
Denmark	5,56	0,0556	2,02	0,0202	5,28	0,0528	0,06	0,0006
Finland	15,14	0,1514	2,42	0,0242	13,40	0,1340	0,07	0,0007
Germany	2,17	0,0217	0,90	0,0090	1,89	0,0189	0,02	0,0002
Netherlands	1,24	0,0124	0,97	0,0097	1,55	0,0155	0,03	0,0003
Portugal	0,02	0,0002	0,01	0,0001	0,01	0,0001	0,00	0,0000
United Kingdom	1,94	0,0194	0,92	0,0092	4,32	0,0432	0,03	0,0003

The location of two different indicators in the environmental mechanism is shown. The steps below are described to illustrate the differences in these indicators.

a) Emissions or outputs crossing the system boundary

Acidification begins with the emission of compounds such as NO_x, NH_3 and SO_2. These emissions are LCI inventory results or outputs that flow across the system boundary to the environment. NO_x, NH_3 and SO_2 are not emitted as acids and are converted to acids in the environment. Other emissions, such as hydrogen chloride (HCl), are emitted directly as acids and need no conversion.

b) Conversion, dispersion and deposition

NO_x, NH_3 and SO_2 are converted to acids in the atmosphere and undergo long-range transport and dispersion to distant receiving locations several hundred to a thousand kilometres from the emission source. The acids are deposited in remote locations by several possible means (e.g. acid rain, dry particles and fog droplets). Several factors determine the amounts of acid that reach a specific receiving area. For environmental relevance, these factors must be included in spatially specific characterization models, such as taking into account that:

— emission conversion into acid has its own chemical reaction and depends on temperature, weather, etc.;

— transport distance and direction depend on source location, stack height, weather, etc.; and

— deposition depends upon each acid’s characteristics, e.g. particle size, and upon weather conditions, e.g. rain.

NOTE Transport and deposition can be annualized from environmental models for the characterization factors.

c) The role of the receiving ecosystem's critical capacity to neutralize acid

Deposited acids can decrease the pH of the receiving water or soil. The pH decrease depends on the amount of acid deposited from the LCA system, the background acid load from other human and natural sources, and the neutralization capacity of the receiving site. Each site has a given capacity to neutralize acid, i.e. the critical capacity. When the critical capacity of an ecosystem is exceeded, the pH decreases and impacts, such as lost plant vitality, are likely. Likewise, when the critical capacity is not exceeded, acidification impacts do not occur from soil exposure. For environmental relevance, it is then essential to identify when parameters such as the critical capacity or ADIs are exceeded.

Compared to a total emission load indicator, it should be recognized, as seen in Table 14, that:

— only a small percentage of the total emissions are actually deposited in sensitive ecosystems where the critical capacity is exceeded, causing impacts, and

— the percentage of total emissions deposited varies substantially depending upon the spatial location of the emission source and the receiving ecosystem.

Thus, a total emission load indicator which omits or ignores these environmental details will have very different indicator results from a sensitive ecosystem indicator, even when the starting LCA inventory results are the same.

Table 14 — Calculations for indicator results using SE model and comparison of differences

Country	**NO_x** g × AF	**SO_2** g × AF	**Indicator result** m^2	**Relative comparison**	
Dispersion and deposition				**to SE result for Albania**	**to EL result as SO_2 g-equiv.**
Albania	10 × 0,00 = 0	100 × 0,000 2 = 0,02	0,02	1	5 350
Belgium	10 × 0,008 2 = 0,008	100 × 0,012 8 = 1,28	1,29	64	83
Finland	10 × 0,024 2 = 0,242	100 × 0,151 4 = 15,14	15,38	769	7

6.3.3.2 Indicator models and characterization factors

The models and characterization factors for two category indicators are described.

a) Emission-loading category indicator model (hereafter EL indicator)

The EL indicator model characterizes the total emission-load released by the LCA systems using a chemical equivalence calculation. The model omits spatial information on fate, dispersion, or the amount of acid deposited into sensitive areas. The model assumes complete conversion to acid, complete deposition to sensitive regions, and occurrence of environmental effects in every location. These are worst-case assumptions and lack environmental information and relevance (see Table 12). However, some parties often refer to the EL indicator results as “potential environmental impacts”.

b) Acid deposited in sensitive ecosystems category indicator (hereafter the SE indicator)

The SE indicator characterization incorporates spatial aspects and fate and transport and addresses environmental relevance as recommended in ISO 14042:2000, 5.3.4 and 5.3.5 (again, see Table 12). This also illustrates the importance of the goal and scope definition process in Annex A of ISO 14042:2000. The SE model is more complex and includes the emission conversion and dispersion from a given country, the acid amounts deposited in receiving countries, and the area of sensitive ecosystems in the receiving countries whose critical capacity is exceeded. The results of the SE indicator provide information on the environmental performance of the system, while the EL indicator does not.

The SE model adapts the European RAINS model[2)]. The RAINS model uses 150 km × 150 km grids or cells for both emissions and receiving ecosystems. These cells allow the mathematical accounting for emissions from each cell, the percentage conversion to acid, transport and deposition from each source cell to each possible receiving cell, the different areas and their critical capacities of soils within each receiving cell, etc.

2) RAINS is an integrated assessment model that combines information on national emission levels with information on long-range atmospheric transport in order to estimate patterns of deposition and concentration for comparison with critical capacities and thresholds for acidification, terrestrial eutrophication-via-air and tropospheric ozone creation.

The LCA adaptation converts the cells to countries, so the inventory need only record the source country of an emission. Each country has a characterization factor (e.g. AF_{NO_x} and AF_{SO_2}, see Table 13) to calculate for each emission its conversion to acid, its transport and deposition, and then calculate the area at each receiving site for which the critical capacity is exceeded. Each emission is converted, using the characterization factor, from kilotons (or grams) of emission to the increased area in hectares (or square metres) for which the critical capacity is exceeded. For the complete derivation of the SE indicator, see [24].

c) Selection of the characterization model and characterization factor

The EL indicator results are expressed as proton equivalents or grams of a major emission, usually SO_2. The conversion and combination of acids is scientifically valid and contrasts with attempts to combine different human toxicities. Combining different human toxicities has been described as a subjective or value-choice score like combining global warming, acidification, and eutrophication [25]. For the EL indicator, the necessary LCI parameters are direct acids, such as hydrochloric acid, and substances possibly converted to acids, such as sulfur dioxide, nitrogen oxides, and ammonia. The characterization factors for several substances (in addition to those in the simplified inventory calculations below) are: 0,88 for HCl emissions, 1,00 for SO_2, 0,80 for SO_3, 0,70 for NO_x, 0,70 for NO_2 and 1,88 for NH_3.

The SE indicator is expressed in hectares or square metres of area in which the increased load of the LCA increases the deposition above the critical capacity (a marginal increase in the area in which the critical capacity is exceeded). The characterization factors for several countries with their spatially specific characterization factors (e.g. AF_{NO_x} and AF_{SO_2}) are given in Table 13, which clearly shows how spatial differences result in large differences in the characterization factors. For the acid SE category indicator, the collection of LCI parameters is more detailed. In addition to the hydrochloric acid, sulfur dioxide, nitrogen oxides, ammonia, etc., noted above, the region in which each emission takes place shall be recorded.

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

Illustration of ISO 14042:2000, 5.4, is omitted. For guidance please refer to the other examples and to the text of ISO 14042:2000.

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

This subclause calculates category indicator results for the EL indicator and the SE indicator. The outcomes, expressed as indicator results, can differ significantly depending upon the location of the emission source in relation to sensitive receiving areas (see Table 14). This reinforces the need to carefully evaluate choices in the goal and scope definition, and reinforces the statement in ISO 14042:2000 that:

> *"The usefulness of the indicator results for a given goal and scope depends on the accuracy, validity and characteristics of the characterization models and characterization factors. ... A trade-off often exists between characterization model simplicity and accuracy".*

The inventory is highly simplified, using only NO_x and SO_2, and is based on the electrolytic refining of primary copper. The details of the mining, the drawing of copper wire, the production of polyvinyl chloride (PVC) coating, the disposal and recycling of the wire with incineration of PVC are omitted. The functional unit is a kiloton (kt) of copper produced by electrolytic refining, and the parameters used are 10 g of NO_x and 100 g of SO_2. Identical processes and the same quantities of emission are assumed to exist in three different locations. For the EL model, a straightforward calculation is made using chemical characterization factors. For the SE model, the production process is calculated for three different emitting locations (Albania, Belgium and Finland). The example calculations for the EL indicator results are:

$$10 \text{ g NO}_x \times 0{,}70 = 7 \text{ g SO}_2 \text{ equivalents / kt copper, and}$$

$$\frac{+\,100 \text{ g SO}_2 \times 1{,}00 = 100 \text{ g SO}_2 \text{ equivalents / kt copper}}{= 107 \text{ g SO}_2 \text{ equivalents / kt copper}}$$

Thus, whether the smelter was in Albania, Belgium or Finland, the same total burden is released and EL indicator results would be the same: 107 g- SO_2 equivalents/kt of electrolytically refined copper.

The calculations on a site-dependent basis for the SE indicator result are shown in Table 14. The characterization factors are country-specific, so that the indicator results for the same quantities of emissions now vary considerably (from 1 to 769) depending on where the emission took place. This difference in sensitivity of the receiving regions is not taken into account in the EL indicator, which represents the full potential impacts. Further, only a percentage of the total emission load represented by the EL indicator deposits in areas where the critical load is exceeded. For comparison, then, the number of SO_2 g-equivalents/kt copper from each country deposited in areas where the critical load is exceeded is compared to the 107 SO_2 g-equivalents/kt copper obtained from the EL indicator results.

The two models yield results that are dramatically different! This clearly illustrates the effect of category model and indicator choices between a study goal and scope that needs only general screening results (EL indicator) and one that needs accuracy and environmental relevance (SE indicator).

When using the EL indicator results in the Interpretation phase, a lower level of total emissions from Belgium would at first appear to be environmentally “better” than a somewhat higher level of total emissions from Albania. However, the environmentally relevant SE indicator clearly shows that emissions from Albania would increase the amount by which the critical capacity is exceeded over a far lower area compared to Belgium. Thus, those making decisions involving important comparisons should consider selecting environmentally relevant indicators whose models incorporate spatial information on the emission source, the destination and transport processes, and sensitive ecosystems.

6.4 Example 3 — Impacts of greenhouse gas (GHG) emissions and carbon sinks on forestry activities

6.4.1 ISO 14042:2000, 5.1 General — Overview

A company, with an integrated system of timberland and diverse forest products, conducts an LCIA with the goal of ascertaining the relative impacts of the issues of climate change on a variety of the corporation's operations, and specifically to ascertain the

— net contribution to greenhouse gases (GHG) from carbon (C) emissions and sequestration and carbon sinks,

— potential for C credits, joint projects or trading,

— allocation of responsibilities among different actors in the product life cycle, and

— opportunities for environmental and economic improvements.

The scope of the study involves a comprehensive approach to identify and quantify not only traditional impact categories and indicators for GHG emission, but also for carbon sinks both in timberlands and along the product system. In that context, the example identifies specific inventory results and transformation models that are an indispensable part of the scope of the study in order to achieve the intended goal.

6.4.2 ISO 14042:2000, 5.2 Concept of category indicators

The example illustrates five major lessons:

a) the need to consider other parameters, in addition to quantification of traditional emissions or resources, through definition of a new impact category. This is necessary in order to meet the goal and scope requirements of the study. Such consideration is anticipated in ISO 14042:2000, 5.3.1;

b) in studies involving biomass and bio-based products, certain transformations within the system boundary have the character of impact categories themselves;

c) indicators result that, when presented in the LCIA results profile, could be additive across impact categories under certain design and selection conditions;

d) information can help ascertain the shared responsibilities of different actors in the product system according to the effects and impacts;

e) the application of LCIA can be expanded to specific company situations for policy and strategic planning.

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

6.4.3.1 General

Subclauses 6.4.3.2 to 6.4.3.6 describe the major steps in the selection of the impact categories. Subclauses 6.4.3.7 to 6.4.3.9 describe the steps in the selection of the indicators, mechanisms and characterization models and factors. By illustration of ISO 14042:2000, 5.4, the procedures to assign LCI results to the impact categories are indicated, and by illustration of ISO 14042:2000, 5.5, (characterization), the indicator results are calculated and the profile generated.

6.4.3.2 Consistency between impact categories and the goal and scope of the study

The goal of the study is to ascertain the relative impacts of the company's various operations on the issues of climate change, in a manner that permits assessing opportunities and consequences of different aspects of domestic legislation and international treaties.

The variety of forest products manufactured by the company can be classified as paper products and wood products. Among the first group are market pulp, printing and writing papers, packaging board and tissue products. Wood products range from lumber to structural wood panels. A variety of engineered wood products, such as MDF, OSB, particleboard, waffle board, etc., are included in the second group. All these products have a common characteristic: their carbon content.

The use of one million metric tons (1×10^6 t) of product carbon content as the functional unit is compatible with the goal of the study, since it facilitates the different calculations in the conversion of inventory results into impact categories and indicators. The selection of impact categories shall be consistent with the characteristics of the system as well as the goal and purposes of the study. In other words, besides the radiative forcing, which is an impact category indicator for GHG emission sources, the study needs an impact category, carbon sequestration sinks, that addresses the impacts of carbon sequestered and stored in sinks that are recognized as desirable tools for improvement. Moreover, since credits, trading and controls are expressed in terms of net values (emissions minus sinks), the impact categories should provide indicator results that, under specific study design conditions, can be added together at the level of the indicator results profile.

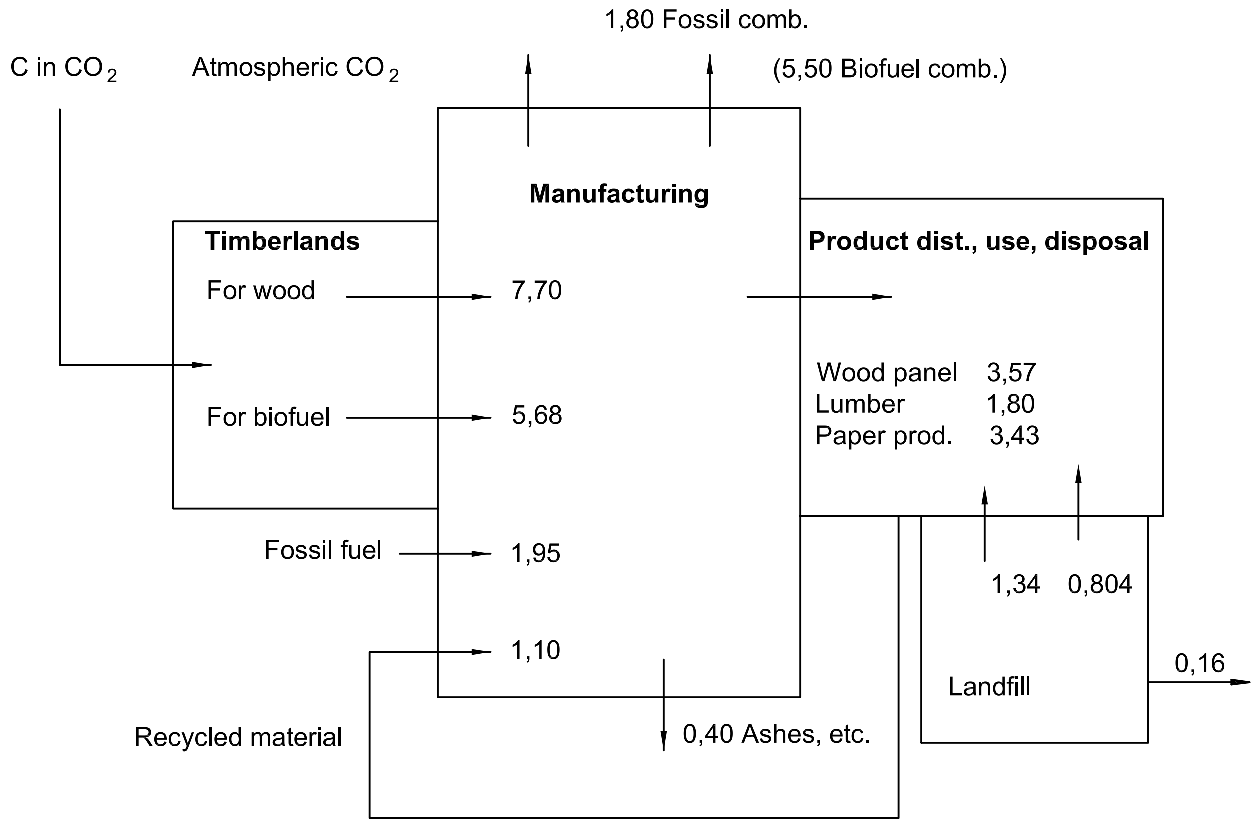
6.4.3.3 Purpose of LCA study and identification of target audiences

The purpose of the LCA study includes gathering the necessary information and data along the product system components that will permit assessment of the net impacts of both GHG emissions and carbon sequestration and storage in carbon sinks. Such assessment would help in decision-making concerning the company’s policies and strategies involving climate change issues. LCIA was considered an additional tool to better understand the inventory issues and information gathered, in terms reflecting the prevailing mechanisms in climate change science and policies [26].

Consequently, the study needs to present information, methods and results in a manner understandable to the company executives responsible for different product lines and administrative functions, while maintaining relevance to climate change terminology and concepts. Additional target audiences are other executives and managers of environmental engineering, government affairs, technology, public relations, production, etc. The original complete study is considered of a confidential nature. In this example, the company’s structure and size at the time of the study are different from those of the company today.

6.4.3.4 Review of the LCI system functions, boundaries and unit processes

Figure 7 presents a simplified schematic diagram of the product system and its boundaries, with some of the production distribution, that will be used and transformed in the characterization step of the LCIA. In terms of carbon (C), atmospheric CO_2 is captured in the timberlands, trees are grown and harvested. Biomass C enters the manufacturing stages either as wood for wood and paper products, or as bio-fuel. C is emitted as CO_2 from the combustion of biofuels and fossil fuels. Products of different natures are manufactured, distributed, used and disposed of. All quantities cited are in annual terms. The example does not address C emissions from fossil fuels in timberland operations, nor in transportation and distribution. These contributions are small in comparison with other contributions.



NOTE For some parts of the system, the arrows represent selected flows (for illustrative purposes). Consequently, for these parts of the product system the inputs and outputs do not add up to the same amount of carbon.

Figure 7 — The product system in terms of carbon (expressed in metric tons $\times 10^6$)

6.4.3.5 Identification of a comprehensive set of environmental issues related to the product system

The goal and scope of the study help define a comprehensive set of environmental issues inherent in the product system. This set shall include both the traditional emissions of anthropogenic fossil fuels and GHG, as well as those reflecting sequestration of C from atmospheric CO_2 and its storage in sinks along the product system. To assess the relative impact of the originally sequestered C along the stages of the product system, it is necessary to quantify specific biomass processing. These quantities will be transformed later during the characterization stage of LCIA. Information is needed on the intended function of the processed biomass, either as biofuels or as different wood and paper products.

Another important environmental issue itself, for the purposes of the goal of the study, is the net growth or balance of carbon sequestered in the forests. This information is provided in terms of merchantable wood and is transformed, by characterization factors, into total biomass C and C-equivalent.

There are also important environmental issues associated with the "net-zero CO_2" mechanism for biomass fuel and the storage in C sinks in forest products. Table 15 provides product functionality information, in accordance with [27] on the biomass processed in accordance with Figure 7.

Table 15 — Functionality of the amounts of processed carbon

Product and functional categories	Percentage	Amount (C) t × 10	Totals t × 10
Biomass			
for combustion as fuels	100 %	5,68	**5,68**
Wood panels for:			
1-family residence	(40 %)	1,44	
multi-family residence	(30 %)	1,07	
upkeep/improvement	(20 %)	0,70	
non-residential use	(10 %)	0,36	**3,57**
Lumber for:			
1-family residence	(30 %)	0,54	
multi-family residence	(30 %)	0,54	
upkeep/improvement	(20 %)	0,36	
non-residential use	(20 %)	0,36	**1,8**
Printing and writing paper	(100 %)	1,43	**1,43**
Other paper/paperboard	(100 %)	2,00	**2,00**
Grand total			**14,48**

6.4.3.6 Selecting the impact categories

According to the above considerations and the goal of the study, it was decided to select two impact categories. We wish to protect the climate against, or minimize, the imbalance created by the anthropogenic GHG and its actions. The inventory results can be assigned to these impact categories. This consideration fits the definitions in ISO 14042:2000, Clause 3. The two impact categories chosen for the study are:

a) climate change with radiative forcing as the indicator;

According to the IPCC, this category reflects the quantifiable imbalance that anthropogenic GHGs create between absorbed sunlight and reflected IR radiation, which is a traditional issue of concern. The inventory results that are needed to initiate the LCIA phase for radiative forcing as an impact category indicator are GHG emissions. They are transformed (via GWP factors) into category indicators and aggregated to yield the category indicator results, metric tons of CO_2-equivalent, or C-equivalent.

b) carbon sequestration and product sinks.

In systems where the resources are biomass, yielding bio-based products and bio-fuels, there is another class of impact category representing environmental issues of concern. This class of impact category is carbon sequestration sinks. Carbon sequestration may be seen as part of the product system. The carbon sinks effects will then be dealt with as part of the inventory analysis and the resulting (negative) CO_2 emissions considered as contributing to climate change. In this example however, the carbon sequestration sink is defined as a separate impact category in parallel with climate change. This impact category can be recognized as one with a reverse sign to the above. The indicator for this impact category is sequestration, because it is recognized that carbon sequestration removes carbon dioxide from the atmosphere and fixes it in carbon sinks in the forest and downstream in the product system.

Both impact categories are linked to the same endpoint: impacts of the change in the balance created by the absorbed and reflected IR radiation.

When considering carbon sequestration sinks as an impact category, the inventory shall look into the timberland as well as into the product system downstream of manufacture. First it is necessary to quantify the C sequestered in the total forest system (or fibre basket) for the company, and not only on the merchantable amount of wood that is transformed into products. The net growth in biomass C, after discounting for harvesting, represents the C sequestered. Once the atmospheric C is sequestered, it remains stored in the timberland and in the products for a period of time, depending on the type of product and the use to which it is put. Since the biomass for fuels was already discounted as part of the harvested amounts, it is easier to understand the “net-zero” CO_2-equivalent emission in the accounting of net C-equivalents.

6.4.3.7 Describing the environmental mechanism for the impact categories

The environmental mechanism is the system of physical, chemical and biological processes linking LCI results to the category indicators and endpoints for a given impact category. The endpoint for the two impact categories is the same; concern about the damage caused because of the change in the balance between absorbed and reflected IR radiations. The difference in the indicator results for the two categories is one of sign. Those increasing the imbalance are negative influences; those reducing the imbalance by sequestration and delaying the effects by storage in sinks are positive influences. The mechanisms in the example link the LCI results to the impact categories and the indicator results through proper characterization models and factors. Two of the mechanisms are conventional, i.e. radiative forcing and photophosphorylation. The other two mechanisms, retirement curves for products still in use, and landfill sinks, are less conventional, but they both are a system of physical processes for the carbon sequestration sinks that link the LCI results to the category indicators. Although expressed in similar units, the mechanisms and the models provide the separation between the LCI and the LCIA phases of the LCA.

6.4.3.8 Selection of indicators

The indicators for the two impact categories were considered to be tons of CO_2-equivalent or tons C-equivalent. The LCI results expressed in tons CO_2 can be converted into C-equivalent for the same time frame. Likewise, the LCI results having to do with C sequestration and storage in sinks are convertible into CO_2-equivalent with the proper factors and models. It is important to keep similar time frames for both impact categories. Here, the example uses a time frame of 100 years for the GWP factors, as is normally done. For the product sink, we also use a time frame of 100 years for the time a given fraction of the product remains in use and hence can still be considered a carbon sink[3)].

6.4.3.9 Selection of characterization models and factors

6.4.3.9.1 The IPCC model for radioactive forcing

The characterization model for the radiative forcing impact category is the one used and fostered by the IPCC. The specific IR radiative forcing for different GHGs permits expressing different GHGs in a common unit, normalized to the value of 1,00 for CO_2. The GWP, as characterization factors, permits different GHGs to be aggregated and expressed in C-equivalent units. IPCC recommends a time frame of 100 years. If the time frame is changed to 500 years or infinity, the methane GWP factor will be reduced considerably. Table 16 gives the GWP characterization factors for the three major GHGs in the example. Nitrous oxides from fuel combustion are negligible and are not included in this example.

3) According to ISO 14042:2000, Clause 5, the modelling of one of the impact categories also includes processes in the product system such as sequestration in timberlands and wood products.

Table 16 — GWP factors

Greenhouse gas	Atmospheric lifetime years	GWP factor (100-year time frame)
Carbon dioxide (CO_2)	50 to 200	1
Nitrous oxide (N_2O)	120	310
Methane (CH_4)	12 ± 3	21

6.4.3.9.2 The Calvin-Benson model for carbon sequestration sinks

The characterization model for the carbon sequestration impact category consists of two phases. In the first phase, sunlight energy is converted by photophosphorylation into adenosine triphosphate (ATP) and the co-enzyme NAPDPH, both energy-rich molecules. In the second phase, the Calvin-Benson cycle fixes the atmospheric CO_2 into organic substances, making use of the converted sunlight energy.

The characterization factor that is used with the model converts the net C (T_C) biomass growth/year from the inventory results (expressed as merchantable wood) to gross biomass growth/year, T'_C by multiplying this value by a biomass/merchantable factor. This factor was derived for specific tree species and regions, and equals 1,70. In addition, another correction factor is used to account for the estimated 25 % of biomass left as residues in the forest.

Merchantable wood × 1,70 = total biomass T_C

$T_C \times 0{,}75$ = useful biomass

6.4.3.9.3 Characterization model for the storing of sequestered carbon in product sinks

To estimate the amount of C-equivalent that can be considered in storage in sinks, an estimate is needed of the rate at which the forest products (and carbon) are withdrawn from use in each end-use sink, according to the functionality of the product. Row and Phelps [27] have developed a characterization model that uses a retirement curve to estimate the proportion (%) of wood products remaining in the end-use sink[28]. It is based on the half-life average and the functional use of the specific product. The Internal Revenue Service (IRS) of the U.S. Department of Treasury generates half-life estimates for a variety of products, according to functional categories such as single-family dwelling, multi-family dwelling, etc. Logically, different kinds of wood products can thus be classified into one given functional category.

The time that a wood product remains in use (t) is determined largely as function of the average useful half-life (L) and the proportion (P) of that product remaining in the sink at a given time. The selected t of 100 years exceeds the higher half-life average value of 67 years. The selection also reflects the 100 years horizon selected for the GWP factors. In this manner, the indicator results from the two impact categories will not only be expressed as C-equivalents, but also in the same time horizon. t and P are expressed as:

$$t = f(L, P)$$

where $P = 0{,}5 / [1 + 2(\ln t - \ln L)]$

6.4.3.9.4 Refining the characterization model and factors

One way to account for recycling is by means of characterization model expressed by an equation developed at the USDA's Forest Service[28]. The official *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* uses these equations and half-life values as indicated in their latest report[29]. The effect of the equation is to extend the useful half-life of the C stored in a particular product end-use sink. (In other words, the equation extends the range of the numbers given in the IRS tables and consequently increases the value of the characterization factors).

The equation is given by the expression below:

$$L_r = L/(1 - R)$$

where

L_r is the revised expected half-life;

L is the original half-life and;

R is the proportion of product being recycled into the same product category.

Recycling has the beneficial effect of increasing the characterization factors and thus the C-equivalent in the sink. Its effect is more pronounced in the recycling of products with long half-lifes.

6.4.3.9.5 Characterization model for biomass fuels — Net-zero C

The characterization model that describes the net-zero C emitted when burning biomass fuel is typically a recycling model, in which CO_2 from the atmosphere (and its C expression) are sequestered by the photosynthesis process described in the Calvin-Benson model. Neglecting C^{12} and C^{13} considerations, the CO_2 emissions from the combustion are considered equal to those already sequestered and those that will be subsequently sequestered. This is different from the CO_2 emissions of fossil fuel that result from the use of C from long-term carbon sinks rather than from the atmosphere. The characterization factor used is 0.

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

A brief description of the classification of LCI results into impact categories is given in Figure 8. The classification stage cannot be completed until there is reasonable certainty of the availability of adequate characterization models and factors. They will yield indicator results to be described in the indicator results profile.

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

6.4.5.1 General

Characterization involves the conversion of the LCI results (million tons C per year) into common units using the characterization factors derived according to the characterization models. A simplified version of the necessary calculations, grouped according the two impact categories, is presented below. Table 17 provides a summary of the calculations leading to indicator results. P_C is the proportion of carbon in the annual production of different forest products, e.g. solid wood and paper, in million tons C per year. P_l is the proportion of carbon in the same types of product which is estimated used as landfill in a year. P_f is the proportion of carbon in the product biomass fuel used in a year. The following matrix indicates the LCI results, characterization factors and indicator results for the different impact categories and indicators.

6.4.5.2 C sequestration and sinks and net-zero for biomass fuel

T'_C indicates the gross biomass growth per year in million metric tons C per year. P'_f is the product biomass fuel carbon emissions, in million metric tons per year, that yields a net zero. P'_C refers to the product carbon remaining in storage, expressed in million tons carbon per year. It is subdivided according to the functionality of the different forest products.

6.4.5.3 C emissions from fossil fuels and methane from landfill

$F'f_C$ addresses the fossil fuel carbon emissions, in millions tons per year. The term L'_C refers to the carbon estimated going to landfills from the total annual production of the company, in million metric tons. This element of the characterization stage is the weakest in accuracy and more work is done to improve its reliability both in the US EPA model and database. Besides a net zero contribution from CO_2 releases, there is a methane contribution that is part of the radiative forcing impact category. The characterization models and factors are both IPCC and US EPA.

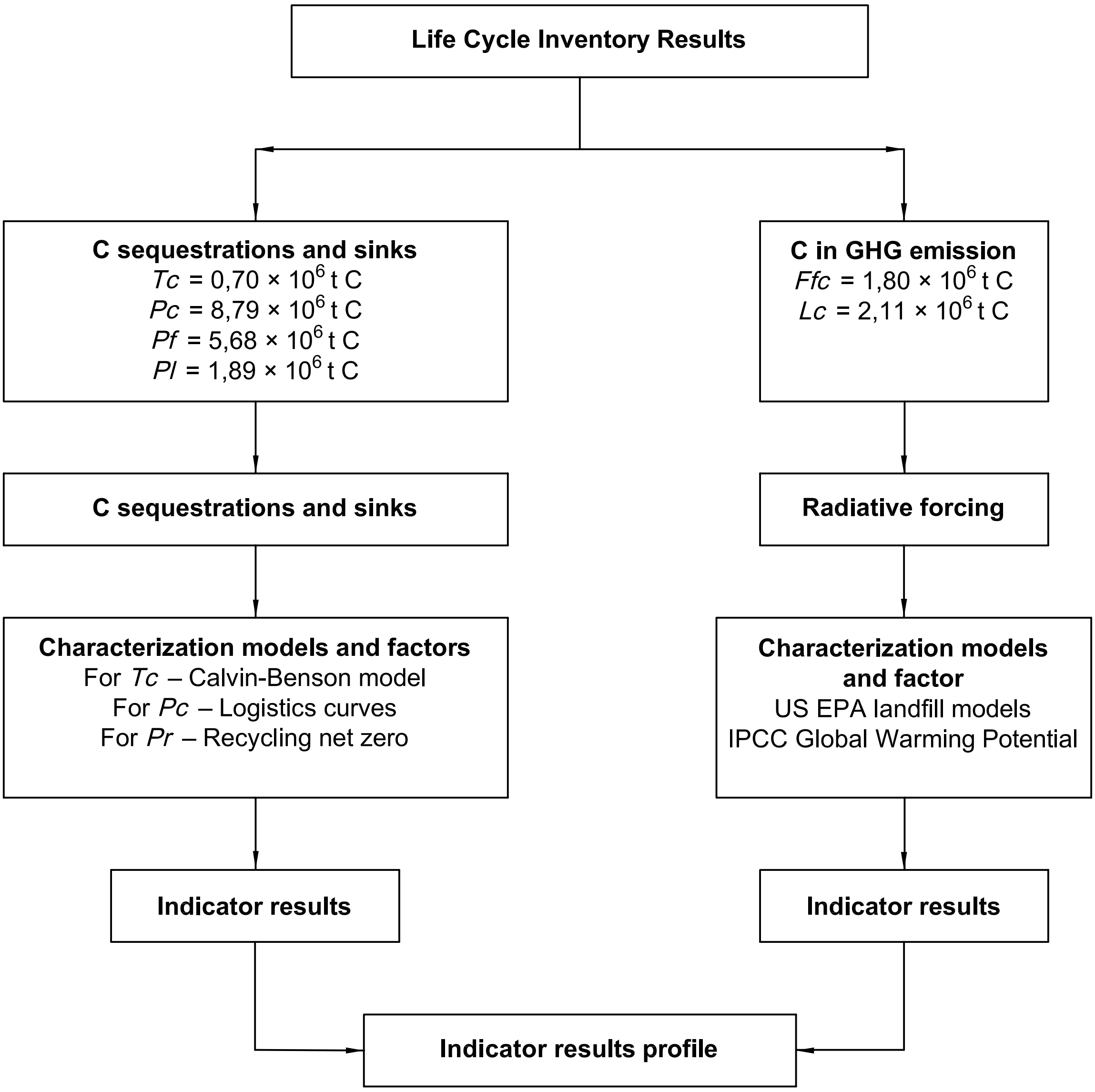


Figure 8 — Schematic of the LCI results assigned to impact categories

Table 17 — Calculation of indicator results

LCIA Indicator	LCI result t C × 10^{-6}	Characterization factors	Indicator results[a] t C-eq × 10^{-6}
$T'c$	**0,70**	**× 1,70 × 0,75**	**0,89**
$P'f$	**5,68**	**Net zero**	**0,00**
P'_C	**9,23**	Various (see below)	**1,49**
Wood panels for:	**3,56**		**0,81**
• 1-family dwelling	1,44	0,25	0,36
• Multi-family dwelling	1,07	0,20	0,24
• Upkeep/improvement	0,70	0,15	0,11
• Non-residential	0,36	0,27	0,10
Lumber for:	**1,80**		**0,39**
• 1-family dwelling	0,54	0,25	0,13
• Multi-family dwelling	0,54	0,20	0,11
• Upkeep/improvement	0,36	0,15	0,05
• Non-residential	0,362	0,27	0,10
Printing and writing papers	**1,80**	**0,10**	**0,18**
Other paper/paperboard	**2,00**	**0,05**	**0,10**
$F'f_C$ **(fossil fuels)**	**1,80**	**1,00**	**1,80**
L'_C **(landfill)**	**2,14**	**21,0 and others**	**1,30**[b]

NOTE In addition to the factor 7,7 for conversion of methane carbon to CO_2 carbon, other conversion factors are used in the US EPA model.

[a] Table 17, Column C equivalents. The table is based on the C amount in the different flows, which for methane would lead to a characterization factor of 7,7 kg CO_2-C/kg CH_4-C. The methane characterization factor of 21, which is applied, is valid for methane as such. The difference has been accounted for.

[b] Table 17, final column, last row. The landfill model calculates the fraction of deposited C which is emitted as CO_2 or CH_4 throughout the existence of the landfill. It is recognised that the landfill model needs improvement.

6.4.5.4 Impact indicator results profile

Table 18 depicts the components of the LCIA indicator results profile (LCIA profile). The results from each impact category are illustrated in terms of the company and the forest products system. This is convenient for two reasons. In the estimation of net growth of C sequestered in timberlands, the company's is only 25 % self-sufficient. The study considers that the remaining 75 % wood fibre supply from small tree farms, etc. reflected similar net growth in the average. This assumption is in line with the trend from regional inventories conducted by state and federal agencies. The second reason is that the methane releases from municipal landfills are part of the forest product system but not of the company. The C-equivalent units for these results are additive, since the C-equivalent on some of the conversions were made compatible for this purpose. In estimating the C-equivalent for the storage in sinks in the product system, 100 years was considered in the logistic curve model. Likewise the IPCC model, for the conversions of methane into C-equivalents, was based on the 100 year time frame. Some research uses a 500 year time frame for the IPCC model. Such an approach lowers the C-equivalent results (for methane the factor will be then 12 rather than 21). If for the product sink model we had used 50 years rather than 100 years, the storage amount would have been higher. These considerations are important to note for the validity of the results.

Table 18 — LCIA profile (per FU)

Impact category	Indicator results			
	Company		Product system	
	t C-eq. × 10^{-6}	per FU	t C-eq. × 10^{-6}	per FU
Radiative forcing				
Manufacturing emissions	**1,80**	**0,195**	**1,80**	**0,195**
Landfill (methane emissions)			**1,30**	**0,141**
C-sequestration and sinks				
Forest	**– 0,88**	**– 0,095**	**– 3,52**	**– 0,381**
Product sinks	**– 1,39**	**– 0,15**	**– 1,39**	**– 0,15**
Net	**– 0,47**	**– 0,052**	**– 1,81**	**– 0,196**

6.4.5.5 Preliminary analysis and conclusions

Internally, the company's management considered the results responsive to the objectives that originated the study. Conclusions and decisions as a result of the study are considered confidential. For the first time, the issues regarding C-sequestration and storage in sinks were put in an LCIA context. The results provide valuable insights on the issues around net GHG emissions, credits, future trading and the role of different actors in the product chain. Other considerations address the issues of validating and apportioning the net growth in C-sequestration from small landowners and from landfill emissions.

The net profile indicated, for the conditions of the study, a positive balance (sinks and net sequestration cancelled and improved on the GHG emissions). Conditions could change without proper incentives. The results emphasize the positive contribution of sustainable commercial forestry and the use of forest products and biomass. In the same manner, the use of fossil fuels has created an imbalance, but the use of biomass products could help regain that balance. Likewise, the need for proper design and construction of public municipal landfills appears of importance and out of the company's hands.

6.5 Example 4 – Assessment of endpoint category indicators

6.5.1 ISO 14042:2000, 5.1 General — Overview

The purpose of this example is to illustrate the use of category indicators at endpoint level when used for internal purposes only in the area of product improvement. The most important reason for choosing the impact category indicator at endpoint level is the high degree of environmental relevance, which makes interpretation and weighting relatively easy in comparison with indicators chosen near the LCI results. The consequence of modelling at endpoint level is that the whole environmental mechanism between LCI results and endpoints must be modelled. This can lead to higher uncertainties and the need to incorporate more value choices, but lower uncertainties in the interpretation of the results. Clearly there is a trade-off between these uncertainties.

The example is based on a study commissioned by the Dutch government that set out to develop a methodology that can be used by designers. Earlier studies had shown that designers benefit from having single scores per material or process that represent the total environmental load. The purpose of calculating single scores[4)] is to provide an easy-to-use tool for product designers to support their day-to-day design decisions (internal applications) in the development of complex products with many components and materials. Such a single score can only be achieved if some form of weighting is used. The example used here does not

4) ISO 14040:1997, 4.1, refers to single scores and how there is no scientific method to reduce LCA results to a single score.

describe the normalization and weighting procedure, but focuses on the implications of developing impact category indicators near the endpoint level. The methodology used here is fully described in [30].

The project from which this example is taken focuses on the European situation. This means all environmental processes are modelled as if the emissions occur in Europe. However, the method could also be developed for other regions, albeit in that case different impact categories may have to be included. In this example there is no specific product system. Instead, the aim is the development of indicators for the most commonly used materials and processes. The companies involved in this project mainly deal with products of non-agricultural origin, such as metals, plastics and glass. In most cases, the environmental analysis of the products reveals a very important contribution from the use phase, especially concerning electricity consumption.

The impact category indicator selected to illustrate the process is ionizing radiation. The example is used to demonstrate how a list of inventory results [in this case expressed in units of becquerels (Bq)] is converted into an impact category indicator, expressed as years of life lost (YLL). The inventory results in Table 19 [31] are taken from data for average European electricity consumption.

6.5.2 ISO 14042:2000, 5.2 Concept of category indicators

With this goal in mind, the approach used here focusses on providing the information for a weighting step, in this case a panel assessment. This particular focus has some very important consequences for the way the LCIA procedure is performed:

— the category indicators are chosen at the level of the endpoints (that is, it is a damage approach). In this way the category indicators have a high environmental relevance and are relatively easy to understand by a panel;

— the number of environmental concerns communicated to the panel has been reduced. This is achieved by developing groups of impact categories in such a way that they have identical units; for instance the category indicators for ionizing radiation and carcinogenic effects are expressed in the same way, i.e. as an impact to human health.

The combined effect of these choices is shown in Figure 9. Eleven category indicators are developed in such a way that they can be expressed in one of the three common units. The three units are chosen to reflect environmental concerns at endpoint level.

This example is only concerned with impacts on human health. The impacts on human health are established in two steps. The first step is the characterization step. For the different impact categories that affect human health, the indicator results are expressed in terms of YLL (see above) and DLY(disability life years). The next step is to combine different disabilities or premature death into a single indicator that expresses damage to human health in terms of disability-adjusted life years (DALYs). This can only be done if the environmental models for impact categories relating to human health include fate (final result) and exposure (subjection to the hazard) analysis, as well as for all the relevant types of disease, the YLL and the DLY This conversion of DLY and YLL into DALY implies a weighting between the different types of disability and between these disabilities and premature death.

The last step in the full procedure applied in this example is to combine the different results concerning resources, ecosystem quality and human health into a single score, as indicated in 6.5.1 This second step is a weighting process and is not used in the present example.

The present example thus only involves the characterization step concerning the establishment of YLL, focusing on the impact category indicator, ionizing radiation. These units (YLL) will not cover all aspects related to human health. In particular, the DLY are not included. The disadvantage of this characterization approach for the impacts on human health is that it does not include weighting. The full procedure is described in [30].

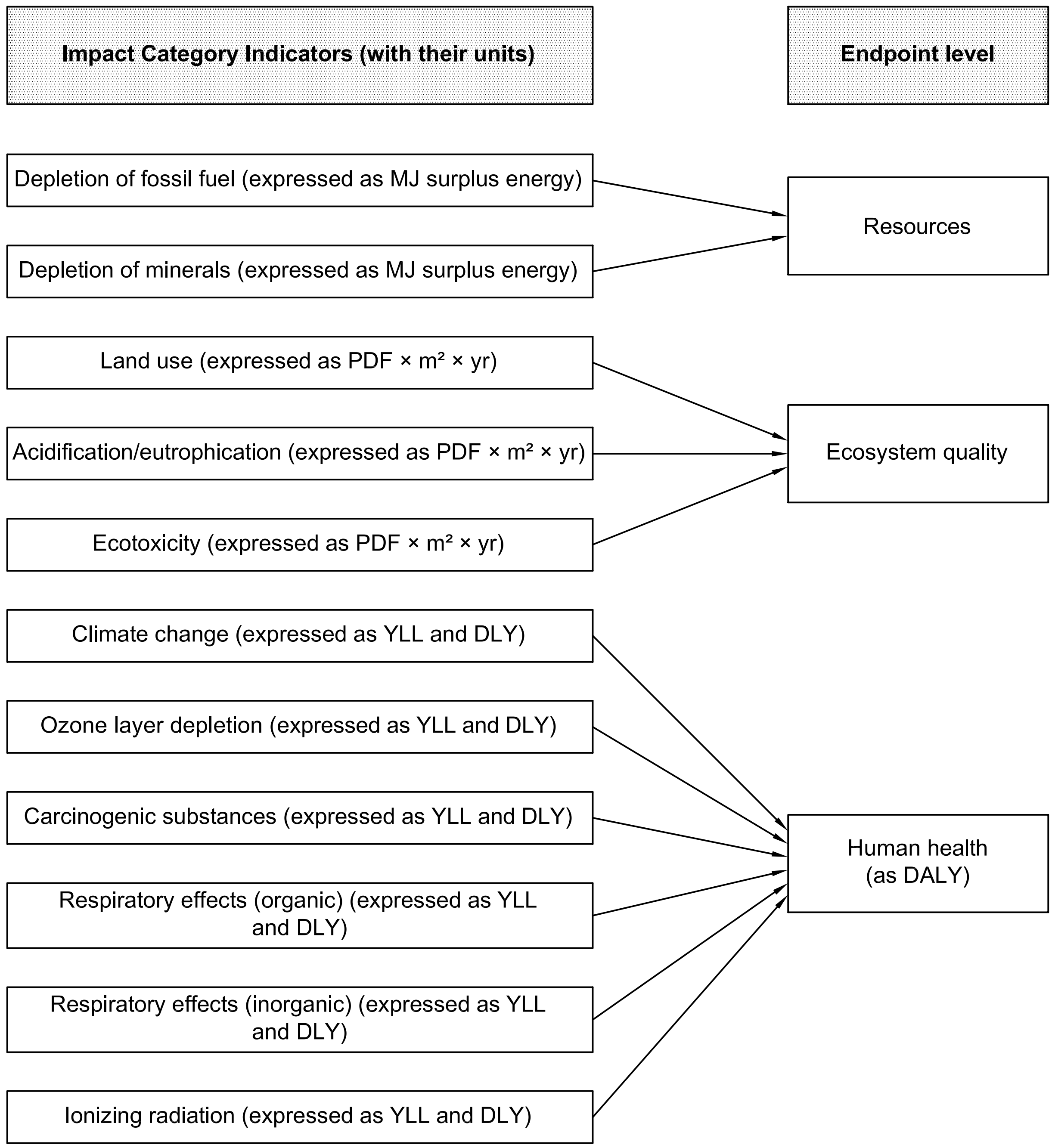


Figure 9 — Schematic overview of impact category indicators and their strong association with endpoints in this example (weighting procedure not explained)

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

6.5.3.1 Selection of impact categories

6.5.3.1.1 General

In this example, the selection of impact categories is based on the following considerations:

— an impact category must represent a real environmental problem in Europe. This means it must contribute significantly to the issues in the three groups of endpoints. The most important data have been obtained from the European Environmental Agency;

— the impact categories are chosen in such a way that they can be sufficiently detailed, consistent and homogeneous. For instance this involves splitting “Human health” into categories such as Carcinogenic effects, Respiratory effects from inorganic substances and Respiratory effects from organic substances (sometimes referred to as summer smog).

For the procedure as a whole, eleven impact category indicators are defined (see Figure 9). Unfortunately, not all impact categories that are considered relevant have actually been made operational yet. According to the above criteria, the most important missing links between impact categories and category endpoints are probably:

— human-health damage due to noise (especially traffic);

— ecosystem quality damages due to climate change and increased UV radiation.

Other links can be regarded as very uncertain, in particular the relationship between climate change and human health indicators.

The following emissions are now considered for the impact category, ionizing radiation:

Table 19 — LCI results for ionizing radiation

Isotope	Compartment	LCI result amount Bq
Cs-137	Water	1,42
Rn-222	Air	1 770
C-14	Air	1,85
Co-60	Water	0,67
Cs-134	Water	0,155
Kr-85	Air	113 000
Ra-226	Water	55,7
H-3	Water	4 540
I-129	Air	0,006 56

6.5.3.1.2 Ensuring consistency between impact categories and the goal and scope of the study

Following the weighting step, which occurs later in the procedure, the results consist of single scores. This weighting is not included in the present example. The single scores are supposed to express the load to “the environment”, in the way this term is understood by the general public (and by customers of the companies involved). In the original methodology report, the term “environment” and the relation with the endpoints is defined explicitly. As the results for YLL directly contribute to the development of the single scores concerned, the selection of indicators is consistent with the goal of the study.

The environmental problems as they are apparent in Europe have been used as starting point, Figure 9.

6.5.3.1.3 LCA study purpose and use in identifying target audiences

The purpose of calculating single scores is to provide an easy-to-use tool for product designers to support their day-to-day decisions when designing complex products, and is used for internal applications only.

6.5.3.1.4 Reviewing LCI system functions, boundaries and unit processes

An important and deliberate limitation in this example is the assumption that emissions occur somewhere in Europe. An exception applies for emissions related to climate change, ozone-layer depletion and some persistent carcinogenic and radioactive substances; for these emissions, the location is irrelevant. Without this assumption it would be impossible to make meaningful fate and exposure calculations (see also description of ISO 14042:2000, 5.2).

6.5.3.1.5 Identifying a comprehensive set of environmental issues related to the product system

The key issues in this example are the environmental impacts from energy conversions that relate to routine emissions of ionizing substances from nuclear fuel cycles.

6.5.3.1.6 Selection of impact categories

The impact category selected for this example is ionizing radiation.

6.5.3.2 Selection of category indicator, model and characterization factor(s) for an impact category

6.5.3.2.1 Describing the environmental mechanism for an impact category

The selection of the category indicators at endpoint level implies particular requirements on the selection of processes in the environmental mechanism. The general description of the environmental mechanism for emissions includes, in this case, the following steps:

a) the fate of the substances must be modelled, as damage in general is not caused by total amounts of an emission, but by the concentration of a substance. A particular difficulty is the fact that LCIs cannot specify flowrates, which is usually an input of a fate model. The result of this step is a temporary change in concentrations over a certain area due to the mass loading specified in the LCI results;

b) the next step is to calculate the exposure of humans to this concentration in a given area during a certain period of time. This includes estimates of the density of the human population expected to be affected;

c) for human health, medical statistics form the basis for linking exposure with the occurrence of diseases, and further statistics including data such as age of disease onset, average duration and mortality;

d) the effects indicated in a), b) and c) above are converted into an effect at endpoint level.

Table 20 gives an overwiew of the environmental mechanism for the impact category Ionizing radiation.

Table 20 — Overview of the environmental mechanism of radioactive releases[33]

Phase of the model	Stage in the mechanism	Units
Inventory analysis	Radioactive releases	Bq; Bq/FU
Fate analysis	Transport, dispersion and deposition Contamination in environment	 Bq/kg, Bq/l, Bq/m^2, Bq/m^3
Exposure analysis	Standard characteristics of people Inhalation, consumption of food and water Absorbed dose Effective and average individual dose Collective dose	 m^3, kg, l gray (1 Gy = 1 J/kg) sievert (Sv) /person · Sv
Effect analysis	Dose/response relationship Fatal, non-fatal cancer, severe hereditary effects	Number of cases /person · Sv
Damage analysis	Years of life lost, disability life years, (endpoint)	YLL, DLY NOTE Fatal for cancer.

NOTE The further procedure involves a disability weighting scale, calculation of DALYs on basis of this weighting step, and the subsequent weighting among the impacts on resources, ecosystem quality and human health. These latter steps are, as mentioned above, not included in this example.

6.5.3.2.2 Identifying possible indicators

For ionizing radiation, and in fact for all impact categories relating to human health, YLL is used as the category indicator in the present example. Several other indicator definitions are possible at endpoint level. For human health, these particularly pertain to the DLY, i.e. the average number of years a person lives with a given disability.

6.5.3.2.3 Reviewing needs and criteria for the indicator

For this example, the following needs and criteria are the most relevant (again the example of human health is used):

a) the indicator should be applicable to all impact categories belonging to human health;

b) the indicator should adequately represent the impacts on human health;

c) the indicator should be able to take into account:

- the difference between serious and less serious disabilities;
- the duration of the disability;
- the years of life lost.

If these criteria are not met, important distortions will occur, as for instance the death of an already critically ill person would get the same weight as the death of the mother of a family or a child. By focusing on YLL, the first criterion is fulfilled, and the second in part. The second and third criteria can only be completely fulfilled if DLY are also taken into account as a second criterion.

6.5.3.2.4 Selection of indicator

The YLL indicator is selected because of the possibility of calculating the results on the basis of scientific information, without any weighting. Effects to be taken into consideration are the following:

a) the effect of uncertainty and accuracy

As this example uses a category indicator that is defined at endpoint level, the environmental mechanism is relatively complex and spans a wide range of processes. This can cause considerable uncertainty. For this reason, in each step the uncertainty is documented and where possible, quantified. A distinction is made between:

— data uncertainty;

— uncertainty about the appropriateness and accuracy of the model.

In most impact categories considered, data uncertainty is specified, as squared geometric standard deviation, for all steps in the environmental mechanism and for the resulting characterization factors.

For the example of ionizing radiation, the most important sources of uncertainty are the exposure model, and difficulties to model the hereditary effects. The 95 % confidence interval lies within a range spanning at least one order of magnitude. This may seem quite large, but falls well within the uncertainty ranges of other types of impact on human toxicity.

In addition to these data uncertainties, an important uncertainty is in the appropriateness of the model for the environmental mechanism. To a large extent, these model uncertainties can be seen as value choices, such as:

— the time frame for the integration of exposure to people (independent of data uncertainty); in the present example this is set at 100 000 years;

— the area to be considered in the fate and exposure analysis; in the present example this is Europe;

— the necessary level of evidence for association between low-level radiation and cancer cases and hereditary effects; here the distinction must be made between well-proven and likely association levels, as included in the Risk Principle, and possible not-well-proven effects included in the Precautionary Principle. The Precautionary Principle, as accepted in the Rio conference, applies much less stringent requirements. Here the focus is on the Risk Principle, including well-proven and likely effects.

b) the effect of the environmental relevance and accuracy of the indicator

For this example, the disadvantages of modelling down to the level of endpoints [see a) above] shall be balanced with the advantages of the high level of environmental relevance of the results due to the fact that they are at endpoint level.

6.5.3.2.5 Selection of characterization model and characterization factors

The characterization results for the impact category ionizing radiation are calculated and shown in Table 21.

Table 21 — Calculation of indicator results for Ionizing radiation in terms of YLL

Isotope	Compartment	LCI result Bq	Characterization factor YLL/Bq	Indicator results YLL
Cs-137	Water	1,42	1,94E-10	2,76E-10
Rn-222	Air	1 770	2,83E-14	5,01E-11
C-14	Air	1,85	2,48E-10	4,58E-10
Co-60	Water	0,67	5,13E-11	3,44E-11
Cs134	Water	0,155	1,68E-10	2,60E-11
Kr-85	Air	113 000	1,64E-16	1,86E-11
Ra-226	Water	55,7	1,50E-13	8,37E-12
H-3	Water	4 540	5,30E-16	2,41E-12
I-129	Air	0,006 56	1,10E-09	7,19E-12
Indicator result (YLL)				8,81E-10
NOTE E plus following number indicates exponent (power of 10).				

6.6 Example 5 – Choice of material for a wind spoiler in car design study

6.6.1 ISO 14042:2000, 5.1 General — Overview — Example of selection of impact categories stressing the relationship with goal and scope

Example 5 illustrates a way to use indicators at the endpoint level in a company’s internal product development process. In this example, designers in a company's internal product development process use LCIA as an engineering tool to determine which of two design alternatives has the lower overall impact on the environment. The selection of indicators at the endpoint level facilitates subsequent weighting in monetary terms and the estimation of the significance of the impacts via the approximate damage costs involved[39], [40].

The example used here concerns a choice between Materials A and B for a rear-end wind spoiler of a car. The functional unit (FU) is one wind spoiler. The inventory results are shown in Table 22.

Table 22 — LCI results for the life cycles of a wind spoiler of a car made of two different materials

Impact parameter	LCI result kg/FU	
	Material A	Material B
Material resources		
Al ore	0,854	0
Coal in ground	3,056	0,826
Oil in ground	6,541	9,405
Emissions to air		
Carbon monoxide	0,077	0,107
CH_4	0	0,011
C_nH_m	0,053	0,08
CO_2	30,188	28,605
N_2O	4,44E-03	0,006
NO_x	0,075	0,072
PAH	4,49E-05	3,11E-06
SO_x	0,099	0,051
Emissions to water		
COD	1,79E-06	2,23E-03
N-tot	0	1,64E-05
NOTE E plus following number indicates exponent (power of 10).		

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

6.6.2.1 General

6.6.2.1.1 Guidance and requirements for the selection of impact categories, category indicators and characterization models include the criteria for environmental relevance.

Impact categories, category indicators and characterization models are selected at the endpoint level in order to facilitate damage cost estimations.

6.6.2.1.2 The selection of impact categories and category indicators is shown in Table 23. The category indicators are chosen so that both modelling of characterization factors and determination of weighting factors will be facilitated. An important motive for accepting a choice of indicators at the endpoint level, and the relatively large uncertainty that follows when determining characterization factors, is that the LCIA is used as an engineering tool. The goal is then to improve the likely environmental performance of the product system rather than to improve the performance of the LCIA model in itself. This has the important implication that omitting a significant impact category or characterization model for uncertainty reasons is not as easily done as when just looking at a single model of an environmental mechanism. Omitting an impact category or characterization factor is equal to saying that its impact is equal to zero. Therefore the coverage of impact categories is as complete as possible for all three areas of protection mentioned in ISO 14040, i.e. human health, ecosystem health and natural resources.

Table 23 — Impact categories and category indicators used

Area of protection	Impact category name	Category indicator name	Indicator unit
Human health	Life expectancy	Years of lost life (YLL)	person-year
	Severe morbidity and suffering	Severe morbidity	
	Morbidity	Morbidity	
	Severe harmful effect	Severe harmful effect	
	Harmful effect	Harmful effect	
Ecosystem services	Crop production capacity	Crop production capacity (Crop)	kilogram
	Wood production capacity	Wood production capacity (Wood)	
	Fish and meat production capacity	Fish and meat production capacity (Fish & meat)	
	Base cation capacity	Base cation capacity	H^+ mole equivalents
	Production capacity of water	Production capacity of irrigation water (Irrigation water)	kilogram
	Production capacity of water	Production capacity of drinking water (Drinking water)	
Abiotic resources	Depletion of element reserves	= “element name” reserves	kilogram of element
	Depletion of fossil reserves	Natural gas reserves	kilogram
		Oil reserves	
		Coal reserves	
	Depletion of mineral reserves	= “mineral name” reserves	
Biodiversity	Extinction of species	Normalized extinction of species (NEX)[a]	dimensionless

[a] Normalized with respect to those species extinct as of 1990.

The selection of characterization models is not dealt with here for editorial reasons. When modelling at the endpoint level the number of characterization models becomes very large, often several thousand. However, some characterization factors are given below to illustrate the example.

6.6.2.1.3 For the selection of impact categories, category indicators and characterization models, ISO 14042:2000, 5.3.3 gives a recommendation that:

> *“The impact categories, category indicators, and characterization models should be internationally accepted, i.e. based on an international agreement or approved by a competent international body”.*

There are very few such indicators available today and all are at the intermediate level. However, the selection is made considering what is commonly used in the scientific literature on impact modelling and in literature on enviro-economics.

When selecting category indicators, as in Table 23, double counting is minimized, but there is a risk of double counting any impact that influences ecosystem production capacity via impacts on biodiversity.

The environmental relevance of the category indicators chosen is more or less obvious, since they directly represent areas of protection, i.e. areas where environmental impacts have been experienced.

6.6.2.2 Spatial and temporal differentiation of characterization models

Uncertainty estimates for characterization factors are included, which include fate and transport and account for spatial and temporal variations. If the final sensitivity analysis shows that the uncertainty is too large, local modelling may be undertaken.

6.6.2.3 Stating the environmental relevance of category indicators and characterization models

When selecting category indicators at the endpoint level, the consequences are reflected quantitatively, but with a certain degree of uncertainty.

The characterization models describe global marginal changes in the present state of the environment, when adding an elementary flow unit. The category endpoint reflects the actual condition in the year 2000. This means that there is a variation in the characterization factors, depending on where the emission or resource depletion occurs. This is taken into account by an estimation of the average characterization value and its standard deviation.

The relative magnitude of the changes that are modelled is small. Few product systems can, on their own, induce major changes in the environment. Most toxic elements are treated as trace elements, and local acute toxicity is not included in the models unless they occur in reality.

To know when a characterization model is valid, the type of emission or resource depletion (elementary flow) is specified as well as the type of environment it enters. The elementary flow is defined by giving the substance in question, its source strength and its geographical system boundaries. In this example, the source strength is such that there are no acute local effects close to the emission points. For example when arsenic is emitted it is considered as a trace element, and no acute health effects are assumed to occur. The geographical system borders are global. The type of environment is also global, and is specified in relation to the medium, e.g. air, water or soil, that receives or supplies the substance in question.

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

For this example, classification is not described separately. See Table 25 and [40].

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

6.6.4.1 General

The selection of characterization factors was described in general terms in 5.2.2. The example below illustrates the calculation of category indicator results, which involves the conversion of assigned LCI results to common units and subsequent aggregation into indicator results.

6.6.4.2 Selection and use of characterization factors

The selection and use of characterization factors for some of the inventory parameters are shown in Table 24. For editorial reasons not all LCI results and characterization factors are shown, although they are included in the uncertainty and sensitivity calculations below. The characterization factors not shown may be found in [40].

6.6.4.3 Aggregation of the converted LCI results into the indicator result

Aggregation of the converted LCI results into the indicator result is shown in Table 25. The same indicator values are used as in Table 24, but they are sorted by category indicator name and added for each category indicator.

Table 24 — Characterization factors for selection of inventory parameters given in Example 1

Substance	Inventory result Alternative A kg/FU	Inventory result Alternative B kg/FU	Category indicator name	Character–ization factor	Uncer–tainty factor[a]	Category indicator value per FU Material A	Category indicator value per FU Material B
CO_2	30,188	28,605	YLL	7,93E–07	3	2,39E–05	2,27E–05
			Severe morbidity	3,53E–07	3	1,07E–05	1,01E–05
			Morbidity	6,55E–07	3	1,98E–05	1,87E–05
			Crop	7,56E–04	2,2	2,28E–02	2,16E–02
			Wood	–4,05E–02	2	–1,22E+00	–1,16E+00
			NEX	1,26E–14	3	3,80E–13	3,60E–13
NO_x	0,075	0,072	YLL	3,88E–05	3	2,91E–06	2,79E–06
			Severe morbidity	–2,06E–06	5	–1,55E–07	–1,48E–07
			Morbidity	3,61E–06	[b]	2,71E–07	2,60E–07
			Harmful effect	0,002 411	2,4	1,81E–04	1,74E–04
			Crop	0,699 54	3	5,25E–02	5,04E–02
			Fish & meat	–0,033 9	3	–2,54E–03	–2,44E–03
			Wood	–2,394	3	–1,80E–01	–1,72E–01
			NEX	7,50E–14	4	5,63E–15	5,40E–15
SO_2	0,099	0,051	YLL	3,76E–05	3	3,72E–06	1,92E–06
			Severe morbidity	–6,58E–06	4,2	–6,51E–07	–3,36E–07
			Morbidity	1,02E–05	4,2	1,01E–06	5,20E–07
			Harmful effect	0,006 45	2,4	6,39E–04	3,29E–04
			Crop	0,001 83	2,6	1,81E–04	9,33E–05
			Fish & meat	0,001 18	3	1,17E–04	6,02E–05
			Wood	0,979	2,4	9,69E–02	4,99E–02
			NEX	–2,94E–13	3	–2,91E–14	–1,50E–14
Al ore	0,854	0	Al reserves	1	1	8,54E–01	0,00E+00
Coal in ground	3,056	0,826	Coal reserves	1	1	3,06E+00	8,26E–01
Oil in ground	6,541	9,405	Oil reserves	1	1	6,54E+00	9,41E+00

[a] Corresponds to the standard deviation in a log-normal distribution.

[b] Is represented by more than one log-normal distribution.

NOTE E plus following number indicates exponent (power of 10).

Table 25 — Aggregation of converted LCI results into indicator results

Substance	Category indicator name	Character-ization factor	Category indicator value per FU Alternative A	Aggregated category indicator result per FU Alternative A	Category indicator value per FU Alternative B	Aggregated category indicator result per FU Alternative B
Al ore	Al reserves	1	0,854	0,854	0	0
Coal in ground	Coal reserves	1	3,056	3,056	0,826	0,826
CO_2	Crop	0,000 756	0,022 822		0,0216 25	
NO_x	Crop	0,699 54	0,052 466		0,050 367	
SO_2	Crop	0,001 83	0,000 181	0,075 469	9,33E-05	0,0720 86
NO_x	Fish & meat	–0,033 9	–0,002 54		-0,002 44	
SO_2	Fish & meat	0,001 18	0,000 117	–0,002 43	6,02E-05	–0,002 38
CO_2	Morbidity	6,55E-07	1,98E-05		1,87E-05	
NO_x	Morbidity	3,61E-06	2,71E-07		2,6E-07	
SO_2	Morbidity	1,02E-05	1,01E-06	2,11E-05	5,2E-07	1,95E-05
CO_2	NEX	1,26E-14	3,8E-13		3,6E-13	
NO_x	NEX	7,5E-14	5,63E-15		5,4E-15	
SO_2	NEX	–2,9E-13	-2,9E-14	3,57E-13	–1,5E-14	3,51E-13
NO_x	Harmful effect	0,002 411	0,000 181		0,000 174	
SO_2	Harmful effect	0,006 45	0,000 639	0,000 819	0,000 329	0,000 503
Oil in ground	Oil reserves	1	6,541	6,541	9,405	9,405
CO_2	Severe morbidity	3,53E-07	1,07E-05		1,01E-05	
NO_x	Severe morbidity	–2,1E-06	–1,5E-07		–1,5E-07	
SO_2	Severe morbidity	–6,6E-06	–6,5E-07	9,85E-06	–3,4E-07	9,61E-06
CO_2	Wood	–0,040 5	–1,222 61		–1,1585	
NO_x	Wood	–2,394	–0,179 55		–0,17237	
SO_2	Wood	0,979	0,096 921	–1,305 24	0,049 929	–1,280 94
CO_2	YLL	7,93E-07	2,39E-05		2,27E-05	
NO_x	YLL	3,88E-05	2,91E-06		2,79E-06	
SO_2	YLL	3,76E-05	3,72E-06	3,06E-05	1,92E-06	2,74E-05

NOTE E plus following number indicates exponent (power of 10).

7 Examples of the optional elements of LCIA

7.1 General

Figure 1 shows examples within the optional elements section. The examples are organized according to topic, i.e. with all the examples illustrating application of ISO 14042:2000, 6.2 (normalization), listed consecutively, which are then followed by an example of Grouping, and so on. Some examples are new, illustrating a particular point, while others are a continuation of examples presented in Clause 6. Readers may work their way through this section either on a topic-by-topic basis, or by following the stem example, or may select whichever example is of particular interest.

7.2 Example 1 — Application of optional elements in ISO 14042:2000, 6.2 Calculating the magnitude of the category indicator results relative to reference information (normalization)

7.2.1 Overview — Reviewing needs, criteria and reference information

In general, and consequently also for the gas pipeline example, it can be argued that the choice of reference information depends on the selected impact categories, and particularly on the scale level at which the characterization modelling is performed. If all categories are considered at the same spatial scale level, then the magnitude of the category loadings for a given region can be taken as reference. If however category results are considered at different spatial levels, then another reference shall be chosen which is insensitive to scale level, e.g. the category loading per inhabitant for the different regions considered.

7.2.2 Selection of one or more types of reference system to be used

In Example 1, the situation in country X is taken as the reference for all impact categories. This is in line with the goal of the study to compare different gas distribution systems in this country. Consequently the magnitude of the loading to the different impact categories can be taken as reference information. The reference information used refers to a specific year Y.

7.2.3 Calculation of normalization factors and results

In Tables 26 and 27, the indicator results of Example 1 are divided by the normalization factors derived from the total loading of the given impact categories for country X in the year Y. The outcome is called “normalization results” or the “normalized LCIA profile”.

Table 26 — Calculation of normalization results of stem example — Material A

Impact category	Material A		
	Indicator results kg-eq.	Normalization reference kg-eq./yr	Normalization results yr
Climate change	1,84E+05	2,27E+11	8,08E–07
Stratospheric ozone depletion	1,86E–02	3,61E+06	5,14E–09
Photo-oxidant formation	6,95E+01	6,26E+07	1,11E–06
Acidification	3,51E+02	6,41E+08	5,48E–07
Eutrophication	1,85E+01	1,08E+09	1,72E–08
Human toxicity	1,81E+04	1,45E+11	1,24E–07
Ecotoxicity	1,66E+02	1,16E+11	1,43E–09
NOTE E plus following number indicates exponent (power of 10).			

Table 27 — Calculation of normalization results of stem example — Material B

Impact category	Material B		
	Indicator results kg-eq.	**Normalization reference** kg-eq./yr	**Normalization results** yr
Climate change	1,46E+05	2,27E+11	6,45E−07
Stratospheric ozone depletion	5,75E−03	3,61E+06	1,59E−09
Photo-oxidant formation	7,01E+01	6,26E+07	1,12E−06
Acidification	2,50E+01	6,41E+08	3,91E−08
Eutrophication	2,42E+00	1,08E+09	2,24E−09
Human toxicity	4,73E+02	1,45E+11	3,26E−09
Ecotoxicity	4,76E+00	1,16E+11	4,10E−11
NOTE E plus following number indicates exponent (power of 10).			

7.2.4 Description of the effect on the study results

In the histogram, Figure 10[4)], the normalization results (the normalized LCIA-profile) are presented for Example 1. On the basis of the results of normalization, it appears that normalization causes a clear shift in significance of the impact category results. For instance, photo-oxidant formation shifts from fifth place to first place. Thus gas distribution appears to be relatively significant as a source of photo-oxidant formation. These impacts are due to gas leakage and are thought to be the same for the two types of material. They concern the major option for improvement. Climate change impacts move from first to second place. In addition, the impacts on acidification appear to be relatively significant for pipelines of Material A. Toxic impacts appear to be of relatively little significance (see however remark in 7.9.2.1.7 Ecotoxicity, about chlorinated organic trace pollutants). Note that normalization results do not indicate the relative importance of the impact categories.

7.3 Example 2 — Application of optional elements in ISO 14042:2000, 6.2 Calculating the magnitude of the category indicator results relative to reference information (normalization)

This subclause gives examples of the conversion of indicator results using several selected reference values, and how these converisons may yield different outcomes (normalization), and illustrates several possible normalization procedures, including a *per capita* approach and a reference approach.

The choice of normalization procedure depends upon the study purpose and the decisions made during the goal and scope definition process. When making this decision, it is necessary to refer back to the goal and scope to understand how the particular normalization procedure will change the indicator result. Therefore, the example illustrates how the original category indicator results from the mandatory clauses of ISO 14042 are altered, both in absolute terms and in relative terms. It also illustrates the warnings and recommendations regarding normalization and other optional procedures. ISO 14042:2000, 6.2 states:

> *"The selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value. The normalization of the indicator results changes the outcome of the mandatory elements of the LCIA phase. It may be desirable to use several reference systems to show the consequence on the outcome of mandatory elements of the LCIA phase. A sensitivity analysis may provide additional information about the choice of reference".*

4) Regarding Figures 10, 11, 12 and 14: The uncertainties for human toxicity and ecotoxicity characterization factors are much larger than for the other factors. For this reason, the impact categories are represented throughout this Technical Report as two groups: one group with relatively high and one with relatively low certainty. In the tables, the two groups are separated by double lines.

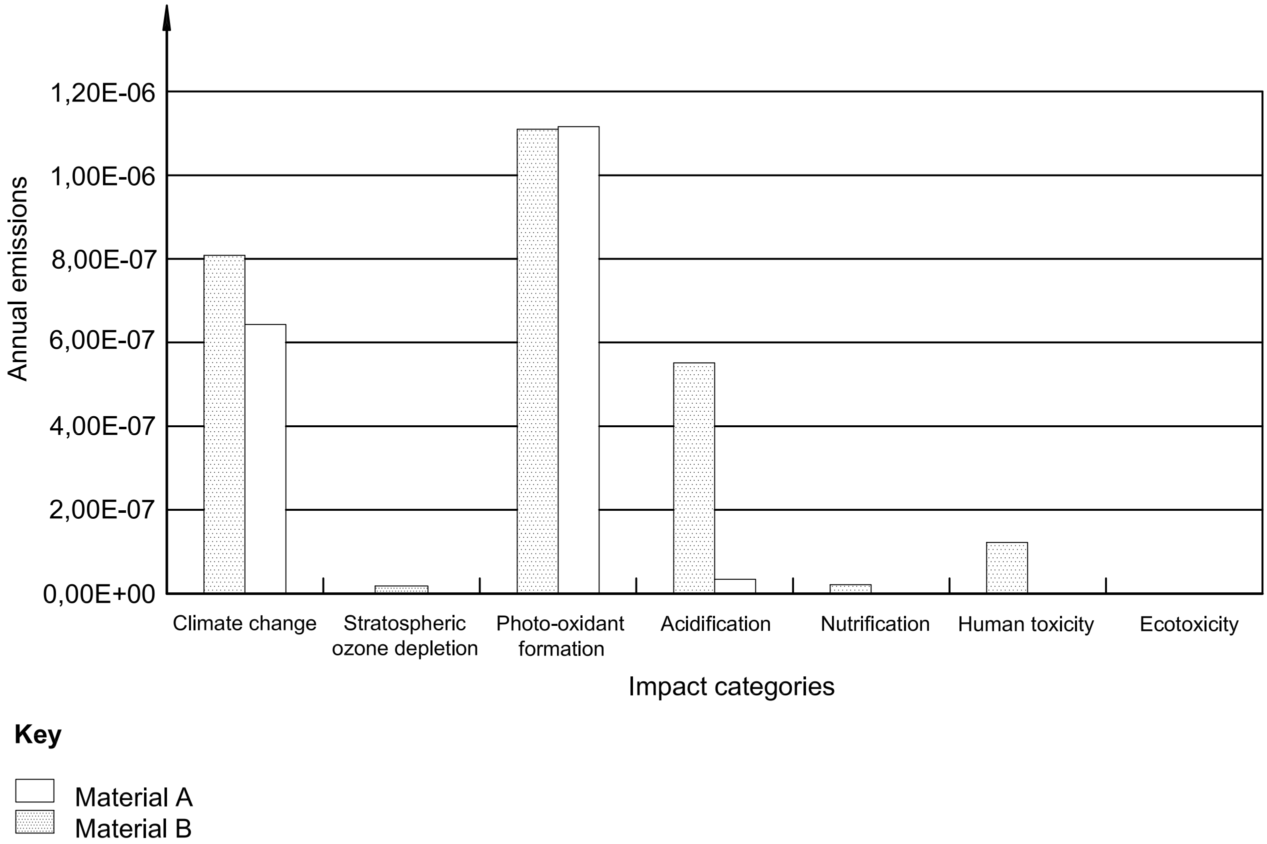


Figure 10 — Normalized LCIA profile for gas distribution system
Reference: Converted total emissions in country X in year Y

Normalization can use several reference values selected using the goal and scope, such as population, area, emission proportions, and historical emission baselines. Table 28 below provides three values for several countries that can be used for reference values, illustrating the large variation that can occur. Such different values can shift and thus alter the relative standing of the indicator, depending upon the country used for the normalization reference. In addition, if only industrial processes were chosen for normalization, then only 2 % of the total SO_2 emissions from Albania, 27 % from Belgium and 24 % from Finland would be used (e.g. a variation from 2 400 to 85 600 to 62 400 tons for a reference value, respectively). This would further increase the differences in the resulting normalized indicators.

Table 28 — Reference and baseline values for normalization

Country	**Population**	**Area**	**Emission quantities** tons/yr	
	$\times 10^{-3}$	km^2	SO_2	NO_x
Albania	3 119	27 000	120 000	30 000
Belgium	10 141	33 000	317 000	352 000
Finland	5 154	305 000	260 000	300 000
Germany	82 133	349 000	4 520 000	2 376 000
Spain	39 628	499 000	2 265 000	1 178 000
UK	58 649	242 000	3 751 000	2 701 000

If the normalization reference is the denominator, the result for those countries with smaller populations, areas or emissions will increase relative to larger countries when normalized. Table 29 applies both population and emissions baseline references to the SE indicator results derived in 6.3.3.2 c) application of ISO 14042:2000, 5.3. Relative changes due are shown in the right hand column of Table 29. Thus it is seen that the choice of normalization reference can cause significant changes in the outcome of the analysis.

Table 29 — Calculation of normalized indicator results using different reference and baseline values

Example of normalization of per capita population					
Country	Indicator result m^2	Population $\times 10^{-3}$	Normalized indicator result	Relative size Before	Relative size After
Albania	0,02	3 119	$0{,}064\ 1 \times 10^{-7}$	1	1
Belgium	1,29	10 141	$0{,}127 \times 10^{-6}$	64	20
Finland	15,38	5 154	298×10^{-6}	769	465

Example of normalization of reference emission baseline										
Country	Indicator result m^2		Emissions t		Normalized indicator result		Relative size Before		Relative size After	
	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x
Albania	0,02	0,00[a]	120 000	30 000	$1{,}67 \times 10^{-7}$	$3{,}33 \times 10^{-10}$	1	1	1	1
Belgium	1,28	0,008	317 000	352 000	$4{,}04 \times 10^{-6}$	$2{,}27 \times 10^{-8}$	64	800	24	68
Finland	15,14	0,242	260 000	300 000	$5{,}82 \times 10^{-5}$	$8{,}07 \times 10^{-7}$	757	24 200	329	2 420

[a] A value of 0,000 01 was used to conduct the normalization so that values from Belgium and Finland would not be divided by zero.

7.4 Example 6 – Normalization of LCIA indicator results for the use of different refrigerator gases in ISO 14042:2000, 6.2 Calculating the magnitude of the category indicator results relative to reference information (normalization).

7.4.1 Overview

Examples are given of the conversion of indicator results using several selected values, and how these conversions can yield different outcomes (normalization). The purpose of this example is to demonstrate a procedure for the optional element normalization, in which the magnitude of the category indicator results is calculated relative to reference information. The significance of the choice of reference system for normalization is illustrated through comparison of three different sets of reference information. ISO 14042 states:

> *"The selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value".*

To check the importance of this recommendation, the use of two reference systems is compared – one representing the current level of emissions in Europe, the other representing the current level of emissions at the geographical scale affected by the impact category, viz. European emission levels for regional impact categories, and global emission levels for global impact categories.

The example is based on a real case from the product development process of a refrigerator. It is important that the decisions made in the product development be valid throughout the life of the product. Since a refrigerator is a long-lived product with an expected lifetime of 10 years or more, it is therefore relevant to check the time dependency of the results of the normalization; Would the answer change if reference information from the latter half of the use stage is used for the normalization? To check the time dependency of the normalization, a reference system is chosen that represents the most probable level of emissions in the near future. Here again, European emission levels are used for regional impact categories and global emission levels for global impact categories.

The case deals with an LCA-based comparison of the environmental impacts from alternative methods used to replace CFCs in the insulation foam and in the cooling system of a household refrigerator.

— One alternative applies Gas A as foaming agent in the insulation and cooling agent;

— the other alternative applies Gas B as foaming agent in the insulation and cooling agent

The functional unit of the study is the service provided from a 200-litre energy-efficient household refrigerator throughout its life cycle, and the goal of the study is to aid the choice to be made by the product development team.

An inventory analysis was performed and Table 30 shows the indicator results for the environmental impact categories considered in the assessment for the two alternatives. The example is adapted from [42], the life cycle impact assessment methodology applied is as documented in [42] and [43].

Table 30 — Characterized LCIA profiles for two alternative refrigerator designs

Impact category	Unit	Gas A	Gas B
Global warming	g CO_2-equivalents	870 000	2 270 000
Ozone depletion	g CFC-11-equivalents	0	0
Photochemical ozone formation	g C_2H_4-equivalents	101	63
Acidification	g SO_2-equivalents	8 000	6 820
Nutrient enrichment	g NO_3- equivalents	5 150	4 380
Chronic ecotoxicity in water	m^3 water	44 000	44 000
Human toxicity via water[5)]	m^3 water	1 610	1 610
Human toxicity via air	m^3 air	563 000 000	613 000 000

In addition to the environmental impacts listed in Table 30, there is a risk of fire and explosion associated with Gas A that is not the case for Gas B.

7.4.2 Determining the need for normalization (referring to goal and scope)

The goal of the study is to decide whether Gas A or Gas B constitutes the best alternative for replacing CFCs in the new generation of the household refrigerator. This question cannot be answered from the indicator results alone, since there are trade-off situations for some of the impact categories. According to the indicator results in Table 30, Gas A performs clearly better for global warming and marginally better for human toxicity via air exposure, while Gas B performs better for photochemical ozone formation and marginally better for acidification and nutrient enrichment. However, the indicator results for the different impact categories are expressed in different units. In order to help interpret the results to meet the goal of the study, they must be brought to a common scale, expressing the significance per category. There is thus a need for normalization.

7.4.3 Reviewing needs, criteria and reference information

The purpose of the normalization is to relate the indicator results of the product to a set of reference values that together constitute a common scale that is familiar and understandable for the user and interpreter of the results of the life cycle assessment. Therefore, some expression of the total impact level is often chosen for each of the impact categories to constitute the reference system. These values may be determined at the global, regional, national or local level, and they may be expressed on a total basis, per capita, per area or similar.

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5) In the later interpretation it should be considered that each of the human toxicity impact categories covers several different toxicological impact mechanisms.

In the cases where normalization also serves as a preparation for weighting, grouping or ranking, the choice of reference system should be in accordance with the principles and criteria for the chosen weighting, grouping or ranking method.

For global impact categories such as global warming and stratospheric ozone depletion, the impact is independent of the location of the point of emission release. The level of impact that we experience in any place on earth is thus caused by the total global emissions for global impact categories. In contrast, for the regional and more local impact categories such as acidification and ecotoxicity, the level of impact we experience is caused by the emissions occurring within our region. ISO 14042 recommends that the selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value. The reference information for normalization is therefore based on the annual global emissions for global impact categories and the annual regional emissions (typically for the region where the decision is made and used) for the rest of the impact categories. To create a common reference system for the global and the regional impact categories, all impacts are expressed per capita in the area for which the emissions are quantified, i.e. per world citizen for the global impact categories and per regional citizen for the rest.

The politically targeted impact level is determined for a target year a few years ahead, and is applied as a proxy for the normalization reference in the near future. It is particularly relevant for products with a life span of several years, where it may be important to know the product's environmental performance when normalized at a point in time towards the end of its lifetime.

7.4.4 Selection of one or more types of reference information to be used

The choice of reference system should be made according to the goal and scope definition of the system and dependent upon whether a weighting or grouping is to be performed, and if so what method and criteria will be applied in the weighting.

To prepare for a possible weighting or grouping, the references chosen for normalization should represent the current or near-future impact level within the region for which the weighting factors are derived — in this case for Europe. This means that the normalization references are based on European emission levels for the regional impact categories and on global emission levels for the global impact categories[6)] . In addition, in order to reveal the influence of this spatial differentiation, a third reference system is applied, in which European emission levels are used for all impact categories, regardless of whether they are regional or global in nature.

In summary, three reference systems are chosen for the comparison of the two refrigerator alternatives:

— *spatially differentiated* references (based on global emissions for global impacts and European emissions for regional and local impacts) representing the *current* levels of impact in Europe — Current spatially differentiated emissions;

— *spatially differentiated* references representing the *near future* levels of impact in Europe (the refrigerator will also be on the market five years from now, and the validity of the decision at that time should be known) – Future spatially differentiated missions;

— references representing the impact level that would correspond to current European levels of emission for all impact categories — Current European emissions.

The indicator results for the three reference systems are expressed per capita in the reference region in Table 31:

— the current (1994) level of European emissions for all impact categories;

6) For some of the non-global impact categories, such as photochemical ozone formation, even the European scale is large compared to the typical scale of the impact.

— the future (2004) spatially differentiated level of emissions corresponding to politically targeted emissions (in Europe for regional impact categories and worldwide for global impact categories).

All normalization references are expressed per capita in the reference region [44].

Table 31 — Reference systems for the environmental impact categories representing the current (1994) spatially differentiated emissions (European emissions for regional impact categories and global emissions for global impact categories)

Impact category	Unit	Current spatially differentiated emissions	Current European emissions	Future spatially differentiated emissions
Year		1994	1994	2004
Global warming	g CO_2-equivalents/person	$8{,}2 \times 10^6$	$1{,}3 \times 10^7$	$6{,}8 \times 10^6$
Photochemical ozone formation	g C_2H_4-equivalents/person	25	25	20
Acidification	g SO_2-equivalents/person	74	74	49
Nutrient enrichment	g NO_3-equivalents/person	$1{,}2 \times 10^5$	$1{,}2 \times 10^5$	$8{,}5 \times 10^4$
Chronic ecotoxicity in water	m^3 water/person	$3{,}5 \times 10^5$	$3{,}5 \times 10^5$	$2{,}9 \times 10^5$
Human toxicity via water	m^3 water/person	$5{,}2 \times 10^4$	$5{,}2 \times 10^4$	$3{,}5 \times 10^4$
Human toxicity via air	m^3 air/person	$3{,}1 \times 10^9$	$3{,}1 \times 10^9$	$2{,}9 \times 10^9$

7.4.5 Calculation of normalization results

Dividing the indicator results in Table 30 by the respective normalization references in Table 31 gives the normalized LCIA profiles of the alternative refrigerator designs, as shown in Tables 32, 33 and 34 and illustrated graphically in Figures 11, 12 and 13.

Since the indicator results of the reference systems are expressed per capita, the normalized indicator results of the product express how large a share the impact of the product constitutes of the full estimated annual impact from an average person. They are expressed in the unit: person-equivalent, or more appropriately, milli-person-equivalent, mPE. The index to the unit mPE refers to the region on which the normalization reference is based and the year that was chosen for reference year.

Table 32 — Normalized LCIA profiles of alternative refrigerator designs using current spatially differentiated level of emissions (Europe for regional impact categories and the world for global impact categories) as reference system

Impact category	Unit	Gas A	Gas B
Global warming	mPE_{W94}	106	277
Photochemical ozone formation	mPE_{EU94}	4,0	2,5
Acidification	mPE_{EU94}	108	92
Nutrient enrichment	mPE_{EU94}	43	37
Chronic ecotoxicity in water	mPE_{EU94}	126	126
Human toxicity via water	mPE_{EU94}	31	31
Human toxicity via air	mPE_{EU94}	182	198
NOTE All normalized indicator results expressed as milli-person-equivalents, mPE.			

Table 33 — Normalized LCIA profiles of alternative refrigerator designs using current level of emissions in Europe as reference system

Impact category	Unit	Gas A	Gas B
Global warming	mPE_{EU94}	67	175
Photochemical ozone formation	mPE_{EU94}	4,0	2,5
Acidification	mPE_{EU94}	108	92
Nutrient enrichment	mPE_{EU94}	43	37
Chronic ecotoxicity in water	mPE_{EU94}	126	126
Human toxicity via water	mPE_{EU94}	31	31
Human toxicity via air	mPE_{EU94}	182	198
NOTE All normalized indicator results expressed as milli-person-equivalents.			

Table 34 — Normalized LCIA profiles of alternative refrigerator designs using future spatially differentiated level of emissions (Europe for regional impact categories and the world for global impact categories) as reference system

Impact category	Unit	Gas A	Gas B
Global warming	mPE_{W2004}	127	332
Photochemical ozone formation	mPE_{EU2004}	5,0	3.2
Acidification	mPE_{EU2004}	163	139
Nutrient enrichment	mPE_{EU2004}	61	52
Chronic ecotoxicity in water	mPE_{EU2004}	152	152
Human toxicity via water	mPE_{EU2004}	46	46
Human toxicity via air	mPE_{EU2004}	194	211
NOTE The future level of emissions is estimated from the politically set reduction targets. All normalized indicator results expressed as milli-person-equivalents.			

7.4.6 Description of the effect on the study results

From the normalized LCIA profiles in Figure 12, it is evident that, provided that the uncertainties of the indicator results are moderate, the contributions to the impact categories global warming and human toxicity via air exposure are largest when the indicator results for the two refrigerator alternatives are compared to the spatially differentiated current levels of emissions. For both of these categories, Gas A has the lower indicator results. In comparison, the indicator results for acidification and particularly for photochemical ozone formation are lower for Gas B.

A comparison between Figure 11 and Figure 13 gives an indication of the stability of the results in time. Figure 13 thus shows similar results when the future spatially differentiated levels for 2004 are used as normalization reference, although particularly the normalized indicator results for acidification gain more prominence and approach the level of the normalized indicator results for human toxicity via air exposure. This is due to a decrease in the normalization reference for acidification.

For the global impact category of global warming, a comparison between Figure 11 and Figure 12 demonstrates the importance of the choice of area for the normalization reference. When the impact level corresponding to European emissions are used for normalization reference, the normalized indicator results for global warming are reduced by more than 30 % compared to the use of the global impact level. In this case, the normalized indicator result for human toxicity via air exposure becomes the largest, exceeding the result for global warming for Gas A.

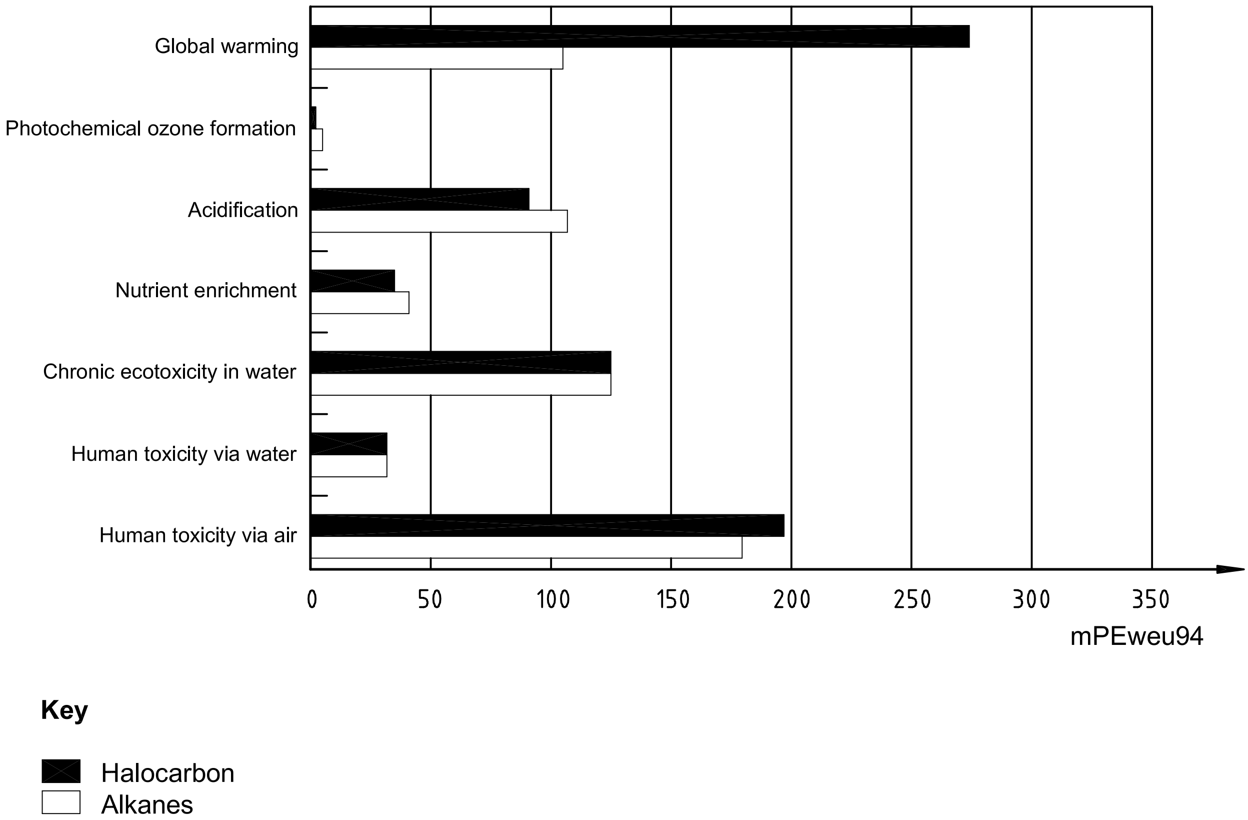
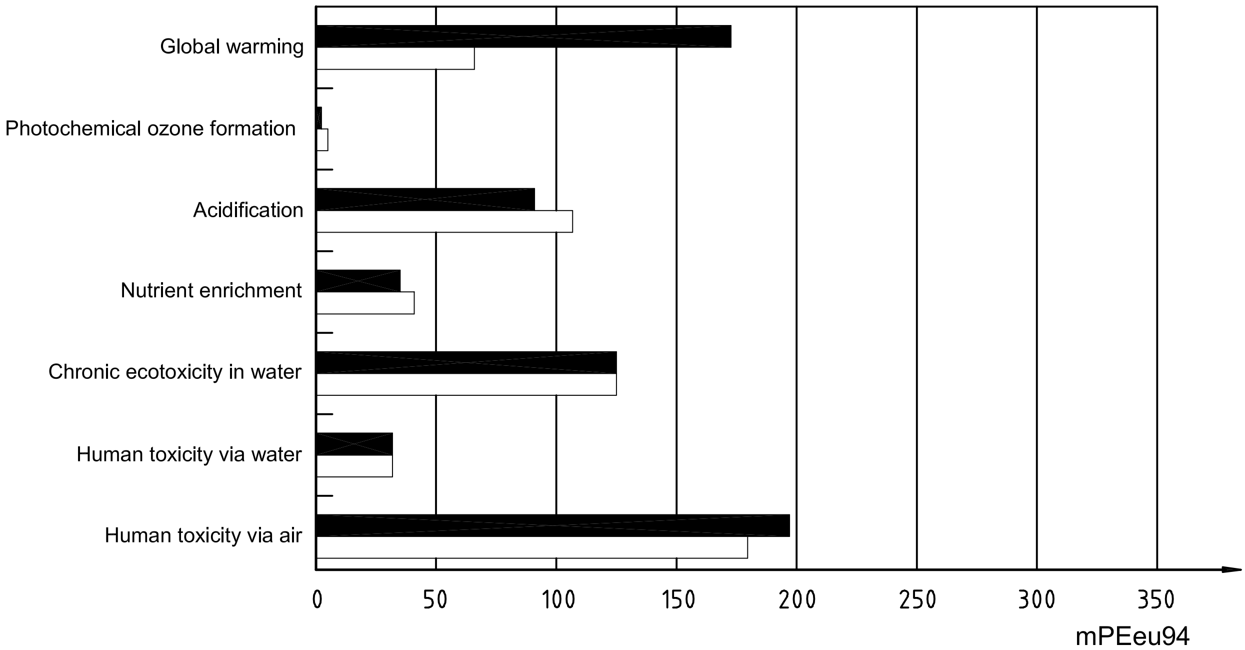


Figure 11 — Normalized LCIA profiles for the two alternatives, applying the 1994 spatially differentiated level of emissions as reference system



Key

Halocarbon
Alkanes

Figure 12 — Normalized LCIA profiles, applying the 1994 level of emissions in Europe as the reference system

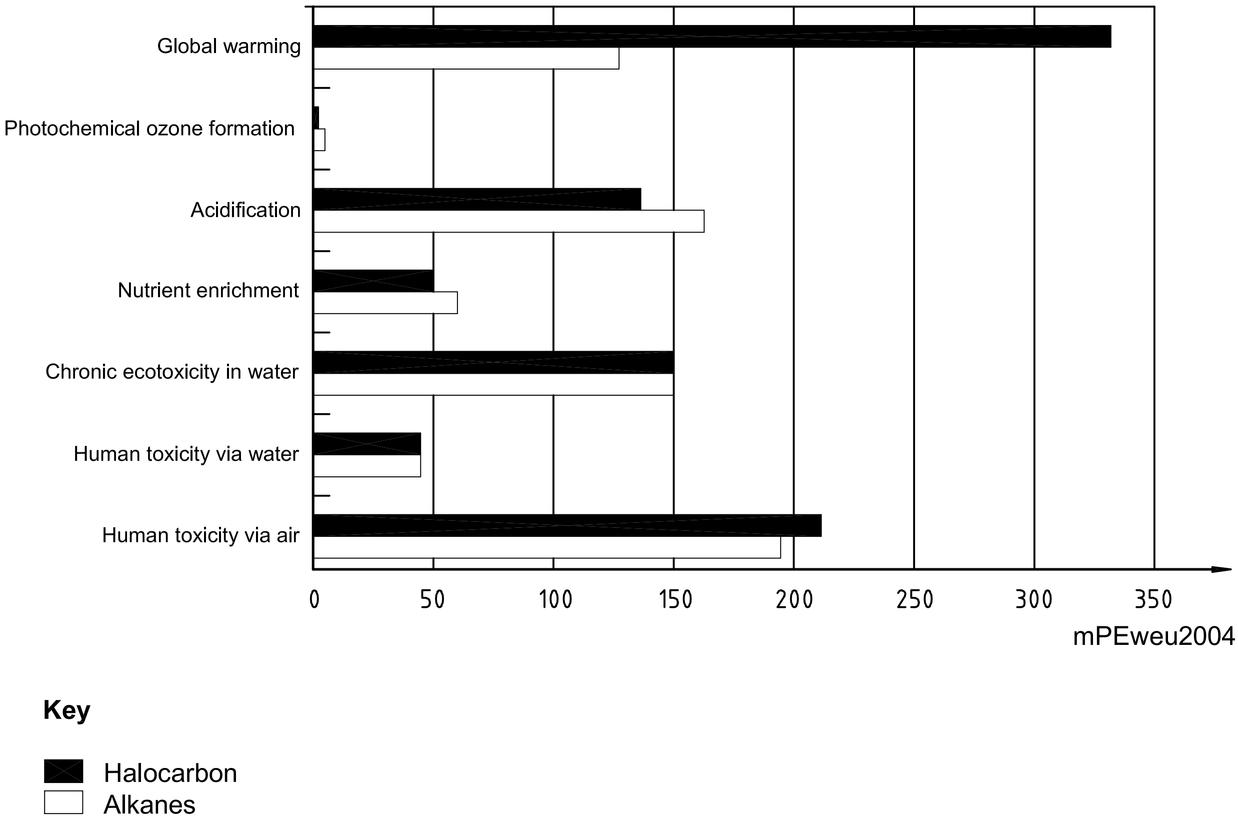


Figure 13 — Normalized LCIA profiles for the two alternatives applying the future spatially differentiated level of emissions as reference system

All together, Figures 11, 12 and 13 show that in the current case, regardless which of the three reference systems is used for normalization, the relative contributions to the impact categories global warming and human toxicity via air exposure are dominant. Gas A has the lower indicator results for both of these impact categories, and this superiority seems stable in time and independent of the introduced differentiation in normalization according to the spatial scale of the different impacts.

The conclusion as to which alternative is better depends not only on this information but also on the importance that is assigned to each of the impact categories, i.e. on a grouping, ranking or weighting.

7.5 Example 7 – Normalization in a waste management study using ISO 14042:2000, 6.2 Calculating the magnitude of the category indicator results relative to reference information (normalization)

7.5.1 Overview

This subclause gives an example of the conversion of indicator results using several selected reference value(s) (normalization). The aim of this example is to show how normalization of the results of an LCIA can be used as a means to communicate those results to the citizens of a local authority. It emphasises the need for consistency and transparency when using the reference information, especially when using different reference systems. Also, it raises the question of the risk of misinterpretation by the public, which is introduced with the additional information provided in the normalization process.

7.5.2 Determining the needs for normalization (referring to goal and scope)

In the following real case, LCIA is applied to integrated waste management systems. The objective of the LCIA is to evaluate the environmental consequences of the implementation of an integrated waste management system by a local authority. The LCIA study compares two scenarios: Scenario A (mono-treatment with incineration) and Scenario B (separate collection/recycling of the packaging fraction and incineration of the residual fraction).

Local authorities intend to use the results of the analysis to encourage the sorting of packaging waste by households. Normalization is thus being explored as a means to communicate the significance of the results to the local citizens.

7.5.3 Reviewing needs, criteria and reference information

The results to be normalized include two types of data:

- inventory results:
  - water consumption;
  - nonhazardous waste generation;
  - water pollution: COD, BOD_5, suspended matter.
- indicator results from the characterization:
  - total primary energy consumption (renewable/nonrenewable);
  - global warming potential;
  - acidification.

NOTE The first three categories are defined at the level of the inventory results.

These data[7)] were chosen because they comply with the following criteria:

- they are related to known public debates;
- they are credible in terms of relevant use within LCIA;
- data sets for normalization are available at a national level.

Flows of other potential pollutants such as dioxins, heavy metals and VOC have not been normalized due to the lack of credible references. They should be analysed using other types of environmental tool (e.g. risk assessment), which are more accurate and credible in the context of a debate at a local level.

The LCIA has been evaluated for both Scenarios A and B. According to the construction of the systems, the results of the comparison of the systems are given as the difference between the two results. Negative numbers for Scenarios A and B come from the methodology used for the construction of both systems, taking into account the avoided impacts for energy recovery and material recovery.

The functional unit is defined as: collecting and treating the quantity of waste generated in a year by a given local authority of 50 000 inhabitants in France. The detailed results shown in Table 35 relate to the specific local authority studied, and apply to this example only. None of the results or conclusions can be applied to any other situation.

7) ISO 14042:2000, 5.3.1, and [40], [41], [42], [43], [44], [45], [46] and [47].

Data related to the collection, treatment and energy recovery are local parameters, whereas recycling and energy data are representative of an average situation in France.

Table 35 — Results of the comparative LCA for the waste management of a given local authority (50 000 inhabitants) in France

	Scenario A Mono-treatment	Scenario B Integrated waste management	Direction of environmental impact	Difference between Scenario B and Scenario A
Inventory results				
Water consumption, m^3	71 567	37 319	**Water saved**	**34 248**
Household waste, tonnes	−287	-2 820	**Waste avoided**	**2 533**
Water pollution, kg			**Water pollution**	
COD	20 770	21 280	**Generated**	**510 kg**
BOD_5	1 052	1 050	**Avoided**	**−2 kg**
Suspended solids	1 252	459	**Avoided**	**−795 kg**
Indicator results				
Total primary energy, MJ	-256×10^6	-330×10^6	**Energy saved**	**74** $\times 10^6$
Nonrenewable energy, MJ	-253×10^6	-298×10^6	**Energy saved**	**45** $\times 10^6$
Renewable energy, MJ	-3×10^6	-32×10^6	**Energy saved**	**29** $\times 10^6$
Global warming potential 20 years, tonne-eq. CO_2	−21 066	−23 304	**GWP emissions avoided**	**2 238 tonne-eq. CO_2**
Acidification, kg-eq. H^+	−5 976	−7 431	**Acidifiant emissions avoided**	**1 455 kg-eq.** H^+

7.5.4 Selection of one or more reference systems to be used

The eight selected flows and category indicators are related as much as possible to “equivalent per capita” impacts on an annual basis. To match the purpose of normalization in this case, (i.e. to relate the environmental consequences of separate collection and recycling of household packaging waste to “per capita” indicators), it is important to consider a relevant:

— geographical area: national or regional data;

— time reference.

In this case, two scales of reference have been selected to normalize the environmental indicators:

— per capita personal reference frame, reflecting environmental impacts per inhabitant, from day-to-day activity (energy consumption at home and/or personal transportation);

— per capita national reference frame, based on the national inventories for energy consumption, emissions to environment and environmental impacts divided by the national population. This reference frame involves industries and other activities.

Data on emissions and resource consumption in France are published on a regular basis. As a first step, before choosing the reference system, the two systems are presented in Table 36 in order to assess the differences between them. These references are consistent because they are calculated for a similar person over the same time period and occur at the same place.

Table 36 — Presentation of the two reference systems used in Example 7

Indicators	Per capita personal based on in-house consumption and personal transportation	Per capita national based on a national average for France
Water consumption	150 litres/day 54,75 m^3/year	Water inflow from public network 1 871 litres/day 683 m^3/year
Household waste	420 kg/year	825 kg/year
Water pollution	COD 130 g/day BOD_5: 65 g/day Suspended matter: 70 g/day	No reference available on a per capita basis
Total primary energy consumption	Consumption per inhabitant at home 30 000 MJ/year	Total primary energy consumption for France 249,36 Mtep[a] 174 603 MJ/ capita national year
Nonrenewable energy		Total nonrenewable energy consumption for France 237,62 Mtep[a] 166 412 MJ/capita national per year
Global warming potential	1 456 kg-eq. CO_2/capita personal/inhabitant per year for home and office heating	8 680 kg-eq. CO_2/year
Acidification	238 g-eq. H^+/capita personal/year for individual transportation	1,86 kg-eq. H^+/year

[a] Million tonnes petrol equivalent.

7.5.5 Calculation of normalized result

The results from Table 35 are normalized with the two reference systems presented in Table 36 and are shown as Table 37. In Table 38, two possible references are compared.

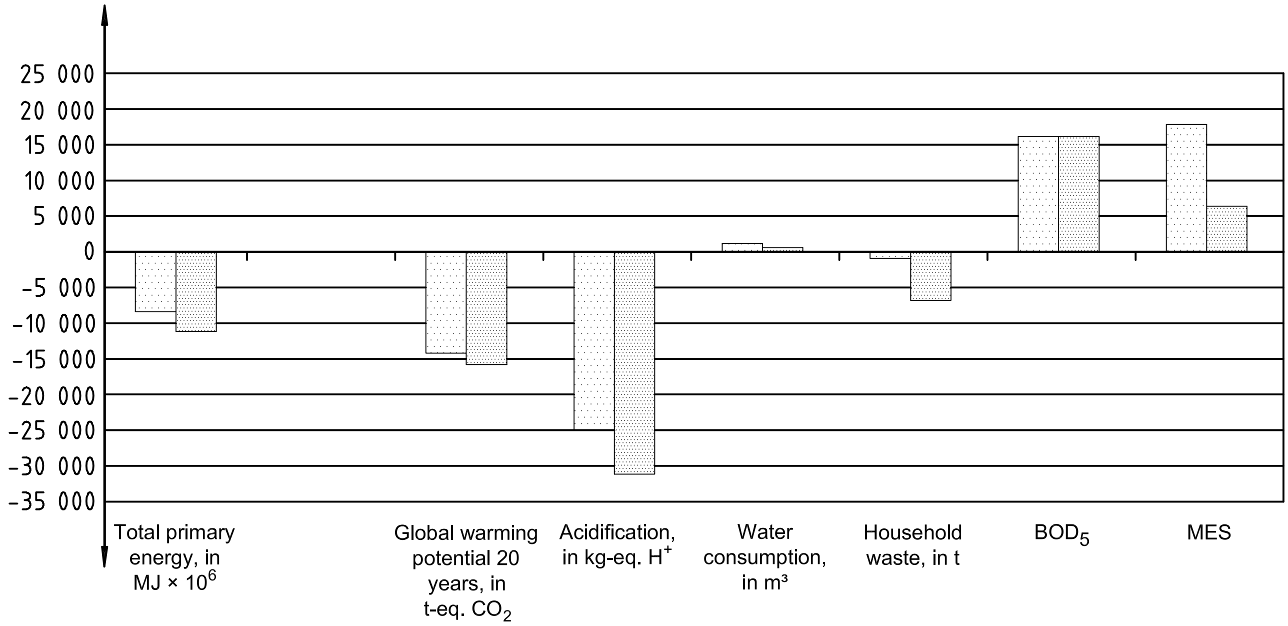
Table 37 — Normalized results for two scenarios of household waste management of a given local authority (50 000 inhabitants) in France (not applicable to any other situation)

	Scenario A			**Scenario B**		
	Result	**Normalization** **Per capita personal**	**Normalization** **Per capita national**	**Result**	**Normalization** **Per capita personal**	**Normalization** **Per capita national**
Inventory results						
Water consumption	71 567 m^3	**1 307**	**105**	37 319 m^3	**682**	**1**
Household waste	−287 tonnes	**−683**	**−348**	−2 820 tonnes	**−6 714**	**−3 418**
Water pollution COD BOD_5 Suspended solids	 20 770 kg 1 052 kg 1 252 kg	 **159 769** **16 185** **17 886**		 21 280 kg 1 050 kg 459 kg	 **163 692** **16 154** **6 557**	
Indicator results						
Total primary energy	-256×10^6 MJ	**−8 533**	−**1 466**	−330	**−11 000**	**−1 890**
Nonrenewable energy	-253×10^6 MJ		−**1 520** $\times 10^6$	-298×10^6 MJ		**−1 791** $\times 10^6$
Global warming potential, 20 years	−21 066 tonne-eq. $C0_2$	**−14 468**	**−2 427**	−23 304 tonne-eq. CO_2	**−16 005**	**−2 685**
Acidification	−5 976 kg-eq. H^+	**−25 109**	**−3 213**	−7 431 kg-eq. H^+	**−31 223**	**−3 995**

Table 38 — Influence of reference system in the normalization of comparative LCA results for two waste management options for a given local authority (50 000 inhabitants) in France

Environmental benefit or charge	**Differential** **Scenario B – Scenario A**	**Normalization based on per capita personal reference**	**Normalization based on per capita national for France**
Water saved	34 248 m^3	630 inhabitants	100 average citizens
Waste avoided	2 33 tonnes	6 000 inhabitants	3 070 average citizens
Water pollution COD (generated) BOD_5 avoided Suspended solids avoided	 (510 kg) 2 kg 795 kg	 (3 900 inhabitants) 30 inhabitants 11 300 inhabitants	
Total primary energy saved	74×10^6 MJ	2 470 inhabitants	430 average citizens
Nonrenewable energy saved	45×10^6 MJ		270 average citizens
GWP emissions avoided	2 238 tonne-eq. CO_2	1 537 inhabitants for home and office heating	257 average citizens
Acidifying emissions avoided	1 455 kg-eq. H^+	6 110 eq. inhabitants for transportation	782 average citizens

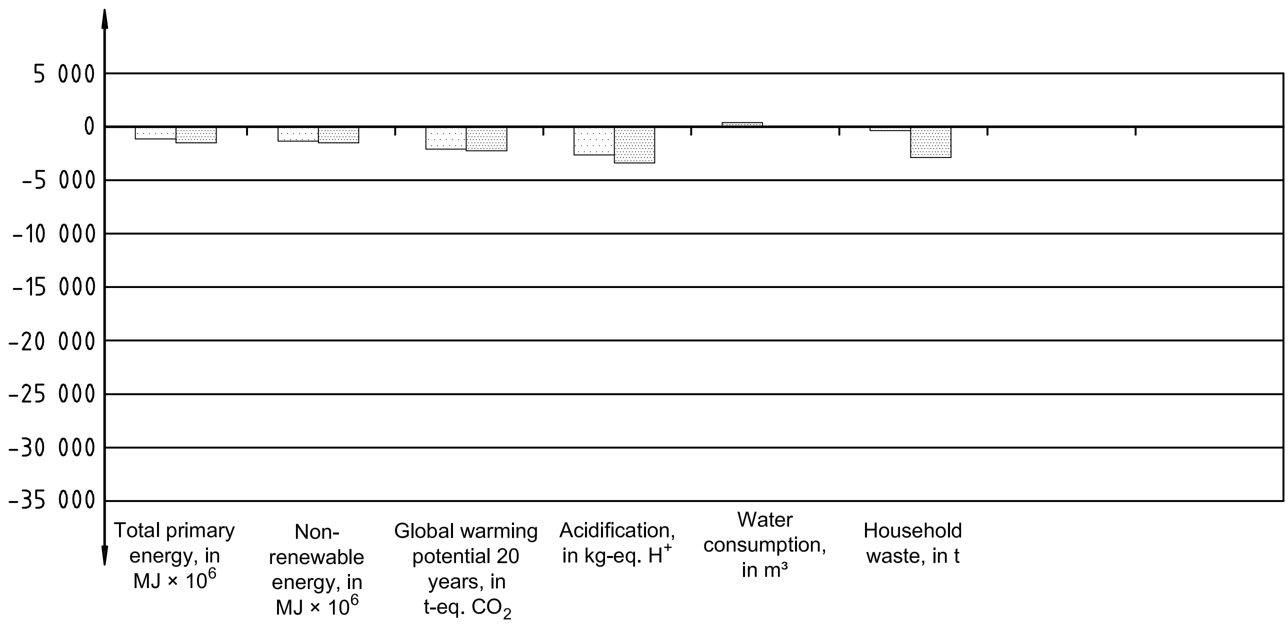
Comments: Equal scales are used in Figures 14 and 15. There is a difference in the size of the values but the trend is similar in both figures.



Key

Scenario A
Scenario B

Figure 14 — Normalization per capita on a local personal basis — Household waste management impacts for local autorithy X (50 000 inhabitants)



Key

Scenario A
Scenario B

Figure 15 — Normalization per capita on a national basis — Household waste management impacts for local autorithy X (50 000 inhabitants)

7.5.6 Description of the effect on study results

The normalization of LCIA results allows easier comprehension of the significance of the observed impacts, compared to other activities at a national level.

When based on a “per capita – personal” reference, the normalized data are very significant because they are based on the inhabitant's day-to-day activity. For instance:

— avoided acidification emissions to air resulting from the recycling of the packaging fraction from the local authority represents the quantity of pollutants emitted for the transportation of 6 000 inhabitants per year, which represents 12 % of the local-authority population;

— energy savings resulting from recycling of the packaging fraction by the local authority are equivalent to the energy consumption of 2 500 inhabitants (that is, 5 % of the population of the local authority), which represents a significant proportion;

— avoided GWP emissions correspond to the emissions released by heating of the homes and offices of 1 500 inhabitants (3 % of the population);

— waste avoided represents the quantity of waste generated by 6 000 inhabitants, i.e. 12 % of the local-authority population.

If the normalization is based on “per capita national” values, which may include energy consumption from industries, transport and agriculture, then normalized values are not as significant.

Using the “per capita personal” reference index appears to be more relevant to the objective of the normalization. In this study, the aim is to show the relative value of environmental consequences of household waste recycling at the scale of each inhabitant in order to encourage and evaluate the contribution of their participation, in comparison with other environmental impacts from their day-to-day activities.

7.5.7 Risk of this type of communication

The two Figures 14 and 15 show that the values of the normalized indicators are very different, and are dependent on the reference frame chosen. In a communication process, using the per capita national reference tends to lower the importance of the environmental impacts of the waste management processes and could wrongly be used to justify a “no change” position.

On another hand, the example also shows that the reference scale used needs to be consistent. For instance, the per capita personal scale uses a different reference frame for two types of air emissions: personal transportation per capita, for acidification gases and home heating for greenhouse gases. The activities involved in the per capita personal reference are not the same for all the indicators. This could be improved by defining a new per capita personal reference involving both home heating and personal transportation.

Also, it should be pointed out that using a certain reference frame (transport emissions, for instance) for acidification gases can suggest to the reader other implied impacts (noise, fumes, odours, accidents) that might bias the information.

Lastly, another potential bias lies in the way the reader will interpret the normalized values. The reader could imagine that the per capita personal environmental benefit will be tangible at a local level. This is not necessarily the case, as the results of the LCIA take into account upstream and downstream effects that might occur many kilometres away from the local authority, and even abroad, as far as resources extraction is concerned. They could also occur at in a different time frame (e.g. landfill emissions from biogases).

This approach might not cover the issue completely, as other subjects such as dioxins, VOC and heavy metals still need to be addressed.

7.6 Example 1 — Application

7.6.1 ISO 14042:2000, 6.3 Grouping — Description of the effect on the study results

In Example 1, the following effect can be observed on the study results. In the normalized LCIA-profile the photo-oxidant impacts appear to be the most significant, followed by climate change. Looking at the two types of grouping, there appears to be some trade-off: the highest contribution is on photo-oxidant formation, a regional category with relative low priority in environmental policy of country X, whereas the contribution to climate change is second in magnitude but regards a global category with high priority in environmental policy of the given country (see Tables 47 and 49). However, the major result, showing better performance for Material B of the gas pipes is not changed because the order between materials holds true for all categories considered.

7.6.2 ISO 14042:2000, 6.4 Weighting — Selecting weighting methods and determining weighting factors

7.6.2.1 General

In Example 1, weighting by the use of social panels is used. The panel in question consisted of experts in the field of energy production and distribution in country X. The factors used together equal 1,000 and are given in the Table 39 [23].

Table 39 — Selected weighting factors in Example 1

Climate change	Stratospheric ozone depletion	Photo-oxidant formation	Acidification	Eutrophication	Human toxicity	Ecotoxicity
0,278	0,104	0,100	0,148	0,113	0,130	0,130

7.6.2.2 Calculation of weighting results

In general, the calculation of weighting results implies two steps: the conversion of the normalization results by multiplying them with the weighting factors which are selected for the different impact categories, and the aggregation of the conversion results to one single score (or a small number of scores).

The results of Example 1 are included in Tables 46 to 49 in 7.11. In this example, the converted normalization results show highest values for climate change, followed by photo-oxidant formation and acidification. Ecotoxicity gives by far the lowest results for the chosen case. These findings are in line with the description of the grouping results in 7.11.

7.6.2.3 Sensitivity analysis of weighting results

In Example 1 a sensitivity analysis of the weighting results is carried out, using a different set of weighting factors, in which particularly photo-oxidant formation is weighted less, and acidification and eutrophication are weighted more, in line with the policy of country X. The weighting set is presented Table 40; the results are also included in Tables 46 to 49. With this second weighting set, the impact category climate change remains in first place. The impact category photo-oxidant formation appears to shift from second to third place, and acidification from third to second place.

Table 40 — Alternative weighting factors for the weighting set of the stem example

	Climate change	Stratospheric ozone depletion	Photo-oxidant formation	Acidification	Eutrophication	Human toxicity	Ecotoxicity
First set	0,278	0,104	0,100	0,148	0,113	0,130	0,130
Alternative set	0,250	0,100	0,050	0,200	0,200	0,100	0,100

The weighting results using the first set of weighting factors are the following:

— for Material A: 4,36 E–07 (see Table 47);

— for Material B: 2,98 E–07 (see Table 49);

while the results using the alternative set are the following:

— for Material A: 3,84 E–07 (see Table 47);

— for Material B: 2,26 E–07 (see Table 49).

The alternative weighting set has not changed the order of preference between the two materials.

7.7 Example 5 — Application of ISO 14042:2000. 6.4 Weighting

In Example 5, the weighting factors [40] are determined to be people's willingness to pay to avoid a change in the indicator values. The weighting factors are expressed in ELU per indicator unit. One ELU is equal to one euro under certain conditions.

In Table 41, category indicator results from Table 25 are multiplied with weighting factors for each category indicator and the resulting terms are added to give aggregated results of 10,82 ELU/FU. for Alternative A and 8,88 ELU/FU for Alternative B.

Table 41 — Weighting of indicator results

Category indicator name	Aggregated category indicator result per FU Alternative A	Aggregated category indicator result per FU Alternative B	Weighting factor ELU/category indicator unit	Uncertainty in weighting factor[a]	Weighting result ELU/FU Alternative A	Weighting result ELU/FU Alternative B
Al ore	0,854	0	0,439	2	0,375	0
Coal in ground	3,056	0,826	0,049 8	2	0,152	0,041 1
Crop	0,075 5	0,072 1	0,15	2	0,0113	0,010 8
Fish & meat	−0,002 43	−0,002 38	1	2	−0,002 43	−0,002 38
Morbidity	2,11E–05	1,95E–05	10 000	3	0,211	0,195
NEX	3,57E–13	3,51E–13	1,10E+11	3	0,039 3	0,038 6
Nuisance	0,000 819	0,000 503	100	3	0,081 9	0,050 3
Oil in ground	6,541	9,405	0,506	1,4	3,310	4,76
Severe morbidity	9,85E–06	9,61E–06	100 000	3	0,985	0,961
Wood	−1,305	−1,28	0,04	1,4	−0,052 2	−0,051 2
YLL	3,06E–05	2,74E–05	85 000	3	2,600	2,33
		Impacts from other LCI results not shown in Tables 24 and 25			3,11	0,55
TOTAL					10,82	8,88

a Corresponds to the standard deviation in a log-normal distribution.

NOTE E plus following number indicates exponent (power of 10).

7.8 Example 8 – A technique for the determination of weighting factors using ISO 14042:2000, 6.4 Weighting

7.8.1 Overview — Example of a technique for determination of weighting factors using a panel of experts

There are two steps involved in this technique. The first step scores the indicators at the intermediate level in each endpoint. The second step compares the endpoints among each other. In this respect it differs from Example 1, (comparison among intermediate level indicators) and from Examples 4 and 5 (comparison among endpoint level indicators).

The weighting factors are related to ISO 14042:2000, 6.4:

"Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. ... Weighting is an optional element with two possible procedures:

— *to convert the indicator results or normalized results with selected weighting factors*

— *to possibly aggregate these converted indicator results or normalized results across impact categories."*

The purpose of the example is to demonstrate the development of a weighting method for evaluating environmental impact. Results obtained in the example are for demonstration purposes only and are not for official use.

7.8.2 Weighting method

The importance of impact categories can be derived by the following method. An example in which two endpoints exist for three different impact categories is used. For the first endpoint, analysts score each impact category by comparing its impact relative to the magnitude of the damage caused by the other impact categories. The second endpoint is treated similarly. The total score of the three impact categories is set to equal 1,00 (see Table 42 and Figure 16).

For each of the two endpoints, assign a "relative importance" score by comparing its damage with the damage of the other endpoint that occurs from the combined environmental problems. The total score of two endpoints is also set to 1,00 (see Table 43).

After obtaining the two types of scores as mentioned above, multiply them and add up the multiplied results for each impact category. The combined total for each impact category can be converted to a simple figure for easy understanding; here the total score is set to 1,00. These converted scores show the relative importance of each impact category (see Table 44).

The weighting factor is calculated by dividing the relative importance of each category by the annual environmental load of each impact category.

Table 42 — Scoring of category indicators in each endpoint

Endpoint	Category indicator			Total
	C_1	C_2	C_3	
E_1	$s_{1,1}$	$s_{1,2}$	$s_{1,3}$	1,00
E_2	$s_{2,1}$	$s_{2,2}$	$s_{2,3}$	1,00

Table 43 — Scoring of endpoint

Endpoint	E_1	E_2	Total
Relative importance	a	b	1,00

Table 44 — Importance of category indicators

Category indicator	Endpoint		Total	Relative importance
	E_1	E_2		
C_1	$a \times S_{1,1}$	$b \times S_{2,1}$	$T_1 = a \times S_{1,1} + b \times S_{2,1}$	T_1/T_t
C_2	$a \times S_{1,2}$	$b \times S_{2,2}$	$T_2 = a \times S_{1,2} + b \times S_{2,2}$	T_2/T_t
C_3	$a \times S_{1,3}$	$b \times S_{2,3}$	$T_3 = a \times S_{1,3} + b \times S_{2,3}$	T_3/T_t
Total	$a \times \Sigma S_{1,i}$	$b \times \Sigma S_{2,i}$	$T_t = a \times \Sigma S_{1,i} + b \times \Sigma S_{2,i}$	1,00

7.8.3 Determining weighting factors

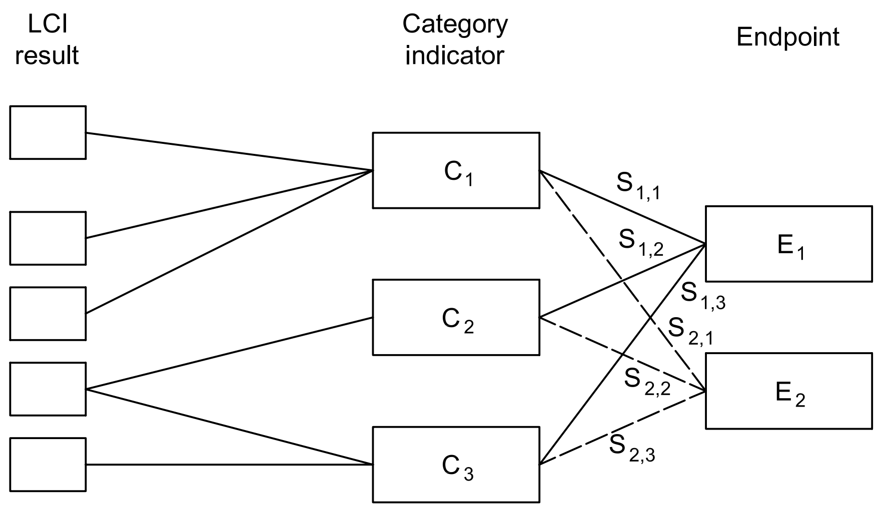


Figure 16 — Scoring of category indicators using each endpoint

7.8.4 Impact categories

The first meeting of experts sought to list environmental problems important to the country [53]. Twenty-five environmental experts, including Environment Agency officials, local government staff members, university professors, consultants and researchers from a national institute, participated. The following six impact categories were selected:

— global climate change: global warming;

— regional air pollution: air pollution caused by nitrogen oxide and oxidants, etc;

— river, lake, marsh and ocean pollution: eutrophication;.

— toxic chemicals: air, water and soil pollution caused by organic chlorine compounds, dioxin and benzene, etc;

- destruction of natural sites: development leading to deforestation, reclaimed seashore and dam construction, etc;
- mass production/consumption/disposal: utilization of large amounts of resources, energy and land.

7.8.5 Endpoints

The second meeting [45] was attended by the twenty-one of the initial members and by an additional four members: twenty-five members in total. The meeting sought to identify appropriate endpoints. As a result, the following four endpoints were selected:

- effect on health: increased mortality and morbidity rates, increased physical pain due to disease;
- effect on products used in everyday life: depletion of limited resources, damage to food production and basic materials;
- effect on the ecosystem: death and mutation of natural lives, decrease of life and species, change of ecosystem;
- mental effects: loss of peacefulness, fears, dread of unknown impacts, and guilty conscience through concern about hurting others.

7.8.6 Weighting factors

All the participants scored the six impact categories in each endpoint. They estimated possible damage occurring in the next 50 years, under the assumption that the present environmental loads will continue (see Figure 17 and Table 42). The participants also scored the four endpoints (see Figure 18 and Table 43). Using mean values obtained from the 25 participants, overall scores were calculated for the impact categories. These scores were designated to indicate the degree of importance represented by the impact categories in the country (see Figure 19 and Table 44). Table 45 shows weighting factors obtained by dividing the importance of the impact categories by annual environmental loads.

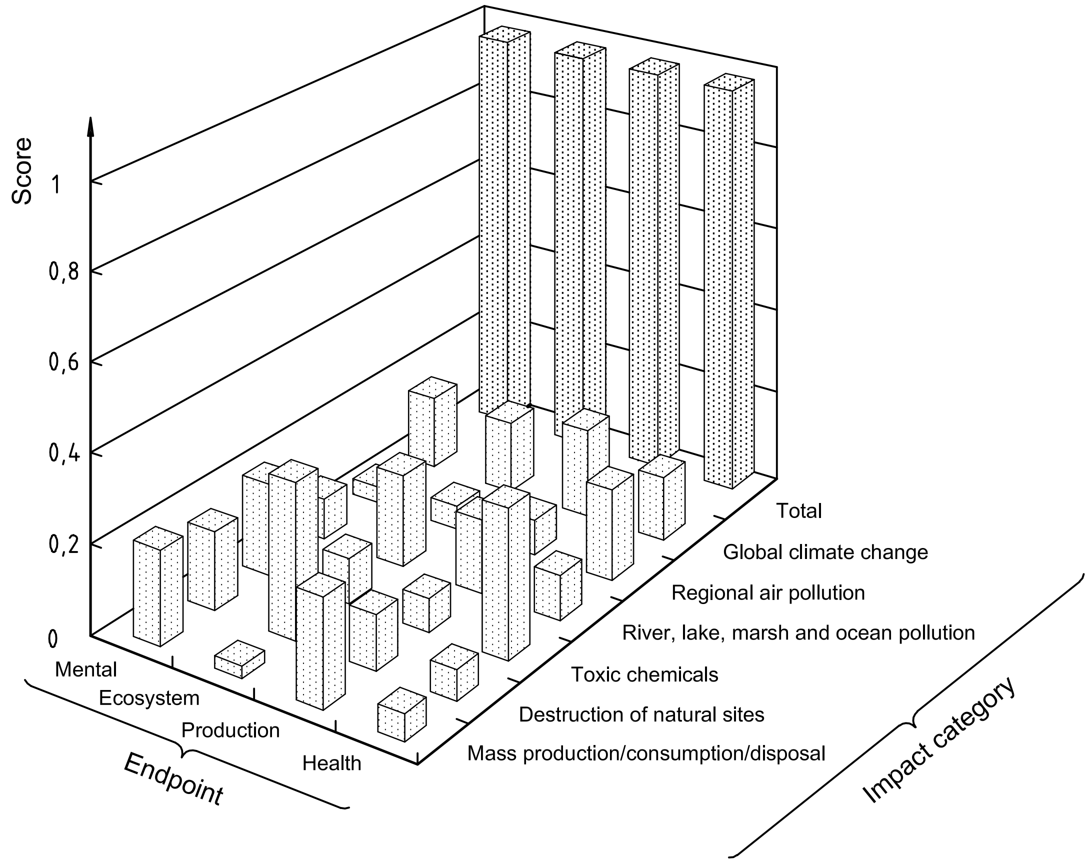


Figure 17 — Scoring of category indicators in each endpoint

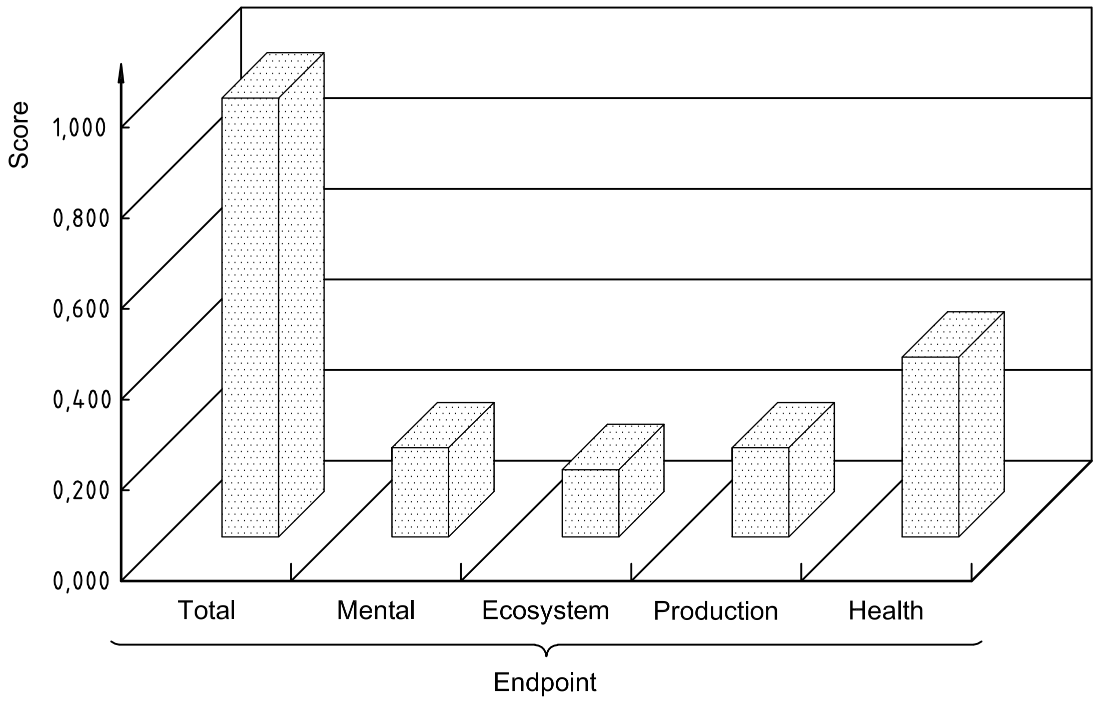


Figure 18 — Scoring of endpoints

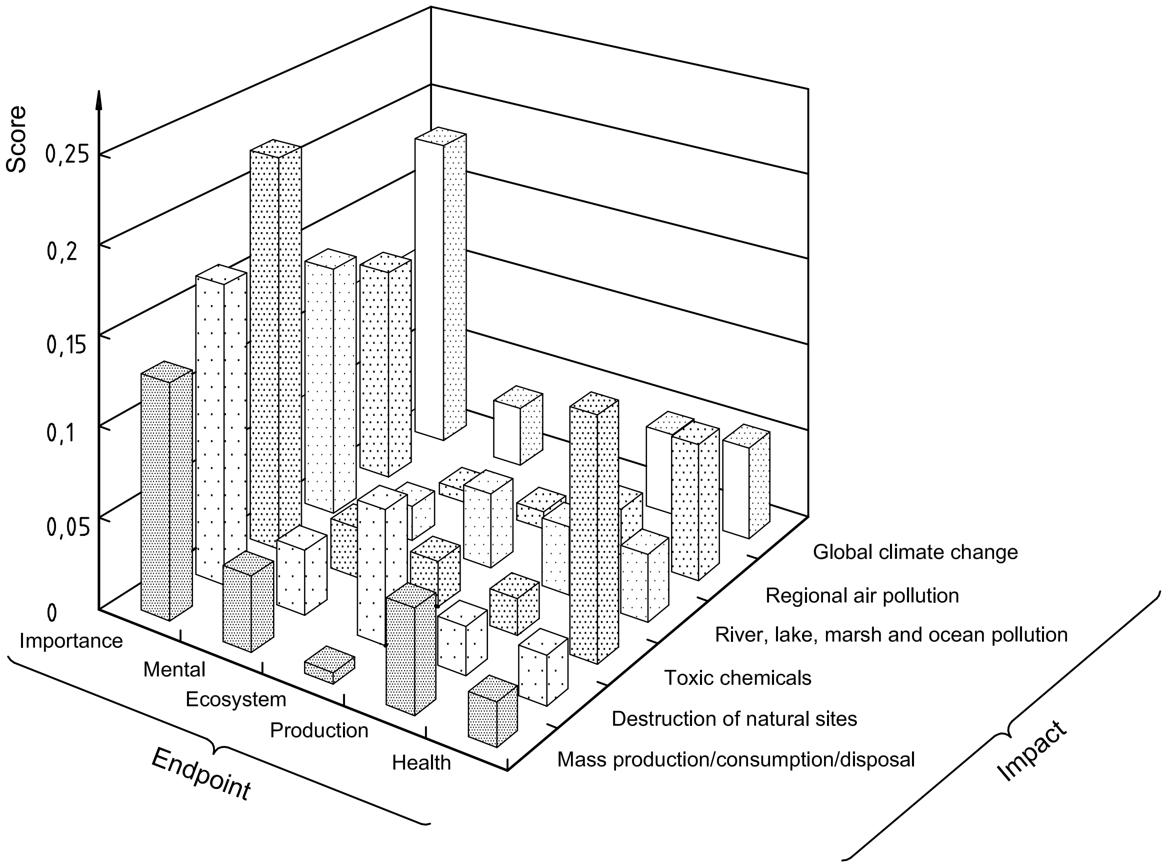


Figure 19 — Importance of impact categories in Japanese environmental problems

Table 45 — Calculations of weighting factor

Impact category	Importance *a*	Annual environmental load *b* (unit)	Weighting factor *a*/*b* (unit)
Global climate change	0,18	4,3E+13 (CO_2-equiv.-kg × yr^{-1})	4,2E–15 [(CO_2-equiv.-kg)$^{-1}$ × yr]
Regional air pollution	0,13		
River, lake, marsh and ocean pollution	0,15	1,7E+09 (N-kg × yr^{-1})	1,8E–10 [(N-kg)$^{-1}$ × yr]
Toxic chemicals	0,23		
Destruction of natural sites	0,18		
Mass production/ consumption/disposal	0,14	5,0E+10 (Solids-kg × yr^{-1})	2,8E–12 [(Solids-kg)$^{-1}$ × yr]
NOTE E plus following number indicates exponent (power of 10).			

The weighting factors were calculated for the following three impact categories: global climate change; river, lake, marsh and ocean pollution; and mass production/consumption/disposal. The LCI results of annual environmental loads in the country were not clear for the two impact categories of toxic chemicals and destruction of natural sites. An impact category indicator was also not available for regional air pollution because the characterization model was not developed. Global climate change was regarded as global warming. Therefore, carbon dioxide-equivalent greenhouse gas emissions (converted to global GWP100) was used as an impact category indicator[46]. River, lake, marsh and ocean pollution was regarded as eutrophication, therefore nitrogen emissions in the country[47] were used as an environmental load. Mass production/consumption/disposal were regarded as waste problems. The amount of waste discarded[48], was also set as an environmental load. These elements were used as impact category indicators.

7.8.7 Conclusion

In summary, twenty-five environmental experts selected six impact categories and calculated the importance of these impact categories. The importance of each impact category was divided by an annual environmental load to calculate weighting factors. Weighting factors were calculated for three impact categories.

7.9 Example 1 — Application

7.9.1 General

Figure 1 shows the number of examples for ISO 14042:2000, Clauses 7 to 10. The examples are organized on the basis of topic, i.e. with all the examples on Clause 7, Data quality analysis, listed consecutively, followed by the examples on Reporting and critical review. The remaining examples are a continuation of examples presented for ISO 14042:2000, Clauses 5 and 6. Readers may work their way through this section either on a topic-by-topic basis, or follow the stem example, Example 1, or select whichever example is of particular interest.

7.9.2 ISO 14042:2000, Clause 7 Data quality analysis

7.9.2.1 Gravity analysis

7.9.2.1.1 General

Below, a gravity analysis is carried out for Example 1. For the different impacts it is shown which LCI results contribute to the indicator results, and subsequently which unit processes contribute to the respective LCI results.

7.9.2.1.2 Climate change

For the two systems examined, the climate change effects are caused by methane and CO_2, the largest contribution coming from methane. For all systems, nearly all the methane released is due to gas leakage during distribution at the junction of pipeline elements. Various processes release CO_2 during the life cycle of the system, with transportation and material production being relatively important. Its contribution is largest with Material A because of its heavy mass.

7.9.2.1.3 Stratospheric ozone depletion

For the two systems examined, the ozone depletion impacts are all or mainly related to bromotrifluoromethane, released with the production of crude oil and with trans-oceanic tanker transport. For Material B, tetrachloromethane, which also impacts ozone depletion, is released during chlorine production.

7.9.2.1.4 Photo-oxidant formation

For the two systems examined, photo-oxidant formation is due to gas leakage, mainly of methane but, in smaller quantities also of ethane and propane.

7.9.2.1.5 Acidification

For the two systems examined, acidification effects are due to the release of SO_x and NO_x, mainly caused by transportation and the production of materials.

7.9.2.1.6 Eutrophication

For the two systems examined, eutrophication is caused by NO_x and phosphorus. The NO_x releases are due to burning of fuel to generate heat, to transportation and to electricity production. The emission of phosphorus to water is related to coal use. The emissions occur during landfill of hard-coal tailings, and mainly involve pipes of Material A.

7.9.2.1.7 Human toxicity

Both systems lead to emission of NO_x, SO_x and heavy metals, and are related to the burning of fossil fuels. In addition, releases of heavy metals are connected with specific processes related to pipes of Material A, and with the use of oil as raw material for pipes of Material B.

7.9.2.1.8 Ecotoxicity

A number of toxic substances, for instance heavy metals and phenols, are related to material production and energy use. More specifically, lead chromate is used as a pigment in the production of Material B.

For the toxicity categories, it should be taken into account that the impact of chlorinated organic trace pollutants is not considered. These can have an impact, specifically for pipes of Material B.

7.9.2.2 Uncertainty analysis

In this example, no data on the uncertainty of the given processes are available; therefore this subject is not discussed.

7.9.2.3 Sensitivity analysis

In this example, the sensitivity of the indicator results to different choices regarding the characterization models is analysed. The effects of the following alternative characterization factors are analysed:

— climate change: GWP_{500} instead of GWP_{100}[6], [7];

— acidification: $AP_{\text{maximum proton release}}$[17], instead of $AP_{\text{critical load}}$[11];

— eutrophication: $NP_{\text{critical load}}$[11], instead of $NP_{\text{maximum biomass formation}}$[10].

In addition sensitivity, analysis can be performed for the categories of eco- and human toxicity. As already stated, the modelling of toxicity categories includes a number of technical assumptions and value choices, which by themselves may have a significant and independent influence on the outcome. A technical assumption is that, for the metals considered, there is no need to account for speciation in regard to bioavailability and toxicity (e.g. the distinction between the metallic and ionic forms of metals). Further research may provide approaches and mechanisms that can be used to account for differences in the bioavailability and toxicity of metals and that can be applied within the context of LCA. Another technical assumption within the adapted USES model is that additional input of metals to the ocean does indeed have the potential to cause environmental impacts, in spite of the high background levels of the metals. Therefore for some metals, it may be appropriate to determine whether the ocean is to be considered a sink, and not as part of the environment. Given these uncertainties, in the present example only fresh water is taken into account in the aquatic ecotoxicity category.

A key value choice with respect to the potential impact of metals is the time horizon of the impacts (e.g. infinite time vs. 500 years vs. 100 years vs. 20 years). If the time horizon is reduced from infinite time to e.g. 100 years, the results for the toxicity categories will be significantly lower, particularly for the impacts of the metals. Using a shorter time horizon for assessing the impacts may provide more confidence in the results, and issues such as these should be considered in the interpretation phase. A further development of the toxicity characterization models is highly desirable, particularly with respect to inorganic substances such as metals. Given the need for further development, caution is needed in the interpretation of the results. In general, information obtained using other tools may well have to supplement the decision-making process.

The outcome of the sensitivity analysis is as follows. When using GWP_{500} instead of GWP_{100}, the climate change results do decrease considerably (more than 50 %). This is due to the fact that the main contributing substance is methane, which is rather short-lived. When changing from N/P factors based on maximum biomass formation to the critical load factors, there is an increase by a factor of about 5. This is an artefact, due to the fact that in the latter only air emissions are taken into account, which gives rise to a different fraction in the normalized results: background nutrient emissions to water are very large in country X, yielding low normalized values of a given release. Thus sensitivity analysis helps here to identify incompleteness in the pathways underlying characterization modelling.

7.10 Example 5 — Application of ISO 14042:2000, Clause 7 Data quality analysis

7.10.1 Overview

Choosing category indicators at the endpoint level and the use of weighting introduce large uncertainties. Sensitivity and uncertainty analysises were therefore carried out to find out if there is a significant difference (in statistical meaning) between Alternatives A and B, and what contributes most to the uncertainty. Uncertainty factors for inventory results are estimated as 1,02 for oil in ground and Al ore, 1,05 for CO_2 and coal in ground and 1,2 for SO_2 and NO_x. The factors represent the standard deviation in a log-normal distribution.

7.10.2 Uncertainty analysis

When comparing the aggregated and weighted indicator results for Alternative A with that for Alternative B, a decrease from 10,82 to 8,88 ELU/FU is obtained. To find out if this is a significant difference, a Monte Carlo simulation was made. The result is shown in Figure 20, where log-normal-distributed random errors have been introduced to all input data. The uncertainty factors and distributions presented in Tables 24 and 45 are used in this example.

NOTE The curve represents the cumulative distribution.

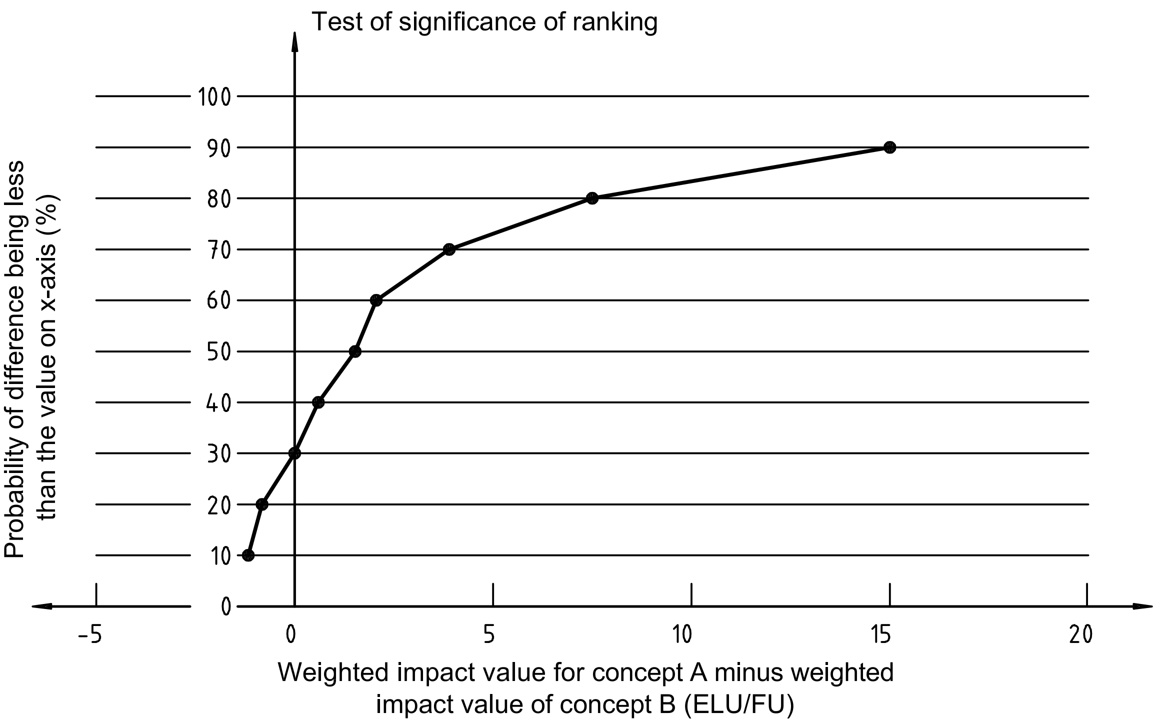


Figure 20 — Result from Monte Carlo simulation of overall improvement in environmental performance by increasing energy recovery in waste management

The result from the Monte Carlo simulation shows for instance that there is about 50 % probability that Material B is at least 2 ELU/FU better than Material A, and that there is about 70 % probability that Material A has more impact on the environment than Material B. This information can be used either qualitatively, to express a degree of precision in the analysis, or quantitatively, e.g. to estimate the efficiency of an investment in environmental performance. If Material B is chosen as an alternative to a cost of $ 100, the most likely efficiency of the investment is $ 40. In 30 % of the cases the wrong decision is made, and in 70 % the right decision is made. The net result is 70 – 30 = 40.

7.10.3 Sensitivity analysis

Because of the low efficiency in improvement investments, it was of interest to know which input data contributes most to the uncertainty shown in Figure 20. This was determined in a special kind of sensitivity analysis [41]. In this, all factors f_i, by which a certain input must be multiplied in order to change the ranking order, are determined and the ratio of the uncertainty factor to f_i for each input is calculated (here called “relative sensitivity”). The factors with the largest ratios in the example are shown in Figure 21.

The ranking in Example 5 was most sensitive to the inventory data for PAH, oil in ground and CO_2 for Alternatives A, B and B respectively. Next comes the characterization factor for PAH with respect to the category indicator YLL. The sensitivity for the inventory results of PAH and the characterization factor of PAH for YLL is notable. Despite a relatively low contribution to the overall weighting result, it still contributes significantly to the uncertainty in ranking. This is because uncertainty in the emission measurements and characterization factor is large. It is however possible to improve the overall ranking precision if more accurate values of the emission of PAH from Alternative A product system is known. New, locally specific characterization factors may also be estimated with less uncertainty.

Gravity analysis was also performed, but is not shown here, as it looks almost the same as for the stem example. The use of the results are however slightly different. When the indicators are weighted and aggregated, the indication of improvement options is more direct and more suitable for a design context.

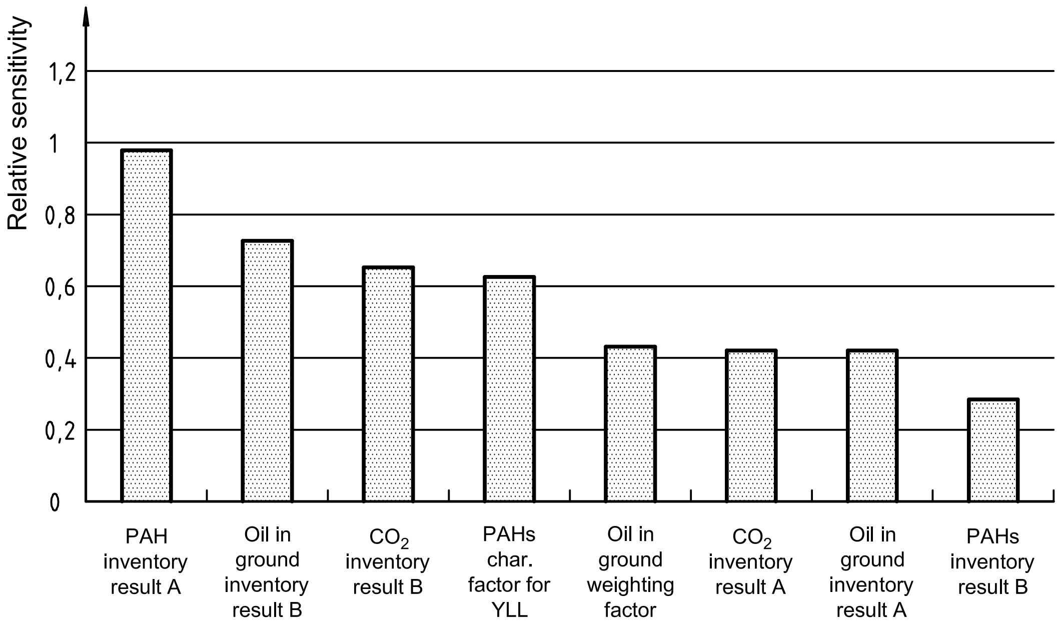


Figure 21 — Input data that contribute most to the uncertainty of the ranking of alternatives

7.11 Example 1 — Application

7.11.1 ISO 14042:2000, Clause 8 Limitations of LCIA

See comments within individual examples in ISO 14042:2000, Clause 8.

7.11.2 ISO 14042:2000, Clause 9 Comparative assertions disclosed to the public

See comments within individual examples in ISO 14042:2000, Clause 9.

7.11.3 ISO 14042:2000, Clause 10 Reporting and critical review

7.11.3.1 Executive summary

This report is provided as an example. It is not intended to illustrate the requirements of a third-party report as in ISO 14040.

Example 1 is a continuing example which covers all the process steps from ISO 14042, from the selection of impact categories to data quality analysis. It aims to compare the environmental consequences of two different types of material for gas pipes in country X and the identification of improvement options. The example is based on a real-life study commissioned by a gas company in the given country. The functional unit chosen is: the supply of 20×10^6 m^3 of natural gas per year in the gas distribution network between the feeder system and 10 000 service connection points. The materials to be compared are called Material A and Material B.

For the selection of impact categories, the default list of impact categories[22] is taken as starting point. The example focuses on air and water emissions. The following impact categories are included: climate change, stratospheric ozone depletion, photo-oxidant formation, acidification, eutrophication, human toxicity and ecotoxicity. Characterization models from different sources are used, which are all referenced in the text. The indicator results are normalized using the converted total emissions during one year, in country X.

The normalized results are sorted and ranked, using different criteria. Weighting across impact categories is carried out using weighting factors according to an expert panel established in country X. A gravity analysis has been included, focusing on the indicator results, and a sensitivity analysis has been carried out using other characterization factors and other weighting factors.

The results obtained in Example 1 are the following. Regarding the choice between the two types of material, Material B scores considerably better overall than Material A. This is mainly due to the heavy mass of Material A and the subsequent high impacts for material production and transportation. Therefore from an environmental point of view Material A is not preferred as the material for the pipes. But it should be noted that chlorinated organic trace pollutants are not taken into account quantitatively, and their release may be significant in the production of Material B. This point should be flagged and handed over to the interpretation phase.

Both materials have a strong impact on photo-oxidant formation, due to gas leakage at the pipe junctions. This is an important point for improvement, which is equally important for both materials. The sensitivity analyses have not led to other conclusions, but have helped in particular to identify shortcomings in the calculation procedures.

7.11.3.2 Data and calculations

The detailed results of Example 1, the full life cycle impact assessment process, are presented in Tables 46 to 49.

Table 46 — Material A mandatory elements — Detailed results of the LCIA process

MANDATORY LCIA ELEMENTS								
Impact category	Substance	Assigned LCI results		Characterization factors		Converted LCI results		Indicator results
		Air emissions	Water emissions	Air emissions	Water emissions	Air emissions	Water emissions	(LCIA profile)
		kg	kg	kg…eq. / kg	kg…eq. / kg	kg…eq.	kg…eq.	kg eq.
Climate change	Carbon dioxide	4,22E+04		1,00E+00		4,22E+04		1,84E+05
	Bromotrifluoro-methane	1,55E–03		5,60E+03		8,66E+00		
	Methane	6,73E+03		2,10E+01		1,41E+05		
Stratospheric ozone depletion	Bromotrifluoro-methane	1,55E–03		1,20E+01		1,86E–02		1,86E–02
	Tetrachloro-methane			1,20E+00				
Photo-oxidant formation	Methane	6,73E+03		6,00E–03		4,04E+01		6,95E+01
	Ethane	1,94E+02		1,23E–01		2,39E+01		
	Propane	2,97E+01		1,76E–01		5,23E+00		
Acidification	Sulfur dioxide	3,06E+02		1,00E+00		3,06E+02		3,51E+02
	Ammonia	8,76E–02	5,44E–01	1,30E+00		1,14E–01		
	Nitrogen dioxide	1,11E+02		4,10E–01		4,53E+01		
Eutrophication	Ammonia	8,76E–02	5,44E–01	3,50E–01	3,30E–01	3,07E–02	1,79E–01	1,85E+01
	Nitrogen dioxide	1,11E+02		1,30E–01		1,44E+01		
	Phosphorus		1,22E+00		3,10E+00		3,79E+00	
	Nitrogen		4,05E–01		4,20E–01		1,70E–01	
Human toxicity	Sulfur dioxide	3,06E+02		9,60E–02		2,94E+01		1,81E+04
	Nitrogen dioxide	1,11E+02		1,30E+00		1,44E+02		
	Arsenic	2,47E–02	4,14E–02	3,48E+05		8,58E+03		
	Lead	4,72E–01	1,16E–01	4,67E+02		2,20E+02		
	Nickel	1,57E–01	1,05E–01	3,50E+04		5,51E+03		
	Vanadium	5,72E–01	1,03E–01	6,24E+03		3,57E+03		
Ecotoxicity	Phenol	9,40E–05	1,15E–01	1,50E+00	2,37E+02	1,41E–04	2,73E+01	1,66E+02
	Cadmium	1,64E–02	1,56E–03	2,89E+02	1,52E+03	4,73E+00	2,38E+00	
	Lead	4,72E–01	1,16E–01	2,40E+00	9,62E+00	1,13E+00	1,11E+00	
	Chromium	3,23E–02	2,08E–01	1,90E+00	6,90E+00	6,14E–02	1,43E+00	
	Copper	3,54E–02	1,04E–01	2,22E+02	1,16E+03	7,84E+00	1,20E+02	
NOTE E plus following number indicates exponent (power of 10).								

Table 47 — Material A optional elements — Detailed results of the LCIA process

OPTIONAL LCIA ELEMENTS								
Impact Category	**Substance**	**Normalization factors** kg eq. / yr	**Normalization results** yr	**Group sorting**	**Group ranking**	**Weighting factors** social set	**Converted normalization results** yr	**Weighting result** yr
Climate change	Carbon dioxide Bromotrifluoro-methane Methane	2,27E+11	8,08E–07	global	high	0,278	2,25E–07	4,36E–07
Stratospheric ozone depletion	Bromotrifluoro-methane Tetrachloro-methane	3,61E+06	5,14E–09	global	medium	0,104	5,35E–10	
Photo-oxidant formation	Methane Ethane Propane	6,26E+07	1,11E–06	regional	low	0,1	1,11E–07	
Acidification	Sulfur dioxide Ammonia Nitrogen dioxide	6,41E+08	5,48E–07	regional	medium	0,148	8,11E–08	
Eutrophication	Ammonia Nitrogen dioxide Phosphorus Nitrogen	1,08E+09	1,72E–08	regional	medium	0,113	1,94E–09	
Human toxicity	Sulfur dioxide Nitrogen dioxide Arsenic Lead Nickel Vanadium	1,45E+11	1,24E–07	local	medium	0,13	1,62E–08	
Ecotoxicity	Phenol Cadmium Lead Chromium Copper	1,16E+11	1,43E–09	local	medium	0,13	1,86E–10	
NOTE E plus following number indicates exponent (power of 10).								

Table 48 — Material B mandatory elements — Detailed results of the LCIA process

MANDATORY LCIA ELEMENTS								
Impact category	Substance	Assigned LCI results		Characterization factors		Converted LCI results		Indicator results
		Air emissions	Water emissions	Air emissions	Water emissions	Air emissions	Water emissions	(LCIA profile)
		kg	kg	kg…eq. / kg	kg…eq. / kg	kg…eq.	kg…eq.	kg eq.
Climate change	Carbon dioxide	4,81E+03		1,00E+00		4,81E+03		1,46E+05
	Bromotrifluoro-methane	4,30E–04		5,60E+03		2,41E+00		
	Methane	6,75E+03		2,10E+01		1,42E+05		
Stratospheric ozone depletion	Bromotrifluoro-methane	4,30E–04		1,20E+01		5,16E–03		5,75E–03
	Tetrachloro-methane	4,90E–04		1,20E+00		5,88E–04		
Photo-oxidant formation	Methane	6,75E+03		6,00E–03		4,05E+01		7,01E+01
	Ethane	1,98E+02		1,23E–01		2,44E+01		
	Propane	2,99E+01		1,76E–01		5,26E+00		
Acidification	Sulfur dioxide	1,83E+01		1,00E+00		1,83E+01		2,50E+01
	Ammonia	8,01E–03	1,23E–01	1,30E+00		1,04E–02		
	Nitrogen dioxide	1,64E+01		4,10E–01		6,72E+00		
Eutrophication	Ammonia	8,01E–03	1,23E–01	3,50E–01	3,30E–01	2,80E–03	4,04E–02	2,42E+00
	Nitrogen dioxide	1,64E+01		1,30E–01		2,13E+00		
	Phosphorus		5,41E–02		3,10E+00		1,68E–01	
	Nitrogen		1,80E–01		4,20E–01		7,54E–02	
Human toxicity	Sulfur dioxide	1,83E+01		9,60E–02		1,76E+00		4,73E+02
	Nitrogen dioxide	1,64E+01		1,30E+00		2,13E+01		
	Arsenic	1,92E–04	1,90E–03	3,48E+05		6,68E+01		
	Lead	3,62E–03	4,93E–02	4,67E+02		1,69E+00		
	Nickel	6,40E–03	6,77E–03	3,50E+04		2,24E+02		
	Vanadium	2,51E–02	5,36E–03	6,24E+03		1,57E+02		
Ecotoxicity	Phenol	9,00E–06	1,54E–02	1,50E+00	2,37E+02	1,35E–05	3,65E+00	4,76E+00
	Cadmium	1,75E–04	1,47E–04	2,89E+02	1,52E+03	5,06E–02	2,24E–01	
	Lead	3,62E–03	4,93E–02	2,40E+00	9,62E+00	8,70E–03	4,74E–01	
	Chromium	3,54E–04	1,02E–02	1,90E+00	6,90E+00	6,73E–04	7,04E–02	
	Copper	1,27E–03		2,22E+02	1,16E+03	2,81E–01		
NOTE E plus following number indicates exponent (power of 10).								

Table 49 — Material B optional elements — Detailed results of the LCIA process

OPTIONAL LCIA ELEMENTS								
Impact category	**Substance**	**Normalisation factors** kg eq. / yr	**Normalisation results** yr	**Group sorting**	**Group ranking**	**Weighting factors results** Social set	**Converted normalisation results** yr	**Weighting result** yr
Climate change	Carbon dioxide Bromotrifluoro-methane Methane	2,27E+11	6,45E–07	Global	High	0,278	1,79E–07	2,98E–07
Stratospheric ozone depletion	Bromotrifluoro-methane Tetrachloro-methane	3,61E+06	1,59E–09	Global	Medium	0,104	1,66E–10	
Photo-oxidant formation	Methane Ethane Propane	6,26E+07	1,12E–06	Regional	Low	0,1	1,12E–07	
Acidification	Sulfur dioxide Ammonia Nitrogen dioxide	6,41E+08	3,91E–08	Regional	Medium	0,148	5,78E–09	
Eutrophication	Ammonia Nitrogen dioxide Phosphorus Nitrogen	1,08E+09	2,24E–09	Regional	Medium	0,113	2,53E–10	
Human toxicity	Sulfur dioxide Nitrogen dioxide Arsenic Lead Nickel Vanadium	1,45E+11	3,26E–09	Local	Medium	0,13	4,23E–10	
Ecotoxicity	Phenol Cadmium Lead Chromium Copper	1,16E+11	4,10E–11	Local	Medium	0,13	5,33E–12	
NOTE E plus following number indicates exponent (power of 10).								

7.11.3.3 Presentation of results

Results are commonly presented as shown in the above tables.

In addition to their presentation in the above tables, the normalized indicator results from Example 1 are also presented in the form of a histogram (see Figure 10).

NOTE If a comparative assertion is made public, the results of the last element are not presented.

7.11.3.4 Discussion and conclusions

In Example 1, the results are used for comparing the environmental consequences of different types of material and for the identification of improvement options. For this example, the following conclusions can be drawn.

a) Regarding the choice between the two types of material, Material B scores overall considerably better than material A. This is mainly due to the heavy mass of pipes made from Material A, and the subsequent high impacts for production and transportation. Thus from an environmental point of view Material A is not preferred.

b) Although Material B scores considerably better than Material A, it should be noted that emission of chlorinated organic trace pollutants, which may accompany the production of Material B, are not taken into account. If this is regarded as important, alternatives for Material B should be considered which do not have this unquantifiable risk.

c) For both materials there is a strong impact on photo-oxidant formation, due to gas leakage at pipe junctions. This is a point for improvement which is equally important for both materials.

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