भारतीय मानक
Indian Standard

IS/ISO/TR 14047 : 2012

पर्यावरण प्रबंधन — जीवन चक्र मूल्यांकन — मूल्यांकन स्थितियों को प्रभावित करने के लिए आईएस/आईएसओ 14044 को कैसे लागू किया जाए, इस पर निदर्शी उदाहरण

Environmental Management — Life Cycle Assessment — Illustrative Examples on How to Apply IS/ISO 14044 to Impact Assessment Situations

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NATIONAL FOREWORD

The Indian Standard which is identical with ISO/TR 14047 : 2012 'Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations' issued by the International Organization for Standardization was adopted by the Bureau of Indian Standards on the recommendation of the Environmental Management Sectional Committee and approval of the Chemical Division Council.

The heightened awareness of the importance of environmental protection and the possible environmental significance of a product system, have 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). The requirements and guidelines for LCA are covered in IS/ISO 14044.

The committee formulated IS/ISO 14044 has felt it necessary to adopt the ISO/TR 14047 : 2012 which comprises of several examples on key areas of IS/ISO 14044 in order to enhance the understanding of the requirements of the standard.

The text of ISO Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words ‘International Standard’ appears referring to this standard, they should be read as‘Indian Standard’.

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Contents

Page

Introduction

The heightened awareness of the importance of environmental protection and the possible environmental significance of a product system [1], have 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).

The 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 their environmental significance. LCIA models selected environmental issues called impact categories. Through the use of category indicators which help condense and explain the LCI results, LCIA provides a picture of the aggregate emissions or of resource use to reflect their potential environment impacts.

This Technical Report provides examples to support ISO 14044:2006. It uses several examples on key areas of ISO 14044 in order to enhance the understanding of the requirements of the standard.

1) In this Technical Report, the term "product system" also includes service systems.

Indian Standard

ENVIRONMENTAL MANAGEMENT — LIFE CYCLE ASSESSMENT — ILLUSTRATIVE EXAMPLES ON HOW TO APPLY IS/ISO 14044 TO IMPACT ASSESSMENT SITUATIONS

1 Scope

The purpose of this Technical Report is to provide examples to illustrate current practice of life cycle impact assessment according to ISO 14044:2006. These examples are only a sample of all possible examples that could satisfy the provisions of ISO 14044. They offer "a way" or "ways" rather than the "unique way" of applying ISO 14044. They reflect the key elements of the life cycle impact assessment (LCIA) phase of the LCA. The examples presented in this Technical Report are not exclusive and other examples exist to illustrate the methodological issues described.

2 Organization of examples in this Technical Report

2.1 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 normalization, grouping or weighting of the indicator results and data quality analysis techniques for assisting the interpretation of the results.

2.2 Scope of examples

The examples provided within this Technical Report illustrate and support the methodology specified in ISO 14044:2006, 4.4. The coverage is indicated in Table 1.

Table 1 — Elements or clauses of ISO 14044:2006 illustrated with examples

ISO 14044:2006 reference	IS0 14044:2006 Clause	Example coverage in this Technical Report
1 to 3	**Scope, Normative references, Terms and definitions**	**Examples of impact categories**
4.4.2 4.4.2.1 4.4.2.2 4.4.2.3 4.4.2.4	**Mandatory elements of LCIA** General Selection of impact categories, category indicators and characterization models Assignment of LCI results to the selected impact categories (Classification) Calculation of category indicator results (characterization)	**Example 1, Example 2, Example 3, Example 4, Example 5**
4.4.3 4.4.3.1 4.4.3.2 4.4.3.3 4.4.3.4	**Optional elements** General Normalization, Grouping Weighting	**Example 1, Example 2, Example 6, Example 7** *(Calculating the magnitude of the category indicator results relative to reference value(s))* **Example 1** **Stem example, Example 5, Example 8**
4.4.4	**Additional LCIA Data Quality analysis**	**Stem example, Example 5**
4.4.5 5 6	LCIA intended to be used in comparative assertions to be disclosed to the public Public Reporting Critical review	Not covered in this Technical Report

In some key areas more than one example is provided to illustrate the different ways that may be possible in applying ISO 14044:2006. It is important to stress this point. In many LCIA studies more than one approach or practice may be used which still allow conformance with the methodology prescribed in ISO 14044:2006. 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 prescribed in ISO 14044:2006. 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.	Title	Purpose of illustration	ISO 14044:2006 clause reference
1	Use of two different materials for gas pipelines	Full procedure of LCIA	4.4.2 and 4.4.3
2	Two acidification impact category indicators	Consequences of using general or site dependant models	4.4.2
3	Impacts of Greenhouse Gas (GHG) emissions and carbon sinks on forestry activities	GHG emissions and carbon sinks	4.4.2
4	Endpoint category indicators assessment	Transforming of ionising radiation inventory results to impact category indicator (YLL)	4.4.2
5	Choice of material for a wind spoiler in car design study	Impact modelling at endpoint level and weighting	4.4.2, 4.4.3.4
6	Normalization of LCIA indicator results for the use of different refrigerator gases	Normalization using different types of reference information	4.4.3.2
7	Normalization in a waste management study	Use of normalization in the communication processes	4.4.3.2 (reference to example 6)
8	A technique for the determination of weighting factors	The use of a panel of experts in such a study	4.4.3.3

2.3 Organization of document and route map

The structure of this Technical Report departs from a more recognized approach used in ISO standards since it provides examples about applications of ISO 14044:2006. It would help visualize better the structure of this Technical Report considering Example 1 as the trunk of a tree which runs through clauses pertaining LCIA both for its mandatory and optional elements. It of course uses its own set of LCI data. Examples 2 to 5 could be considered « branches » addressing specific different applications of the mandatory elements of LCIA. Example 2 extends into the optional element of normalization. Each of these examples is based on its own set of LCI data. Examples 6 to 8 are also « branches » addressing specific applications of the optional elements of the LCIA. Figure 1 lays the structure out in a flow diagram.

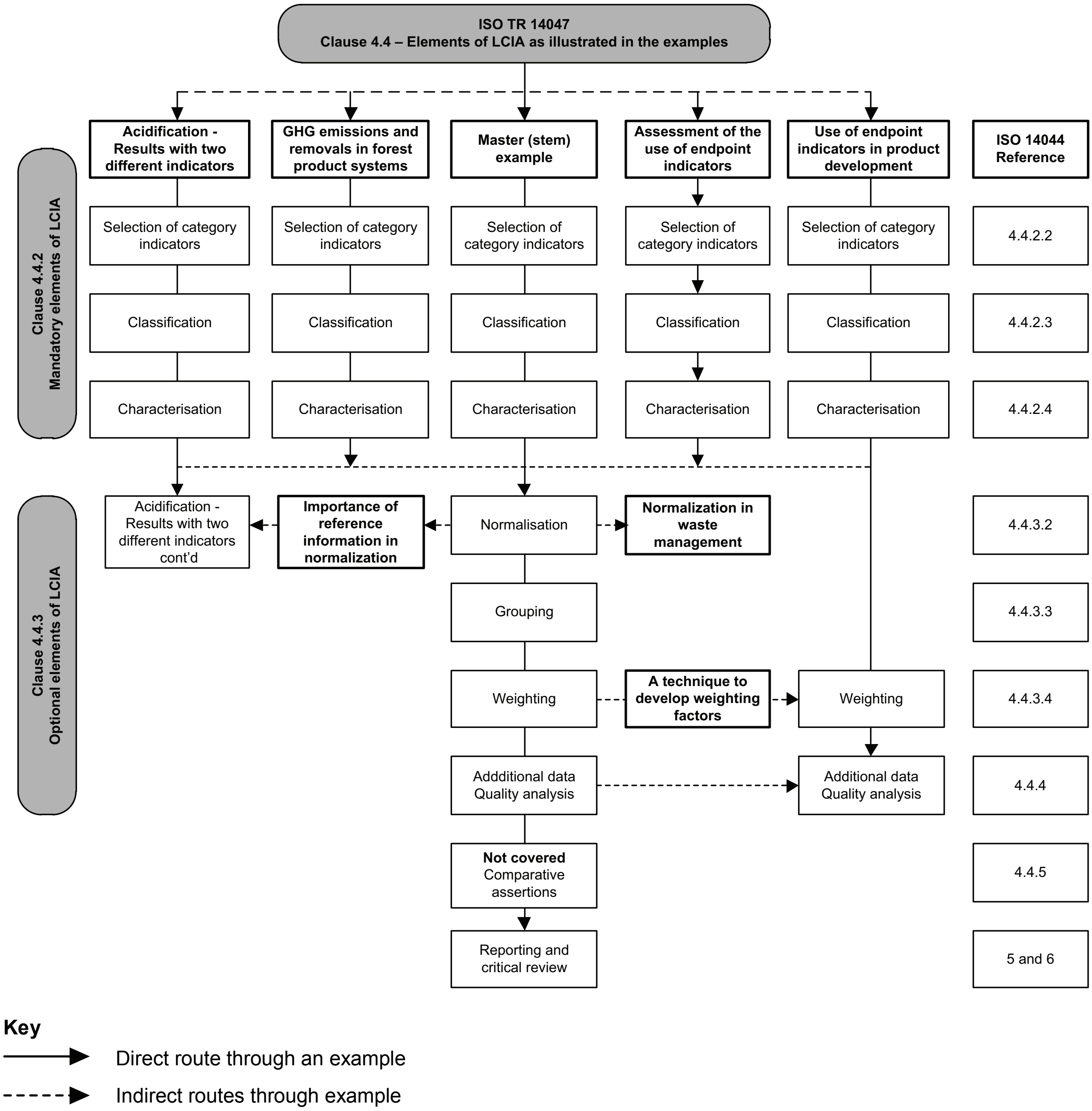

Figure 1 — Organization and route map for this Technical Report

NOTE Following Clause 3 the examples are organized thus:

— Examples in Clause 4, Mandatory elements running consecutively, i.e. Example 1, Illustration of ISO 14044:2006, 4.2.2, followed by Example 2, followed by Example 3, etc.

— Examples in Clause 5 are organized on a "topic" basis, e.g. with all examples on Illustration of ISO 14044:2006, 4.4.3.2, on normalization followed by examples on Illustration of ISO 14044:2006, 4.4.3.3, on grouping, etc.

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 that is intended to state the key area of ISO 14044:2006 that is illustrated. The body of the example follows the overview. Where an example continues through this Technical Report, it generally has not been necessary to precede each clause/subclause with an overview.

3 Elements of LCIA as illustrated in the examples

3.1 Overview

This clause gives a general description of LCIA explaining key elements of the procedure and it places the examples in the context of ISO 14044. The LCIA process elements are shown in Figure 2.

3.2 Mandatory elements

According to ISO 14044:2006, 4.4.2, 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).

3.2.1 Selection of impacts categories, category indicators and characterization models

For each impact category a distinction can be made between LCI results, including resources (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.

When defining the impact categories, an indicator is 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.

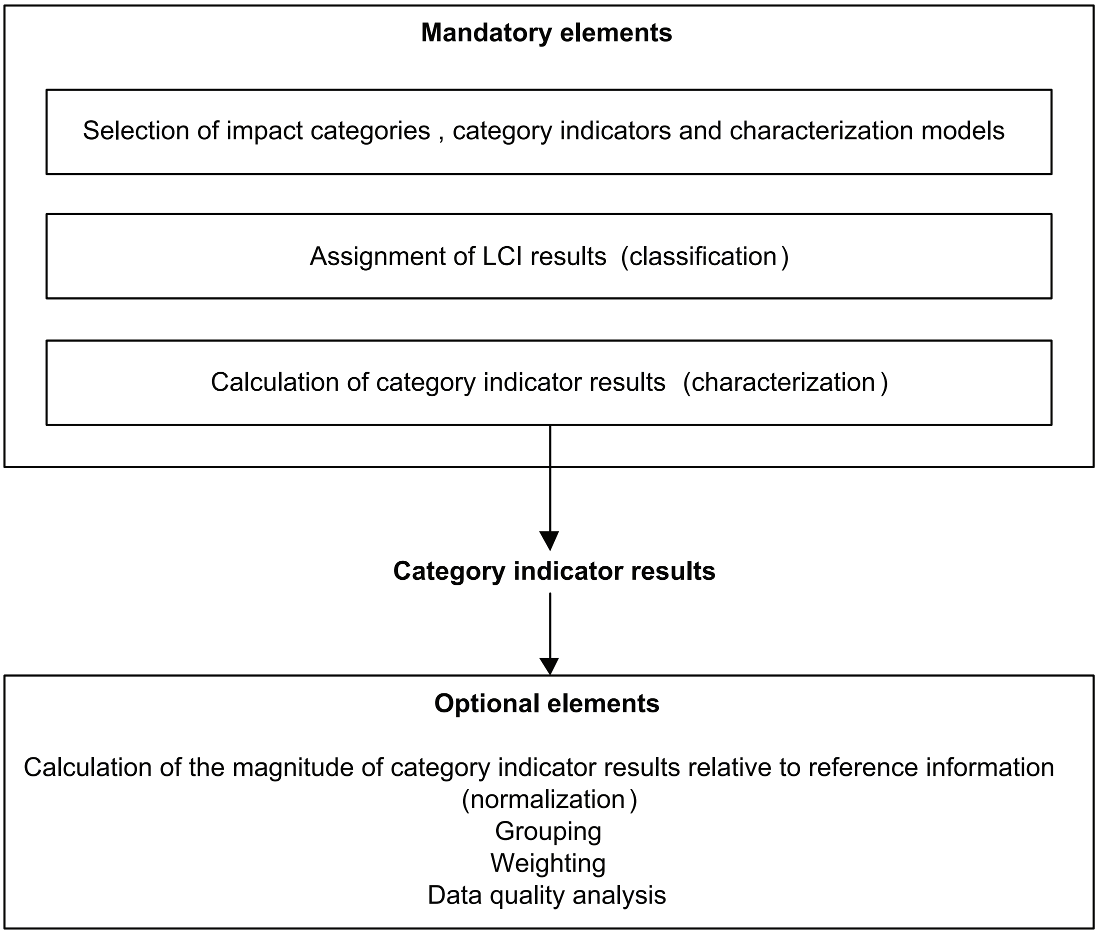

Figure 2 — Element of the LCIA phase (ISO 14044:2006)

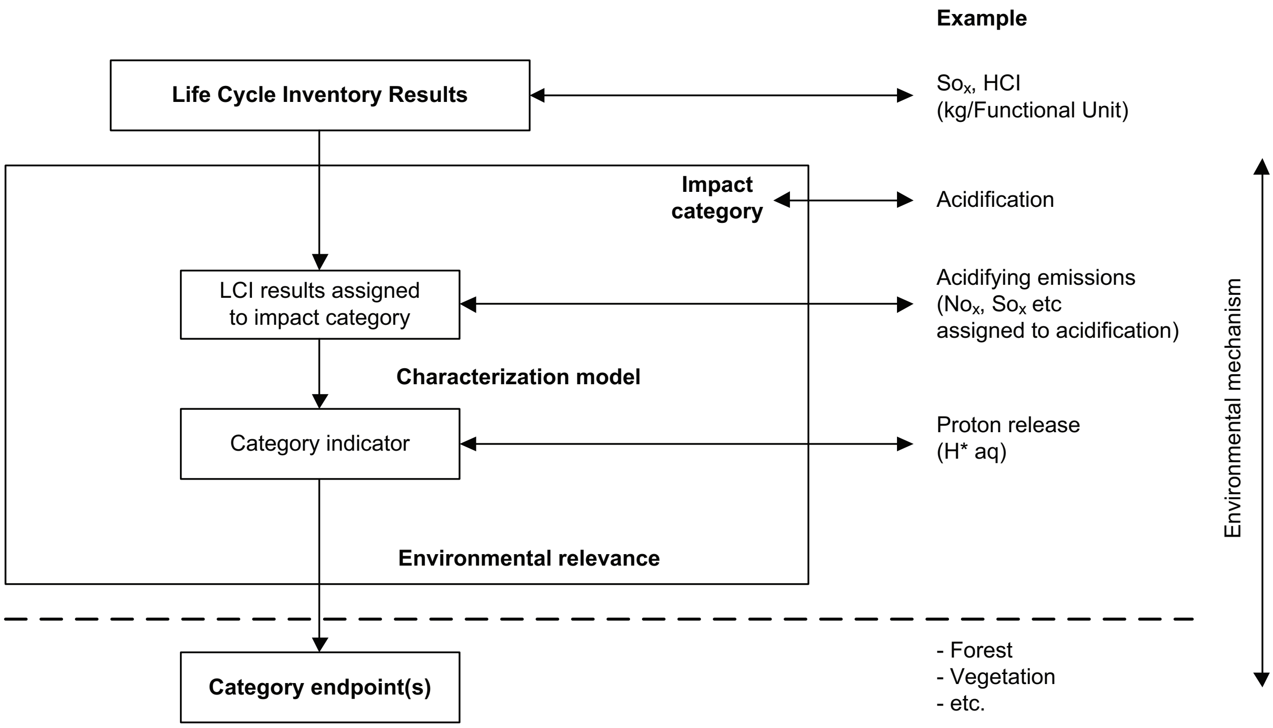

Figure 3 — Concept of category indicators (Figure 3 from ISO 14044:2006)

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 macro-nutrients (N, P)	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)
Eco-toxicity	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 per the same functional unit (the one selected in definition of the scope of the LCI phase).

In Table 4, the terms used for defining an impact category and describing the chosen characterization model are exemplified for six different impact categories to further illustrate the principles of table from ISO 14044:2006. Impact categories 1 and 2 are input related, impact categories 3 to 6 are output related.

In Table 4 all six examples chose 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 given examples are not the only alternative. 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 compares five different characterizations models. For the sixth alternative, the indicator is chosen close to the endpoint. The main distinguishing features are presented in bold.

Table 4 — Examples of definitions and descriptions of impact categories

Term	Impact Category 1	Impact Category 2	Impact Category 3	Impact Category 4	Impact Category 5	Impact Category 6
Impact category	Depletion of fossil energy resources	Depletion of mineral resources, (excluding energy resources)	Climate change	Stratospheric ozone depletion	Nutrification	Ecotoxicity
LCI results	Extraction of resources of different fossil fuels	Extraction of resources, expressed as useful material	Emissions of Greenhouse gases	Emissions of ozone depleting gases	Emissions of nutrients	Emissions of organic substances to air, water and soil
Characterization model	Cumulated energy demands	Static scarcity model	The model as developed by the Intergovernmental Panel on Climate Change (IPCC[a]) defining the global warming potential of different greenhouse gases [6], [7]	The model as developed by the World Meteorological Organization (WMO[b] defining the ozone depletion potential for different ozone depleting gases [8], [9]	The stoichiometric procedure as described by [10], which identifies the equivalence between N and P for both terrestrial and aquatic systems.	USES 2.0[c] model developed at RIVM, describing fate, exposure and effects of toxic substances, adapted to LCA by [11]
Category indicator	Energy content of energy resources	Extraction of material in the ore per estimated supply horizon of the reserve base	Increase of infrared radiative forcing (W/M^2)	Increase of stratospheric ozone breakdown	Deposition increase ÷ N/P equivalents in biomass	Predicted Environmental Concentration increase ÷ Predicted No-Effect Concentration
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	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)	Nutrification Potential (NP) for each eutrophicating emission to air, water and soil (kg PO_4^{3-}- eq. / kg emission)	Eco-toxicity Potential (ETP) for each emission of a toxic substance to air, water and soil (kg 1,4 -dichlorobenzene eq. / kg emission)
Indicator result	Total low calorific value (Mega Joules)	Total mass of used material in the ore divided by estimated supply horizon of the reserve base	Kg of CO_2-equivalents	Kg CFC -11 equivalents	kg PO_4^{3-} -equivalents	kg 1,4 -dichlorobenzene equivalents
Category endpoint	Heating, mobility	Availability of resources	Years of life lost, coral reefs, crops, buildings	Illness days, marine productivity, crops	Biodiversity, natural vegetation, algal bloom	Biodiversity
Environmental relevance	Diverse problems known from energy crises	Diverse problems from mineral resources	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	The nutrification indicator represents a clear causal factor in the mechanism of nitrification 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

[a] Intergovernmental Panel on Climate Change
[b] Word Meteorological Organization
[c] Uniform System for the Evaluation of Substances

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

Term	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Impact category	Photo -oxidant formation	Photo -oxidant formation	Photo -oxidant formation	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 (VOC, CO) to air	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	UNECE Trajectory model [12], [13]	Trajectory model [14]	Maximum Incremental Reactivity (MIR) scenario; Single cell model [15], [16]	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	Quantity of tropospheric ozone formed	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	Photochemical Ozone Creation Potentia (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 formed ozone for each emission of VOC or CO to air (kg ozone / kg emission)	Kg formed ozone for each emission of VOC or CO to air (kg ozone / kg emission)	Kg formed ozone for each emission of VOC or CO to air (kg ozone / kg emission)	Extent of exposure above critical level for each emission of NO_x, VOC or CO to air (m^2*ppm*hours / kg emission)
Indicator result	Kg ethylene equivalents	Kg ethylene equivalents	Kg ozone	Kg ozone	Kg ozone	m^2*ppm*hours
Category endpoint	Illness days, crops	Illness days, crops	Illness days, crops	Illness days, crops	Illness days, crops	Crops, natural vegetation
Environmental relevance	Ozone formation estimated with relative 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	Highest ozone concentration per added amount of standard VOC mixture, relative high NO_x concentration, realistic for peak situations	NO_x and VOC contribute equally to ozone production, relative low NO_x concentration, lower concentrations of NO_x and VOC both reduce ozone creation	Includes the contribution from NO_x together with VOCs and CO, permits spatial differentiation to take regional differences in reactivity and ecosystem sensitivity into account. Models close to endpoint

3.2.1.1 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 is chosen in the environmental mechanism, which as much 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 focuses at a distinct category indicator. The three models, and connected indicators, differ in their degree of sophistication. The first category indicator is the simplest one 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; the third indicator is defined at endpoint level, also known as damage approach. Again, the major distinguishing cells are presented in bold.

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 [21]
Category indicator	Maximum release of protons (H+)	Deposition / Acidification Critical Load	Increase in $PDF_{vegetation}$ (Potentially Disappeared Fraction) of plants 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	Kg SO_2 equivalents	Kg SO_2 equivalents	PDF.m^2.yr
Category endpoint	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 ISO 14044:2006, 4.4.2.2. These requirements are addressed for the indicators of the acidification impact category.

— Maximum proton release indicator: very crude indicator, far removed from endpoints (i.e. small 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.

3.2.1.2 Environmental relevance

The link between the LCI results (resources consumption, emissions and types of land use), and the category indicator is usually given by clear modelling algorithms. The term environmental relevance refers to how much the category indicator has a bearing on the category endpoint it attempts to reflect in a general and qualitative way. This helps to 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 14044:2006, 4.4.2.2.4).

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 sub-polar 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 break down 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 report the category indicator is chosen at the level of an intermediate parameter in the environmental mechanism. Exceptions are example 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 line of the first two alternatives of Table 6.

3.2.1.3 Choice of impact categories

Table 7 — Commonly used impact categories [22]

Output related categories:
— Climate change
— Stratospheric ozone depletion
— Photo-oxidant formation
— Acidification
— Nutrification
— Human toxicity
— Eco-toxicity
Input related categories:
— Depletion of a-biotic resources (e.g. fossilize 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 the reference [22] 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 in 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 and 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.

3.2.2 Assignment of LCI results (classification)

Assignment of LCI results to impact categories means that it is identified which results have an impact on which categories. Often this information is provided by the table of characterization factors coming from the chosen model for the impact category. A main distinction in ISO 14044:2006, 4.4.2.3, concerns the difference between serial and parallel processes. The characteristic which causes a problem in parallel processes is that one substance which has an impact on different categories may have to be divided between these categories because part of the emission leads to effects in one category and another part to effects in another category. As an example, the emission of SO_2 contributes to three categories: acidification, climate change (counteracting) and human toxicity. Refer to Figure 4.

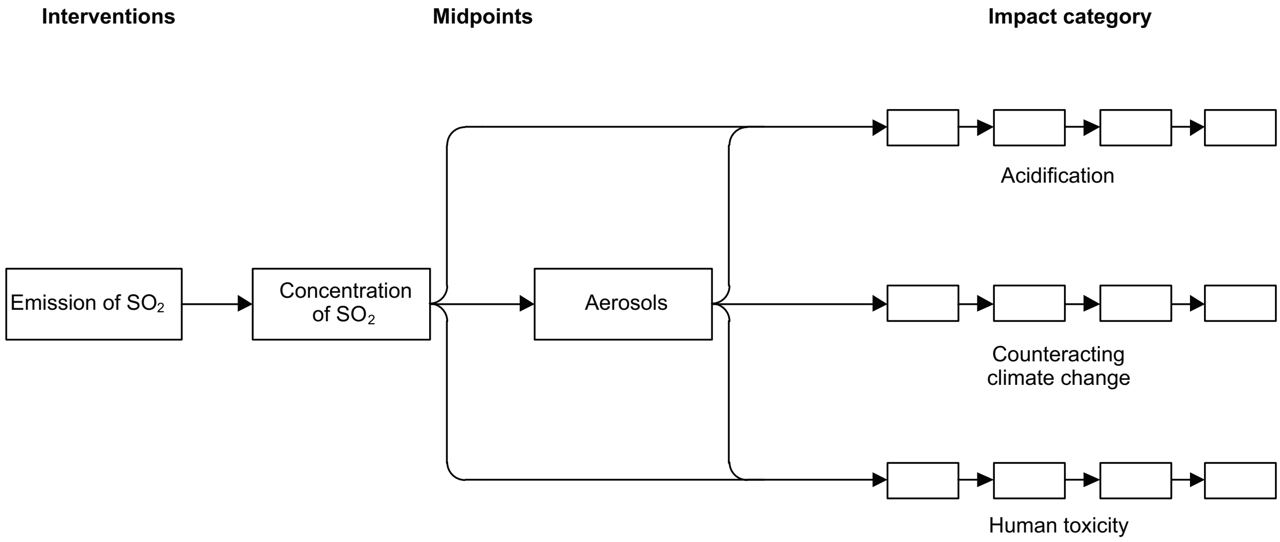

Figure 4 — Example of parallel processes

Serial processes are illustrated for the emission of CFCs. The characteristic, which causes a problem in serial processes, is that a substance may subsequently have a contribution to different impact categories, again necessitating a choice concerning the contribution to these subsequent categories. The emission of CFCs contributes to the following two impact categories: firstly climate change at tropospheric level then stratospheric ozone depletion. Refer to Figure 5.

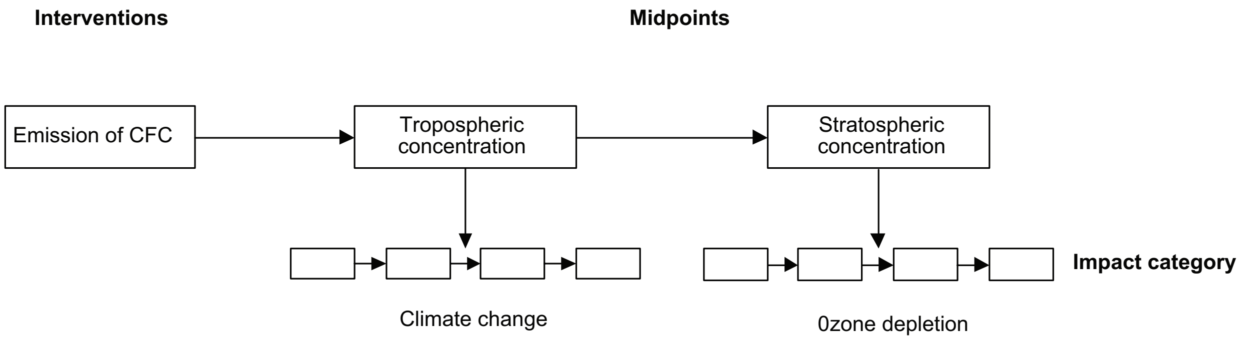

Figure 5 — Example of a serial process

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 to its full amount to the different types of impact one after the other. It should be noted however, that in case 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 ISO 14044:2006, 4.4.2.3.

3.2.3 Calculation of category indicator results (characterization)

Following the identification of impact categories, choice of indicators and the selection or development of characterization model, and the assignment of LCI results to impact categories, indicator values are calculated. These are 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.

3.3 Optional elements (related to ISO 14044:2006, 4.4.3)

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 14044:2006 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 - the LCIA profile.

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

ISO 14044:2006, 4.4.3.2.1, states:

"*Normalization is the calculation of the magnitude of the category indicator results relative to some reference information. The aim of the normalization is to understand better the relative magnitude for each indicator result of the product system under study. It is an optional element that 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.

3.3.2 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 type of impacts.

Example 1 illustrates sorting and ranking.

3.3.3 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 with the (normalized) indicator results. Since weighting may include aggregation of the weighted indicator results, the outcome of this step may 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 14040:2006 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 methods can be distinguished:

- Monetary weighting, based on willingness-to-pay or on revealed preference approaches
- Distance-to-target weighting, using policy standards
- Social panel weighting, using the judgment of experts or of stakeholders in the decision process.

Examples 1, 5 and 8, illustrates weighting. Example 1 uses weighting factors based on a social panel process.

Example 5 uses weighting factors based on monetarisation of the different impacts. Example 8 describes the development of weighting factors applying a panel process in a two-step procedure firstly, relating indicator scores to endpoints, and secondly, weighting the endpoints relative to each other.

3.3.4 Data quality analysis

The data quality tools mentioned in ISO 14044:2006 comprises: 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 like 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.

4 Examples of the mandatory elements of LCIA

4.1 General description

Figure 1 highlights the number of examples within the mandatory elements section. This clause can be read by starting either at Example 1, and then through each of the other examples in turn, or by selecting whichever example is of particular interest.

4.2 Example 1 - Use of two different materials for gas pipelines

4.2.1 Overview

This example, which acts as a stem, is used to illustrate the mandatory part of the LCIA process within ISO 14044:2006, 4.4.2. At different points alternative examples are presented.

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

In the example, a comparison is made between the production and use of gas pipes in country x in the year y, made from materials A and B. The functional unit is the supply of 20 cubic metres 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 pipe system in total, the use of the gas pipe system, waste management, and electricity production along the life cycle and transportation along the life cycle.

The example only analyses the emissions to air and water connected with the two product systems. The following types and quantities of emissions are considered in the example.

Table 8 — LCI results of Example 1

Substance	LCI results			
	Material A		Material B	
	kg	kg	kg	kg
	Air emissions.	Water emissions.	Air emissions.	Water emissions.
Carbon dioxide	4,22E+04		4,81E+03	
HALON-1301	1,55E-03		4,30E-04	
Tetra chloromethane			4,90E-04	
Methane	6,73E+03		6,75E+03	
Ethane	1,94E+02		1,98E+02	
Propane	2,97E+01		2,99E+01	
Sulphur 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	

4.2.2 Selection of impact categories, category indicators and characterization models (ISO 14044:2006 4.4.2.2)

4.2.2.1 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;

— eco-toxicity.

4.2.2.2 Selection of the indicator(s)

The following category indicators have been selected:

- 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];
- eco-toxicity: 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 on the indicator for human toxicity. The results of this model are not fully science-based due to the inclusion of ADI-values as measure of the no-effect level.

4.2.2.3 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 characterisation 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 basis of their occurrence in biomass is selected [10];
- For human toxicity, the model USES 2.0 of RIV M 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, due to the inclusion of ADI-values, not fully science based;
- For eco-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. Aquatic eco-toxicity potentials are used as proxy for the eco-toxicity potentials. The characterization factors are presented in the given references.

4.2.2.4 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.

Table 9 — Characterization factors for Example 1

Impact Category	Substance	Characterization factors								
		Climate Change kg CO2 eq./ kg	Stratosph ozone depletion kg CFC-11 eq. / kg	Photo-oxidant formation kg ethylene eq. / kg	Acidifi-cation kg SO2-eq./ kg	Eutrophication Kg PO4- eq. / kg		Human Toxicity Kg 1,4-DCB / kg	Eco-toxicity 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								
	HALON-1301	5600								
	Methane	21								
Stratospheric Ozone depletion	HALON-1301		12							
	Tetrachloro methane		1,2							
Photo-oxidant Formation	Methane			0,006						
	Ethane			0,123						
	Propane			0,176						
Acidification	Sulphur dioxide	a			1					
	Ammonia				1,3					
	Nitrogen dioxide				0,41					
Nutrification	Ammonia					0,35	0,33			
	Nitrogen dioxide					0,13				
	P						3,1			
	N						0,42			
Human toxicity	Sulphur dioxide							0,096		
	Nitrogen dioxide							1,3		
	Arsenic							347699,7		
	Lead							466,52		
	Nickel							35032,84		
	Vanadium							6240,35		
	Chlorinated organ. trace pollutants								b	b
Eco-toxicity	Phenol								1,5	237
	Cadmium								289	1523
	Lead								2,4	9,615719
	Chromium								1,9	6,9
	Copper								221,6538	1157,307
	Chlorinated organ. trace pollutants								b	b

a It is recognised that the emission of SO2 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 in very small quantities emitted with material B.

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

4.2.3 Assignment of LCI results (classification) (ISO 14044:2006, 4.4.2.3)

SO_2 has a number of parallel impacts as illustrated in 3.1.2. To avoid double counting these should be divided between the impact categories concerned. However, at present only a simplified procedure is possible:

— Acidification: all emissions of SO_2 to be assigned to acidification (incl. aerosols);

— Climate change: only SO_2-aerosols to be assigned to climate change, although at the present this type of impact is not yet quantified in terms of a negative GWP-value (see notes 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 illustrated earlier in Clause 3. These substances first have an impact on climate change due to their concentration in the troposphere; after that they contribute to ozone depletion, after they have been distributed to the stratosphere.

4.2.4 Calculation of category indicator results (characterization) (ISO 14044:2006, 4.4.2.4)

4.2.4.1 General

In this subclause the characterization results are calculated. The functional unit and the unit processes are given in 4.1. There also, the emissions are given for the two materials considered. The impact categories, which are considered, are selected as shown in point 1) of the illustration of ISO 14044:2006, 4.4.2.2. The category indicators are selected as shown in point 2) of the illustration of ISO 14044:2006, 4.4.2.2. The characterization models and characterization factors are used according to point 3) of the illustration of ISO 14044:2006, 4.4.2.2. 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 10 — Calculation of indicator results of stem example – Material A

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	Kg…eq/kg	Kg…eq
Climate change	Carbon dioxide	4,22E+4		1,00E+00		4,22E+04		1,84E+05
	HALON-1301	1,55E-03		5,60E+03		8,66E+00		
	Methane	6,73E+3		2,10+01		1,41E+05		
Stratospheric ozone depletion	HALON-1301	1,55E-03		1,20E+01		1,86E-02		1,86E-02
	Tetrachloride-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	Sulphur 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		
	P		1,22E+00		3,10E+00		3,79E+00	
	N		4,05E-01		4,20E-01		1,70E-01	
Human toxicity	Sulphur 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		
Eco-toxicity	Phenol	9,40E-05	1,55E-01	1,50E+00	2,37E+02	1,41E-04	2,37E+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	

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

Material B								
Impact category	**Substance**	**Assigned LCI results**		**Characterization factors**		**Converted LCI results**		**Indicator results (LCIA profile)**
		Air emission	Water emission	Air emission	Water emission	Air emission	Water emission	
		kg	kg	kg eq/kg	kg eq/kg	kg eq/kg	kg eq/kg	kg eq
Climate change	Carbon dioxide	4,81E+3		1,00E+00		4,81E+03		1,46E+05
	HALON-1301	4,30E-04		5,60E+03		2,41E+00		
	Methane	6,75E+3		2,10E+01		1,42E+05		
Stratospheric ozone depletion	HALON-1301	4,30E-04		1,20E+01		5,16E-03		5,75E-03
	Tetrachloride-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	Sulphur 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		
	P		5,41E-02		3,10E+00		1,68E-01	
	N		1,80E-01		4,20E-01		7,54E-02	
Human toxicity	Sulphur 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		
Eco-toxicity	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		

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

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

4.3 Example 2 – Two acidification impact category indicators

4.3.1 Overview – Examples illustrating the effect of selecting different acidification impact category indicators

The example illustrates the importance of ISO 14044:2006 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 between sites (Table 14), even when the same inventory results are used.

Such differences are important to consider during the goal and scope in order to fulfil the purpose of a study and to understand the inventory data that needs to be collected.

Due to the focus on a single impact category, illustration of the concept of category indicator is omitted. For guidance, see other examples and the text of ISO 14044:2006.

4.3.2 Selection of impact categories, category indicators and characterization models (ISO 14044:2006, 4.4.2.2)

4.3.2.1 Describing the environmental mechanism for an impact category

Two alternative 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 or 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 and no information on the environment itself, e.g. condition, intensity of impact, reversibility, etc. The second alternative uses the area where the critical capacity 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. Figure 6 shows 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. The location of two different indicators in the environmental mechanism is shown. The steps are described to illustrate the differences in these indicators.

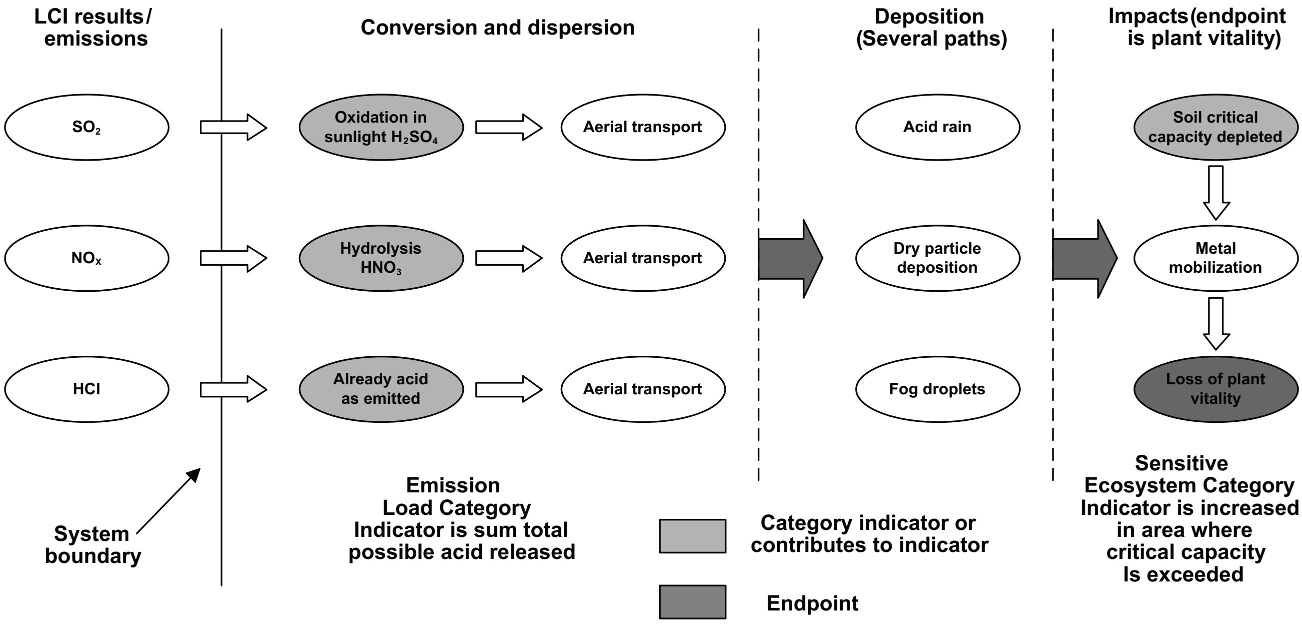

Figure 6 — Simplified environmental mechanism for acidification

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 hundreds 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 in fog droplets). Several factors determine the acid amounts that reach a specific receiving area. For environmental relevance, these factors are included in spatially specific characterization models, such as:

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

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

— Deposition depends upon each acid’s characteristics, e.g. particle size, and 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 may decrease the receiving water or soil pH. The pH decrease depends both on the amount of acid deposited from the LCA system, the background acid load from other human and natural sources, and the receiving site's neutralization capacity. 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 (e.g. lost plant vitality) are likely. For acidification, when critical capacity is exhausted then impacts begin to occur. Thus, 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 measures such as the critical capacity or ADIs are exceeded.

Compared to a total emission load indicator, one should recognize as seen later in Table 14:

— 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 varies substantially depending upon the spatial locations of the emission source and the receiving ecosystems.

Thus, a total emission load indicator by omitting or ignoring these environmental details has very different indicator results from a sensitive ecosystem indicator, even when the starting LCA inventory results are the same.

4.3.2.2 Indicator models and characterization factors

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

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

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 practitioners often refer to the EL indicator results as "potential environmental impacts".

Table 12 — Coverage of 14044:2006 recommendations and criteria

ISO 14044 Notes	EL Indicator	SE Indicator
LCI Results – Both indicators use the same LCI parameters, but spatial detail needed for SE indicator		
ISO 14044:2006, 4.4.2.2.3		
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 a re 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 14044:2006, 4.4.2.2.4		
Reflect the consequences of the LCI results on the category endpoint(s), at least qualitatively	Strictly 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.

b) Acid deposited in sensitive Ecosystems category indicator (SE indicator)

The SE indicator characterization incorporates spatial aspects and fate and transport and addresses environmental relevance as recommended by ISO 14044:2006, 4.4.2.2.4 (again, see Table 12). This also illustrates the importance of the goal and scope selection process. 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 by 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. The LCA adaptation converts the cells to countries, so the inventory only records the country of an emission. Each country has a characterization factor (e.g. AF_{NOx} and AF_{SO2} – see Table 13) to calculate for each emission conversion to acid, transport, and deposition and then calculate area at each receiving sites where the critical capacity is exceeded. Each emission is converted with the characterization factor from kilotons (or grams) of emission to the increased area in hectares (or square meters) where the critical capacity is exceeded. For the complete derivation of the SE indicator see [24].

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 deposit on and concentration for comparison with critical capacities and thresholds for acidification, terrestrial eutrophication-via-air and tropospheric ozone creation.

4.3.2.2.1 Selection of the characterization model and characterization factor

The EL indicator results are expressed as proton equivalent s 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 sulphur 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 meters of area where the increased load of the LCA increases the deposition above the critical capacity (a marginal increase in the area where the critical capacity is exceeded). The characterization factors for several countries with their spatially specific characterization factors (e.g. AF_{NOx} and AF_{SO2}) are given in Table 13 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, sulphur dioxide, nitrogen oxides, ammonia, etc., noted above, the region where each emission takes place is recorded.

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

Country or Region	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	0,02	0,0002
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

4.3.3 Assignment of LCI results (classification) (ISO 14044:2006, 4.4.2.3)

Illustration of ISO 14044:2006, 4.4.2.3, is omitted. For guidance, see other examples and the text of ISO 14044:2006.

4.3.4 Calculation of category indicator results (characterization) (ISO 14044:2006, 4.4.2.4)

4.3.4.1 Calculation of the LCI results into the indicator result

This subclause calculates category indicator results for the EL indicator and the SE indicator. The outcome in the value of the indicator results can differ significantly depending upon where the emission source is located in relation to sensitive receiving areas (see Table 14). This reinforces the need to carefully evaluate choices in the study goal and scope and reinforcing the statement in ISO 14044:2006 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. The number and kind of simplifying assumptions and value-choices used in the characterization model for the category indicator also vary between impact categories and can depend on the geographical region. A trade-off often exists between the simplicity and accuracy of the characterization model."

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 PVC, the disposal and recycling of the wire with incineration of PVC are omitted. The functional unit is a kiloton of electrolytic refined copper produced and the parameters used are 10 grams of NO_x and 100 grams of SO_2. Identical processes and the same emission quantities 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:

$$(10gNO_x \times 0{,}70) + (100gSO_2 \times 1) = 107gSO_2 \text{ equivalents / kt of copper}$$

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 SO_2 g equivalents/kt of electrolytic 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 differ considerably depending on where the emission took place (1 to 769). 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 load represented by the EL indicator deposits in areas where the critical load is exceeded. For comparison, then, the amounts 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 size of the EL indicator results.

Table 14 — Calculations for Indicator Results using SE Model and Comparison of Differences

Country	**NO_x** (g x AF)	**SO_2** (g x AF)	**Indicator result** (m ^{2})	**Relative Comparison**	
Dispersion & Deposition				**To SE result for Albania**	**To EL result as SO_2 eq.**
Albania	10 x 0,00 = 0	100 x 0,0002 = 0,02	0,02	1	5350
Belgium	10 x 0,0082 = 0,008	100 x 0,0128 = 1,28	1,29	64	83
Finland	10 x 0,0242 = 0,242	100 x 0,1514 = 15,14	15,38	769	7

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 only needs general screening results (EL indicator) and one that needs accuracy and environmental relevance (SE indicator).

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 would clearly show that emissions from Albania would increase the critical capacity exceedence in a far lower area compared to Belgium. Thus, decisions making important comparisons should consider selecting environmentally relevant indicators whose models incorporate spatial information on the emission source, the fate and transport processes, and the sensitive ecosystems.

4.4 Example 3 – Impacts of Greenhouses Gas (GHG) emissions and carbon sinks on forestry activities

4.4.1 Overview

A company, with an integrated system of timberland and diverse forest products, conducts an LCA with the goal of ascertaining the relative impacts of the issues of climate change on the corporation's variety of operations. 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's 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 category and indicators for GHG emission but also for carbon sinks both in timberlands and along the product system. In that sense, 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.

Five major didactic values are offered by the example:

a) The need to consider other parameters in addition to traditional emissions or resources quantification through definition of a new impact category. This is needed to meet the goal and scope requirements of the study. Such consideration is anticipated in ISO 14044:2006, 4.4.2.2.1.

b) In studies involving biomass and bio-based products, there are transformations within the system boundary that have the character of impact category themselves.

c) Indicators results that when presented in the LCIA results profile could be additive across impact categories under certain design and selection conditions.

d) Information that would help ascertain the shared responsibilities of different actors in the product system according to the effects and impacts.

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

4.4.2 Selection of impact categories, category indicators and characterization models (ISO 14044:2006, 4.4.2.2)

The following paragraphs under 4.3.2.1 describe the major steps in the selection of the impact categories. Paragraphs 4.3.2.2 to 4.3.2.4, describe the steps in the selection of the indicators, mechanisms and characterization models and factors. Illustration of ISO 14044:2006, 4.4.2.3, indicates the procedures to assign LCI results to the impact categories and illustration of ISO 14044:2006, 4.4.2.4, characterization, the indicator results are calculated and the profile generated.

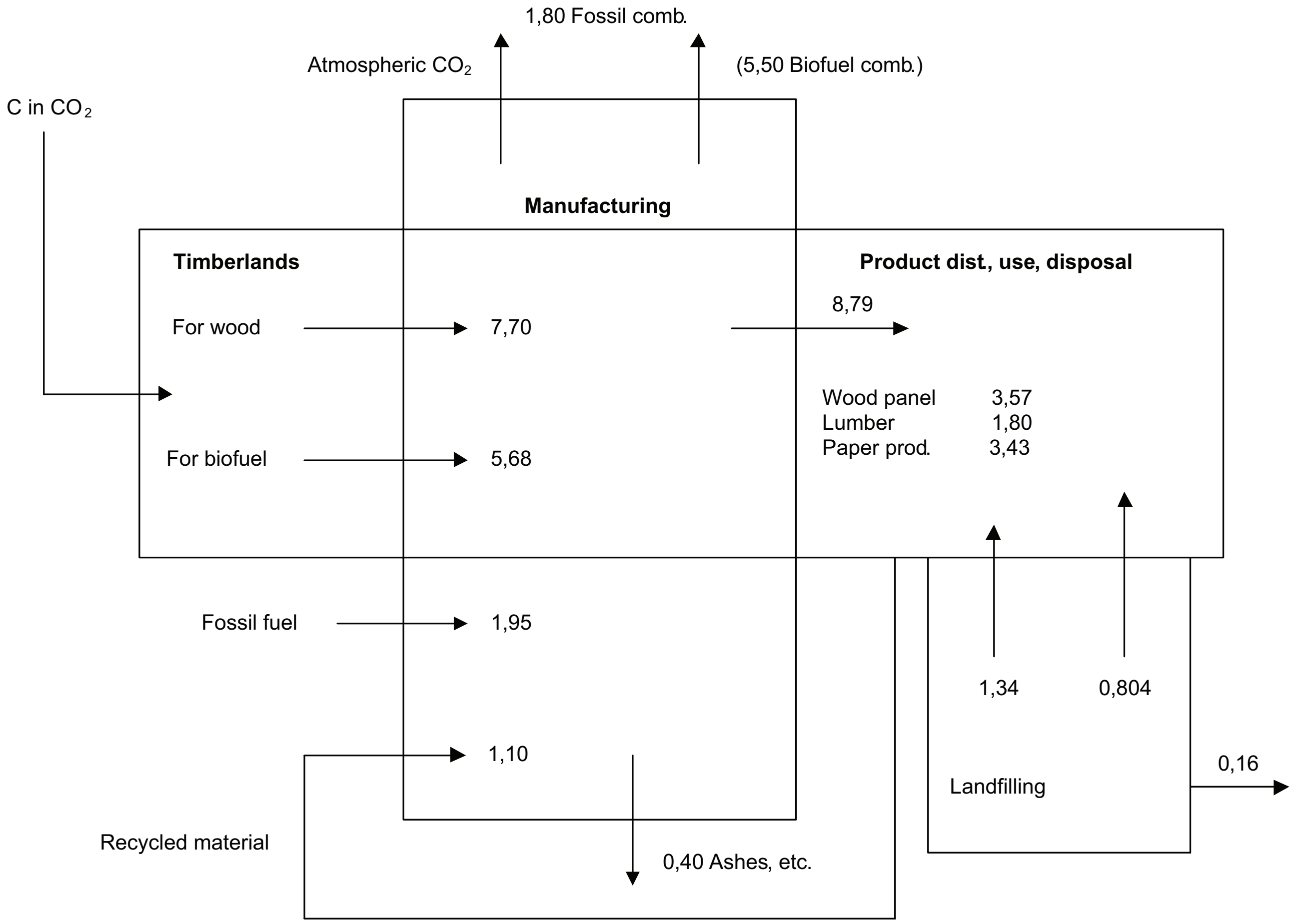

Figure 7 — The Product System in terms of Carbon [3] (units – millions metric tonnes)

4.4.2.1 Selection of impact categories

4.4.2.1.1 Ensuring impact categories are consistent with the goal and scope of the study

The goal of the study is to ascertain the relative impacts of the company's variety of 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, there are market pulps, communication 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 (MM tons) of product carbon content as the functional unit is compatible with these goals since it facilitates the different calculations in the transformations of environmental results into the impact categories and indicators. The selection of impact categories is consistent with the characteristics of the system as well as the goal and purposes of the study. In other words, besides the radiative forcing that is an impact category for GHG emission sources, the study needs an impact category that addresses the impacts of carbon sequestered and storage in sinks that are recognized desirables amelioration tools. Moreover, since credits, trading and controls are exerted in terms of net values (emissions minus sinks), the impact categories should provide indicator results that under specific study design conditions are amenable of addition at the level of the indicator results profile.

3) 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.

4.4.2.1.2 Considering the LCA study purpose and identifying the audiences

The purpose of the LCA study considers gathering the necessary information and data along the product system components that is permitted to assess the net impacts of GHG emissions as well as carbon sequestration and storage in carbon sinks. Such assessment would help in the decision-making of the company's policies and strategies around climate change issues. LCIA was considered an added tool to better understand the inventory issues and gathered information 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 of different product lines and administrative executive level functions while keeping relevance with the climate change terminology and concepts. Additional audiences were other executives and managers on environmental engineering, government affairs, technology, public relations, production, etc. The original complete study is considered of confidential nature. In this example, company's structure and size at the time of the study is different from the actual company.

4.4.2.1.3 Reviewing the LCI system functions, boundaries and unit processes

In Figure 7, there is a simplified schematic of the product system and its boundaries with some of the production distribution that is used and transformed in the characterization step of the LCIA. In terms of Carbon, 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 fuels. Carbon is emitted as CO_2 from the combustion of bio fuels and fossil fuels. Products of different nature are manufactured, distributed, used and disposed. All quantities cited are in annual terms. The example does not address C emissions from fossil fuels in the timberland process, neither in transportation and distribution. Contributions are small in comparison with the other contributions.

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

The goal and scope of the study helps define a set of comprehensive environmental issues present in the product system. This set includes both the most traditional emissions of anthropogenic fossil fuels 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 Carbon along the stages of the product system, it is necessary to quantify specific biomass processing. These quantities are transformed later during the characterization stage of LCIA. Information is needed on the functionality of the processed biomass, either for bio fuels or for 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 transformed, by characterization factors, into total biomass carbon and C-equivalent.

There are also important environmental issues associated with the "net -zero CO_2" mechanism for Biomass fuel and the storage in sinks of the C in forest products. Table 15 provides the functionality Information on the biomass processed per Figure 7.

Table 15 — Functionality of the Amounts of Processed Carbon

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

4.4.2.1.5 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 actions. The inventory results can be assigned to these impact categories. This consideration fits the definitions in ISO 14044:2006, Clause 3.

One of the two selected impact categories is climate change with radiative forcing as the indicator because according to the IPCC it 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 are greenhouse emissions, GHG. They are transformed (via global warming potential, GWP factors) into category indicators and aggregated to yield the category indicator results, metric ton of CO_2- equivalent, or C-equivalent.

The other impact category chosen for the study is carbon sequestration and product sinks. In systems where 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 and the carbon sinks thus created. Carbon sequestration may be seen as part of the product system. The carbon sinks effects are then 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 sequestration 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.

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 and sinks as an impact category, the inventory looks into the timberland as well as into the product system downstream of manufacturing. There is need first to quantify carbon 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 carbon, after discounting for harvesting, represents the C sequestered. Once the atmospheric carbon is sequestered it remains stored in the timberland and in the products for a period of time according to the type of product and the function to which it is put to use. Since the biomass for fuels was discounted as part of the harvested amounts, it is easier to understand the "net -zero" CO_2-equivalent emission in the accounting of net carbon-equivalent.

4.4.2.2 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 endpoints for the two impact categories are the same; concern on the damage because of the change to the balance between absorbed and reflected IR radiation. The difference in the indicator results for the two categories is one of sign. Those aggravating the imbalance are negative influences. Those reducing the imbalance by sequestration and delaying the effects by storage in sinks are the positive influences. The mechanisms in the example properly link the LCI results to the impact categories and the indicator results through proper characterization models and factors. Two of the mechanisms are conventional, radiative forcing and photophosphorylation. The other two mechanisms are less conventional but they explain, nevertheless, 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 existence of the mechanisms and the models provides the separation between the LCI and the LCIA phases of the LCA.

4.4.2.3 Selection of indicators

The indicators for the two impact categories were considered to be tons of CO_2-equivalent or tons C carbon-equivalent. The LCI results expressed in tons CO_2 are amenable to transformation into C-equivalent for the same time horizon. Likewise, the LCI results having to do with C sequestration and storage in sinks are transformable into CO_2-equivalent with the proper factors and models. It is important to keep similarity into the time horizons for both impact categories. In this sense, the example uses a time horizon of 100 years for the GWP factors as it is normally done. For the product sink we also use a time horizon of a 100 years as the time a given fraction of the product still remains in use and hence can be considered a carbon sink [4)].

4.4.2.4 Selection of characterization models and factors

4.4.2.4.1 The IPCC model for radioactive forcing

The characterization model for the radiative forcing impact category is the one used and fostered by the Inter-governmental panel on Climate Change, IPCC. The specific IR radiative forcing for different GHGs permits expressing different GHGs in a common unit, standardized to the value of 1,00 for CO_2. The Global Warming Potential, as characterization factors, allow for different GHGs to be aggregated and expressed in carbon-equivalent units. IPCC recommends a time horizon of 100 years. If the time horizon is changed to 500 years or infinity, the methane GWP factor is considerably reduced. Table 16 gives the GWP characterization factors for the two major GHGs in the example.

4) According to ISO 14044:2006, 4.4.2.2.1, the environmental mechanism describing the impact categories also includes the total of environmental processes in the product system such as sequestration in timberlands and wooden products.

Table 16 — Global Warming Potential Factors

Green House Gas (CHG)	Atmospheric lifetime (years)	GWP factor (100 year time horizon)
Carbon dioxide (CO_2)	50 to 200	1
Nitrous Oxide (N_2O)	120	310
Methane (CH_4)	12 (+/- 3)	21

4.4.2.4.2 The Calvin-Benson model for carbon sequestration

The characterization model for this impact category can be described in two phases. In the first phase, the sun light energy is converted by the photophosphorylation reaction into adenosine triphosphate (ATP) and the coenzyme NAPDPH, both rich-energy molecules. In the second phase, the Calvin-Benson cycle fixes the atmospheric carbon dioxide into organic substances making use of the transformed sunlight energy.

The characterization factor used with the model converts the net C (Tc) biomass growth/year from the inventory results (expressed as merchantable wood) to gross (total) biomass growth, T'c by multiplying this value by a biomass/merchantable ratio. This ratio was derived for specific species and regions and it is 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 x 1,70 = total biomass, T'c.

T'c x 0,75 = Useful biomass.

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

To estimate the amount of carbon equivalent that can be considered in storage in sinks there is need to estimate the rate at which the forest products (and carbon) are retired from use in each end-use sink according to the functionality of the product. Row and Phelps (USDA) have developed a characterization model that uses a logistics curve to estimate the proportion (%) of wood products remaining in the end- use sink. 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 building, multi-family building, etc. Logically, different kinds of wood products can be classified into one given functional category.

The time a wood product remains in use (T) is determined largely as function of the average useful life (L) and the proportion (P) of that product remaining in the sink at a selected 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 are not only expressed as C-equivalent but also in the same time horizon. T and P are expressed as:

$T = f(L,P)$

Where $P = 0{,}5 / [1 + 2 (\ln T – \ln L)]$

4.4.2.4.4 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. 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, to extend the value of the figures given by the IRS tables and consequently increase the value of the characterization factors).

The equation is given by the expression below in which, L = Revised expected half-life, H = the original half-life and, R = the proportion the product is being recycled into same product category.

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

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

4.4.2.4.5 Characterization model for biomass fuels – Net-zero C emission

The characterization model that describes the net -zero C emission when burning biomass fuel is typically a recycling model whereby CO_2 from the atmosphere (and its C expression) are sequestered by the photosynthesis process described in the Calvin-Benson model. Staying away from C_{12} and C_{13} considerations, the CO_2 emissions from the combustion are considered equal to the ones already sequestered and 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 time carbon sinks rather than from the atmosphere. The characterization factor used is equal to 0.

4.4.3 Assignment of LCI results (classification) (ISO 14044:2006, 4.4.2.3)

4.4.3.1 Classification of inventory results into impact categories

A brief description of the classification of LCI results into impact categories is given in Figure 8. From the different types of inventory results to the classification into impact categories, classification cannot be completed until there is a reasonable certainty of the availability of adequate characterization models and factors. These models and factors provide indicator results which are illustrated in the indicator results profile.

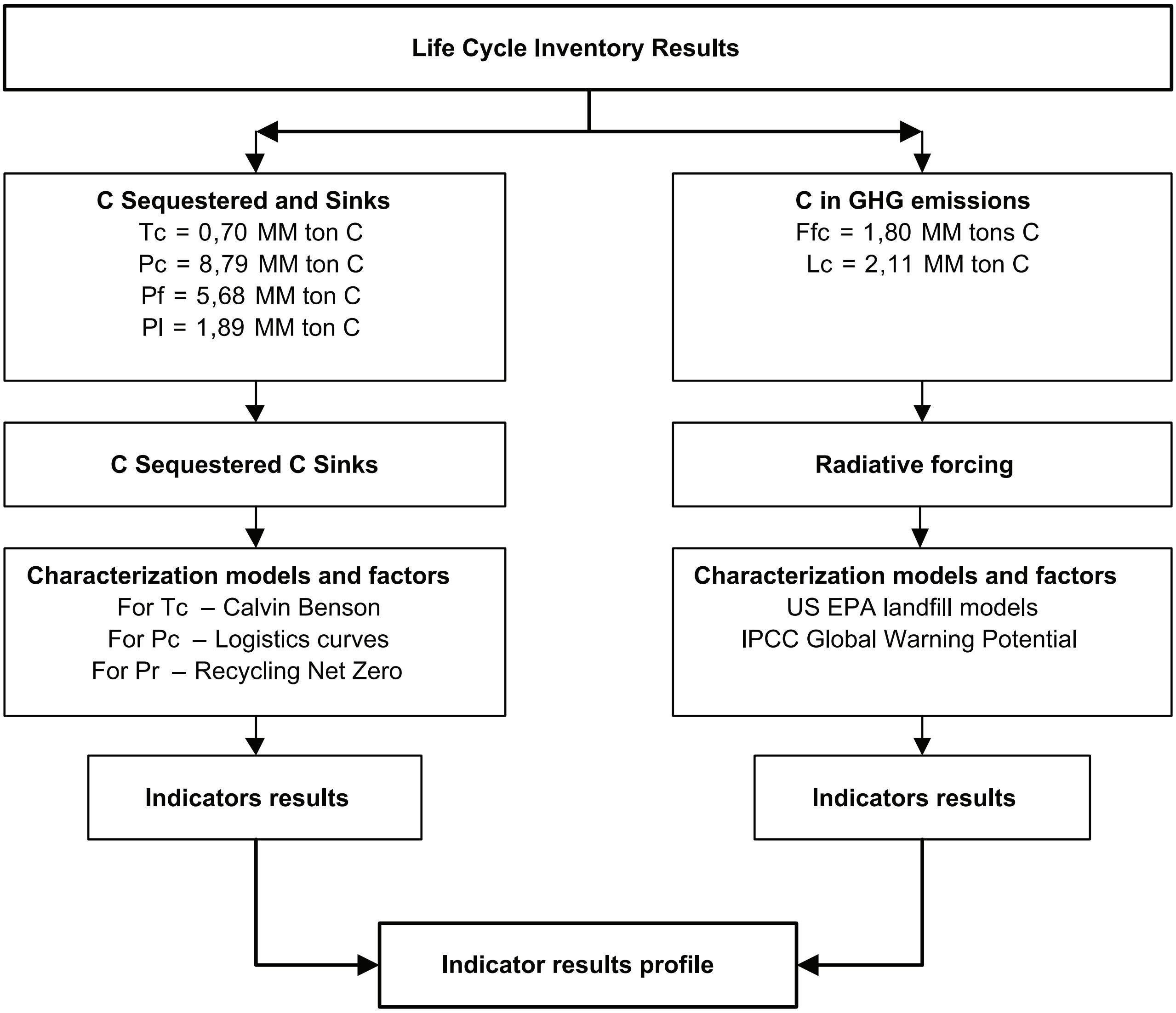

Figure 8 — Schematic of the LCI results assigned to impact categories

4.4.4 Calculation of category indicator results (characterization) (ISO 14044:2006, 4.4.2.4)

The 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 needed calculations, grouped according the two impact categories is presented below. Table 17 provides a summarized version of the calculations leading to the indicator results. Pc is the carbon in the annual production of different forest products - solid wood and paper. Pl is the carbon in the same type of products estimated landfilled in the year. Pf is the carbon in the product biomass fuel used in the year. The following matrix indicates the LCI results, characterization factors and indicator results for the different impact categories and indicators.

4.4.4.1 C sequestration and sinks and Net -zero for biomass fuel

T'c indicates the net biomass C growth stored in the forest. P'f is the product biomass fuel that yields a net zero. P'c refers to the product carbon storage. It is sub-divided according to the functionality of the different forest products.

4.4.4.2 C emissions from fossil fuels and landfill methane

F'fc addresses the fossil fuel carbon. The term L'c refers to the carbon estimated going to landfills from the total annual production of the company. 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 U.S. EPA.

Table 17 — Calculation of Indicator results [5)]

LCIA Indicator	**LCI result** **MM tons C**	**Characterization factors**	**Indicator results** **MM tons** **C eq.**	
T'c	**0,70**	**X 1,70 x 0,75**		**0,89**
P'f	**5,68**	**Net zero**		**0,00**
P'c	**9,23**	Various (see below)		**1,39**
Wood panels	**3,56**			**0,81**
• 1 family residence	1,44	**0,25**	0,36	
• Multi family	1,07	**0,20**	0,24	
• Upkeep/improvement	0,70	**0,15**	0,11	
• Non-residential	0,36	**0,27**	0,10	
Lumber	**1,80**			**0,39**
• 1 family residence	0,54	0,25	0,13	
• Multi family	0,54	0,20	0,11	
• Upkeep/improvement Non-residential	0,36	0,15	0,05	
	0,362 07	**0,27**	0,10	
Printing & writing papers	**1,80**	**0,10**	**0,09**	
Other paper/paperboard		**0,05**	**0,10**	
F'fc (fossil fuels)	**1,80**	**1,00**		**1,80**
L'c (Landfills)	**2,114**	**21,0 & others**		**1,30** [a]

NOTE Besides the factor of 7,7 converting methane carbon to CO_2 carbon, there are other transformation factors 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.

5) Table 17, final column, last row. The landfill model calculates the fraction of the 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.

4.4.4.3 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 trend from regional inventories conducted by state and federal agencies. A second reason is the methane releases from municipal landfills, which 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 transformations 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 transformations of methane into C-equivalents was based on the 100 years horizon. Some researches use a 500 years horizon for the IPCC model. Such 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 credibility in the results.

Table 18 — LCIA Profile (per FU)

Impact category	**Indicator results**			
	Company		**Product system**	
	MM tons C eq.	Per F.U.	MM tons C eq.	Per F.U.
Radiative forcing				
Manufacturing emissions	**1,80**	**0,195**	**1,80**	**0,195**
Landfill (methane)			**1,30**	**0,141**
C Sequestration & 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**

4.4.5 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 a 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 C sequestration from small landowners and the 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 unbalanced, the use of biomass products could help regain that balance. Likewise, the need for proper design and construction of public municipal landfills appear of importance and out of the company's hands.

4.5 Example 4 – Endpoint category indicators assessment

4.5.1 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 is 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 benefited from having single scores per material or process that represent the total environmental load. The purpose of calculating single scores[6)] 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. This example does not 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 that in case different impact categories may have to be included (see also 4.3.2). In this example there is not a 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 from non-agricultural origins, 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 by electricity consumption.

The impact category indicator selected to illustrate the process is Ionising radiation. The example is used to illustrate how a list of inventory results (in this case expressed as Bequerels (Bq) is transformed in an impact category indicator, expressed as Years of Life Lost (YLL). The inventory results in Table 19 [31], are taken from the data for average European electricity.

4.5.1.1 Concept of category indicators (ISO 14044:2006, 4.4.2.1)

With this goal in mind the approach used here is focused on providing the information for such a weighting step, in this case an experts 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 Ionising radiation and Carcinogenic effects are expressed in the same way as an impact to Human Health.

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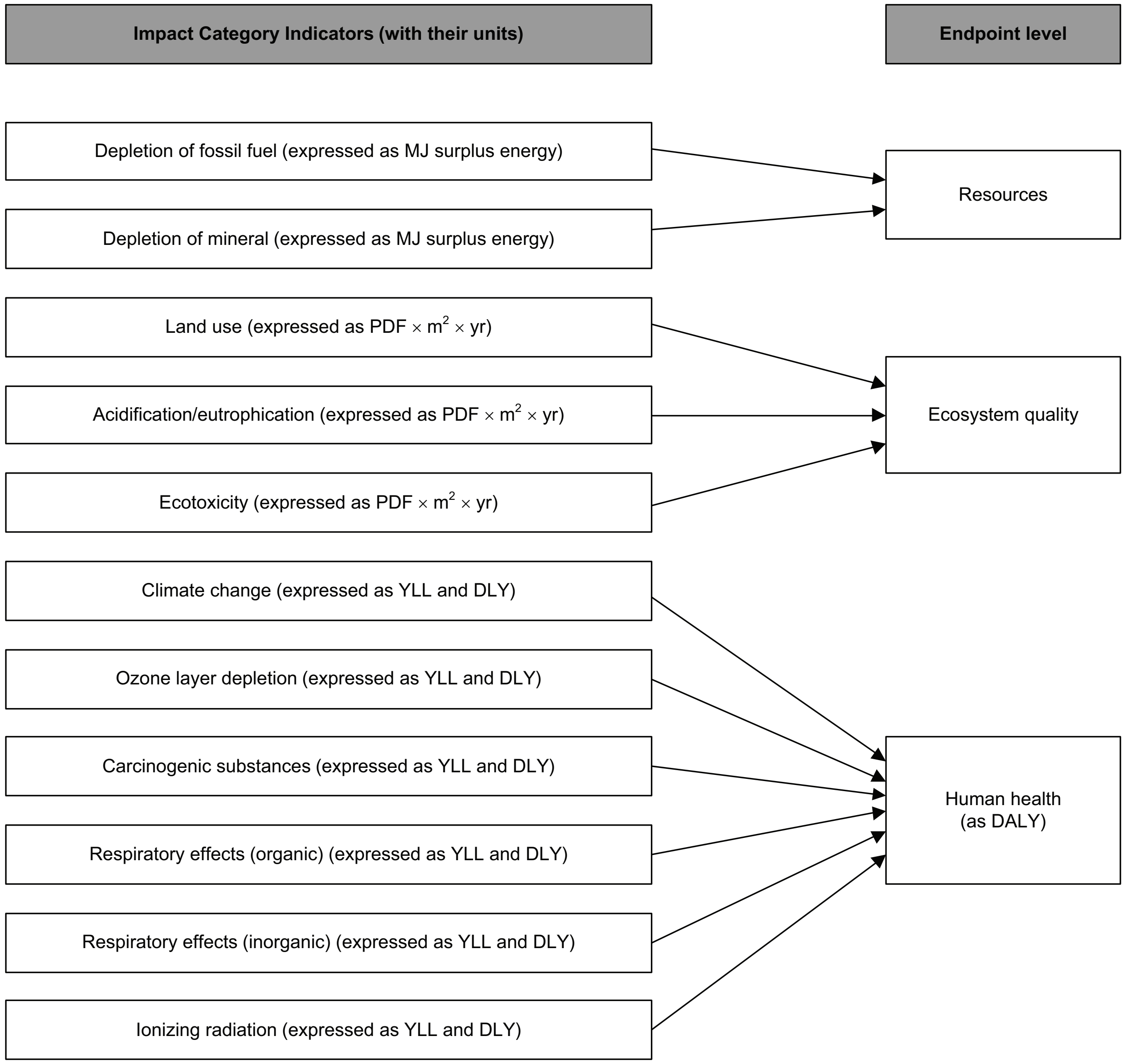
6) ISO 14040:2006, 4.1, refers to single scores and how there is no scientific method to reduce LCA results to a single score.

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 in such a way that they reflect environmental concerns at endpoint level.



NOTE The weighting procedure is not explained in this example.

Figure 9 — Schematic overview of the impact category indicators and their strong association with the endpoints in this example

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, meaning the disability life years. The next step is that different disabilities or premature death are combined into a single indicator that expresses damage to human health in terms of DALYs, that is the disability adjusted life years. This can only be done if the environmental models for impact categories relating to human health include fate and exposure analysis, as well as for all the relevant types of disease, the years of life lost and the years lived disabled. This translation 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 that the different results concerning resources, ecosystem quality and human health, are combined into a single score, as indicated in paragraph 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, Ionising radiation. These units (YLL) do not cover all aspects related to the Human Health. In particular, the disability life years are not included. The disadvantage of this approach characterization approach for the impacts on human health is that it does not include weighting. The full procedure is described in reference [30].

4.5.2 Selection of impact categories, category indicators and characterization models (ISO 14044:2006, 4.4.2.2)

4.5.2.1 Selection of impact categories

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

— An impact category should represent a real environmental problem in Europe. This means it contributes significantly to the issues in the three groups of endpoints. The most important information was obtained from the European Environmental Agency;

— The impact categories are chosen in such a way that they can be sufficiently detailed, consistent and homogenous. For instance this involves splitting “Human Health” in categories such as Carcinogenic effects, Respiratory effects from inorganic substances and Respiratory effects from organic substances (often 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 linkages 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 linkages can be regarded as very uncertain, as particularly the relationship between climate change and the human health indicators.

The following emissions are now considered for the impact category, Ionising Radiation:

Table 19 — LCI results for Ionising Radiation

Isotope	Compartment	LCI result amount in Bq
Cs -137	Water	1,42
Rn-222	Air	1770
C-14	Air	1,85
Co-60	Water	0,67
Cs -134	Water	0,155
Kr-85	Air	113000
Ra-226	Water	55,7
H-3	Water	4540
I-129	Air	0,00656

4.5.2.1.1 Ensuring impact categories are consistent with 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 that are 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.

4.5.2.1.2 Considering the LCA study purpose and use identifying the 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 used for internal applications only. See also footnote 6.

4.5.2.1.3 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 illustration of ISO 14044:2006, 4.4.2.1).

4.5.2.1.4 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 ionising substances from nuclear fuel cycles.

4.5.2.1.5 Selecting the impact categories

The impact category selected for this example is Ionising radiation.

4.5.2.2 Describing the environmental mechanism for an impact category

The selection of the category indicators at endpoint level implies some special requirements on the selection of processes in the environmental mechanism. The general description of the environmental mechanism for emissions is in this case:

- The fate of the substances should be modelled, as damages are in general not caused by amounts of an emission, but by concentrations of a substance. A particular difficulty is the fact that LCI's cannot specify flow rates, which is usually the 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;

- The next step is to calculate the exposure of humans to this concentration in an area, during a certain period of time. This includes estimates for the density of the human population that is expected to be affected;

- For Human Health, medical statistics form the basis for linking exposure with the occurrence of diseases, and further statistics on data like age of onset, average duration and mortality;

- The effects indicated in the 3 points above are translated into an effect at endpoint level.

Table 20 demonstrates how the characterization factors are calculated for the impact category ionising radiation.

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

Phase of the Model	Phase of the mechanism	Units
Inventory Analysis	Radiation releases	Becquerel, Bq; Bq/FU[1]
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	M3, Kg, l Gray, 1Gy = 1 J/kg Sievert, Sv Man.Sievert Man.Sv
Effect Analysis	Dose response relationship Fatal, non fatal cancer, severe hereditary effects	Number of cases / man.Sv
Damage Analysis	Years of Life Lost, Disability Life Years (Endpoint)	YLL, DLY Fatal for cancer

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

4.5.2.3 Selection of indicators

4.5.2.3.1 Identify possible indicators

For ionising radiation, and in fact for all impact categories relating to human health, the YLL is used as category indicator in the present example. Several other indicator definitions are possible at endpoint level. For Human Health these particularly pertain to the Disability Life Years (DLY), i.e. the average number of years a person has to live with a given disability.

4.5.2.3.2 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 numbers of life years lost.

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

4.5.2.3.3 Selected indicator

The YLL indicator is selected because of the possibility of calculating the results on the basis of scientific information, without any weighting.

a) The effect of certainty 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 uncertainties. For this reason, in each step uncertainties are documented and where possible, quantified. A distinction is made between:

— Data uncertainties;

— Uncertainties about the appropriateness and accuracy of the model In most impact categories considered, data uncertainties are specified for all steps in the environmental mechanism and the resulting characterization factors, as squared geometric standard deviations.

For the example of Ionising 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.

Next 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 horizon for the integration of exposure to people (independent of data uncertainties); 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 is 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 i) above) are to be balanced with the advantages regarding the high level of environmental relevance of the results due to the effect that they are at endpoint level.

4.5.2.4 Selection of characterization model and characterization factors

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

Table 21 — Calculation of indicator results for Ionising 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	1770	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	113000	1,64E-16	1,86E-11
Ra-226	Water	55,7	1,50E-13	8,37E-12
H-3	Water	4540	5,30E-16	2,41E-12
I-129	Air	0,00656	1,10E-09	7,19E-12
Indicator result (YLL)				8,81E-10

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

4.6.1 Overview – Example of the selection of impact categories stressing the relationship with the goal and scope

Example 5 illustrates a way of using indicators at the endpoint level in a company's internal product development process. In this example, designers in a company internal product development process use LCIA as an engineering tool to get a clear indication which one of two design alternatives has the lowest 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 cost involved [39], [40].

The example used here is about a choice between material A and B as for a rear end wing spoiler of a car. The functional unit (f.u.) is one spoiler. The inventory results are shown in Table 22.

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

	LCI result (kg/f.u)	
LCI result\material	**A**	**B**
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
CH4	0	0,011
CnHm	0,053	0,08
CO_2	30,188	28,605
N2O	4,44E-03	0,006
NO_x	0,075	0,072
PAH	4,49E-05	3,11E-06
SOx	0,099	0,051
Emissions to water		
COD	1,79E-06	2,23E-03
N-tot	0	1,64E-05

4.6.2 Selection of impact categories, category indicators and characterization models (ISO 14044:2006, 4.4.2.2)

The selection of impact categories, category indicators and characterization models are at the endpoint level in order to facilitate damage cost estimations.

The selection of impact categories and category indicators are shown in Table 23. The category indicators are chosen so that both modelling of characterization factors and determination of weighting factors are 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 in 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 say that its impact is equal to zero. Therefore there is as full a coverage of impact categories as possible for all three areas of protection mentioned in ISO 14040:2006, 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, (YOLL)	Person-year
Human health	Severe morbidity and suffering	Severe morbidity	Person-year
Human health	Morbidity	Morbidity	Person-year
Human health	Severe nuisance	Severe nuisance	Person-year
Human health	Nuisance	Nuisance	Person-year
Ecosystem services	Crop production capacity	Crop production capacity (crop)	kg
Ecosystem services	Wood production capacity	Wood production capacity (wood)	kg
Ecosystem services	Fish & meat production capacity	Fish & meat production capacity (fish & meat)	kg
Ecosystem services	Base cat-ion capacity	Base cat-ion capacity	H+ mole equivalents
Ecosystem services	Production capacity of water	Production capacity of irrigation water (irrigation water)	kg
Ecosystem services	Production capacity of water	Production capacity of drinking water (drinking water)	kg
Abiotic resources	Depletion of element reserves	= “element name” reserves	kg of element
Abiotic resources	Depletion of fossil reserves	Natural gas reserves	kg
Abiotic resources	Depletion of fossil reserves	Oil reserves	kg
Abiotic resources	Depletion of fossil reserves	Coal reserves	kg
Abiotic resources	Depletion of mineral reserves	= “mineral name” reserves	kg
Bio-diversity	Extinction of species	normalized extinction of species, (NEX) See Note	Dimension-less
NOTE normalized with respect to the species extinct 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.

ISO 14044:2006, 4.4.2.2.3 a) 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 minimised, but there is a risk of double counting some impact that influences ecosystem production capacity via impacts on biodiversity.

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

4.6.2.1 Considering spatial and temporal differentiation of characterization models

Uncertainty estimates for characterization factors are included, which include fate & 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.

4.6.2.2 Stating the environmental relevance of the 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 condition at the category endpoint is what was real 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 considered 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 its 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 through its substance and 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. E.g. when As 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 specified through the media that receives or supplies the substances in question, e.g. air, water or soil.

4.6.3 Assignment of LCI results (classification) (ISO 14044:2006, 4.4.2.3)

Not described separately. See Table 25 and [40].

4.6.4 Calculation of category indicator results (characterization) (ISO14044:2006, 4.4.2.4)

The selection of characterization factors was described in general terms in ISO 14044:2006, 4.4.2.2. 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.

4.6.4.1 The 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].

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

Substance	Inventory alternative	Inventory alternative (kg/f.u.)	Category indicator name	Characteri-sation factor	Uncer-tainty factor [a]	Category value per f.u. Material A	Category value per f.u. Material B
CO_2	30,188	28,605	YOLL	7,93E-07	3	2,39E-05	2,27E-05
CO_2	30,188	28,605	Severe morbidity	3,53E-07	3	1,07E-05	1,01E-05
CO_2	30,188	28,605	Morbidity	6,55E-07	3	1,98E-05	1,87E-05
CO_2	30,188	28,605	Crop	7,56E-04	2,2	2,28E-02	2,16E-02
CO_2	30,188	28,605	Wood	-4,05E-02	2	-1,22E+00	-1,16E+00
CO_2	30,188	28,605	NEX	1,26E-14	3	3,80E-13	3,60E-13
NO_x	0,075	0,072	YOLL	3,88E-05	3	2,91E-06	2,79E-06
NO_x	0,075	0,072	Severe morbidity	-2,06E-06	5	-1,55E-07	-1,48E-07
NO_x	0,075	0,072	Morbidity	3,61E-06	b	2,71E-07	2,60E-07
NO_x	0,075	0,072	Nuisance	0,002411	2,4	1,81E-04	1,74E-04
NO_x	0,075	0,072	Crop	0,69954	3	5,25E-02	5,04E-02
NO_x	0,075	0,072	Fish & meat	-0,0339	3	-2,54E-03	-2,44E-03
NO_x	0,075	0,072	Wood	-2,394	3	-1,80E-01	-1,72E-01
NO_x	0,075	0,072	NEX	7,50E-14	4	5,63E-15	5,40E-15
SO_2	0,099	0,051	YOLL	3,76E-05	3	3,72E-06	1,92E-06
SO_2	0,099	0,051	Severe morbidity	-6,58E-06	4,2	-6,51E-07	-3,36E-07
SO_2	0,099	0,051	Morbidity	1,02E-05	4,2	1,01E-06	5,20E-07
SO_2	0,099	0,051	Nuisance	0,00645	2,4	6,39E-04	3,29E-04
SO_2	0,099	0,051	Crop	0,00183	2,6	1,81E-04	9,33E-05
SO_2	0,099	0,051	Fish & meat	0,00118	3	1,17E-04	6,02E-05
SO_2	0,099	0,051	Wood	0,979	2,4	9,69E-02	4,99E-02
SO_2	0,099	0,051	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 lognormal distribution.

[b] Is represented by more than one lognormal distribution.

4.6.4.2 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 25 — Aggregation of converted LCI results into indicator results

Substance	Category indicator name	Characte-risation factor	Category Indicator value per f.u. alternative A	Aggregated Category indicator result per f.u. Alternative A	Category Indicator Value per f.u, Alternative B	Aggregated Category indicator result per f.u. 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	0,000756	0,022822		0,021625	
NO_x	Crop	0,69954	0,052466		0,050367	
SO_2	Crop	0,00183	0,000181	0,075469	9,33E-05	0,072086
NO_x	Fish & meat	-0,0339	-0,00254		-0,00244	
SO_2	Fish & meat	0,00118	0,000117	-0,00243	6,02E-05	-0,00238
CO_2	Morbidity	6,55E-07	1,98E-05		1,87E-05	
NOx	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	
NOx	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	Nuisance	0,002411	0,000181		0,000174	
SO_2	Nuisance	0,00645	0,000639	0,000819	0,000329	0,000503
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	-0,0405	-1,22261		-1,1585	
NO_x	Wood	-2,394	-0,17955		-0,17237	
SO_2	Wood	0,979	0,096921	-1,30524	0,049929	-1,28094
CO_2	YOLL	7,93E-07	2,39E-05		2,27E-05	
NO_x	YOLL	3,88E-05	2,91E-06		2,79E-06	
SO_2	YOLL	3,76E-05	3,72E-06	3,06E-05	1,92E-06	2,74E-05

5 Examples of the optional elements of LCIA

5.1 Overview

Figure 1 shows examples within the optional elements section. The examples are organized on a topic basis, i.e. with all the examples on illustration of normalization of ISO 14044:2006, 4.4.3.2, listed consecutively which are then followed by the example on grouping, etc. Some examples are self-contained illustrating a particular point; others are a continuation of examples presented in Clause 4. The readers may work their way through this clause either on a topic-by-topic basis, or follow the stem example or may select whichever example is of particular interest.

5.2 Example 1 continued

5.2.1 Calculating the magnitude of the category indicator results relative to reference information (normalization) (ISO 14044:2006, 4.4.3.2)

5.2.1.1 Overview – reviewing needs, criteria and reference information

In general, and consequently also for the gas pipe example, it can be argued that the choice of the reference information depends on the selected impact categories, and more in particular 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 the given region can be taken as reference. If however category results are considered at different spatial levels, then another reference is chosen which is insensitive for scale level. For instance, the category loading per inhabitant for the different regions considered.

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

In Example 1, the situation in country x is taken as 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.

5.2.1.3 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

Material A			
Impact category	**Indicator Results**	**Normalization reference**	**Normalization Results**
	kg.eq.	kg.eq./yr	Yr
Climate change	1,84E+05	2,27E+11	8,08E-07
Stratospheric ozone depletion	1,86E-02	3,61E+à-	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
Eco-toxicity	1,66E+02	1,16E+11	1,43E-09

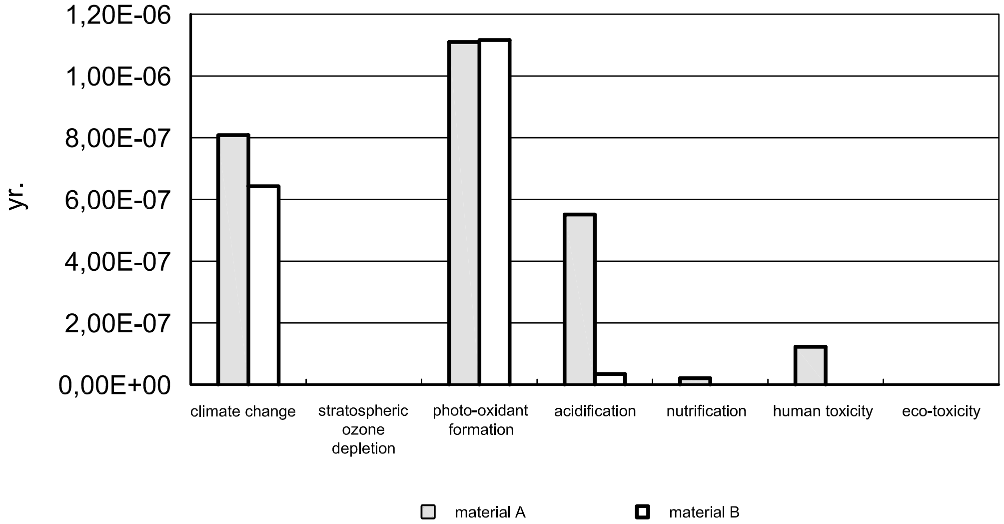
Table 27 — Calculation of normalization results of stem example – Material B

Material B			
Impact category	**Indicator Results**	**Normalization reference**	**Normalization Results**
	kg.eq.	kg.eq./yr	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	250E+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
Eco-toxicity	4,76E+00	1,16E+11	4,10E-11

5.2.1.4 Description of the effect on the study results

In the histogram in Figure 10[7)], 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 shifting of significance of the impact category results. For instance, photo-oxidant formation shifts from the fifth place to the first place. So gas distribution appears to be relatively significant as a source for 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 change from the first to the second place.

In addition, the impacts on acidification also appear to be relatively significant for the pipes of material A. Toxic impacts appear to be of relatively little significance (see however remark in 5.8.1.1 7), eco-toxicity, about chlorinated organic trace pollutants). Note that normalization results do not indicate the relative importance of the impact categories.



Reference: Converted total emissions in country x in the year y

Figure 10 — Normalized LCIA profile for gas distribution system

5.3 Example 2 continued

5.3.1 Calculating the magnitude of the category indicator results relative to reference information (normalization) (ISO 14044:2006, 4.4.3.2)

5.3.1.1 Examples of the transformation of indicator results using several selected references values, and how these transformations may yield different outcomes (normalization)

This subclause illustrates several possible normalization procedures, including a per capita approach and a reference approach.

7) Regarding Figures 10, 11, 12 and 14. The uncertainty for human toxicity and eco-toxicity characterization factors are much larger than for the other factors. For this reason, the impact categories are represented throughout the report as two groups: a group with relatively high and with relatively low certainty. In the tables, the two groups are separated with double lines.

The choice of normalization procedure depends upon the study purpose and the decision made during the goal and scope process. In making this choice, the goal and scope should be informed on how the particular normalization procedure changes the indicator result. Therefore, the example illustrates how the original category indicator results from the mandatory clauses of ISO 14044:2006 are changed both in absolute terms and in relative terms. This illustration illustrates the cautions and recommendations regarding normalization and other optional procedures. ISO 14044:2006, 4.4.3.2.2, 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".

Normalization can use several reference values as selected by the goal and scope, such as, population, area, emission proportions, and historical emission baselines. Table 28 provides three values for several countries that can be used for reference values illustrating the large variation. Such different values shift and 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 Albanian, 27 % of Belgian, and 24 % for Finnish total SO_2 emissions would be used (e.g. 2,400 to 85,600 to 62,400 tons for a reference value, respectively). This would further increase the differences in the resulting standardized indicators.

Table 28 — Reference and baseline values for normalization

Country	**Population (Thousands)**	**Area (Sq km)**	**Emission quantities per yr (tons)**	
			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	2,701000

If the normalization reference is the denominator, those countries with smaller populations, areas, or emissions will increase relative to larger countries when standardized. Table 29 applies both population and emissions baseline references to the SE indicator results derived in 5.2 example 2 paragraph 2) iii), illustration of ISO 14044:2006, 4.4.2.2. Relative changes due are shown in the right hand column of Table 29. Significant changes in the results occur in the outcome of the analysis by the choice of the normalization reference.

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

Example of per capita population normalization					
Country	Indicator Result (m^2)	Population (Thousands)	Standardized Indicator Result	Relative size	
				Before	After
Albania	0,02	3,119	$0{,}0641 \times 10^{-7}$	1	1
Belgium	1,29	10,141	$0{,}127 \times 10^{-6}$	64	20
Finland	15,38	5,154	$2{,}98 \times 10^{-6}$	769	465

Example of reference emission baseline normalization										
Country	Indicator Result (m^2)		Emissions (Tons)		Standardized Indicator Result		Relative size			
							Before		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	24200	329	2420

[a] A value of 0,00001 was used to conduct the normalization so that values from Belgium and Finland would not be divided by zero.

5.4 Example 6 – Normalization of LCIA indicator results for the use of different refrigerator gases

5.4.1 Calculating the magnitude of the category indicator results relative to reference information (normalization): examples of the transformation of indicator results using several selected values, and how these transformations may yield different outcomes (normalization) (ISO 14044:2006, 4.4.3.2)

5.4.1.1 Overview

The purpose of this example is to demonstrate a procedure for the optional element of 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 14044:2006, 4.4.3.2.2 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".

To check the importance of this recommendation, the use of two reference systems are 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 the refrigerator is a long-lived product with an expected lifetime of 10 years or more, it is therefore relevant to check the temporal dependency of the results of the normalization.
To check the temporal 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 ways of replacing CFCs in the insulation foam and 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 litres energy efficient household refrigerator throughout its life cycle, and the goal of the study is to support the choice to be made by the product development function.

An inventory analysis has been 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 [41][42], the life cycle impact assessment methodology applied is as documented in [42], [43].

Table 30 — Characterised LCIA profiles for the 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 CFC11-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 [a]	m^3 water	1,610	1,610
Human toxicity via air	m^3 air	563,000,000	613,000,000

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

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.

5.4.1.2 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, the Gas A performs clearly better for global warming and marginally better for human toxicity via air exposure while the 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 are brought to a common scale, expressing the significance per category. There is thus a need for normalization.

5.4.1.3 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, a regional, a national or a local level and they may be expressed at a total basis, per capita, per area or similar.

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 the global impact categories like global warming and stratospheric ozone depletion the impact is independent of the location of point of release for the emission. 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 like acidification and eco-toxicity, the level of impact we experience is caused by the emissions occurring within our region. ISO 14044:2006 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.

5.4.1.4 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 are applied in the weighting.

To prepare for a possible weighting or grouping the references chosen for normalization are requested to 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[8)]. 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 whether they are regional or global of 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 in 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 *emissions* 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;

— 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].

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

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	$3,1 \times 10^9$	$3,1 \times 10^9$	$2,9 \times 10^9$

5.4.1.5 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

All normalized indicator results expressed as milli-person-equivalents, mPE

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

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

All normalized indicator results expressed as milli-person-equivalents

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

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. The future level of emissions is estimated from the politically set reduction targets

All normalized indicator results expressed as milli-person-equivalents

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

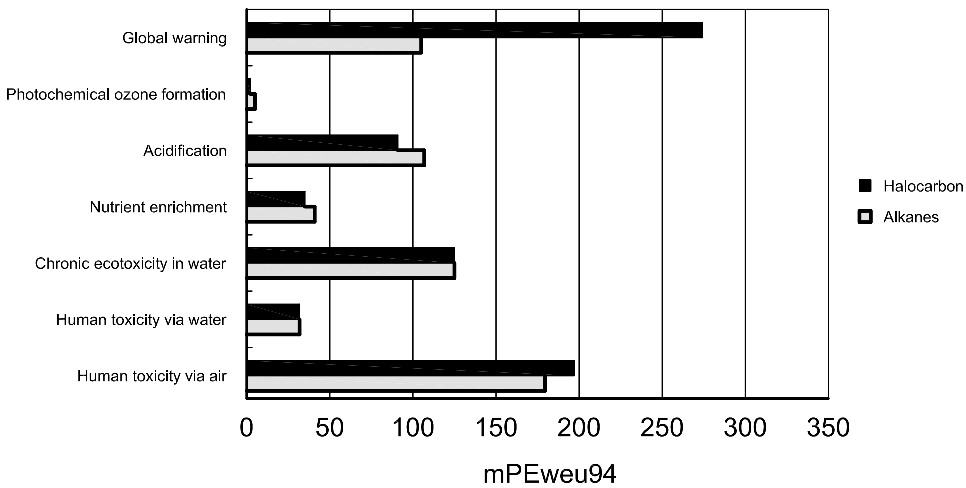


Figure 11 — Normalized LCIA profiles for the two alternatives applying the current spatially differentiated level of emissions as reference system

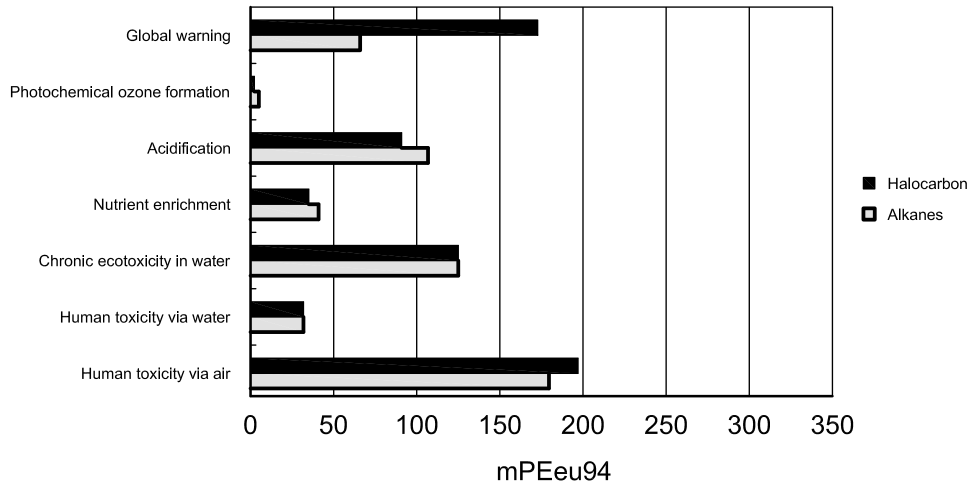


Figure 12 — Normalized LCIA profiles applying the current level of emissions in Europe as the reference system

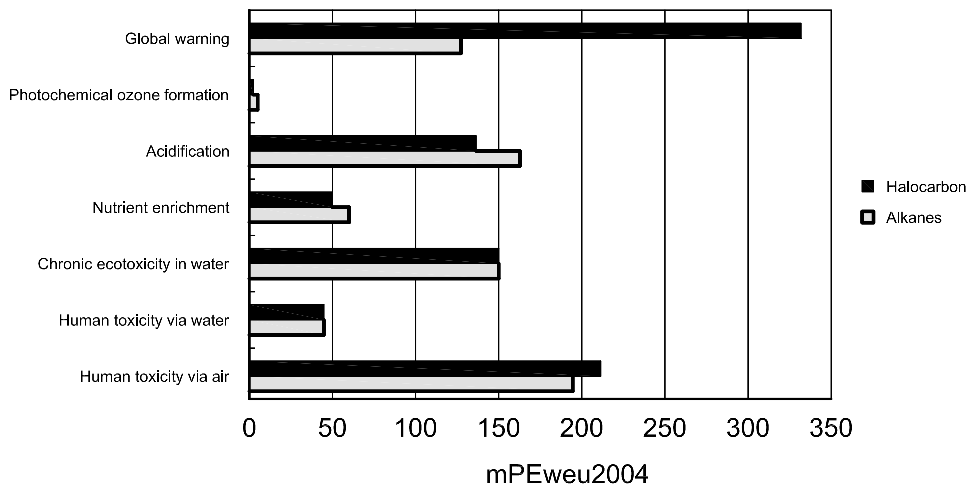


Figure 13 — Normalized LCIA profiles for the two alternatives applying the future spatially differentiated level of emissions as reference system

5.4.1.6 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 is moderate, the contributions to the impact categories global warming and human toxicity via air exposure are the 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 lowest indicator results. In comparison, the indicator results for acidification and particularly photochemical ozone formation, where Gas B performs best, are lower.

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 of the normalization reference for acidification.

For the global impact category, global warming, a comparison between Figure 11 and Figure 12 demonstrate 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 the Gas A.

Altogether, 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. The Gas A has the lowest 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 of which alternative is the better not only depends 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.

5.5 Example 7 – Normalization in a waste management study

5.5.1 Calculating the magnitude of the category indicator results relative to reference information (normalization): Example of the transformation of indicator results using several selected reference value(s) (normalization) (ISO 14044:2006, 4.4.3.2)

5.5.1.1 Overview

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.

5.5.1.2 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. This explains why the normalization is explored as a means to communicate the significance of the results to the local citizens.

5.5.1.3 Reviewing needs, criteria and reference information

The results to be normalized include two types of data:

- Inventory results:
  - Water consumption;
  - Non hazardous waste generation;
  - Water pollution: COD, BOD5, Suspended matters.

— Indicators results from the characterization:

— Total primary energy consumption (renewable / non renewable);

  — Global warming potential;

  — Acidification.

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

These data [9] 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.

Other flows 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 scenario A and B. According to the construction of the systems, the results of the comparison of the systems lie in 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 in Table 35 relate to the specific Local Authority studied and are illustrative of this example only. None of the results or conclusions can be applied to any other situation.

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.

9) ISO 14044:2006, 4.4.2.2. [40], [41], [42], [43], [44], [45], [46], [47].

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 in m3	71567	37319	**Water saved**	**34248 m3**
Household waste in tonnes	- 287	-2820	**Waste avoided**	**2533 tonnes**
Water pollution in kg COD BOD_5 Suspended solids	 20770 1052 1252	 21280 1050 459	**Water pollution** **Generated** **Avoided** **Avoided**	 **510 kg** **- 2 kg** **- 795 kg**
Indicators results				
Total primary energy in million MJ	-256	-330	**Energy saved**	**74 millions MJ**
Non renewable energy in million MJ	-253	-298	**Energy saved**	**45 millions MJ**
Renewable energy in million MJ	-3	-32	**Energy saved**	**29 millions MJ**
Global warming potential 20 years in tonnes eq. CO_2	- 21066	-23304	**GWP emissions avoided**	**2238 tonnes eq.** CO_2
Acidification in kg eq. H+	-5976	-7431	**Acidifiant emissions avoided**	**1455 kg eq. H+**

5.5.1.4 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;

— Temporal reference.

In this case, two scales of reference have been selected to normalise 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 [45]	Water inflow for public network 1871 litres/day 683 m^3/ye ar [46]
Household waste	420 kg//year [50]	825 kg//year [51]
Water pollution	COD 130 g/day BOD5: 65 g/day Suspended Matters: 70g/day [45]	No reference available on a per capita basis
Total primary energy consumption	Consumption per inhabitant at home 30 000 MJ/year [47]	Total primary energy consumption for France 249,36 Mtep 174603MJ/ capita national year [48]
Non renewable energy		Total non renewable energy consumption for France 237,62 Mtep 166412 MJ/capita national per year [48]
Global warming potential	1456 kg eq. C02/ capita personal/inhabitant per year for houses and offices heating [52]	8680 kg eq. C02/year [49]
Acidification	238 g eq. H+/capita personal/year for individual transportation [52]	1,86 kg eq. H+/year [49]

Table 37 — Normalized results for the 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	71567 m^3	**1307**	**105**	37319 m^3	**682**	**1**
Household waste	- 287 tonnes	**- 683**	**- 348**	-2820 tonnes	**- 6714**	**- 3418**
Water pollution COD BOD_5 Sus Solids	 20770 kg 1052 kg 1252 kg	 **159769** **16185** **17886**		 21280 Kg 1050 kg 459 kg	 **163692** **16154** **6557**	
Indicators results						
Total primary energy	- 256 million MJ	**- 8533**	**- 1466**	- 330	**- 11000**	**- 1890**
Non renewable energy in million MJ	- 253 million MJ		**- 1520**	- 298		**- 1791**
Global warming potential 20 years	- 21066 tonnes e q. $C0_2$	**- 14468**	**- 2427**	- 23304 tonnes eq. $C0_2$	**- 16005**	**- 2685**
Acidification	- 5976 kg eq. H+	**- 25109**	**- 3213**	- 7431 kg eq. H+	**- 31223**	**- 3995**

5.5.1.5 Calculation of standardized 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 38 — Influence of the reference system in the normalization of a 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	34248 m^3	630 inhabitants	100 average citizens
Waste avoided	2533 tonnes	6000 inhabitants	3070 average citizens
Water pollution COD (Generated) BOD_5 Avoided Susp Solids Avoided	 (510 kg) 2 kg 795 kg	 (3900 inhabitants) 30 inhabitants 11300 inhabitants	
Total primary energy saved	74 millions MJ	2470 inhabitants	430 average citizens
Non renewable energy saved	45 millions MJ		270 average citizens
GWP emissions avoided	2238 tonnes eq. $C0_2$	1537 inhabitants for houses and offices heating	257 average citizens
Acidifying emissions avoided	1455 kg eq. H+	6110 eq. Inhabitants for transportation	782 average citizens

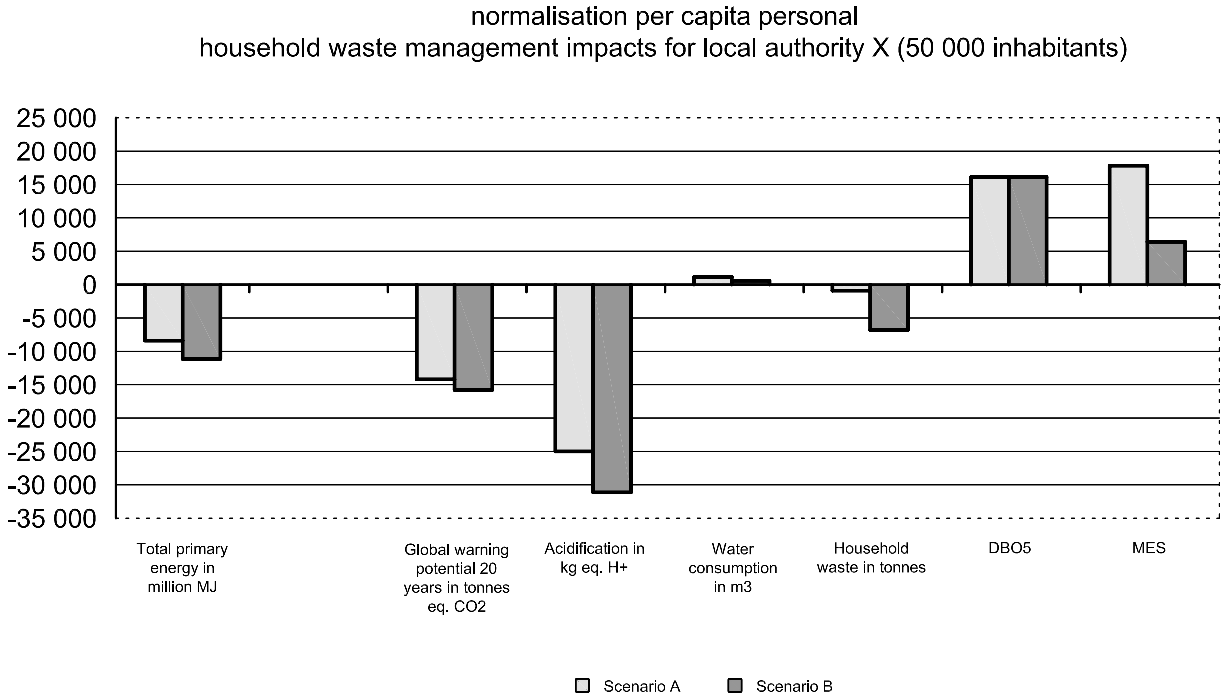


Figure 14 — Normalization per capita on a local personal basis

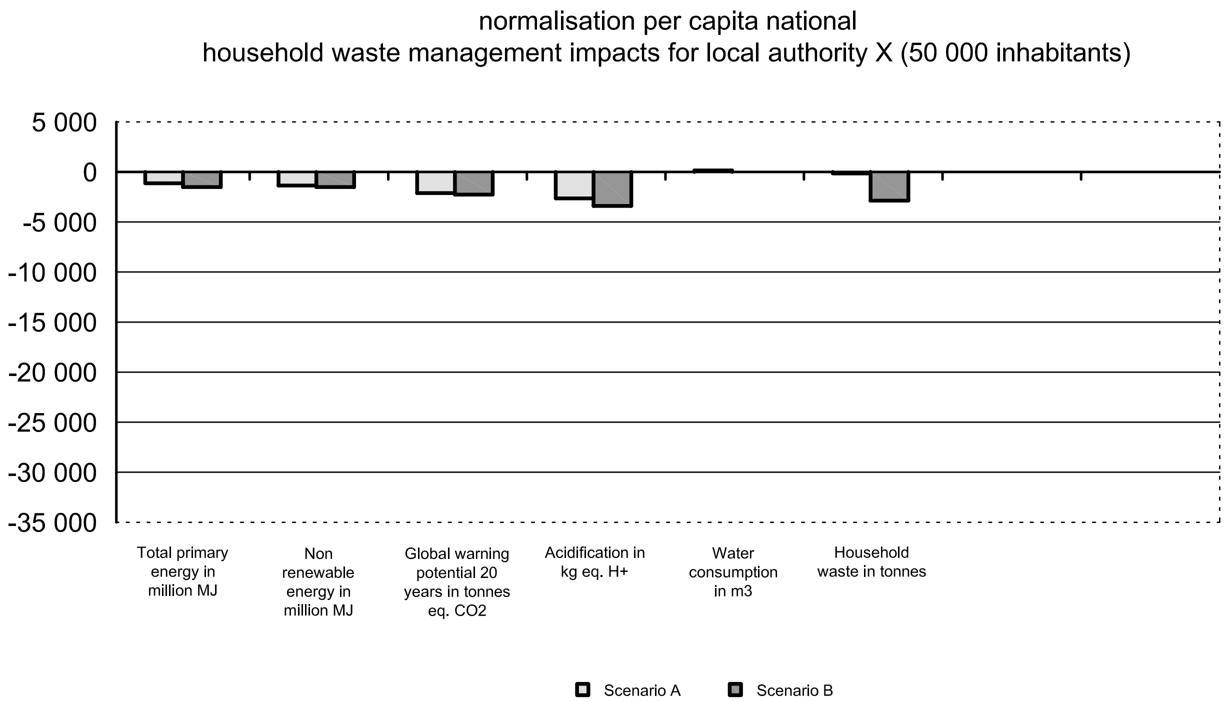


Figure 15 — Normalization – per capita on a national basis

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.

5.5.1.6 Description of the effect on the study results

The normalization of LCIA results allows an 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 figures 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 6000 inhabitants per year, which represents 12 % of the local authority population;

— Energy savings resulting from the recycling of the packaging fraction by the Local Authority are equivalent to the energy consumption of 2500 inhabitants (that is 5 % of the population of the Local Authority), which shows a significant order of magnitude;

— Avoided GWP emissions correspond to the emission released by the heating of houses and offices for 1500 inhabitants (3 % of the population);

— Waste avoided represents the quantity generated by 6000 inhabitants - 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 of which 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 impacts from their day -to-day activities.

5.5.1.7 Risk of this type of communication

The two diagrams, Figures 14 and 15, show that the values of the normalized indicators are very different, and are dependant 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 green house 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 has to be pointed out that using a certain reference frame (transport emissions, for instance) for acidification gases can induce in the reader’s mind other implied impacts (noise, fumes, odours, accidents) that might bias the information.

Lastly, another potential bias lies in the way the reader interprets the normalized values. The reader could imagine that the per capita personal environmental benefit is 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 km 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 in a complete way, as other subjects such as dioxins, VOC and heavy metals still need to be addressed.

5.6 Example 1 continued

5.6.1 Grouping: description of the effect on the study results (ISO 14044:2006, 4.4.3.3)

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 Table 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.

5.6.2 Weighting: selecting weighting methods and determining weighting factors (ISO 14044:2006, 4.4.3.4)

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 the following [23].

Table 39 — Selected weighting factors in Example 1

Climate change	Stratospheric ozone depletion	Photo – oxidant formation	Acidifi-cation	Eutrophication	Human toxicity	Eco-toxicity
0,278	0,104	0,100	0,148	0,113	0,130	0,130

5.6.2.1 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 this example the converted normalization results show highest values for climate change, followed by photo-oxidant formation and acidification. Eco-toxicity by far gives the lowest results for the chosen case. These findings are in line with the description of the grouping results in 5.10.

5.6.2.2 Sensitivity analysis on weighting results

In Example 1 a sensitivity analysis on the weighting results is carried out, by 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 below; the results are also included in Tables 46 to 49. With this second weighting set the impact category climate change remains on the first place. The impact category photo-oxidant formation appears to shift from the second to the third place and acidification from the third to the second place.

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

	Climate change	Stratospheric ozone depletion	Photo - oxidant formation	Acidifi-cation	Eutrophi-cation	Human toxicity	Eco-toxicity
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 materials A: 4,36 E-07 (see Table 47).

— For materials B: 2,98 E-07 (see Table 49).

While the results using the alternative set are the following:

— For materials A: 3,84 E-07 (see Table 47).

— For materials B: 2,26 E-07 (see Table 49).

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

5.7 Example 5 continued

5.7.1 Weighting (ISO 14044:2006, 4.4.3.4)

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.

Table 41 — Weighting of indicator results

Category indicator name	Aggregated category indicator result per f.u. Alternative A	Aggregated category indicator result per f.u. Alternative B	Weighting factor, (ELU/ category indicator unit)	Uncertainty in weighting factor, [a]	Weighting Result, Alternative A (ELU/f.u.)	Weighting Result, Alternative B (ELU/f.u.)
Al ore	0,854	0	0,439	2	0,375	0
Coal in ground	3,056	0,826	0,0498	2	0,152	0,0411
Crop	0,0755	0,0721	0,15	2	0,0113	0,0108
Fish & meat	- 0,00243	- 0,00238	1	2	- 0,00243	- 0,00238
Morbidity	2,11E-05	1,95E-05	10000	3	0,211	0,195
NEX	3,57E-13	3,51E-13	1,10E+11	3	0,0393	0,0386
Nuisance	0,000819	0,000503	100	3	0,0819	0,0503
Oil in ground	6,541	9,405	0,506	1,4	3,310	4,76
Severe morbidity	9,85E-06	9,61E-06	100000	3	0,985	0,961
Wood	- 1,305	- 1,28	0,04	1,4	- 0,0522	- 0,0512
YOLL	3,06E-05	2,74E-05	85000	3	2,600	2,33
		Impacts from other LCI results not shown in Tables 24 and 25			3,11	0,55
				SUM	10,82	8,88

[a] Corresponds to the standard deviation in a lognormal distribution

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/f.u. for alternative A and 8,88 ELU/f.u. for alternative B.

5.8 Example 8 – A technique for the determination of weighting factors

5.8.1 Weighting (ISO 14044:2006, 4.4.3.4)

5.8.1.1 Overview – Example of a technique for the determination of weighting factors using a panel of experts

This example deals with a technique for determination of weighting factors by using a panel of experts. There are two steps. The first step scores the indicators at the intermediate level in each endpoint. The second step compares the endpoints between each other. In this respect it is different from Example 1, (comparison between intermediate level indicators) and from Examples 4 and 5 (comparison between endpoint level indicators).

The weighting factors are related to ISO 14044:2006, 4.4.3.4.1:

"Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices

— *To convert the indicator results or normalized results with selected weighting factors."*

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 yet officially used.

5.8.1.2 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 to demonstrate this. 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 are 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

		Category indicator			**Total**
		C_1	**C_2**	**C_3**	
Endpoint	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		Total
	E_1	E_2	
Relative importance	a	b	1,00

Table 44 — Importance of Category Indicators

		Endpoint		Total	Relative importance
		E_1	E_2		
Category indicator	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

5.8.1.3 Determining weighting factors

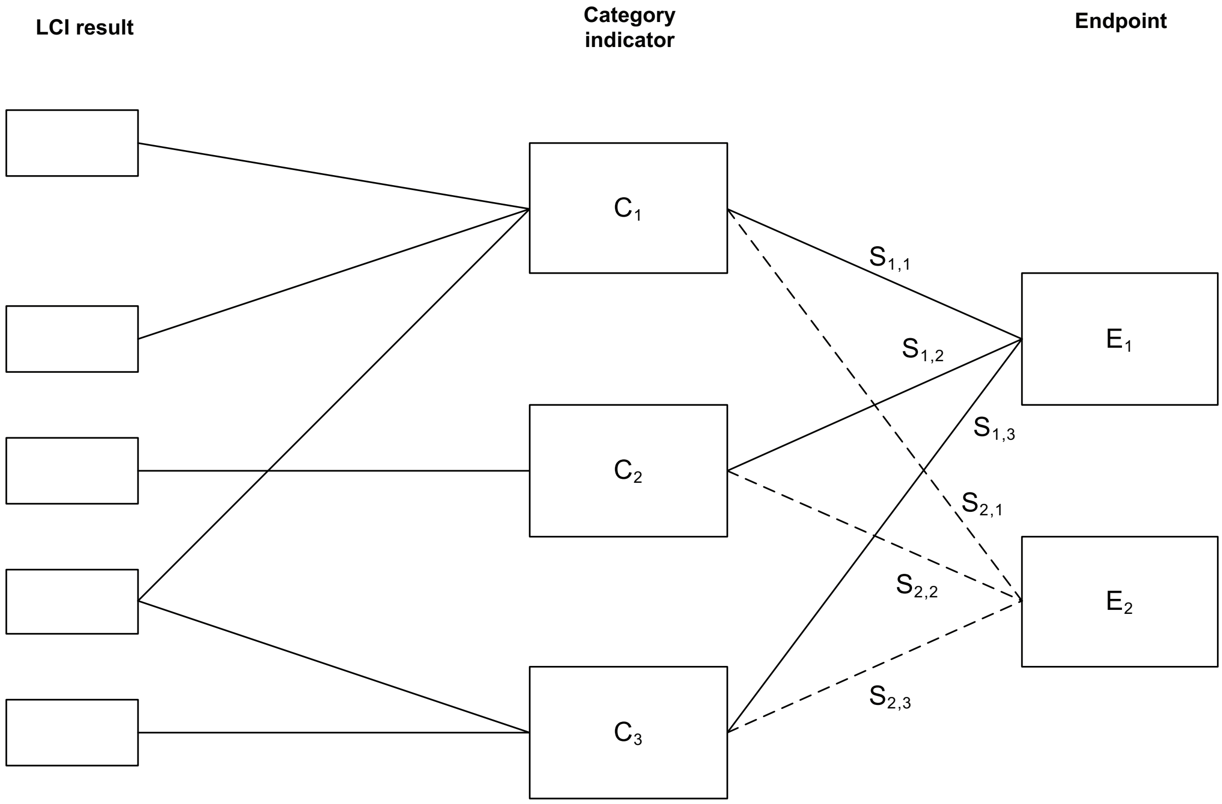


Figure 16 — Scoring of category indicators using each endpoint

5.8.1.4 Impacts categories

The first meeting 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 oxidant etc.
- River, lake, marsh and ocean pollution: Eutrophication.
- Toxic chemicals: Air, water and soil pollution caused by organic chlorine compound, dioxin and benzene etc.
- Destruction of natural sites: Development such as deforestation, reclaimed seashore and dam construction etc.
- Mass production/consumption/disposal: Utilisation of a lot of resources, energy and land.

5.8.1.5 Endpoints

The second meeting, [53], was attended by the initial twenty-one 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:

- Health effect: Increased mortality and morbidity, increased physical pain by disease;
- Base for production and daily-life: Depletion of limited resources , damage to food production and fundamental materials;
- Ecosystem effect: Death and mutation of natural lives, decrease of life and species, change of ecosystem;
- Mental effect: Loss of peacefulness, fears, dread coming from unknown impacts, and guilty conscience through concern about hurting others.

5.8.1.6 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 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.

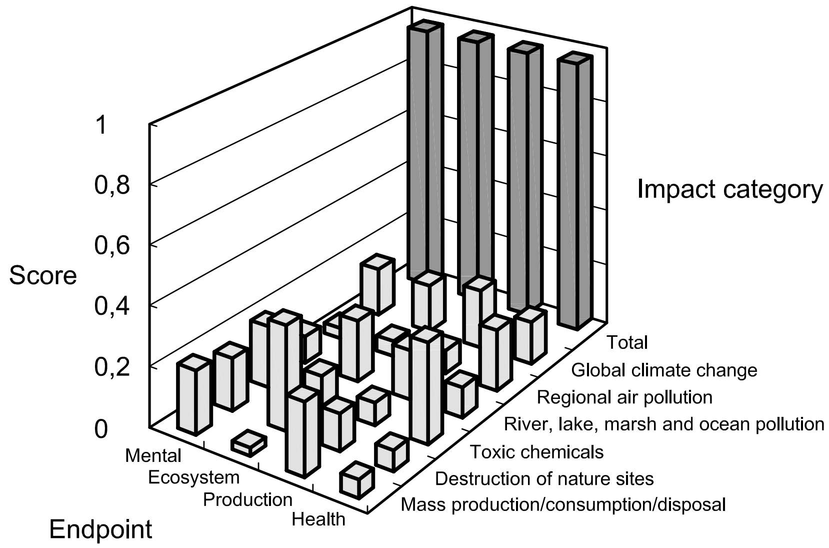


Figure 17 — Scoring of Category Indicators in each endpoint

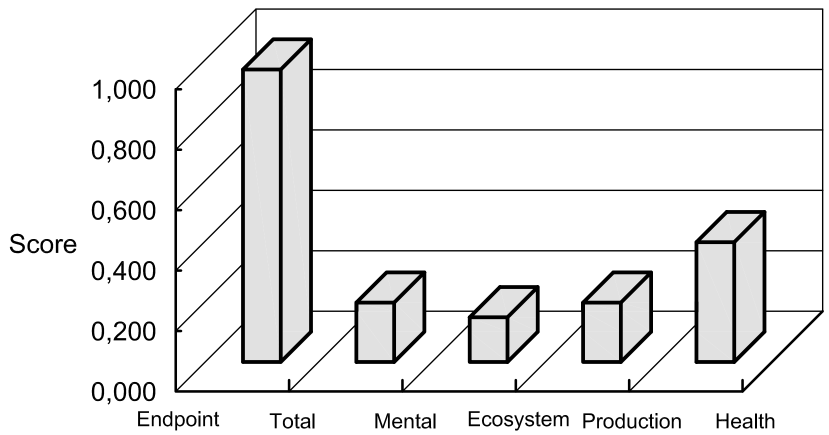


Figure 18 — Scoring of endpoints

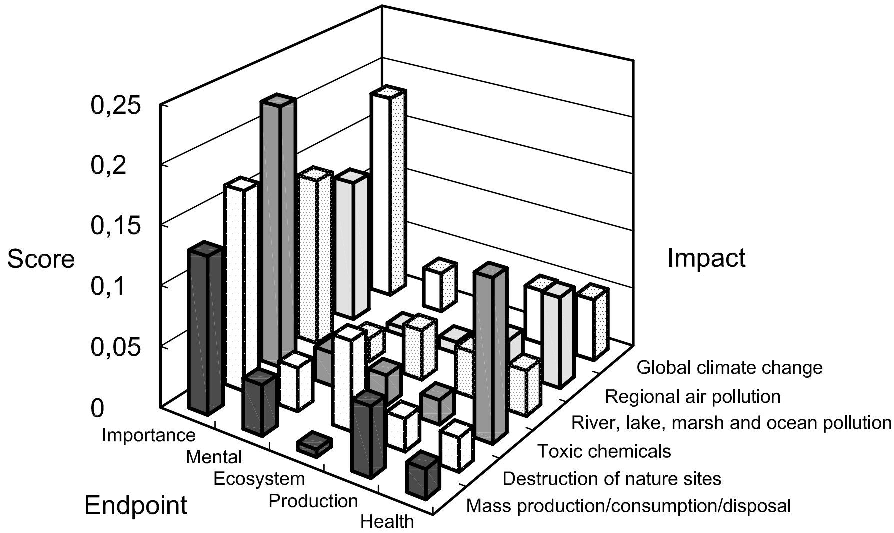


Figure 19 — Importance of Impact Categories in Japanese Environmental problems

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 ($C0_2$equiv.-kg x y^{-1})	4,2E-15 (($C0_2$equiv.-kg)$^{-1}$ x y)
Regional air pollution	0,13		
River, lake, marsh & ocean pollution	0,15	1,7E+09 (N-kg x y^{-1})	1,8E-10 ((N-kg)$^{-1}$ x y)
Toxic chemicals	0,23		
Destruction of natural sites	0,18		
Mass production/ consumption/disposal	0,14	5,0E+10 (Solid-kg x y^{-1})	2,8E-12 ((Solid-kg)$^{-1}$ x y)

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) were used as an impact category indicator, [54], [55]. River, lake, marsh and ocean pollution was regarded as eutrophication, therefore nitrogen emissions in the country [56], was used as an environmental load. Mass production/consumption/disposal were regarded as waste problems. The amount of waste discarded [57], was also set as an environmental load. These elements were used as impact category indicators.

5.8.1.6.1 Conclusion

As a result of their participation, 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.

5.9 Example 1 continued

5.9.1 Additional LCIA data quality analysis (ISO 14044:2006, 4.4.4)

5.9.1.1 Gravity analysis

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

a) Climate change

For the two systems the climate change effects are caused by methane and CO2, the largest contribution coming from methane. For all systems methane is nearly fully released as gas leakage during gas distribution at the junction of the pipe elements. Various processes release CO2 over the life cycle, with transportation and material production being relatively important. Its contribution is largest with material A because of the heavy weight.

b) Stratospheric ozone depletion

For the two systems the ozone depletion impacts mainly or fully relate to halon-1301, released with the production of crude oil and with trans-oceanic tanker transport. Specifically for material B there is the release of tetrachloromethane during chlorine production.

c) Photo-oxidant formation

For the two systems the oxidant formation is due to gas leakage, mainly of methane but to a smaller part also of ethane and propane.

d) Acidification

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

e) Eutrophication

For the two systems eutrophication is caused by NOx and phosphorus. The NOx releases are due to fuel burning when generating heat, with transportation and with electricity production. The emission of phosphorus to water has its origin in coal use. The releases appear during landfill of hard coal tailings and are mainly at stake for pipes of material A.

f) Human toxicity.

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

g) Eco-toxicity

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

NOTE For the toxicity categories it should be taken into account that the impact of chlorinated organic trace pollutants are left out of consideration. These may have an impact specifically for pipes of material B.

5.9.1.2 uncertainty analysis

In this example, no data on the uncertainty of the given processes is available; therefore this element is not elaborated on.

5.9.1.3 sensitivity analysis

In this example the sensitivity of the indicator results for 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 eco- and human toxicity categories. 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 form and ion form 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 inputs of metals to the ocean do 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 for instance 100 years, the results for the toxicity categories is 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, the information of other tools may well have to supplement the decision making process.

The outcome of the sensitivity analysis is as follows. When taking GWP_{500} instead of GWP_{100} the climate change results do decrease considerable (decrease 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 with about a factor of 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. So sensitivity analysis here helps to identify incompleteness in the pathways underlying characterization modelling.

5.10 Example 5 continued

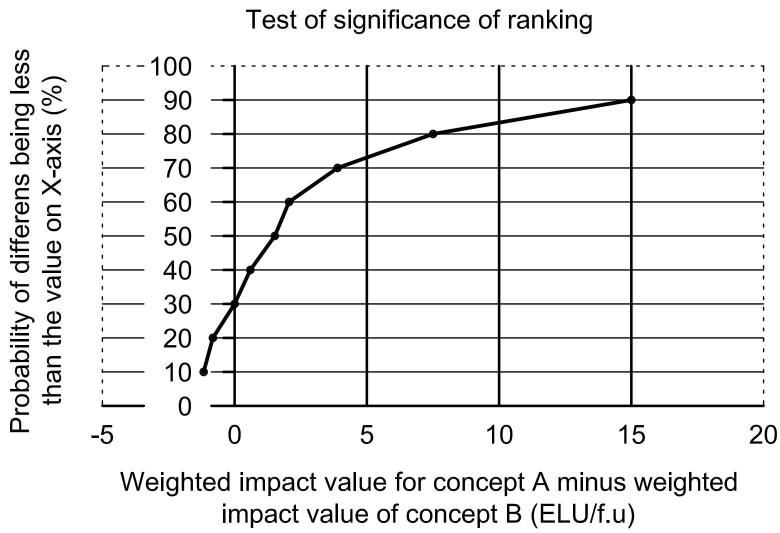
5.10.1 Additional LCIA data quality analysis (ISO 14044:2006, 4.4.4)

5.10.1.1 Overview

Choosing category indicators at the endpoint level and the use of weighting introduce large uncertainties. Sensitivity and uncertainty analysis was therefore carried out to find out if there is a significant difference (in its statistical meaning) between alternative A and B and what contributes most to the uncertainty. Uncertainty factors for inventory results are estimated to 1.02 for oil in ground and Al ore, 1,05 for CO_2 and coal in ground and to 1,2 for SO_2 and NO_x. The factors represent the standard deviation in a lognormal distribution.

5.10.1.2 Uncertainty analysis

When comparing the aggregated and weighted indicator results for alternative A with that for alternative B, an decrease from 10,82 to 8,88 ELU/f.u. 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 lognormal 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 the overall improvement of environmental performance when increasing the 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/f.u. better than material A and that there are about 70 % probability that A is more impacting on the environment than 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 in an investment in environmental performance. If 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 - 40 = 40.

5.10.1.3 Sensitivity analysis

Because of the low efficiency in improvement investments, it was of interest to know, which input data that contributes most to the uncertainty shown in Figure 20. This was determined in a special kind of sensitivity analysis [41]. In this, all factors by which a certain input data is multiplied with in order to change the ranking order, f_i are determined and the ratio of the uncertainty factor and f_i for each input data 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 alternative A, B and B respectively. The characterization factor for PAH comes next with respect to the category indicator YOLL. The sensitivity for the inventory results of PAH and the characterization factor of PAH for YOLL 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 concept A product system is known. New, locally specific characterization factors may also be estimated with less uncertainty.

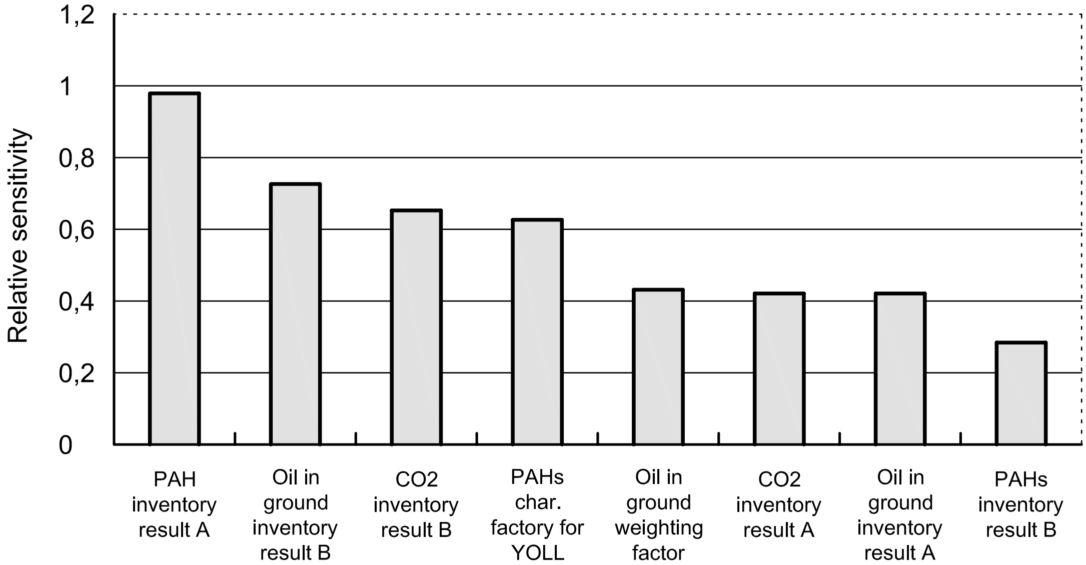


Figure 21 — Input data that contributes most to the uncertainty of the ranking of alternatives

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.

5.11 Example 1 continued

5.11.1 Conclusions, limitations and recommendations (ISO 14044:2006, 4.5.4)

See comments within individual examples and ISO 14044:2006, 4.5.4.

5.11.2 LCIA intended to be used in comparative assertions intended to be disclosed to the public (ISO 14044:2006, 4.4.5)

See comments within individual examples and ISO 14044:2006, 4.4.5.

5.11.3 Reporting (ISO 14044:2006, Clause 5)

5.11.3.1 Executive summary

This report is provided as a summary of the example to conclude the illustration. 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 14044:2006, starting with the selection of impact categories up to data quality analysis. It aims at the comparison of the environmental consequences of two different types of materials for gas pipes in country and at the identification of improvement options. The example is based on a real life study commissioned by a gas company in the given country. As functional unit is chosen the: supply of 20 mln m^3 of natural gas per year in the gas distribution network between the feeder system and 10 000 service connection points. The included materials are called material A and 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 eco-toxicity. For characterization models are used from different sources, 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 the example are the following. Regarding the choice between the two types of materials, material B scores overall considerably better than material A. This is mainly due to the heavy weight of the material A and the subsequent high impacts for material production and transportation. Therefore from an environmental point of view material A is not to be preferred as material for the pipes. But it should be noted that chlorinated organic trace pollutants are not taken into account quantitatively, the release of which may be significant in the production of material B. This point is taken along as flag and is to be handed over to the interpretation phase.

For both materials there is 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 particularly have helped to identify shortcomings in the calculation procedures.

5.11.3.2 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 Life Cycle Impact Assessment (LCIA) process

Material A								
MANDATORY LCIA ELEMENTS								
		Assigned LCI results		**Characterization factors**		**Converted LCI results**		**Indicator results**
Impact category	**Substance**	**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	Kg…eq/kg	Kg…eq
Climate change	Carbon dioxide	4,22E+4		1,00E+00		4,22E+04		1,84E+05
	HALON-1301	1,55E-03		5,60E+03		8,66E+00		
	Methane	6,73E+3		2,10+01		1,41E+05		
Stratospheric ozone depletion	HALON-1301	1,55E-03		1,20E+01		1,86E-02		1,86E-02
	Tetrachloride-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	Sulphur 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		
	P		1,22E+00		3,10E+00		3,79E+00	
	N		4,05E-01		4,20E-01		1,70E-01	
Human toxicity	Sulphur 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		
Eco-toxicity	Phenol	9,40E-05	1,55E-01	1,50E+00	2,37E+02	1,41E-04	2,37E+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	

Table 47 — Material A, optional elements; Detailed results of the Life Cycle Impact Assessment (LCIA) process

Material A								
OPTIONAL LCIA ELEMENTS								
Impact category	**Substance**	**Normalisation factors** kg eq. / yr	**Normalisation results** yr	**Grouping sorting**	**Grouping ranking**	**Weighting** social set	**Converted normalization results** yr	**Weighting** yr
Climate Change	Carbon dioxide HALON -1301 Methane	*2,27E+11*	*8,08E-07*	global	high	*0,278*	*2,25E-07*	*4,36E-07*
Stratospheric ozone Depletion	HALON -1301 Tetrachlorid 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	Sulphur dioxide Ammonia Nitrogen dioxide	*6,41E+08*	*5,48E-07*	regional	medium	*0,148*	*8,11E-08*	
Eutrophication	Ammonia Nitrogen dioxide P N	*1,08E+09*	*1,72E-08*	regional	medium	*0,113*	*1,94E-09*	
Human toxicity	Sulphur dioxide Nitrogen dioxide Arsenic Lead Nickel Vanadium	*1,45E+11*	*1,24E-07*	local	medium	*0,13*	*1,62E-08*	
Eco-toxicity	Phenol Cadmium Lead Chromium Copper	*1,16E+11*	*1,43E-09*	local	medium	*0,13*	*1,86E-10*	

Table 48 — Material B, mandatory elements; Detailed results of the Life Cycle Impact Assessment (LCIA) process

Material B								
MANDATORY LCIA ELEMENTS								
Impact category	**Substance**	**Assigned LCI results**		**Characterization factors**		**Converted LCI results**		**Indicator results (LCIA profile)**
		Air emission	**Water emission**	**Air emission**	**Water emission**	**Air emission**	**Water emission**	
		kg	kg	kg eq/kg	kg eq/kg	kg eq/kg	kg eq/kg	kg eq
Climate change	Carbon dioxide	4,81E+3		1,00E+00		4,81E+03		1,46E+05
	HALON-1301	4,30E-04		5,60E+03		2,41E+00		
	Methane	6,75E+3		2,10E+01		1,42E+05		
Stratospheric ozone depletion	HALON-1301	4,30E-04		1,20E+01		5,16E-03		5,75E-03
	Tetrachloride-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	Sulphur 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		
	P		5,41E-02		3,10E+00		1,68E-01	
	N		1,80E-01		4,20E-01		7,54E-02	
Human toxicity	Sulphur 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		
Eco-toxicity	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		

Table 49 — Material B, optional elements; Detailed results of the Life Cycle Impact Assessment (LCIA) process

Material B								
OPTIONAL LCIA ELEMENTS								
Impact category	**Substance**	**Normalisation factors** Kg eq. / yr	**Normalisation results** Yr	**Grouping sorting**	**Grouping ranking**	**Weighting results** Social set	**Converted normalization results** Yr	**Weighting** Yr
Climate change	Carbon dioxide HALON -1301 Methane	*2,27E+11*	6,45E-07	Global	High	*0,278*	1,79E-07	2,98E-07
Stratospheric ozone Depletion	HALON -1301 Tetrachloride-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	Sulphur dioxide Ammonia Nitrogen dioxide	*6,41E+08*	3,91E-08	Regional	Medium	*0,148*	5,78E-09	
Eutrophication	Ammonia Nitrogen dioxide P N	*1,08E+09*	2,24E-09	Regional	Medium	*0,113*	2,53E-10	
Human toxicity	Sulphur dioxide Nitrogen dioxide Arsenic Lead Nickel Vanadium	*1,45E+11*	3,26E-09	Local	Medium	*0,13*	4,23E-10	
Eco-toxicity	Phenol Cadmium Lead Chromium Copper	*1,16E+11*	4,10E-11	Local	Medium	*0,13*	5,33E-12	

5.11.3.3 Presentation of results

The main way of presentation of the results concerns the above tables. Note: In a public comparative assertion the results of the last element are not to be presented.

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

5.11.3.4 Discussion and conclusions

In Example 1, the results are used for comparing the environmental consequences of different types of materials and for the identification of improvement options. For this example the following conclusions can be drawn. Regarding the choice between the two types of materials material B scores overall considerably better than material A. This is mainly due to the heavy weight of the pipes from material A and the subsequent high impacts for production and transportation. So from an environmental point of view material A is not to be preferred. Although material B scores considerable better than material A, it should be noted that the possible emission of chlorinated organic trace pollutants are not taken into account, which may accompany the production of material B. Thus if this is regarded important, alternatives for material B should be considered which do not have this unquantifiable risk. For both materials there is 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.

Bibliography

[1] ISO 14001, *Environmental management systems — Requirements with guidance for use*

[2] ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

[3] ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

[4] ISO/TR 14049, *Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis*

[5] ISO 14050, *Environmental management — Vocabulary*

[6] Houghton, J.T., L.G. Meira Filho, J. Bruce, H. Lee, B.A. Callander, E. Haites, N. Harris & K. Maskell (eds), 1994: Climate change 1994. Radiative forcing of climate change an evaluation of the IPCC IS92 Emissions scenarios. Cambridge University Press, Cambridge.

[7] Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg & K. Maskell, 1995: Climate change 1995. The science of climate change; contribution of WGI to the second assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.

[8] WMO (World Meteorological Organization), 1992: Scientific assessment of ozone depletion: 1991.Report no. 25. Geneva.

[9] WMO (World Meteorological Organization), 1995: Scientific assessment of ozone depletion: 1994.Report no. 37. Geneva.

[10] Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A., Ansems, A.M.M., Eggels, P.G., van Duin, R., and de Goede, H.P. 1992: Environmental life cycle assessment of products: Guide and Backgrounds. Centre of Environmental Science, Leiden University, the Netherlands.

[11] Huijbregts, M.A.J., U. Thissen, J.B. Guinée, T. Jager, D. van de Meent, A.M.J. Ragas, A. Wegener Sleeswijk and L. Reijnders (2000): Toxicity assessment of toxic substances in life cycle assessment. I: Calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effect model USES-LCA. Chemosphere 41, pp. 541-573.

[12] Jenkins, M.E. and G.D. Hayman, 1999: Photochemical ozone creation potential for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. Atmospheric environment 33, pp. 1775-1293.

[13] Derwent, R.G., M.E. Jenkin, S.M. Saunders & M.J. Pilling, 1998: Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. Atmospheric Environment, 32. p 2429-2441.

[14] Andersson-Sköld, Y., P. Grennfelt & K. Pleijel, 1992: Photochemical ozone creation potentials: a study of different concepts. J. Air Waste Manage. Assoc. 42(9), p 1152-1158.

[15] Carter, W.L.P, 1994: Development of ozone reactivity scales for volatile organic compounds, Journal of Air & Waste Manage. Assoc, 44 p. 881-899.

[16] Carter, W.L.P, D. Luo & I.L. Malkina, 1997: Environmental chamber studies for development of an updated photochemical mechanism for VOC relativity assessment. Draft, final report to CARB, CRC, NREL.

[17] Hauschild, M & H. Wenzel, 1998: Environmental Assessment of products. Volume 1: Methodology, tools and case studies in product development; Volume 2: Scientific background. Chapman & Hall, London.

[18] Goedkoop, M. and R. Spriensma, 1999: The Eco-indicator 99, a damage oriented method for life cycle impact assessment. Ministry of Housing, Physical Planning and Environment, Zoetermeer, the Netherlands (www.pre.nl).

[19] Latour, J.B., I.G. Staritsky, J.R.M. Alkemade, J. Wiertz, Nature Planner, Decision support system nature and environment, RIVM report 711901019, RIVM, Bilthoven, the Netherlands.

[20] Kros et al., 1995. Modelling of soil acidity and nitrogen availability in natural ecosystems in response to Changes in Acid deposition and Hydrology. Report 95, SC-DLO, Wageningen, the Netherlands.

[21] Alkemade, J.R.M., J. Wiertz, J.B. Latour, 1996. Kalibratie van Ellenbergs milieuindicatiegetallen aan werkelijk gemeten bodemfactoren. Rapport 711901016, RIVM, Bilthoven, the Netherlands.

[22] Udo de Haes, H.A., O. Jolliet, G. Finnveden, M. Hauschild, W. Krewitt, R. Müller-Wenk. (1999). Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Assessment. Background Document for the Second Working Group on Life Cycle Assessment of SETAC-Europe (WIA-2). International Journal of LCA, 4, nr 2, pp. 66-74; and 4, nr. 3, pp. 167-174. ECOMED publishers, Landsberg, Germany.

[23] Huppes, G., H. Sas, E. de Haan and J. Kuyper, 1997: Efficient environmental investments. Report SENSE, international workshop. CML, Leiden, the Netherlands.

[24] Potting J. et al., 1998: Journal of Industrial Ecology, Volume 2, pages 63-87.

[25] Burke et al, 1996: Human Health Assessment and Life-cycle Assessment: Analysis by an Expert Panel. International Life Sciences Institute, Washington, DC.

[26] Galeano, S. F., 1999: Carbon Sequestration Inventory Issues - the Significance of their Resolution for the Forest Products Industry". TAPPI International Environmental Conference - Nashville, TN.

[27] Row, C., Phelps, R.B., 1996: Wood carbon flows and storage after timber harvest. Forest and global change, American Forests, Volume 2, Chapter 2, Washington D.C.

[28] Miales, J.A., Skog, K.E., 1997: The decomposition of forest products in landfills. International Biodeterioration & Biodegradation, Volume 39, No 2-3, United Kingdom.

[29] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998. EPA 236-R-00-001. April 2000 (Fulfilling reporting commitments of the UNFCCC).

[30] Goedkoop,M.J., R. Spriensma, 1999: The Eco-indicator 99, a Damage Oriented Approach for LCIA, Ministry VROM, The Hague.

[31] Frischknecht R. (final editor), U. Bollens, S. Bosshart, M. Ciot, L. Ciseri, G. Doka, R. Hischier, A. Martin (ETH Zürich), R. Dones, U. Gantner (PSI Villigen), 1996: Ökoinventare von Energiesystemen, Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, 3rd Edition, Gruppe Energie - Stoffe - Umwelt, ETH Zürich, Sektion Ganz - heitliche Systemanalysen, PSI Villigen [ESU 1996].

[32] Murray, C., A. Lopez, 1996: The Global Burden of Disease, WHO, World Bank and Harvard School of Public Health. Boston.

[33] Frischknecht R., A. Braunschweig, P. Hofstetter, P. Suter. 1999: Modelling human health effects of radioactive releases in Life Cycle Impact Assessment, Draft from 20 February 1999, accepted for publication in Environmental impact Assessment Review No. 2, 2000.

[34] European Environmental Agency, 1998: Europe's environment, The Dobris Assessment, Copenhagen.

[35] Dreicer M., V. Tort, P. Manen, 1995: ExternE, Externalities of Energy, Vol. 5. Nuclear, Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), edited by the European Commission DGXII, Science, Research and Development JOULE, Luxembourg.

[36] Hofstetter, P., 1998: Perspectives in Life Cycle Impact Assessment; A Structured Approach to Combine Models of the Technosphere, Ecosphere and Valuesphere. Kluwers Academic Publishers.

[37] Müller-Wenk, R., 1998-1: Depletion of Abiotic Resources Weighted on the Base of "Virtual" Impacts of Lower Grade Deposits in Future. IWÖ Diskussionsbeitrag Nr. 57, Universität St. Gallen, ISBN 3-906502-57-0.

[38] Thompson M., R. Ellis, A. Wildavsky, 1990: Cultural Theory, Westview Print, Boulder.

[39] Steen, B. 1999: A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – General system characteristics. Chalmers University of Technology (CPM), Report 1999;4.

[40] Steen, B. 1999: A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – Models and data. Chalmers University of Technology (CPM), Report 1999;5.

[41] Steen, B., 1997: On uncertainty and sensitivity of LCA based priority setting. Journal of cleaner production, Volume 5, Number 4, pp. 255 – 262.

[42] Wenzel, H., M. Hauschild, L. Alting, 1997: Environmental assessment of products. Vol. 1 - Methodology, tools, techniques and case studies, 544 pp. Chapman & Hall, United Kingdom, Kluwer Academic Publishers, Hingham, MA. USA. ISBN 0 412 80800 5.

[43] Hauschild, M.Z., H. Wenzel, 1998: Environmental assessment of products. Vol. 2 - Scientific background, 565 pp. Chapman & Hall, United Kingdom, Kluwer Academic Publishers, Hingham, MA. USA. ISBN 0412 80810 2

[44] Stranddorff, H., L. Hoffmann, A. Schmidt, 2001: Normalization and weighting– update of selected impact categories. Environmental report from the Danish Environmental Protection Agency. Copenhagen.

[45] "La pollution des eaux – Que sais-je? N° 983”, 1994.

[46] Institut Français de l'Environnement, 1999. Chiffres clés.

[47] Centre d'Etude et de Recherche sur l'Energie - France.

[48] Observatoire de l’énergie, 1998. Bilan.

[49] Institut Français de l'Environnement, 1998. From Centre Interprofessionnel Technique d'Etudes de la Pollution Atmospherique.

[50] ADEME – ITOMA, 1998. Household waste.

[51] ADEME – ITOMA, 1998. Municipal Solid waste.

[52] Centre Interprofessionnel Technique d'Etudes de la Pollution Atmospherique, 1994. CORINAIR.

[53] Matsuhashi A., A. Terazono, Y. Moriguchi, 1998: Identification of Environmental Problem Area and Safeguard Subjects for a Valuation Process in LCIA, Proceedings of The Third International Conference on Ecobalance, Tsukuba, Japan.

[54] Gruebler A., (IIASA), K. Riahi (IIASA), S. van Rooijen (ECN), S. Smith (NCAR), , Global Emissions, Harmonized Data, http://sres.ciesin.org/index.html.

[55] [Intergovernmental Panel on Climate Change, 1996: Climate Change 1995 - The Science of Climate Change.

[56] Kawashima H., T. Kawanishi, C. Yasue, Y. Hayashi, 1997: Estimation of Real Nitrogen Load affecting Environment generated from Food Production and Consumption Processes , J.JASS 13(2) pp91-95.

[57] Data compiled by Japanese Ministry of Health and Welfare, 1996. Ministry of Health and Welfare, 1996.

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