



BSI Standards Publication

# Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations

**National foreword**

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# TECHNICAL REPORT

# ISO/TR 14047

Second edition  
2012-06-01

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## **Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations**

*Management environnemental — Analyse du cycle de vie — Exemples  
illustrant l'application de l'ISO 14044 à des situations d'évaluation de  
l'impact du cycle de vie*



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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

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

This second edition cancels and replaces the first edition (ISO/TR 14047:2003), which has been technically revised.

## Introduction

The heightened awareness of the importance of environmental protection and the possible environmental significance of a product system<sup>1)</sup>, 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.

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

# Environmental management — Life cycle assessment — Illustrative examples on how to apply 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                          | ISO 14044:2006 Clause                                                                                                                                                                                                                                                           | Example coverage in this Technical Report                                                                                                                                                                                 |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 to 3                                            | <b>Scope, Normative references, Terms and definitions</b>                                                                                                                                                                                                                       | <b>Examples of impact categories</b>                                                                                                                                                                                      |
| 4.4.2<br>4.4.2.1<br>4.4.2.2<br>4.4.2.3<br>4.4.2.4 | <b>Mandatory elements of LCIA</b><br>General<br>Selection of impact categories, category indicators and characterization models<br>Assignment of LCI results to the selected impact categories (Classification)<br>Calculation of category indicator results (characterization) | <b>Example 1, Example 2, Example 3, Example 4, Example 5</b>                                                                                                                                                              |
| 4.4.3<br>4.4.3.1<br>4.4.3.2<br>4.4.3.3<br>4.4.3.4 | <b>Optional elements</b><br>General<br>Normalization,<br>Grouping<br>Weighting                                                                                                                                                                                                  | <b>Example 1, Example 2, Example 6, Example 7</b><br><i>(Calculating the magnitude of the category indicator results relative to reference value(s))</i><br><b>Example 1</b><br><b>Stem example, Example 5, Example 8</b> |
| 4.4.4                                             | <b>Additional LCIA Data Quality analysis</b>                                                                                                                                                                                                                                    | <b>Stem example, Example 5</b>                                                                                                                                                                                            |
| 4.4.5<br><br>5<br>6                               | LCIA intended to be used in comparative assertions to be disclosed to the public<br><br>Public Reporting<br>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.

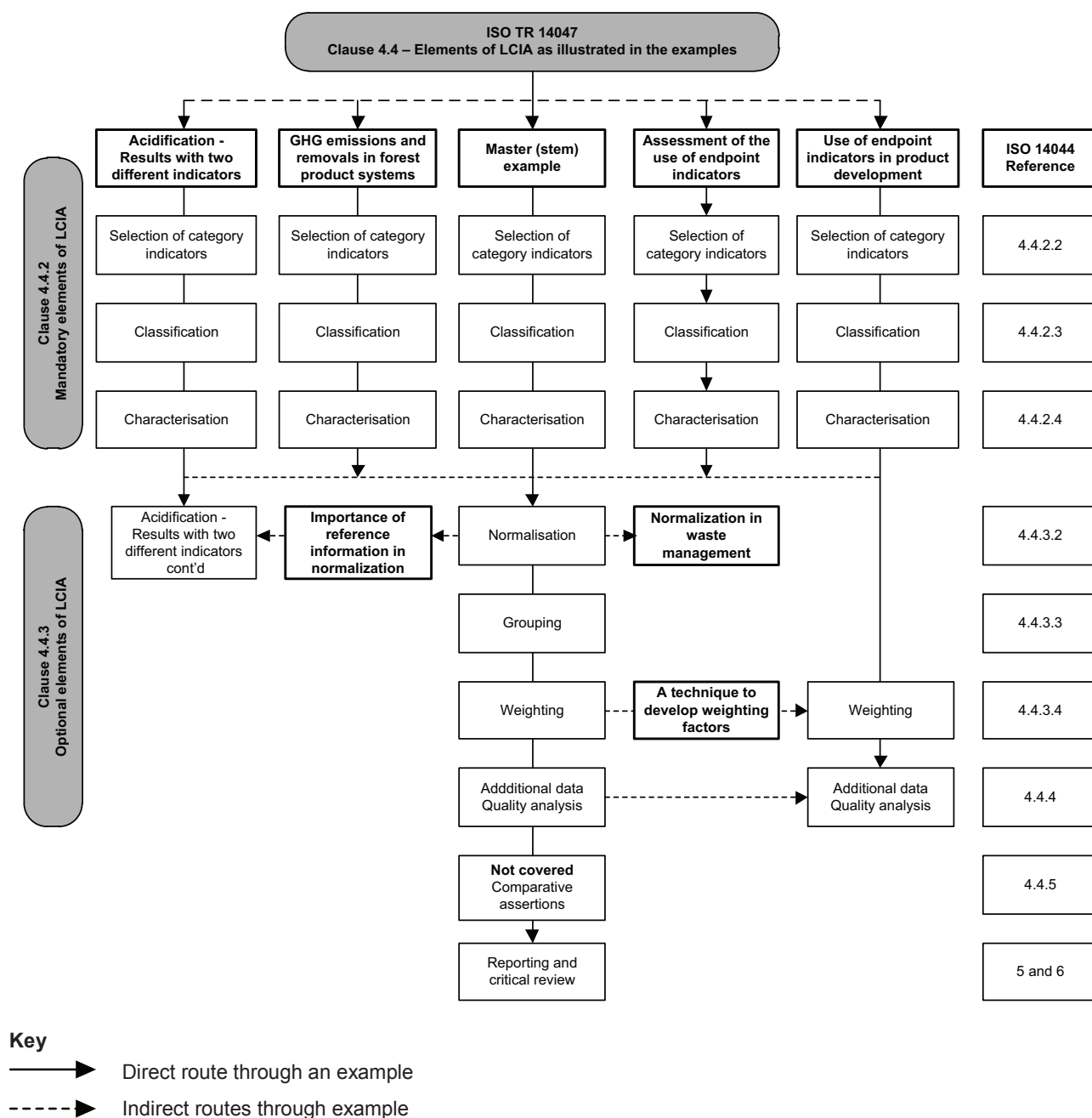


Figure 1 — Organization and route map for this Technical Report

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.

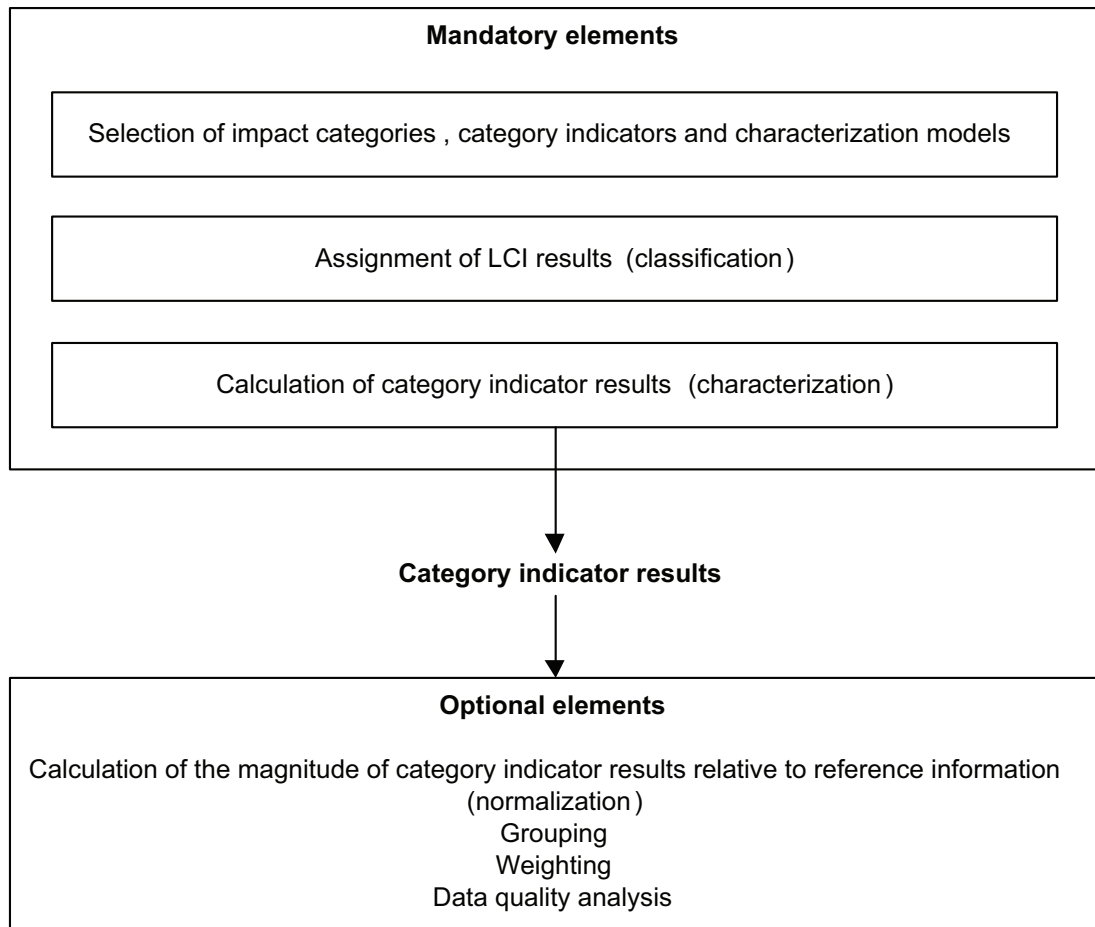


Figure 2 — Element of the LCIA phase (ISO 14044:2006)

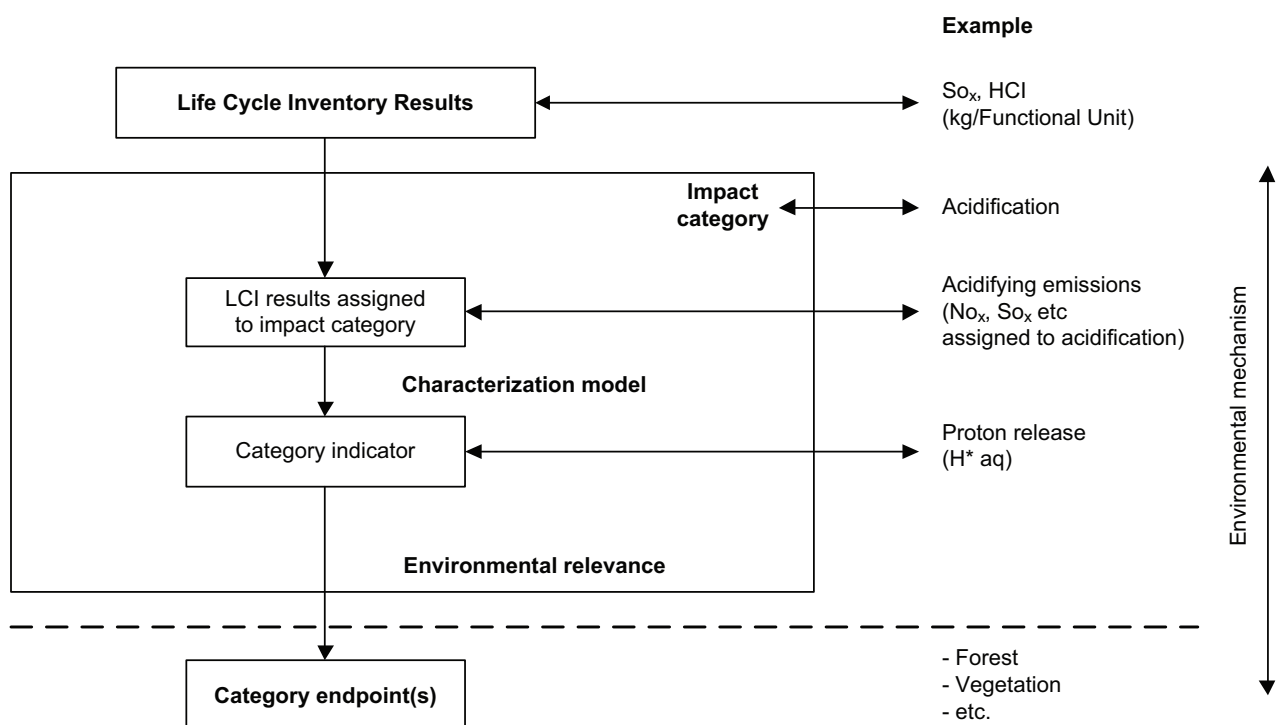


Figure 3 — Concept of category indicators (Figure 3 from ISO 14044:2006)

**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                                                                                                                                           | Nutrication                                                                                                                                                       | 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 <sup>a</sup> ) defining the global warming potential of different greenhouse gases [6], [7]                                   | The model as developed by the World Meteorological Organization (WMO <sup>b</sup> ) 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 <sup>c</sup> 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 <sup>2</sup> )                                                                                                                                                  | 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 <sub>2</sub> eq. / kg emission)                                                                     | Ozone Depletion Potential in the steady state (ODP <sub>steady state</sub> ) for each emission (kg CFC - 11 eq. / kg emission)                                          | Nutrication Potential (NP) for each eutrophication emission to air, water and soil (kg PO <sub>4</sub> <sup>3-</sup> - 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 <sub>2</sub> -equivalents                                                                                                                                                                          | Kg CFC - 11 equivalents                                                                                                                                                 | kg PO <sub>4</sub> <sup>3-</sup> -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 nutrification for different types of ecosystems; it is defined at a global level | The PNEC represents a threshold for a possible effect of the substance on the species composition of an ecosystem: no spatial differentiation is considered |
| <p><sup>a</sup> Intergovernmental Panel on Climate Change</p> <p><sup>b</sup> Word Meteorological Organization</p> <p><sup>c</sup> Uniform System for the Evaluation of Substances</p> |                                                   |                                                                                                       |                                                                                                                                                                                                             |                                                                                                                                                                         |                                                                                                                                                                   |                                                                                                                                                             |

**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 <sub>x</sub> , 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 Potential (POCP) for each emission of VOC or CO to air (kg ethylene eq. / kg emission) | Photochemical Ozone Creation Potential (POCP) for each emission of VOC or CO to air (kg ethylene eq. / kg emission) | Kg 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 <sub>x</sub> , VOC or CO to air (m <sup>2</sup> *ppm*hours / kg emission)                                                                             |
| Indicator result        | Kg ethylene equivalents                                                                                             | Kg ethylene equivalents                                                                                             | Kg ozone                                                                                                                                                        | Kg ozone                                                                                                                                         | Kg ozone                                                                                                                                                          | m <sup>2</sup> *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 <sub>x</sub>                                             | Ozone formation estimated with low background NO <sub>x</sub>                                                       | Highest rise in ozone levels per added amount of standard VOC mixture, very high NO <sub>x</sub> concentration, high concentration is inhibiting ozone creation | Highest ozone concentration per added amount of standard VOC mixture, relative high NO <sub>x</sub> concentration, realistic for peak situations | NO <sub>x</sub> and VOC contribute equally to ozone production, relative low NO <sub>x</sub> concentrations of NO <sub>x</sub> and VOC both reduce ozone creation | Includes the contribution from NO <sub>x</sub> 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**

| <b>Term</b>             | <b>Alternative examples for the category indicator for acidification</b>                                          |                                                                                                         |                                                                                                                        |
|-------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Impact category</b>  | <b>Acidification</b>                                                                                              | <b>Acidification</b>                                                                                    | <b>Acidification</b>                                                                                                   |
| 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 <sup>+</sup> )                                                                      | Deposition / Acidification Critical Load                                                                | Increase in PDF <sub>vegetation</sub> (Potentially Disappeared Fraction) of plants species in natural areas            |
| Characterization factor | Acidification Potential (AP) for each acidifying emission to air and water (kg SO <sub>2</sub> eq. / kg emission) | Acidification Potential (AP) for each acidifying emission to air (kg SO <sub>2</sub> eq. / kg emission) | Potentially Disappeared Fraction (PDF) for each acidifying emission to air (PDF.m <sup>2</sup> .yr/kg emission)        |
| Indicator result        | Kg SO <sub>2</sub> equivalents                                                                                    | Kg SO <sub>2</sub> equivalents                                                                          | PDF.m <sup>2</sup> .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]**

|                                                                    |
|--------------------------------------------------------------------|
| <b>Output related categories:</b>                                  |
| — Climate change                                                   |
| — Stratospheric ozone depletion                                    |
| — Photo-oxidant formation                                          |
| — Acidification                                                    |
| — Nutrification                                                    |
| — Human toxicity                                                   |
| — Eco-toxicity                                                     |
| <b>Input related categories:</b>                                   |
| — 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<sub>2</sub> contributes to three categories: acidification, climate change (counteracting) and human toxicity. Refer to Figure 4.

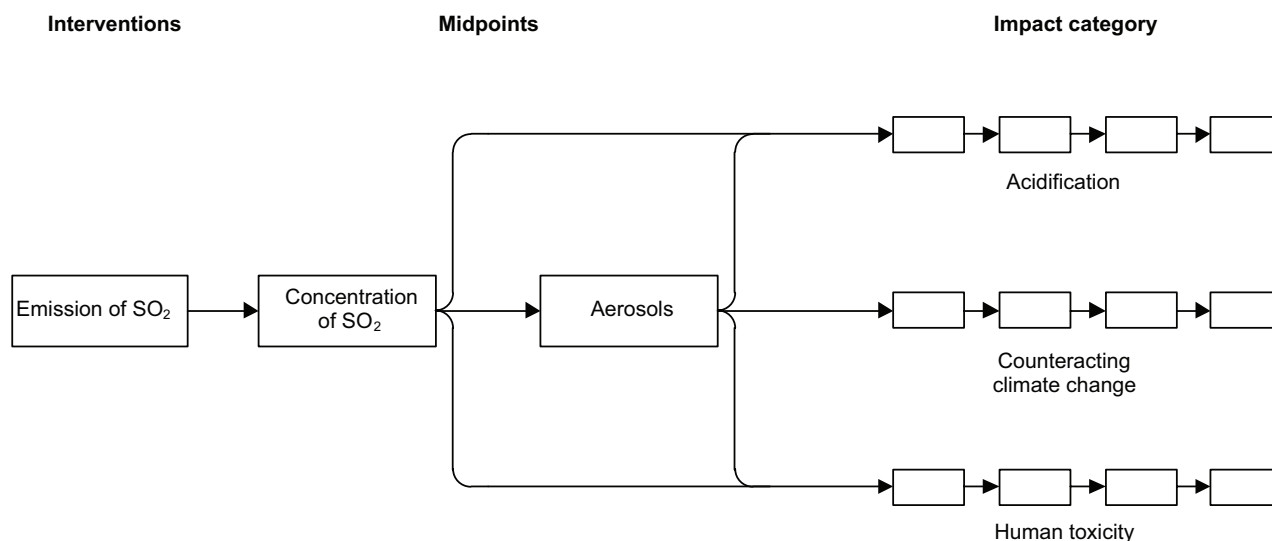


**Figure 4 — Example of parallel processes**

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.

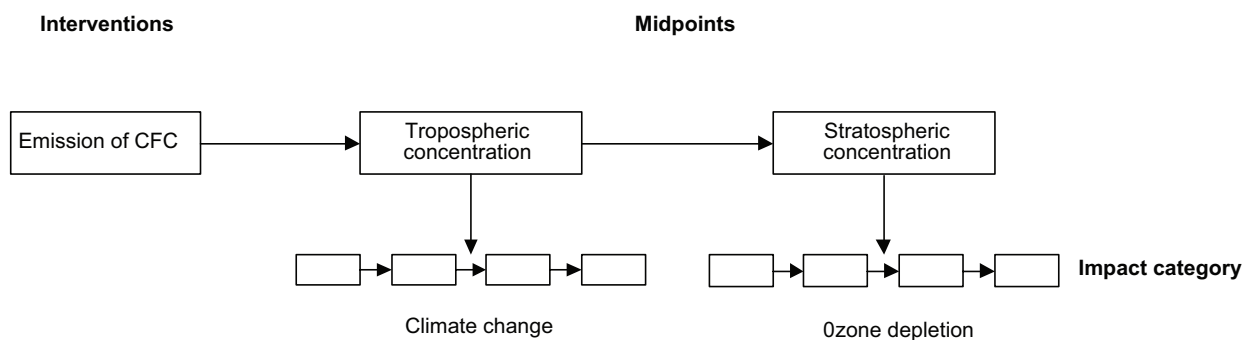


**Figure 5 — Example of a serial process**

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<br>kg CO <sub>2</sub> eq./ kg | Stratosph<br>ozone<br>depletion<br>kg CFC-11<br>eq. / kg | Photo-<br>oxidant<br>formation<br>kg<br>ethylene<br>eq. / kg | Acidifi-<br>cation<br>kg SO <sub>2</sub> -<br>eq./ kg | Eutrophication<br>Kg PO <sub>4</sub> - eq. / kg | Human<br>Toxicity<br>Kg 1,4-<br>DCB / kg                  | Eco-toxicity<br>kg 1,4-DCB / kg                                                              |
|                                                                                                                                                                                        |                                                                                              | Air<br>emissions                             | Air<br>emissions                                         | Air<br>emissions                                             | Air<br>emissions                                      | Air Emissions    Water<br>Emissions             | Air<br>emissions                                          | Air Emissions    Water<br>Emissions                                                          |
| Climate change                                                                                                                                                                         | Carbon dioxide<br>HALON-1301<br>Methane                                                      | 1<br>5600<br>21                              |                                                          |                                                              |                                                       |                                                 |                                                           |                                                                                              |
| Stratospheric<br>Ozone<br>depletion                                                                                                                                                    | HALON-1301<br>Tetrachloro<br>methane                                                         |                                              | 12<br>1,2                                                |                                                              |                                                       |                                                 |                                                           |                                                                                              |
| Photo-<br>oxidant<br>Formation                                                                                                                                                         | Methane<br>Ethane<br>Propane                                                                 |                                              |                                                          | 0,006<br>0,123<br>0,176                                      |                                                       |                                                 |                                                           |                                                                                              |
| Acidification                                                                                                                                                                          | Sulphur dioxide<br>Ammonia<br>Nitrogen dioxide                                               | a                                            |                                                          |                                                              | 1<br>1,3<br>0,41                                      |                                                 |                                                           |                                                                                              |
| Nutrition                                                                                                                                                                              | Ammonia<br>Nitrogen dioxide<br>P<br>N                                                        |                                              |                                                          |                                                              |                                                       | 0,35    0,33<br>0,13    3,1<br>0,42             |                                                           |                                                                                              |
| Human<br>toxicity                                                                                                                                                                      | Sulphur dioxide<br>Nitrogen dioxide<br>Arsenic<br>Lead<br>Nickel<br>Vanadium                 |                                              |                                                          |                                                              |                                                       |                                                 | 0,096<br>1,3<br>347699,7<br>466,52<br>35032,84<br>6240,35 |                                                                                              |
|                                                                                                                                                                                        | Chlorinated<br>organ.<br>trace pollutants                                                    |                                              |                                                          |                                                              |                                                       |                                                 |                                                           | b    b                                                                                       |
| Eco-toxicity                                                                                                                                                                           | Phenol<br>Cadmium<br>Lead<br>Chromium<br>Copper<br>Chlorinated<br>organ. trace<br>pollutants |                                              |                                                          |                                                              |                                                       |                                                 |                                                           | 1,5    237<br>289    1523<br>2,4    9,615719<br>1,9    6,9<br>221,6538    1157,307<br>b    b |
| a It is recognised that the emission of SO <sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> to be assigned to acidification (incl. aerosols);
- Climate change: only SO<sub>2</sub>-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<sub>2</sub> 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**

| <b>Material A</b>             |                       |                             |                |                                 |                |                              |                |                                             |
|-------------------------------|-----------------------|-----------------------------|----------------|---------------------------------|----------------|------------------------------|----------------|---------------------------------------------|
| <b>Impact category</b>        | <b>Substance</b>      | <b>Assigned LCI results</b> |                | <b>Characterization factors</b> |                | <b>Converted LCI results</b> |                | <b>Indicator results<br/>(LCIA profile)</b> |
|                               |                       | 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     |                                             |
| 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                     |                | 2,10E+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**

| <b>Material B</b>             |                       |                      |                |                          |                |                       |                |                                     |
|-------------------------------|-----------------------|----------------------|----------------|--------------------------|----------------|-----------------------|----------------|-------------------------------------|
| Impact category               | Substance             | Assigned LCI results |                | Characterization factors |                | Converted LCI results |                | Indicator results<br>(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       |                                     |
| 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.