SimaPro database manual

Methods library

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Title: SimaPro database manual

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About SimaPro

PRé

Fact-based sustainability

SimaPro was developed by PRé with the goal of making sustainability a fact-based endeavor. PRé has been a leading voice in sustainability metrics and life cycle thinking development for nearly 30 years, pioneering the field of environmental and social impact assessment. We develop tools that help you create value and drive sustainable change.

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1 Introduction

SimaPro contains a number of impact assessment methods, which are used to calculate impact assessment results. This manual describes how the various impact assessment methods are implemented in SimaPro. For specific details on the method see the literature references given or contact the authors of the method.

Important note on changing methods

If you want to change methods in SimaPro, it is strongly advised to copy the original method to your project first. By copying, you make sure you always have the original method intact in your database. Please note that once changes are saved, they cannot be undone!

2 Structure of methods in SimaPro

The basic structure of impact assessment methods in SimaPro is:

1. Characterization
2. Damage assessment
3. Normalization
4. Weighting
5. Addition

The last four steps are optional according to the ISO standards. This means they are not always available in all methods. In SimaPro you can switch the optional steps on or off when you edit a method.

2.1 Characterization

The substances that contribute to an impact category are multiplied by a characterization factor that expresses the relative contribution of the substance. For example, the characterization factor for CO_2 in the Climate change impact category can be equal to 1, while the characterization factor of methane can be 25. This means the release of 1 kg methane causes the same amount of climate change as 25 kg CO_2. The total result is expressed as impact category indicators (formerly characterization results).

Note

A new substance flow introduced in ecoinvent 2.0 called ‘carbon dioxide, land transformation’ is included in all the methods available in SimaPro. This substance flow represents the CO2 emissions from clear cutting and land transformation.

CO_2 uptake and emissions of CO_2 and CO from biogenic sources were removed from every method with effects on climate change. The characterization factors for methane from biogenic sources were corrected for the CO_2 sequestration.

In SimaPro, sub-compartments can be specified for each substance. For example, you can define an emission to water with a sub-compartment of ocean. This allows you to create detailed impact assessment methods, with specific characterization factors for each sub-compartment.

Some impact assessment methods are not as detailed as the inventory in terms of specification of sub-compartments. In this case SimaPro will choose the “unspecified” characterization factor as the default factor for a substance that has a sub-compartment specified in the inventory but has no specific characterization factor in the chosen impact assessment method.

2.2 Damage assessment

Damage assessment is added for methods with a midpoint-endpoint framework, such as ReCiPe 2016 and IMPACT World+ methods. The purpose of damage assessment is to make use of mid- to endpoint factors thereby combining a number of impact category indicators into a damage category (also called area of protection).

In the damage assessment step, an extra step in the environmental mechanism is added to midpoint impact category indicators to measure the impact at endpoint level. This way, with a common unit can be added. For example, in the IMPACT World+ method, all impact categories that cause damage to human health are expressed in DALY (disability adjusted life years). In this method DALYs caused by carcinogenic substances can be added to DALYs caused by climate change.

2.3 Normalization

Many methods allow the impact category indicator results to be compared by a reference (or normal) value. This mean that the impact category is divided by the reference. A commonly used reference is the average yearly environmental load in a country or continent, divided by the number of inhabitants. However, the reference may be chosen freely. You could also choose the environmental load of lighting a 60W bulb for one hour, 100 km of transport by car or 1 liter of milk. This can be useful to communicate the results to non LCA experts, as you benchmark your own LCA against something everybody can imagine. In SimaPro, there are often alternative normalization sets available.

After normalization the impact category indicators all have the same unit, which makes it easier to compare them. Normalization can be applied on both characterization and damage assessment results.

PLEASE NOTE: SimaPro does not divide by the reference value (N), but multiplies by the inverse. If you edit or add a normalization value in a method, you must therefore enter the inverted value (1/N).

2.4 Weighting

Some methods allow weighting across impact categories. This means the impact (or damage) category indicator results are multiplied by weighting factors, and are added to create a total or single score. Weighting can be applied on normalized or non-normalized scores, as some methods like EPS do not have a normalization step. In SimaPro, there are often alternative weighting sets available, always in combination with a normalization set.

2.5 Checking impact assessment results

Although impact assessment methods become very extensive and include more and more substances, they still do not cover all substances that you can find in your inventory. This can be a methodological issue, as some methods for example do not include raw materials as impact category. Issues can arise if you added a new substance that is not automatically included in the impact assessment method or if you introduced synonyms by importing data from other parties.

SimaPro has a built-in check to show you which substances are not included in the selected impact assessment method. For each result, the substances and their amounts *not included* in the method are shown under 'Checks' in the result window.

Further, under 'Inventory results' you can see the impact assessment results per substance. If a substance is not defined in the method, a pop-up hint will tell you this.

On a method level, you can run a check which will show you which of all substances, available in the SimaPro database, are included in the method on impact category level. To run this check, select a method and click the 'Check' button in the right hand side of the methods window.

3 European methods

3.1 CML-IA

In 2001, a group of scientists under the lead of CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterization methods for the impact assessment step. The impact assessment method implemented as CML-IA methodology is defined for the midpoint approach. Normalization is provided but there is neither weighting nor addition.

There are two version of this method available in SimaPro: a 'baseline' version with 10 impact categories; and an extended version with 'all impact categories' including other impact categories as well as variations of existing impact categories, e.g. for different time frames.

The current version of CML-IA implemented in SimaPro has been updated using a version of the method uploaded in August 2016 from the website http://www.cml.leiden.edu/software/data-cmlia.html.

3.1.1 Classification and characterization

The CML Guide (Guinée et al. 2002) provides a list of impact assessment categories grouped into

- Obligatory impact categories (category indicators used in most LCAs)
- Additional impact categories (operational indicators exist, but are not often included in LCA studies)
- Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories; a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem oriented approach)" and are presented below. Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.

Depletion of abiotic resources

This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

Climate change

Climate change can result in adverse effects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale.

Stratospheric Ozone depletion

Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterization model is developed by the World Meteorological Organization (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinity.

Human toxicity

This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterization factors, Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale.

Fresh-water aquatic eco-toxicity

This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco-toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances. The time horizon is infinite Characterization factors are expressed as 1,4-dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/ regional and local scale.

Marine ecotoxicity

Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description fresh water toxicity).

Terrestrial ecotoxicity

This category refers to impacts of toxic substances on terrestrial ecosystems (see description fresh water toxicity).

Photo-oxidant formation

Photo-oxidant formation is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with "summer smog". Winter smog is outside the scope of this category. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission. The time span is 5 days and the geographical scale varies between local and continental scale.

Acidification

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

Characterization factors including fate were used when available. When not available, the factors excluding fate were used (In the CML baseline version only factors including fate were used). The method was extended for Nitric Acid, soil, water and air; Sulphuric acid, water; Sulphur trioxide, air; Hydrogen chloride, water, soil; Hydrogen fluoride, water, soil; Phosphoric acid, water, soil; Hydrogen sulfide, soil, all not including fate. Nitric oxide, air (is nitrogen monoxide) was added including fate.

Eutrophication

Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO4 equivalents per kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

The method available with all impact categories has, comparing with the baseline version, the following impact categories available:

- Global warming (different time frames)
- Upper limit of net global warming
- Lower limit of net global warming
- Ozone layer depletion (different time frames)
- Human toxicity (different time frames)
- Fresh water aquatic ecotoxicity (different time frames)
- Marine aquatic ecotoxicity (different time frames)
- Terrestrial ecotoxicity (different time frames)
- Marine sediment ecotoxicity (different time frames)
- Average European (kg NOx-eq); Average European (kg SO2-eq)
- Land competition
- Ionising radiation
- Photochemical oxidation; Photochemical oxidation (low NOx)
- Malodorous air
- Equal benefit incremental reactivity
- Max. incremental reactivity; Max. ozone incremental reactivity

3.1.2 Normalization

Normalization is regarded as optional for simplified LCA, but mandatory for detailed LCA. For each baseline indicator, normalization scores are calculated for the reference situations: the world in 1990, Europe in 1995 and the Netherlands in 1997. Normalization data are available for the Netherlands (1997/1998), Western Europe (1995) and the World (1990 and 1995) (Huijbregts et al. 2003).

References

Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J. 2002. Handbook on life cycle assessment. Operational guide to the ISO standards. Part III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 692 pp.

Huijbregts, M.A.J.; Breedveld L.; Huppes, G.; De Koning, A.; Van Oers, L.; Suh, S. 2003. Normalisation figures for environmental life-cycle assessment: The Netherlands (1997/1998), Western Europe (1995) and the World (1990 and 1995). Journal of Cleaner Production 11 (7): 737-748.

3.2 Environmental Prices

Environmental Prices is a method developed by CE Delft for expressing environmental impacts in monetary terms. Environmental prices thus indicate the loss of economic welfare that occurs when one additional kilogram of the pollutant finds its way into the environment.

Development of the Environmental Prices consisted of five steps:

- updating monetary values of the endpoint categories on basis of literature, General SCBA Guidelines and Discount Rate Working Group;
- updating the impact pathway analyses, which specify the relationship between emissions in the Netherlands and impacts on endpoints;
- valuation of 15 pollutants on basis of inputs from the previous steps and literature;
- allocation of those pollutants to midpoint impact categories in ReCiPe 2008;
- deriving weighted average value for damage to midpoint categories in order to calculate the damage cost for each substance characterized in ReCiPe 2008 and midpoint damage factors.

In LCA context environmental prices are used as weighting sets, which allows calculation of single score results.

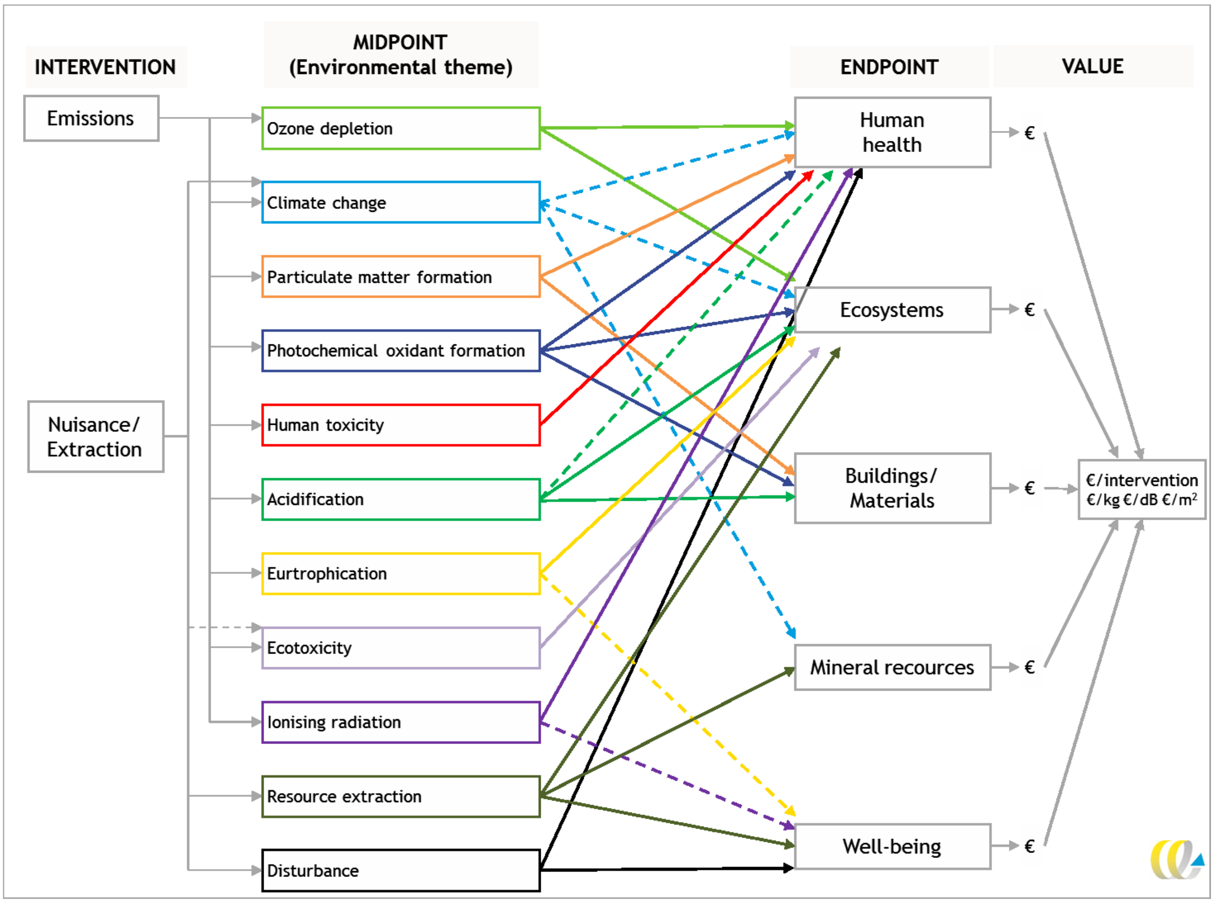

Figure 1. The relationships mapped in the Environmental Prices Handbook (de Bruyn, et al. 2017)

3.2.1 Characterization

The characterization step is a copy of ReCiPe (2008) Midpoint, hierarchist perspective with an exception for Climate change based on IPCC (2013), as prescribed by the developers. An overview is provided in section 7.13.

3.2.2 Normalization and weighting

Normalization is not included in this method.

The Environmental Prices in SimaPro use the midpoint-level prices (pollutant- and endpoint-level were also developed). In practical terms, it means that the prices of environmental themes are combined in a weighting set. CE Delft developed two weightings sets:

- Dutch Environmental Prices (2015) – based on average emissions in the Netherlands in 2015,
- European Environmental Prices (2015) – based on average emissions in the EU28 in 2015.

The environmental prices are not available for the following impact categories: Natural land transformation, Water, Metal and Fossil depletion.

References

S.M. de Bruyn, S. Ahdour, M, Bijleveld, L. de Graaff, A. Schroten, Handboek Milieuprijzen 2017, Methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieu-impacts, CE Delft, 2017.

S.M. de Bruyn, M, Bijleveld, L. de Graaff, E. Schep, A. Schroten, R. Vergeer, S. Ahdour Environmental Prices Handbook, EU28 version, CE Delft, 2018.

3.3 Ecological scarcity 2013

The “ecological scarcity” method (also called Ecopoints or Umweltbelastungspunkte method) is a follow up of the Ecological scarcity 2006 (see section 6.9) and the Ecological scarcity 1997 method (see section 7.4) which was named Ecopoints 97 (CH) in the SimaPro method library.

The ecological scarcity method weights environmental impacts - pollutant emissions and resource consumption - by applying "eco-factors". The distance to target principle is applied in the Ecological scarcity method. The eco-factor of a substance is derived from environmental law or corresponding political targets. The more the current level of emissions or consumption of resources exceeds the environmental protection target set, the greater the eco-factor becomes, expressed in eco-points (EP = UBP). An eco-factor is essentially derived from three elements (in accordance with ISO Standard 14044): characterization, normalization and weighting.

The most important changes since last update are as follows:

- A reduction target of 80% has been set for CO2 and other greenhouse gases. This falls in the upper range of the Swiss reduction target and within the range of the reduction required to achieve the 2°C target.
- To assess energy, the federal government's long-term target (2,000 W per capita) is interpolated to the usual time frame set out in the legislation, which is 2035.
- With regard to air pollutants, additional eco-factors are provided for PAHs and radioactive isotopes.
- In this version, PAHs, dioxins and furans, and benzene are all assessed for their carcinogenic potential.
- As for water pollutants, additional eco-factors for oil emissions to the sea are provided based on an international agreement to protect the North Sea. Furthermore, eco-factors for the emissions of radioactive isotopes and persistent organic pollutants in watercourses are included for the first time.
- In some parts of the world, freshwater is a scarce resource. The regionalized ecofactors introduced in the last update are now indicated for all countries and as determined on the basis of scarcity in OECD and BRIC countries (Brazil, Russia, India and China).
- It is now recommended that the eco-factor for freshwater be applied to consumptive water use (and not water extraction).
- In Switzerland, resource efficiency has become a relevant area of environmental policy. For that reason, a new eco-factor for mineral primary resources (minerals and metals) was introduced. The ratio of annual production to available reserves is used as the basis for the characterization.

- New eco-factors were introduced for land use in various biomes. Characterization is based on the impacts of land uses upon plant and animal biodiversity.
- New eco-factors are provided for noise pollution caused by road, rail and air traffic.

3.3.1 Characterization, normalization and weighting

In the ecological scarcity method, a characterization may be applied if the corresponding environmental impact played a key role when the target was set. Accordingly, the current CO2 Act stipulates that all greenhouse gases must be taken into account. Therefore, it is both possible and appropriate to use global warming potential values. Characterization is not, however, appropriate in every theoretically conceivable case. It should not be used in cases where the environmental impact of the characterization does not match the legislators' intention with regard to the way the reduction target (or the limit or target value) was set.

The ecoinvent implementation contains nineteen specific impact categories, with for each substance a final UBP (environmental loading points) score as characterization factor which compile the characterization, normalization and distance-to-target weighting. The impact categories considered by this method are not defined as an impact indicator but rather as type of emission or resource:

1 Water sources
2 Energy sources
3 Mineral sources
4 Land use
5 Global warming
6 Ozone layer depletion
7 Main air pollutants and PM
8 Carcinogenic substances into air
9 Heavy metals into air
10 Water pollutants
11 POP into water
12 Heavy metals into water
13 Pesticides into soil
14 Heavy metals into soil
15 Radioactive substances into air
16 Radioactive substances into water
17 Noise
18 Non radioactive waste to deposit
19 Radioactive waste to deposit
20 Deposited waste

Weighting is conducted on the basis of goals set by Swiss environmental policy. In specific cases, global, international or regional goals are used and converted to the Swiss level. The method can also be applied to other countries and regions. To do so, information about the current environmental situation and the official environmental targets is required.

References

Frischknecht Rolf, Büsser Knöpfel Sybille, 2013: Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland. Environmental studies no. 1330. Federal Office for the Environment, Bern: 254 pp.Bern 2013. www.bafu.admin.ch/uw-1330-e

3.4 EF 3.0 Method (adapted)

EF method is the impact assessment method of Environmental Footprint (EF) initiative, introduced by the European Commission. The EF method 3.0 is the one to be used by Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs), as well as PEF and OEF studies, developed during the EF Transition Phase (until end of 2024). The main differences between the EF 2.0 and the EF 3.0 methods are the updated human toxicity, ecotoxicity and land use impact categories. Minor differences also affect other impact categories.

The method included in the SimaPro Professional database includes a number of adaptations, which make the EF method compatible with the data libraries provided in SimaPro.

Since the method was modified, it is not suitable for conducting the EF-compliant studies but can be used for other assessments. The original version of the method will be distributed in the dedicated SimaPro EF database.

The implementation is based on EF method with the following modifications:

- It does not include any substances which would be new to SimaPro because these are not used by data libraries;
- Additional substances have been included as they are extensively used by the background databases and their synonyms are part of the original EF method:
    - For flows representing geographies not covered in the original EF 3.0 method, the global factor was applied;
    - Climate change - carbon dioxide (emission to air) is added with factor of carbon dioxide, fossil; carbon dioxide, to soil or biomass stock is added with factor -1 (this flow is necessary for the correct modeling of land use in ecoinvent).
    - Resource use, energy carriers - flows expressed in mass units (not only in net calorific value as in EF); characterization factor corresponds to the lower heating values of given fuel;
    - Resource use, mineral and metals - additional flows for already characterized mineral and metals;

3.4.1 Characterization

Table 1. List of impact categories included, recommended characterization model (including reference) and indicator

Impact category	Recommended default LCIA method	Indicator
Climate change	Baseline model of the IPCC 2013, including the carbon feedbacks for different substances. Reference: *IPCC 2013 supplementary material chap. 8 tab 8SM15* https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/supplementary/WG1AR5_Ch08SM_FINAL.pdf	Global Warming Potential 100 years
Ozone depletion	Steady-state ODPs Reference: *Scientific Assessment of Ozone Depletion: 2014. Global Ozone Research and Monitoring Project - Report No. 55,* ISBN 92-807-1722-7, Geneva.	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years
Human toxicity, cancer	USEtox model based on USEtox 2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018 Reference: Saouter, El, Biganzoli, F., Ceriani, L., Versteeg, D., Crenna, E., Zampori, L., Sala, S., Pant, R. *Environmental Footprint: Update of the Life cycle Impact Assessment Methods – Ecotoxicity freshwater, human toxicity cancer, and non-cancer.* EUR 29495 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-98182-1, doi: 10.2760/178544, EC-JRC114227	Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).
Human toxicity, non-cancer	USEtox model based on USEtox 2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018 Reference: Saouter, El, Biganzoli, F., Ceriani, L., Versteeg, D., Crenna, E., Zampori, L., Sala, S., Pant, R. *Environmental Footprint: Update of the Life cycle Impact Assessment Methods – Ecotoxicity freshwater, human toxicity cancer, and non-cancer.* EUR 29495 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-98182-1, doi: 10.2760/178544, EC-JRC114227.	Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogram).
Respiratory inorganics	PM method recommendaed by UNEP Reference: Fantke, P., Evans, J., Hodas, N., Apte, J., Jantunen, M., Jolliet, O., McKone, T.E. (2016). *Health impacts of fine particulate matter. In: Frischknecht, R., Jolliet, O. (Eds.), Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative, Paris, pp. 76-99*	Disease incidence

Ionising radiation, human health	**Human health effect model as developed by Dreicer et al. 1995** **Reference: Frischknecht, R., Braunschweig, A., Hofstetter P., Suter P. (2000), *Modelling human health effects of radioactive releases in Life Cycle Impact Assessment. Environmental Impact Assessment Review, Volume 20, Number 2, April 2000, pp. 159-189***	**Ionizing Radiation Potentials: Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235**
Photochemical ozone formation, human health	**LOTOS-EUROS model** **Reference: Van Zelm, R., Huijbregts, M.A.J., Den Hollander, H.A., Van Jaarsveld, H.A., Sauter, F.J., Struijs, J., Van Wijnen, H.J., Van de Meent, D. (2008). *European characterization factors for human health damage of PM10 and ozone in life cycle impact assessment.* Atmospheric Environment 42, 441-453**	**Photochemical ozone creation potential (POCP): Expression of the potential contribution to photochemical ozone formation**
Acidification	**Accumulated Exceedance** **References:** **Seppälä, J., M. Posch, M. Johansson and J. P. Hettelingh (2006). *Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator*. International Journal of Life Cycle Assessment 11(6): 403-416** **Posch, M., J. Seppälä, J. P. Hettelingh, M. Johansson, M. Margni and O. Jolliet (2008). *The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterization factors for acidifying and eutrophying emissions in LCIA.* International Journal of Life Cycle Assessment 13(6): 477-486**	**Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit.**
Terrestrial eutrophication	**Accumulated Exceedance** **References:** **Seppälä, J., M. Posch, M. Johansson and J. P. Hettelingh (2006). *Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator*. International Journal of Life Cycle Assessment 11(6): 403-416** **Posch, M., J. Seppälä, J. P. Hettelingh, M. Johansson, M. Margni and O. Jolliet (2008). *The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterization factors for acidifying and eutrophying emissions in LCIA*. International Journal of Life Cycle Assessment 13(6): 477-486**	**Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which eutrophying substances deposit**
Freshwater eutrophication	**EUTREND model** **Reference: Struijs, J., Beusen, A., van Jaarsveld, H. and Huijbregts, M.A.J. (2008b). Aquatic**	**Phosphorus equivalents: Expression of the degree to which the emitted**

	Eutrophication. Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (2008). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition. Chapter in anthology Chapter on aquatic eutrophication in the ReCiPe report (report I: characterization factors, 2008).*	nutrients reaches the freshwater end compartment (phosphorus considered as limiting factor in freshwater).
Marine eutrophication	EUTREND model Reference: Struijs, J., Beusen, A., van Jaarsveld, H. and Huijbregts, M.A.J. (2008b). Aquatic Eutrophication. Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (2008). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition. In press. Chapter in anthology Chapter on aquatic eutrophication in the ReCiPe report (report I: characterization factors, 2008)*	Nitrogen equivalents: Expression of the degree to which the emitted nutrients reaches the marine end compartment (nitrogen considered as limiting factor in marine water)
Land use	CFs set re-calculated by JRC starting from LANCA® v 2.5 as baseline model. Reference: De Laurentiis V, Secchi M, Bos U, Horn R, Laurent A, Sala S (2019). *Soil quality index: exploring options for a comprehensive assessment of land use impacts in LCA*. J Clean Prod, 215, 63-74	Soil quality index
Freshwater ecotoxicity	USEtox model based on USEtox 2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018 Reference: Saouter, El, Biganzoli, F., Ceriani, L., Versteeg, D., Crenna, E., Zampori, L., Sala, S., Pant, R. *Environmental Footprint: Update of the Life cycle Impact Assessment Methods – Ecotoxicity freshwater, human toxicity cancer, and non-cancer.* EUR 29495 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-98182-1, doi: 10.2760/178544, EC-JRC114227	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg)
Water use	Available WAter REmaining (AWARE) as recommended by UNEP Boulay A.M., Bare J., Benini L., Berger M., Lathuillière M.J., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A.V., Ridoutt B., Oki T., Worbe S., Pfister S. (2016). *The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE)*	m^3 water eq. deprived
Resource depletion, fossils	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). van Oers, L, Koning, A, Guinée, JB, Huppes, G (2002) *Abiotic resource depletion in LCA.* Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam	Abiotic resource depletion fossil fuels (ADP-fossil); based on lower heating value

	http://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf	
Resource depletion, minerals and metals	**ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016).** **van Oers, L, Koning, A, Guinée, JB, Huppes, G (2002) *Abiotic resource depletion in LCA.* Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam** **http://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf**	**Abiotic resource depletion (ADP ultimate reserve)**

3.4.2 Normalization and Weighting

Global normalization set for a reference year 2010 is part of the EF method 3.0. Methodological details are available in Crenna et al. (2019).

The EF 3.0 method includes, compared to the EF 2.0 method, only one version of the weighting factors. The weighting step of the EF 3.0 method always includes the three toxicity-related impact categories that could be excluded when using the EF 2.0 method.

After an evaluation of existing weighting methods, three weighting sets were developed: i) panel based approach - general public survey; ii) panel based approach - LCA experts' survey; iii) hybrid evidence-and judgement-based approach. Those three weighting sets were then aggregated by first averaging the sets based on panel based approach.

References

Crenna, E., Secchi, M., Benini, L., Sala, S. *Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA.* The International Journal of Life Cycle Assessment 24, 1851-1877 (2019).

Fazio, S. Castellani, V. Sala, S., Schau, EM. Secchi, M. Zampori, L., *Supporting information to the characterization factors of recommended EF Life Cycle Impact Assessment methods*, EUR 28888 EN, European Commission, Ispra, 2018, ISBN 978-92-79-76742-5, doi:10.2760/671368, JRC109369.

Normalization and weighting factors: *Annex A of the Product Environmental Footprint Category Rules Guidance v6.3*, May 2018. http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf.

Sala S., Cerutti A.K., Pant R., *Development of a weighting approach for the Environmental Footprint*, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-68042-7, EUR 28562, doi 10.2760/945290.

3.5

3.5 EN 15804 + A2 method

The EN 15804 standard covers Environmental Product Declarations (EPDs) of Construction Products. The 2019 A2 revision of this standard has aligned their methodology with the EF 3.0 method, except for their approach on biogenic carbon. According to the EN 15804, biogenic carbon emissions cause the same amount of Climate Change as fossil carbon, but can be neutralized by removing this carbon from the atmosphere. Temporary and permanent carbon storage is not allowed therefore the 15804 standard provides a set of requirement to prevent its accounting.

Thus, this method is identical to the EF 3.0 method above, except for a few characterization factors (CF) in both the Climate Change and Climate Change – Biogenic impact categories.

Table 2. Differences between EN 15804 + A2 method compared to the EF 3.0 Method (adapted)

Substance	Compartment	CF EN 15804 +A2	CF EF 3.0
carbon dioxide (biogenic)	**Emission**	**1**	**0**
carbon monoxide (biogenic)	**Emission**	**1.57**	**0**
methane (biogenic)	**Emission**	**36.75**	**34**

carbon dioxide (biogenic)	**Resource**	**-1**	**0**

References

European Commission – Joint Research Centre (2021). EN 15804 reference package. https://eplca.jrc.ec.europa.eu/LCDN/EN15804.xhtml

3.6 EPD (2018)

This method is the successor of EPD (2013) and is to be used for the creation of Environmental Product Declarations (EPDs), as published on the website of the Swedish Environmental Management Council (SEMC). An EPD is always created according to a Product Category Rule. This method is especially important for everybody who is reporting a Product Category Rule (PCR) published by Environdec.

3.6.1 Characterization

In the standard EPDs one only has to report on the following impact categories:

Original names	**Names in SimaPro**
Acidification potential	Acidification (fate not incl.)
Eutrophication potential	Eutrophication
Global warming potential	Global warming (GWP100a)
Photochemical oxidant creation potential	Photochemical oxidation
Abiotic depletion potential - elements	Abiotic depletion, elements
Abiotic depletion potential - fossil fuels	Abiotic depletion, fossil fuels
Water Scarcity Footprint (WSF)	Water scarcity

Additional indicators:

The following impact categories are optional indicators and the inclusion of them should be specified in the PCR.

Original names	**Names in SimaPro**
Ozone-depleting gases (expressed as the sum of ozone-depleting potential in mass of CFC 11-equivalents, 20 years)	Ozone layer depletion (ODP) (optional)

Most impact categories are taken directly from the CML-IA baseline method (eutrophication, global warming, ozone depletion and abiotic resource depletion) and CML-IA non baseline method (acidification). Water scarcity category is based on AWARE method and Photochemical oxidation is based on ReCiPe 2008. All those individual methods can be found in SimaPro.

Normalization and weighting are not a part of this method.

References

General programme instructions for the international EPD® system, 3.0. 11 December 2017. http://www.environdec.com/Documents/GPI/General_programme_instructions_2_01_20130918.pdf.

3.7 EPS 2015d and EPS 2015dx

EPS 2015 default methodology (Environmental Priority Strategies in product design) is a damage oriented method, the successor of EPS 2000. In the EPS system, willingness to pay to restore changes in the safe guard subjects is chosen as the monetary measurement. The indicator unit is ELU (Environmental Load Unit), which includes characterization, normalization and weighting.

The method is available in two versions:

- EPS 2015d - including climate impacts from secondary particles,
- EPS 2015dx - excluding climate impacts from secondary particles.

The reason for developing two versions is the uncertain but important valuations of near-term climate forcers (NTCF) such as Nitrogen oxides (NOx) and Sulphur dioxide (SO2) emissions. Based on the recommendation from UNEP-SETAC Life Cycle Initiative, method developer suggests that the version including the secondary impacts (2015d) is used with care (e.g. in sensitivity analysis) and by LCA practitioners and experts understanding the underlying concept. For more details explanation, you can check the website dedicated to EPS system: http://www.ivl.se/eps

The top-down development of the EPS system has led to an outspoken hierarchy among its principles and rules. The general principles remain unchanged since previous version:

- The top-down principle (highest priority is given to the usefulness of the system);
- The index principle (ready-made indices represent weighted and aggregated impacts);
- The default principle (an operative method as default is required);
- The uncertainty principle (uncertainty of input data has to be estimated);
- Choice of default data and models to determine them.

The EPS system is mainly aimed to be a tool for a company's internal product development process. The system is developed to assist designers and product developers in finding which one of two product concepts has the least impact on the environment. The models and data in EPS are intended to improve environmental performance of products. The choice and design of the models and data are made from an anticipated utility perspective of a product developer. They are, for instance not intended to be used as a basis for environmental protection strategies for single substances, or as a sole basis for environmental product declarations. In most of those cases additional site-specific information and modelling is necessary.

Implementation of EPS 2015 in SimaPro required few adaptations:

- Some state indicators were not implemented, either because they do not correspond with the flows used in the inventory (Land use), or the inventory does not cover flows used in the method (Noise and Waste). Also, none of the state indicators under social safe guard subject is included (as they are quantitative, not monetary valued) and only one state indicator from economical safe guard subject is included - housing availability.
- Approx. 50 substances from the EPS spreadsheet were not implemented as they were not available in SimaPro;
- Depletion of abiotic resources includes all the elements covered by the method. Originally, each element has a separate state indicator.

3.7.1 Classification and characterization

Emissions and resources are assigned to impact categories when actual effects are likely to occur in the environment, based on likely exposure. Empirical, equivalency and mechanistic models are used to calculate default characterization values.

Ecosystem services

Weighting factors for damage to ecosystem are included for the following indictors, all expressed in kg:

- Crop growth capacity,
- Production capacity of fruits and vegetables,
- Wood growth capacity,
- Fish and meat production capacity.

Access to water

Weighting factors for damage to water access are included for the following indictors, all expressed in kg:

- Drinking water,
- Irrigation water.

Biodiversity

Default impact category for biodiversity is extinction of species, expressed in Normalized Extinction of species (NEX).

Building technology

Default impact category for building technology is housing availability, expressed in square meters.

Human health

Weighting factors for damage to human health are included for the following indictors, all expressed in personyears:

- Life expectancy (YOLL - years of life lost),
- Malnutrition,
- Diarrhea,
- Gravation of angina pectoris,
- Working capacity,
- Asthma cases,
- COPD severe,
- Cancer,
- Skin cancer,
- Low vision,
- Poisoning,
- Intellectual disability: mild.

Abiotic resources

Default impact category for abiotic resources is depletion of abiotic resources, expressed in kg of element. In SimaPro, characterization values for abiotic depletion result from both the impact of depletion and impacts due to extraction of the element/mineral or resource.

3.7.2 Normalization/weighting

In the EPS default method, normalization/weighting is made through valuation. Normalization/weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

References

Steen B. 2015. *The EPS 2015 impact assessment method – An overview*. Swedish Life Cycle Center, Report number 2015:5.

Steen B. 1999. *A systematic approach to environmental strategies in product development (EPS). Version 2000 - General system characteristics*. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:4.

4 Global

4.1 IMPACT World+

IMPACT World+, is the update of the IMPACT 2002+, LUCAS, and EDIP methods. The method has global scope and is available both as midpoint and endpoint (damage level). Most of the regional impact categories are spatially resolved and all the long-term impact categories are subdivided between shorter-term damages (over the 100 years after the emission) and long-term damages.

The implementation in SimaPro is based on version 1.29 (midpoint) and 1.47 (endpoint) of the original method and it includes:

- Only recommended (not interim) indicators,
- Partial regionalization - any regionalized flows, which would be new to SimaPro, were not included in this implementation. This is because they are not used in the inventories and would give false impression of contributing to the results. For fully regionalized version of the method, please use SimaPro Flow,
- Damage on areas of protection (human health and ecosystems quality), not areas of concern (water and carbon).

The relationship between midpoint and endpoint indicators and areas of protection is presented in Figure 1.

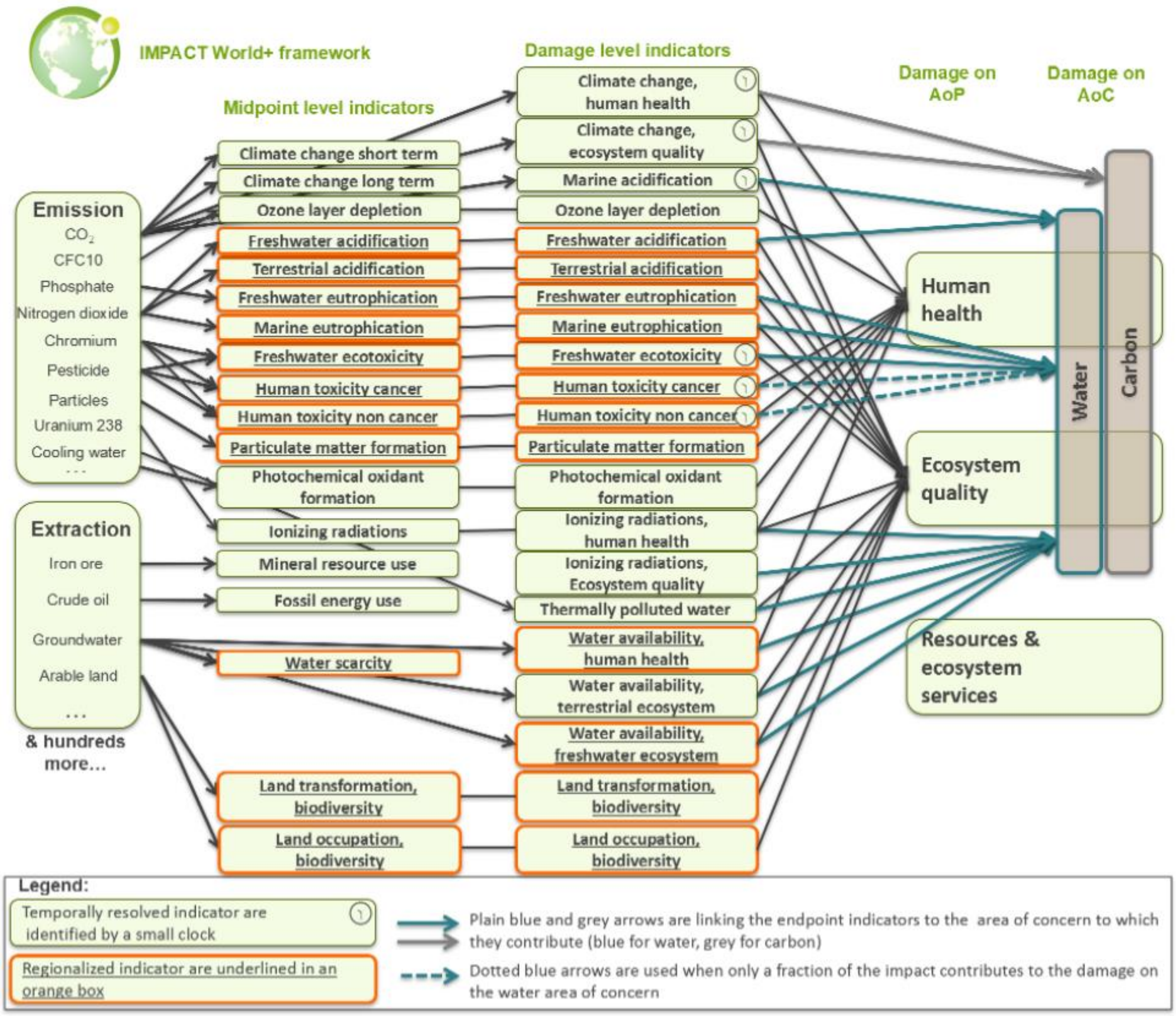

Figure 1. Representation of the relations between the impact categories midpoint and the areas of production (endpoint) in ReCiPe 2016 (retrieved from http://www.impactworldplus.org/)

4.1.1 Characterization at midpoint level

Climate change short- and long-term

Global Warming Potential (GWP100) and Global Temperature Potentials (GTP100) are used for, respectively, climate change short- and long-term impacts. Those two indicators are needed because they express different impacts: GTP100 (climate change long-term) are impacts related to long-term cumulative warming (e.g. sea level rise), while GWP100 (climate change shorter-term) are impacts related to a rapid increase in temperature to which humans and species must adapt very quickly.

Fossil and nuclear energy use

For fossil energy use impact, IMPACT World+ uses the primary energy content (Frischknecht 2003) as a midpoint indicator considering that it is a reasonable proxy to assess the MJ deprived per MJ consumed, under the assumption that fossil resources are mainly functional for energy purposes.

Mineral resources use

The material competition scarcity index from de Bruille (2014) is applied as a midpoint indicator for mineral resources use,

Photochemical oxidant formation, ionizing radiation and ozone layer depletion

Photochemical oxidant formation, ionizing radiation and ozone layer depletion are based on ILCD handbook recommendations (European Commission 2011). Model calculations were updated to account for the most up-to-date World Meteorological Organization (WMO, 2014) values of ozone depletion potential,

Ecotoxicity and human toxicity

Ecotoxicity and human toxicity impact is based on the parameterized version of USEtox 2.0 for continents. The developers considered indoor emissions and differentiated between shorter-term impacts taking place over the first 100 years and long-term impacts from 100 years to infinity, of which the latter are only substantial for very persistent substances, such as metals.

Terrestrial and freshwater acidification

Terrestrial and freshwater acidification impact assessment is based on Roy et al. (Roy et al. 2014; Roy et al. 2012a; Roy 24 et al. 2012b) and combines, at a resolution of 2°x 2.5° (latitude x longitude), global atmospheric source-deposition relationships with soil and water ecosystems sensitivity, The midpoint characterization factors express the change in pH in receiving environments (soil and freshwater, respectively) due to an emission of nitrogen oxides (NOx), ammonia (NH3) and sulphur dioxide (SO2).

Marine acidification

Marine acidification impact is based on the same fate model as climate change, combined with the H+ concentration affecting 50% of the exposed species,

Freshwater eutrophication

Freshwater eutrophication impact is spatially assessed at a resolution grid of 0.5°x0.5°, based on a model from Helmes et al. (2012), This fate factor expresses the increase in phosphorus mass per kg P discharged to freshwater and is used as the midpoint CF for freshwater eutrophication.

Marine eutrophication

The same atmospheric fate model as used by Roy et al. (2012b) for acidification (GEOS Chem) is used to determine the source-to-deposition relationship of Ammonia (NH3) and (NOx) atmospheric emissions on coastal zones.

Particulate matter formation

Impacts on human health related to particulate matter formation are modeled using the USEtox regional archetypes to calculate intake fractions and epidemiologically derived exposure response factors,

Land occupation and transformation

Impacts from land occupation and transformation on biodiversity are based on de Baan et al. (2013), which provides local empirical characterization factors at the biome level.

Water scarcity

IMPACT World+ uses the water scarcity AWARE model (Boulay et al. 2016) at the midpoint level as a proxy midpoint for all the water scarcity impacts.

4.1.2 Damage assessment

Recommended version of IMPACT World+ includes two damage categories: human health and ecosystem quality. Resources & ecosystem services are not included in SimaPro implementation, as the developers consider that category interim.

4.1.3 Normalization

IMPACT World+ only provides normalization factors at damage level, as the developers consider a midpoint-damage modelling based on natural science a more robust approach to put in perspective the relative importance of the different midpoint indicators affecting the same areas of protection than any normalization/weighting scheme.

The overall global inventory, which was used to determine normalization factors, is characterized by a mix of reference years within the period 2000 and 2010.

4.1.4 Weighting

IMPACT World+ does not provide recommended weighting factors. Nevertheless, LCA practitioners might apply public available weighting approaches, such as the STEPWISE 2006 factors proposed by Weidema et al. (2006) which are compatible with IMPACT World+ and can optionally be used to obtain a single monetized score.

References

Bulle, C., Margni, M., Patouillard, L. et al. IMPACT World+: a globally regionalized life cycle impact assessment method. Int J Life Cycle Assess 24, 1653–1674 (2019). https://doi.org/10.1007/s11367-019-01583-0

4.2 LC-IMPACT

Multi-impact category method LC-IMPACT results from the outcomes of the FP7-funded project LC-IMPACT. At the end of the EU FP7 project, a number of project partners collaborated to combine the methodological developments from the project into a complete, consistent and applicable impact assessment method. The method provides a **global** life cycle impact assessment methodology at **endpoint (damage) level**. It thereby addresses the three main areas of protection (human health, ecosystem quality and resources), and includes spatially differentiated information wherever necessary and feasible.

The LC-IMPACT methodology aims to provide a "living" life cycle impact assessment methodology, which aims to be regularly updated to include the most important developments in LCIA.

The implementation in SimaPro is based on LC-IMPACT version 1.0, retrieved from the LC-IMPACT website (https://lc-impact.eu/, visited 31 August, 2021). Full documentation of the method can be found on this website and in the scientific publication by Verones et al., 2020.

Most impact categories are spatially resolved. Partial regionalization, i.e. only the most essential regionalized flows, was included in this implementation. This is because flows other than water flows are not used in the background library inventories. Additionally, the fully regionalized version of this method will soon become available in the online SimaPro Platform.

Novelties of LC-IMPACT include:

- Spatial resolution of characterization factors according to the nature of impact as well as spatially aggregated characterization factors on country and global level, to facilitate coupling with life cycle inventory.
- A new approach for assessing impacts to ecosystems, assessing global extinctions. This approach is more relevant and consistent than previous approaches, which mixed scales of extinctions.
- Explicit documentation of type of approach (marginal and/or average, see below).
- Explicit documentation of value choices (time horizon, and level of reliability, see below).
- Quantitative uncertainty assessments for selected impact categories and qualitative discussion of uncertainties for all impact categories.

4.2.1 Characterization at endpoint level

This method only has characterization at endpoint level. It includes damage to three areas of protection:

- Human health, expressed in DALY (Disability Adjusted Life Years)
- Ecosystem quality, distinguishing terrestrial, freshwater and marine ecosystems, and expressed in
    - o PDF·m^3·d (Potentially Disappeared Fraction of species in a cubic meter during one day) for all ecotoxicity impacts,
    - o PDF·year (Potentially Disappeared Fraction of species during one year) for all other impacts on ecosystems.
- Mineral scarcity, expressed in potential kg ore surplus

4.2.2 Approach and value choices

The LC-IMPACT model provides **different types of characterization factors**, which results in eight methods in SimaPro to cover for all combinations of the choices below:

- Average or marginal modelling
- Only certain impact or all impacts
- 100 years time horizon or infinite time horizon

Average or marginal modelling

In a marginal approach, the influence of raising the background concentration/pressure by an incremental amount is investigated. This means that the reference state is today's situation or the current background concentration and the additional impact of a marginal change is quantified.

By contrast, in the case of average modeling, rather than taking the derivative of the curve at the point of current level of impact, the average effect change per unit of change is used. The reference state is the current situation, relating the change either to a zero effect, a preferred state (e.g. environmental targets) or a prospective future state. **In SimaPro, only the average versions are made available.** See below the availability of the modelling approaches for each impact category, as provided by the method developers.

Only certain impact or all impacts

In LC-IMPACT, a distinction was made between certain and all impacts characterization factors, reflecting the level of reliability of the calculations in a qualitative way. All effects include certain and uncertain effects. The LC-IMPACT team advises to **use the certain impact characterization factors always alongside characterization factors for all impacts**. The 'all impacts' characterization factors can for example be used as a sensitivity analysis to see how the results, and possibly the conclusions, change.

100 years time horizon or infinite time horizon

100 years refers to the 100 year time horizon used for calculating the characterization factors, which is distinct from the long-term or infinite horizon. Not all alternative types are available for each impact category (see below).

Table 3. Value choices of impact categories contributing to Human health

Impact category	Average/marginal	Certain/all	100 years/infinite
Climate change	**No differentiation**	**Both available**	**Both available**
Stratospheric ozone depletion	**Only average**	**Both available**	**Both available**
Ionizing radiation	**Only average**	**Both available**	**Both available**
Photochemical ozone formation	**Only average**	**No differentiation**	**No differentiation**
Particular matter formation	**Only average**	**No**	**Both available[1]**

[1] 100 years and infinite only differentiated for particulates, not for secondary emissions.

		differentiation	
Human toxicity (carcinogenic)	Only average	Both available	Both available
Human toxicity (non-carcinogenic)	Only average	Both available	Both available
Water stress (human health)	Both available	Both available	No differentiation

Table 4. Value choices of impact categories contributing to Ecosystems (terrestrial and aquatic)

Impact category	Average/marginal	Certain/all	100 years/infinite
Climate change	**No differentiation**	**Both available**	**Both available**
Photochemical ozone formation	**Only average**	**No differentiation**	**No differentiation**
Terrestrial acidification	**Only Marginal**	**No differentiation**	**No differentiation**
Freshwater eutrophication	**Only average**	**No differentiation**	**No differentiation**
Marine eutrophication	**Only average**	**No differentiation**	**No differentiation**
Land stress	**Both available**	**Both available**	**Both available**
Water stress (ecosystems)	**Only Marginal**	**Both available**	**No differentiation**

Table 5. Value choices of impact categories contributing to Ecotoxicity (terrestrial and aquatic)

Impact category	Average/marginal	Certain/all	100 years/infinite
Freshwater ecotoxicity	**Only average**	**No differentiation**	**Both available**
Marine ecotoxicity	**Only average**	**No differentiation**	**Both available**
Terrestrial ecotoxicity	**Only average**	**No differentiation**	**Both available**

Table 6. Value choices of impact categories contributing to Mineral scarcity

Impact category	Average/marginal	Certain/all	100 years/infinite
Mineral resources extraction	**Only average**	**Both available**	**No differentiation**

References

Verones, F., Huijbregts, M.A.J., Azevedo, L.B., Chaudhary, A., Cosme, N., de Baan, L., Fantke, P., Hauschild, Henderson, A.D., M., Jolliet, O., Mutel, C.L., Owsianiak, M., Pfister, S., Preiss, P., Roy, P.-O., Scherer, L., Steinmann, Z., van Zelm, R., Van Dingenen, R., Vieira, M., van Goethem, T., Hellweg, S. (2020). LC-IMPACT Version 1.0. A spatially differentiated life cycle impact assessment approach. https://lc-impact.eu/

Verones, F., Hellweg, S., Antón, A., Azevedo, L.B., Chaudhary, A., Cosme, N., Cucurachi, S., de Baan, L., Dong, Y., Fantke, P., Golsteijn, L., Hauschild, M., Heijungs, R., Jolliet, O., Juraske, R., Larsen, H., Laurent, A., Mutel, C.L., Margni, M., Núñez, M., Owsianiak, M., Pfister, S., Ponsioen, T., Preiss, P., Rosenbaum, R.K., Roy, P.-O., Sala, S., Steinmann, Z., van Zelm, R., Van Dingenen, R., Vieira, M., Huijbregts, M.A.J. (2020). LC-IMPACT: A regionalized life cycle damage assessment method. Journal of Industrial Ecology, 24(6), 1201-1219.

4.3 ReCiPe 2016

ReCiPe 2016 is an updated and extended version of ReCiPe 2008. Like the predecessor, ReCiPe 2016 includes both midpoint (problem oriented) and endpoint (damage oriented) impact categories, available for three different perspectives (individualist (I), hierarchist (H), and egalitarian (E)). The characterization factors are representative for the global scale, instead of the European scale as it was done in ReCiPe 2008. Because of that the method was moved from the European category to Global.

ReCiPe comprises two sets of impact categories with associated sets of characterization factors. At the midpoint level, 18 impact categories are addressed:

1. Climate change
2. Stratospheric ozone depletion
3. Ionizing radiation
4. Ozone formation, human health
5. Fine particulate matter formation
6. Ozone formation, terrestrial ecosystems
7. Terrestrial acidification
8. Freshwater eutrophication
9. Marine eutrophication
10. Terrestrial ecotoxicity
11. Freshwater ecotoxicity
12. Marine ecotoxicity
13. Human carcinogenic toxicity
14. Human non-carcinogenic toxicity
15. Land use
16. Mineral resource scarcity
17. Fossil resource scarcity
18. Water use

At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories:

- Human health
- Ecosystems
- Resource scarcity

The Figure 2 sketches the relations between the 18 midpoint impact categories and the 3 endpoint categories.

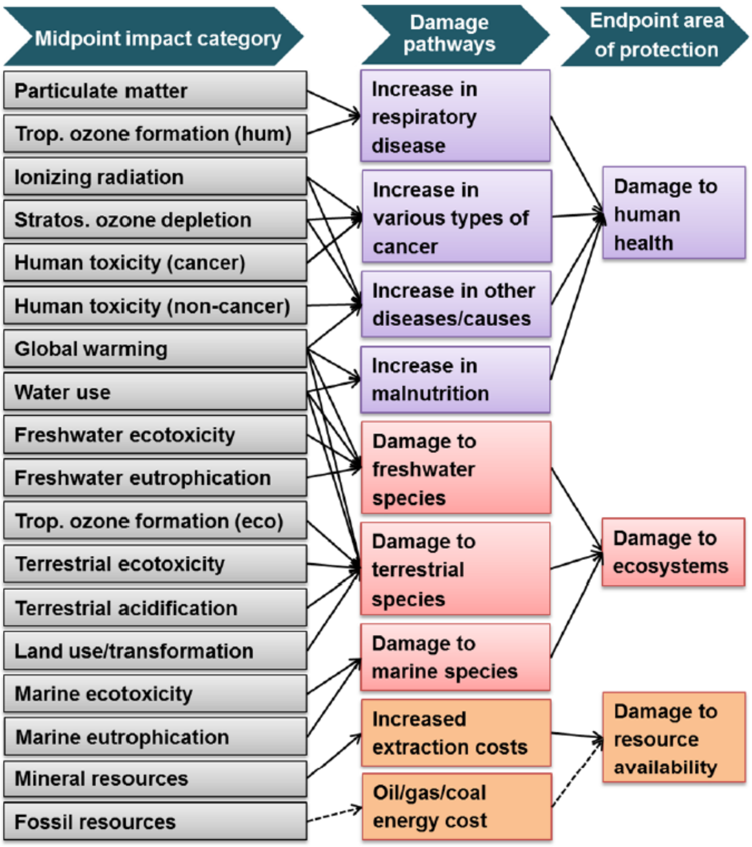

Figure 3: Representation of the relations between the impact categories midpoint and the areas of production (endpoint) in ReCiPe 2016 Source: Huijbregts MAJ et al.(2017) Department of Environmental Science, Radbound University Nijmegen.

4.3.1 Value choices

It is obvious that the environmental mechanisms and damage models are sources of uncertainty: the relationships modelled reflect state of the art knowledge of the environmental mechanisms that has a certain level of incompleteness and uncertainty. In ReCiPe 2016 it was decided to group different sources of uncertainty and different (value) choices into a limited number of perspectives or scenarios, according to the “Cultural Theory” by Thompson 1990. This is the same approach as in the first version of ReCiPe.

Three perspectives are discerned: individualist (I), hierarchist (H), and egalitarian (E). These perspectives do not claim to represent archetypes of human behavior, but they are merely used to group similar types of assumptions and choices. For instance:

1. Individualist perspective (I) is based on the short-term interest, impact types that are undisputed, technological optimism as regards human adaptation.
2. Hierarchist perspective (H) is based on the most common policy principles with regards to time-frame and other issues.

3. Egalitarian perspective (E) is the most precautionary perspective, taking into account the longest time-frame, impact types that are not yet fully established but for which some indication is available.

4.3.2 Characterization at midpoint level

Climate change

The characterization factor of climate change is the global warming potential, based on IPCC 2013 report. For the Individualist perspective 20 year time horizon was used, for Hierarchist 100 years and for Egalitarian 1000 years. Climate-carbon feedbacks are included for non-CO2 GHGs in the Hierarchist perspective. The unit is yr/kg CO2 equivalents.

Ozone depletion

The characterization factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). The unit is yr/kg CFC-11 equivalents

Ionizing radiation

The characterization factor of ionizing radiation accounts for the level of exposure for the global population. The unit is yr/kBq Cobalt-60 equivalents to air.

Fine particulate matter formation

The characterization factor of particulate matter formation is the intake fraction of PM2.5. The unit is yr/kg PM2.5 equivalents.

Photochemical ozone formation, terrestrial ecosystems

The characterization factor is determined from the change in intake rate of ozone due to change in emission of precursors (NOx and NMVOC). The unit of ecosystem ozone formation potential is yr/kg NOx equivalents.

Photochemical ozone formation, human health

The characterization factor is determined from the change in intake rate of ozone due to change in emission of precursors (NOx and NMVOC). The unit of human health ozone formation potential is yr/kg NOx equivalents.

Terrestrial acidification

The characterization factor for terrestrial acidification is Acidification Potential (AP) derived using the emission weighted world average fate factor of SO2. The unit is yr/kg SO2 equivalents.

Freshwater eutrophication

The characterization factor of freshwater eutrophication accounts for the environmental persistence (fate) of the emission of P containing nutrients. The unit is yr/kg P to freshwater equivalents.

Marine eutrophication

The characterization factor of marine eutrophication accounts for the environmental persistence (fate) of the emission of N containing nutrients. The unit is yr/kg N to marine equivalents.

Human toxicity and ecotoxicity

The characterization factor of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The unit is yr/kg 1,4-dichlorobenzeen (1,4-DCB) emitted.

Land use

The amount of land transformed or occupied for a certain time. The unit is m2*yr.

Water use

The factor for the water use is the amount of fresh water consumption. The unit is m3 water consumed. Current implementation includes regionalized characterization factors in the endpoint version of the method.

Mineral resource scarcity

The characterization factor for mineral resource scarcity is the surplus ore potential. The unit is kg Copper (Cu) equivalents.

Fossil resource scarcity

The characterization factor of fossil resource scarcity is the fossil fuel potential, based on the higher heating value. The unit is kg oil equivalents.

4.3.3 Damage assessment

The endpoint characterization factors used in ReCiPe can be described as follows:

1. Human Health, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and WHO. The unit is years.
2. Ecosystems, expressed as the loss of species over a certain area, during a certain time. The unit is years.
3. Resource scarcity, expressed as the surplus costs of future resource production over an infinitive timeframe (assuming constant annual production), considering a 3% discount rate. The unit is USD2013. Mind that fossil resource scarcity does not have constant mid-to-endpoint factor but individual factors for each substance.

4.3.4 Normalization

Global normalization factors for reference year 2010 are included since version 1.03 of ReCiPe 2016. However, the reference report has not been published yet and the global reference inventory is still to be implemented in SimaPro.

4.3.5 Weighting

Development of weighting factors was not part of ReCiPe 2016 project. Therefore, weighting sets from the previous version of ReCiPe are reused here. Those are based on panel weighting performed at damage category (endpoint) level. A specific weighting set is available for each perspective. Additionally, the average result of the panel assessment is available as weighting set.

The hierarchist version of ReCiPe with average weighting is chosen as default. In general, value choices made in the hierarchist version are scientifically and politically accepted.

4.3.6 Updates in ReCiPe 2016

Environmental mechanism	Update
Climate change	- The time horizon for the Egalitarian perspective was explicitly taken as 1,000 years, which is the longest time horizon reported for CO2 response functions in the literature. - A much larger set of greenhouse gas emissions (207 GHGs in total) is included on the basis of the latest IPCC report - Damage factors for human health and terrestrial ecosystems were updated - Damage to freshwater (river) ecosystems was now included
Stratospheric ozone depletion	- New semi-empirical ODPs were included with a more detailed specification between various chlorofluorocarbons (CFCs) - A preliminary ODP for N2O was included - Three time horizons were consistently implemented: 20 years (Individualist), 100 years (Hierarchist) and infinite (Egalitarian)
Ionizing radiation	- Three time horizons were consistently implemented: 20 years (Individualist), 100 years (Hierarchist) and 100,000 years (Egalitarian) - Dose and dose rate effectiveness factors (DDREFs) were specified per cultural perspective - Updated DALYs per fatal cancer incidence were applied.
Fine particulate matter formation	- The European factor was replaced by a world average factor - Lung cancer and cardiovascular mortality were included as critical effects - Value choices were added - World-region specific characterization factors were added (not implemented in SimaPro)
Photochemical ozone formation	- The European factor was replaced by a world average factor - Respiratory mortality was included - To derive characterization factors for individual VOCs, most recent photochemical ozone formation potentials (POCPs) reported in the literature were used - Damage to terrestrial ecosystems was included as well - World-region specific characterization factors were added (not implemented in SimaPro)
Terrestrial acidification	- The European factor was replaced by a world average factor, based on grid specific factors

	- Soil sensitivity was based on H+ concentration instead of base saturation - Effects of all vascular plant species included, not only forest species - Country-specific characterization factors were provided (not implemented in SimaPro)
Freshwater eutrophication	- Fate factors were derived with a state-of-the-art global fate model for phosphorus instead of a European fate model - Effect factors were updated based on a global analysis instead of using information from the Netherlands only - Country-specific characterization factors were provided as well (not implemented in SimaPro)
Marine eutrophication	- Fate factors were derived with a state-of-the-art global fate model for nitrogen, instead of a European fate model. - Endpoint characterization factors were included by determining effect and damage factors based on a global analysis. - Continent-specific characterization factors were provided as well.
Toxicity	- Characterization factors for human cancer and non-cancer effects were separately included. - Fate and exposure for dissociating organics was explicitly modelled. - The USEtox organic and inorganic database was implemented (3094 substances). - A time horizon of 20 years was included for the Individualist perspective. - Only linear effect factors were included for reasons of simplicity. - Effects on agricultural and urban soil were excluded to prevent double counting with the land use impact category.
Water use	- Consumption/extraction ratios were provided - Characterization factors on an endpoint level for human health, terrestrial and aquatic ecosystems were included - Country-specific characterization factors were provided (to be implemented in SimaPro)
Land use	- Characterization factors were based on global scale data, whereas the previous factors focused on Europe - The local impact of land use was covered only, as the modelling of regional impacts in the previous ReCiPe version was considered too uncertain to recommend
Mineral resource scarcity	- Cumulative grade-tonnage relationships and cumulative cost-tonnage relationships were used, based on mine-specific cost and production data - An estimation of future production was included in the modelling without future discounting
Fossil resource scarcity	- Cumulative cost-tonnage relationships were based on recent cost and future production data - An estimation of future production was included in the modelling without future discounting

References

Huijbregts MAJ, Steinmann ZJN, Elshout PMF, Stam G, Verones F, Vieira MDM, Van Zelm R, 2017. ReCiPe2016 v1.1. A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization. Department of Environmental Science, Radbound University Nijmegen. http://www.rivm.nl/en/Topics/L/Life_Cycle_Assessment_LCA/Downloads/Documents_ReCiPe2017/Report_ReCiPe_Update_2017

Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F. et al. Int J Life Cycle Assess (2017) 22: 138. doi:10.1007/s11367-016-1246-y https://link.springer.com/article/10.1007/s11367-016-1246-y

5 North American

5.1 BEES

BEES is the acronym for Building for Environmental and Economic Sustainability, a software tool developed by the National Institute of Standards and Technology (NIST). BEES combines a partial life cycle assessment and life cycle cost for building and construction materials into one tool. Results are presented in terms of life cycle assessment impacts, costs, or a combination of both as it can be seen in Figure 3. BEES strives to assist the architect, engineer, or purchaser choose a product that balances environmental and economic performance, thus finding cost-effective solutions for protecting the environment.

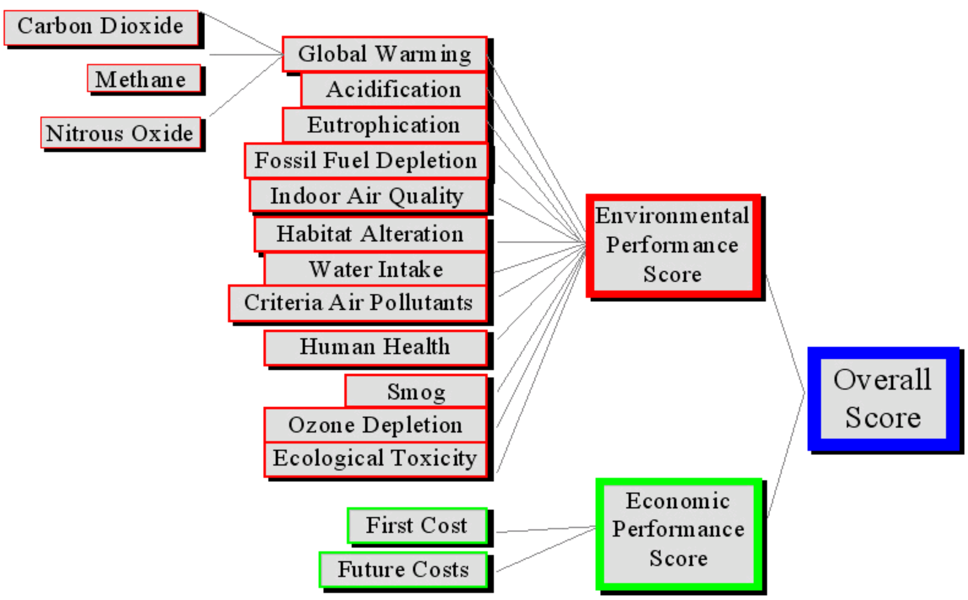

Figure 4: Structure of the BEES 4.0 methodology

5.1.1 Characterization

BEES uses the SETAC method of classification and characterization. The following six life cycle assessment impact categories are used by BEES:

1. global warming potential
2. acidification
3. eutrophication potential
4. natural resource depletion
5. solid waste
6. indoor air quality

Smog Characterization factors for two substances from equiv12.xls, biphenyl and diphenyl (both to air) have been averaged and assigned to biphenyl (air). Smog Characterization factors for

Butane (C4H10) and Butane-n (n-C4H10) (both to air) have been averaged and assigned to Butane (air).

5.1.2 Normalization and weighting

Normalization is implemented as described in the report (Lippiatt, 2007) and weighting as described in Gloria et al. (2007).

References

Gloria, T.P.; Lippiatt, B.C.; Cooper, J. 2007. Life Cycle Impact Assessment Weights to Support Environmentally Preferable Purchasing in the United States. Environ Sci Technol 41 (21): 7551-7557.

Lippiatt, B.C. 2007. BEES 4.0: Building for Environmental and Economic Sustainability. Technical Manual and User Guide. NISTIR 7423. National Institute of Standards and Technology.

5.2 TRACI 2.1

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), a stand-alone computer program developed by the U.S. Environmental Protection Agency specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined.

TRACI facilitates the characterization of environmental stressors that have potential effects, including ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human health criteria–related effects, human health cancer effects, human health non-cancer effects, fossil fuel depletion, and land-use effects. TRACI was originally designed for use with life-cycle assessment (LCA), but it is expected to find wider application in the future.

TRACI is a midpoint oriented life cycle impact assessment methodology, consistently with EPA's decision not to aggregate between environmental impact categories. It includes classification, characterization and normalization.

5.2.1 Characterization

Impact categories were characterized at the midpoint level for reasons including a higher level of societal consensus concerning the certainties of modelling at this point in the cause-effect chain. Research in the impact categories was conducted to construct methodologies for representing potential effects in the United States.

TRACI is a midpoint oriented LCIA method including the following impact categories:

- Ozone depletion
- Global warming
- Smog

- Acidification
- Eutrophication
- Carcinogenics
- Non carcinogenics
- Respiratory effects
- Ecotoxicity
- Fossil fuel depletion

5.2.2 Normalization

Ryberg et al (2014) calculated normalization factors for the US and US + Canada. Data from 2008 and 2005 combined with 2008 was used for these reference geographies, respectively.

References

Bare, J.; Gloria, T.; Norris, G. 2006. Development of the Method and U.S. Normalization Database for Life Cycle Impact Assessment and Sustainability Metrics. Environ Sci Techol 40 (16): 5108-5115.

Bare, J.C.; Norris, G.A.; Pennington, D.W.; McKone, T. 2003. TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology. http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Ryberg, M.; Vieira, M.D.M.; Zgola, M.; Bare, J.; Rosenbaum, R.K. 2014. Updated US and Canadian normalization factors for TRACI 2.1. Clean Technologies and Environmental Policy 16: 329-339.

6 Single issue

6.1 Cumulative Energy Demand

The method to calculate Cumulative Energy Demand (CED) is based on the method published by Ecoinvent version 1.01 and expanded by PRé for energy resources available in the SimaPro database. Extra substances, according to the Ecoinvent database version 2.0, are implemented. This default version of CED is based on the fuels' higher heating values.

6.1.1 Characterization

Characterization factors are given for the energy resources divided in 5 impact categories:

1. Non renewable, fossil
2. Non renewable, nuclear
3. Renewable, biomass
4. Renewable, wind, solar, geothermal
5. Renewable, water

Normalization is not a part of this method. In order to get a total ("cumulative") energy demand, each impact category is given the weighting factor 1.

References

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

6.2 Cumulative Energy Demand (LHV)

This method is a variation of Cumulative Energy Demand, based on fuels' lower heating values (LHV). Cumulative Energy Demand (CED) is calculated from data published by Ecoinvent and expanded by PRé for energy resources available in the SimaPro database.

Ratio between lower and higher heating value for each fuel type was derived from Table 5.1 of Overview and methodology - Data quality guideline for the ecoinvent database version 3. It was then used to convert the higher heating values from the default Cumulative Energy Demand method into lower heating values. For peat this ratio was not available in the Data quality guideline, therefore we assume a slightly lower ratio than what was calculated for lignite (0.85).

6.2.1 Characterization

Characterization factors are given for the energy resources divided in 5 impact categories:

1. Non renewable, fossil

2. Non renewable, nuclear
3. Renewable, biomass
4. Renewable, wind, solar, geothermal
5. Renewable, water

Normalization is not a part of this method. In order to get a total ("cumulative") energy demand, each impact category is given the weighting factor 1.

References

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G. (2013). Overview and methodology.

Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1 (v3). St. Gallen: The ecoinvent Centre.

6.3 Cumulative Exergy Demand

The indicator Cumulative Exergy Demand (CExD) is introduced to depict total exergy removal from nature to provide a product, summing up the exergy of all resources required. CExD assesses the quality of energy demand and includes the exergy of energy carriers as well as of non-energetic materials. The exergy concept was applied to the resources contained in the ecoinvent database, considering chemical, kinetic, hydro-potential, nuclear, solar-radiative and thermal exergies. Details on the CExD method may be found in Bösch et al. (2007).

In order to quantify the life cycle exergy demand of a product, the indicator Cumulative Exergy Demand (CExD) is defined as the sum of exergy of all resources required to provide a process or product.

Exergy is another way to express quality of energy rather than energy content. Both are expressed in MJ. Exergy is a measure for the useful "work" a certain energy carrier can offer. For instance, natural gas has a high exergy value, as it can be used to create high temperatures and high pressured steam. If natural gas is used to heat a house in a highly efficient boiler, very little energy content is lost, but the exergy content is almost entirely lost (there is very little one can do with water between 50 and 80 degrees).

In this method exergy is used as a measure of the potential loss of "useful" energy resources.

This method has been directly taken from Ecoinvent 2.0. The amount of substances present is compatible with the EI 2.0 database and extended for other databases.

6.3.1 Characterization

The impact category indicator is grouped into the eight resource categories fossil, nuclear, hydropower, biomass, other renewables, water, minerals, and metals. However, in SimaPro, 10 different impact categories are presented:

- Non renewable, fossil
- Non renewable, nuclear
- Renewable, kinetic
- Renewable, solar
- Renewable, potential
- Non renewable, primary
- Renewable, biomass
- Renewable, water
- Non renewable, metals
- Non renewable, minerals

Exergy characterization factors for 112 different resources were included in the calculations.

$$CExD = \sum_i m_i * Ex_{(ch),i} + \sum_j n_j * r_{ex-e(k,p,n,r,t),j}$$

$CExD$	= cumulative exergy demand per unit of product or process (MJ-eq)
m_i	= mass of material resource i (kg)
$Ex_{(ch),i}$	= exergy per kg of substance i (MJ-eq/kg)
n_j	= amount of energy from energy carrier j (MJ)
$r_{ex-e(k,p,n,r,t),i}$	= exergy to energy ratio of energy carrier j (MJ-eq/MJ)
ch	= chemical
k	= kinetic
p	= potential
n	= nuclear
r	= radiative
t	= thermal exergy

The assignment of the adequate type of exergy depends on resource use:

- Chemical exergy is applied on all material resources, for biomass, water and fossil fuels (i.e. all materials that are not reference species in the reference state)
- Thermal exergy is applied for geothermy, where heat is withdrawn without matter extraction
- Kinetic exergy is applied on the kinetic energy in wind used to drive a wind generator
- Potential exergy is applied on potential energy in water used to run a hydroelectric plant

- Nuclear exergy is applied on nuclear fuel consumed in fission reactions
- Radiative exergy is applied on solar radiation impinging on solar panels

6.3.2 Normalization and weighting

Normalization is not a part of this method. In order to get a total (“cumulative”) exergy demand, each impact category is given the weighting factor 1.

References

Bösch, M.E.; Hellweg, S.; Huijbregts, M.A.J.; Frischknecht, R. 2007. Applying Cumulative Energy Demand (CExD) Indicators to the ecoinvent Database. In: Int J LCA 12 (3): 181–190.

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

6.4 Freshwater eutrophication (Payen et al. 2021)

In different water bodies, different nutrients can be limiting factors for eutrophication after aquatic nutrient enrichment. For years, freshwater eutrophication indicators in LCA viewed phosphorus as the sole contributor to such impacts. However, there are numerous freshwater systems across the world where eutrophication in freshwater is actually co-limited by nitrogen and phosphoros or even solely nitrogen-limited.

This method quantifies impacts on freshwater eutrophication as published by Payen et al. (2021). It includes spatially differentiated characterization factors for Nitrogen and Phosphorus.

As formulated in the paper, “Spatially explicit freshwater eutrophication indicators in life cycle assessment focus on phosphorus as the sole contributor to such impacts. Nitrogen may also be an ecological limiting factor in freshwater systems, but commonly not modelled. This method aims at filling this gap by consistently developing fate factors for both dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), using the same underlying model of nutrient export by rivers.” The environmental fate of dissolved inorganic nitrogen forms and dissolved inorganic phosphorus is essential to understanding the eutrophication impacts they may trigger in freshwater.

The characterization factors in this method represent the potential contribution of N and P to the impact category "Freshwater eutrophication, nitrogen" (in N-eq) and "Freshwater eutrophication, phosphorus" (in P-eq). The N and P components can be aggregated into a single indicator expressed in “algae-equivalent” (algae-eq) for the damage category "Co-limited catchments" or when the limitation status is unknown.

Aspects considered for the implementation of the method in SimaPro

Two aspects were considered when implementing the method in SimaPro:

- which substances to characterize and how; and

- which spatial differentiation and substances to regionalize.

Regionalized substances

Note that this method is only relevant for regionalized inventory data.

Payen et al. (2021) provided CFs calculated at a river basin resolution with a global coverage, and at the country and global scales by means of emission-weighting aggregation and distinguishing agricultural from non-agricultural emissions.

Since data libraries included in SimaPro do note include region-specific substances (apart from water), we decided to include **regionalized substances in SimaPro** that a user is likely to include in his/her model, e.g. BOD and COD which are often measured in wastewater and N- and P-based emissions resulting from the application of fertilizers and/or of manure.

The characterization factors for substances other than those measured in kg of phosphorus (P) or nitrogen (N) were calculated based on stoichiometry as recommended in the paper of Payen et al. (2021). Citing Payen et al. (2021): “To express the indicator as N or P content in each form of the respective DIN or DIP, we multiply it by the corresponding molar mass conversion factor (in $g \cdot mol^{-1}/g \cdot mol^{-1}$): N in NH_4^+ (0.776); N in NO_3^- (0.226); N in NO_2^- (0.304); P in PO_4^{3-} (0.326), P in H_3PO_4 (0.316) and P in P_4O_{10} (0.218).”

The characterization factors for BOD5 (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) were calculated based on the recommendation by GLAM (Frischknecht & Jolliet, 2019).

Scale

The regionalized substances were included with CFs **at country-level**. For a version of the method supporting CFs for all substances at country level, please use the version soon to be available in the online version of SimaPro.

The method developers also provided CFs per river basin, however these are not included in SimaPro.

References

Payen, S., Cosme, N., & Elliott, A. H. (2021). Freshwater eutrophication: spatially explicit fate factors for nitrogen and phosphorus emissions at the global scale. The International Journal of Life Cycle Assessment, 26(2), 388-401.

Frischknecht R, Jolliet O (Editors) (2019). Global Guidance on Environmental Life Cycle Impact Assessment Indicators: Volume 2. UNEP/SETAC Life Cycle Initiative, Paris, France, pp. 80–103.

6.5 IPCC 2021

IPCC 2021 is the successor of the IPCC 2013 method, which was developed by the Intergovernmental Panel on Climate Change.

This method is based on the final government distribution version of the **IPCC report "AR6 Climate Change 2021: The Physical Science Basis"**, which is still subject to copy-editing, corrigenda and trickle backs. The following note is given by the authors: "The Technical Summary (TS), the full Report Chapters, the Annexes and the Supplementary Materials are the Final Government Distribution versions, and remain subject to revisions following the SPM approval, corrigenda, copy-editing, and layout. Although these documents still carry the note from the Final Government Distribution “Do Not Cite, Quote or Distribute” they may be freely published, as the report has now been approved and accepted."

Contact info: http://www.ipcc.ch/contact/contact.htm

6.5.1 Value choices

The IPCC 2021 method provides different types of characterization factors, which results in six methods that quantify global warming potential (GWP) and two methods that quantify global temperature potential (GTP).

In SimaPro, we included always two version of a same method, **one considering carbon dioxide update and one without**. For GWP, we also implemented **different time horizons**: 20 years, 100 years (default), and 500 years. Note that the GWP 100 factors are recommended as default in the Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) (Frischknecht & Jolliet, 2016), and the GWP20 and GTP100 factors for sensitivity analysis.

This result in the following eight methods in SimaPro:

	Indicator	
Time horizon	**Global Temperature Potential (GTP)**	**Global Warming Potential (GWP)**
20 years		IPCC2021 GWP20 IPCC2021 GWP20 (incl. CO_2 uptake)
100 years	IPCC2021 GTP100 IPCC2021 GTP100 (incl. CO_2 uptake)	IPCC2021 GWP100 IPCC2021 GWP100 (incl. CO_2 uptake)
500 years		IPCC2021 GWP500 IPCC2021 GWP500 (incl. CO_2 uptake)

- IPCC2021 GTP100: the Global Temperature Potential (GTP) climate change factors of IPCC with a timeframe of 100 years, where carbon dioxide uptake is implicitly included.
- IPCC2021 GTP100 (incl. CO2 uptake): the Global Temperature Potential (GTP) climate change factors of IPCC with a timeframe of 100 years, where carbon dioxide uptake and biogenic carbon dioxide emissions are explicitly included.
- IPCC2021 GWP100: the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 100 years, where carbon dioxide uptake is implicitly included.
- IPCC2021 GWP100 (incl. CO2 uptake): the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 100 years, where carbon dioxide uptake and biogenic carbon dioxide emissions are explicitly included.
- IPCC2021 GWP20: the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 20 years, where carbon dioxide uptake is implicitly included.
- IPCC2021 GWP20 (incl. CO2 uptake): the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 20 years, where carbon dioxide uptake and biogenic carbon dioxide emissions are explicitly included.

- IPCC2021 GWP500: the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 500 years, where carbon dioxide uptake is implicitly included.
- IPCC2021 GWP500 (incl. CO2 uptake): the Global Warming Potential (GWP) climate change factors of IPCC with a timeframe of 500 years, where carbon dioxide uptake and biogenic carbon dioxide emissions are explicitly included.

6.5.2 Characterization factors

IPCC characterization factors for the global warming and temperature potential are modelled as follows:

- including carbon cycle response (previously referred to as climate carbon feedback).
- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of Near Term Climate Forcers (NTCF: nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), black carbon (BC), organic carbon (OC), and sulphur oxides (SOx)), as recommended by UNEP-GLAM (2017). They recommend to include these in sensitivity analysis, however, there are no factors available in the AR6 report for these substances.
- not including indirect effects of CO emissions.

The characterization factors are based on Table 7.15 of Chapter 7 (Forster et al., 2021) and Table 7.SM.7 in the supplementary materials of Chapter 7 (Smith et al., 2021).

There were 62 substances in Table 7.SM.7 that could not be mapped with substances in the SimaPro database and were not added (a list can be requested via SimaPro support).

In SimaPro, the results can be presented in a few impact categories (see below). These impact categories can be aggregated into a single impact assessment result by selecting Damage assessment in SimaPro.

Impact categories in SimaPro	
Including CO_2 uptake	**Default (not including CO_2 uptake)**
fossil carbon dioxide uptake[2] biogenic emissions[3] land transformation	fossil biogenic emissions land transformation

[2] this impact category is only in the methods including CO_2 uptake.
[3] Note that the factor for biogenic methane is not corrected for carbon dioxide uptake in the version including CO_2 uptake, so when using that version, the correction needs to be done in the inventory in line with the IPCC reports.

6.5.3 Normalization and weighting

Normalization and weighting are not a part of this method.

References

Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Forster, P., T. Storelvmo, K. Armour, W. Collins, J. L. Dufresne, D. Frame, D. J. Lunt, T. Mauritsen, M. D. Palmer, M. Watanabe, M. Wild, H. Zhang, 2021, The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K.Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Smith, C., Z. R. J. Nicholls, K. Armour, W. Collins, P. Forster, M. Meinshausen, M. D. Palmer, M. Watanabe, 2021, The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity Supplementary Material. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Available from https://ipcc.ch/static/ar6/wg1.

Frischknecht, R., & Jolliet, O. (2016). Global Guidance for Life Cycle Impact Assessment Indicators Volume 1 Paris.

6.6 Selected LCI results

The selected life cycle inventory indicators are, in most cases, the summation of selected substances emitted to all different sub-compartments.

6.6.1 Classification

The list of selected LCI indicators is divided in two. The first list contains the common set of elementary flows shown in the results discussion of the ecoinvent reports. One example is "fossil CO2 emissions to air". The second list contains additional elementary flows used in at least one of the ecoinvent reports (Table 4). One example of this extended list is "actinides emitted to water". These two lists are implemented as two different methods into SimaPro: Selected LCI results and Selected LCI results, additional.

The selection does not necessarily reflect the environmental importance of the listed pollutants and resources. The pollutants and resources are selected in view of a better characterization of the analyzed products and services.

The selection helps practitioners to get a more convenient access to a selection of LCI results of products and services. It does not replace the use of the complete set of LCI results and the application of LCIA methods.

Subcategory	**Name**	**Location**	**Unit**	**Used in ecoinvent report**
resource	land occupation	GLO	m2a	all
resource	water	GLO	m^3	No. 6 VIII
resource	carbon, biogenic, fixed	GLO	kg	No. 17
air	carbon monoxide	GLO	kg	No. 11 II
air	CO_2, fossil	GLO	kg	all
air	lead	GLO	kg	No. 6 VI
air	methane	GLO	kg	No. 6 IV
air	N2O	GLO	kg	No. 6 VI
air	nitrogen oxides	GLO	kg	all
air	NMVOC	GLO	kg	all
air	particulates, <2.5 um	GLO	kg	all
air	particulates, >2.5 um and <10 um	GLO	kg	No. 6 VI
air	particulates, >10 um	GLO	kg	No. 6 VI
air	particulates	GLO	kg	No. 11 II
air	sulphur dioxide	GLO	kg	all
air	zinc	GLO	kg	No. 6 VI
air, radioactive	radon (+ radium)	GLO	kBq	No. 6 VI
air, radioactive	noble gas	GLO	kBq	No. 6 VI
air, radioactive	aerosol	GLO	kBq	No. 6 VI
air, radioactive	actinides	GLO	kBq	No. 6 VI
soil	cadmium	GLO	kg	all
water	BOD	GLO	kg	all
water, radioactive	radium	GLO	kBq	No. 6 VII
water, radioactive	tritium	GLO	kBq	No. 6 VII
water, radioactive	nuclides	GLO	kBq	No. 6 VII
water, radioactive	actinides	GLO	kBq	No. 6 VII
total	oils, unspecified	GLO	kg	No. 6 IV
total	heat, waste	GLO	MJ	No. 6 VII

Table 4: List of selected life cycle inventory indicators implemented in ecoinvent data v2.0.

References

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

6.7 USEtox 2

The USEtox 2 is a successor of USEtox - an environmental model for characterization of human and eco-toxicological impacts in Life Cycle Impact Assessment and Comparative Risk Assessment. It has been developed by a team of researchers from the Task Force on Toxic Impacts (TF LCIA 2) under the UNEP-SETAC Life Cycle Initiative (see www.usetox.org). USEtox 2 is designed to describe the fate, exposure, effects of chemicals and includes both midpoint and endpoint factors. The model was peer-reviewed and USEtox team continuously maintains and updates the method. USEtox is officially endorsed by the UNEP/SETAC Life Cycle Initiative and officially recommended as assessment method by the European Commission, the European Commission's Joint Research Centre, the World Business Council for Sustainable Development, and by the United States Environmental Protection Agency.

The current version available in SimaPro is USEtox 2.12, a corrective update released by the USEtox team on 11 November 2019.

6.7.1 Characterization

The USEtox model calculates characterization factors for carcinogenic impacts, non-carcinogenic impacts, and total impacts (Carc + non-carc) for chemical emissions to household indoor air, industrial indoor air, urban air, rural air, freshwater, sea water, agricultural soil, natural soil and from human exposure to pesticide residues in food crop consumption. At midpoint level the unit of the characterization factor for freshwater aquatic ecotoxicity is PAF.m3.day/kgemission and for human toxicity cases/kgemission. Both are summarized as Comparative Toxic Unit (CTU) to stress the comparative nature of the characterization factors. Equal weighting between cancer and non-cancer effects is assumed.

The provided characterization factors have been classified as:

- Recommended
- Interim

Recommended factors are given for substances where the USEtox™ model is considered fully appropriate and the underlying substance data is of sufficient quality to support a recommendation. In cases where relatively high uncertainty in addressing fate, exposure and/or effects of a chemical is expected, the characterization factor is labelled as interim. This recommendation is given in cases where the substance is a metal or an inorganic chemical, an organometallic chemical, an amphiphilic chemical (e.g. detergents) or dissociating under environmental conditions. It is also recommended that aquatic eco-toxicological characterization factors are specified as interim, if effect factors are based on species toxicity data covering less than three different trophic levels. This is to ensure a minimum variability of biological responses.

	SimaPro compartments	USEtox compartments		
Air	(unspecified)	*50 Em.airU / 50 Em.airR*	50/50 urban/rural	Estimated

Air	high. pop.	*Em.airU*	Urban air	Calculated
Air	low. pop.	*Em.airR*	Rural air	Calculated
Air	low. pop., long-term	*Em.airR*	Rural air	Estimated
Air	stratosphere + troposphere	*Em.airR*	Rural air	Estimated
Air	indoor	*Em.air*	Household indoor air	
Water	(unspecified)	*Em.fr.waterC*	Freshwater	Estimated
Water	river	*Em.fr.waterC*	Freshwater	Calculated
Water	river, long-term	*Em.fr.waterC*	Freshwater	Estimated
Water	lake	*Em.fr.waterC*	Freshwater	Calculated
Water	ocean	*Em.sea waterC*	Sea water	Calculated
Soil	agricultural	*Em.agr.soilC*	Agri. Soil	Calculated
Soil	(unspecified)	*Em.nat.soilC*	Natural soil	Estimated
Soil	forestry	*Em.nat.soilC*	Natural soil	Calculated

Table 5. List of correspondence of SimaPro and USEtox sub-compartments.

Following recommendations of the USEtox developers, the following rules have been followed for the characterization factors for inorganic emissions:

i. Antimony: average of factors for Antimony (III) and (V);

ii. Arsenic: average of factors for Arsenic (III) and (V);

iii. Chromium: equals factor for Chromium (III), because Cr (IV) is emitted only in very specific processes, while for others Cr (III) is a predominant fraction;

iv. Iron: equals factor for Iron (III) as this is the oxidation state that usually occurs in the environment.

What version should you use?

The version Recommended + interim should be used. The version including only the Recommended characterization factors is only provided for purposes of sensitivity analysis.

6.7.2 Damage assessment

USEtox 2 includes the mid-to-endpoint factors, making it possible to assess the effects at the endpoint level. For the impacts on human health the unit is DALY (disability adjusted life years) and for impact on ecosystems PDF (potentially disappeared fraction of species).

References

USEtox 2.12. 2021. Retrieved from https://usetox.org/model/download/usetox2.12

7 Water Footprint

7.1 AWARE

AWARE is a regionalized, water use midpoint indicator representing the relative Available WAter REmaining per area in a watershed after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. AWARE is the recommended method from WULCA (working group under the umbrella of the Life Cycle Initiative) to assess water consumption impact assessment in LCA.

It is first calculated as the water Availability Minus the Demand (AMD) of humans and aquatic ecosystems and is relative to the area (m^3 m^{-2} $month^{-1}$). In a second step, the value is normalized with the world average result (AMD = 0.0136 m^3 m^{-2} $month^{-1}$) and inverted. The result represents the relative value in comparison with the average m^3 consumed in the world (the world average is calculated as a consumption-weighted average). The indicator is limited to a range from 0.1 to 100, with a value of 1 corresponding to the world average, and a value of 10, for example, representing a region where there is 10 times less available water remaining per area than the world average.

Implementation of AWARE in SimaPro includes only the generic factors for unknown water usage and not the factors specific for agricultural and non-agricultural use of water (irrigation/non-irrigation, these are currently not supported in SimaPro and its inventory data).

Documentation is available from: http://www.wulca-waterlca.org

References

Boulay A.M., Bare J., Benini L., Berger M., Lathuilliere M.J., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A.V., Ridoutt B., Oki T., Worbe S., Pfister S. (2018). The WULCA consensus characterization model for 108 water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE). The International Journal of Life Cycle Assessment 23(2): 368-378.

7.2 Berger et al 2014, WAVE (Water Scarcity)

This method is based on the publication Berger et al (2014).

The method analyzes the vulnerability of basins to freshwater depletion. Based on local blue water scarcity, the water depletion index (WDI) denotes the risk that water consumption can lead to depletion of freshwater resources. Water scarcity is determined by relating annual water consumption to availability in more than 11 000 basins. Additionally, WDI accounts for the presence of lakes and aquifers which have been neglected in water scarcity assessments so far. By setting WDI to the highest value in (semi)arid basins, absolute freshwater shortage is taken into account in addition to relative scarcity. This avoids mathematical artifacts of previous indicators which turn zero in deserts if consumption is zero.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www2.worldwater.org/data.html).

After calculating your results, we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Markus Berger, Ruud van der Ent, Stephanie Eisner, Vanessa Bach, and Matthias Finkbeiner. 2014. Water Accounting and Vulnerability Evaluation (WAVE): Considering Atmospheric Evaporation Recycling and the Risk of Freshwater Depletion in Water Footprinting. Environ. Sci. Technol., 2014, 48 (8), pp 4521–4528.

7.3 Boulay et al 2011 (Human Health)

This method is based on the publication Boulay et al (2011).

The method is an endpoint indicator expressed in DALY and is obtained by modelling each water user's loss of functionality. It addresses three different impact pathways:

1) malnutrition from water deprivation for agricultural users,
2) malnutrition from water deprivation for fisheries, and
3) water-related diseases associated with a lack of water for domestic use.

The cause-effect chain modelling is based on hydrological and socio-economic data. The water scarcity index is used at the midpoint level [Boulay et al 2011 (Water Scarcity)]. The level of economic development is considered through the adaptation capacity based on gross national income.

The method contains two different types of human health categories: distribution and marginal.

Distribution effects apply to all types of water consumption. Distribution refers to the impact assessment in which all users are competing and proportionally affected according to their distributional share of water use for off-stream users (here, agriculture, fisheries and domestic).

Marginal effects apply to agricultural water consumption. Marginal refers to a modelling choice in which any additional water use will deprive only one off-stream user (agricultural).

The "HH, marginal" category is comparable with the "HH, agricultural water scarcity" category in the Motoshita et al 2010 (Human Health) method and the "Human Health" category of the Pfister et al 2009 (Eco-indicator 99) and Pfister et al 2010 (ReCiPe) methods. Note that the "HH, distribution" category includes more effects and is NOT complementary to the "HH, marginal" category.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Boulay, A.M., Bulle, C., Bayart, J.B., Deschenes, L., Margni, M. (2011). Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health. Environmental Science & Technology 45: 8948-8957.

7.4 Boulay et al 2011 (Water Scarcity)

This method is based on the publication Boulay et al (2011). This water scarcity indicator (WSI) method is based on a consumption to availability (CTA) ratio and modelled using a logistic function (S-curve) in order to fit the resulting indicator to values between 0 and 1 m3 deprived/m3 consumed. The curve is tuned using OECD water stress thresholds, which define moderate and severe water stress as 20% and 40% of withdrawals, respectively and converted with an empirical correlation between withdrawal to availability (WTA) and CTA. The scarcity indicators are also available for surface and groundwater. The indicator is applied to the consumed water volume and assesses consumptive water use only.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Boulay, A.M., Bulle, C., Bayart, J.B., Deschenes, L., Margni, M. (2011). Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health. Environmental Science & Technology 45: 8948-8957.

7.5 Hoekstra et al 2012 (Water Scarcity)

This method is based on the publication Hoekstra et al (2012). This water scarcity indicator (WSI) is based on a consumption-to-availability ratio (CTA) calculated as the fraction between consumed (referred to as blue water footprint) and available water. The latter considers all runoff water, of which 80% is subtracted to account for environmental water needs. The data is from (Fekete et al., 2002) for water runoff and Mekonnen et al. for water consumption. Results are available for the main watersheds worldwide but many outlying regions are not covered. The indicator is applied to the consumed water volume and only assesses consumptive water use.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Hoekstra, Arjen Y., Mesfin M. Mekonnen, Ashok K. Chapagain, Ruth E. Mathews, and Brian D. Richter. 'Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability'. *PLOS ONE* 7, no. 2 (29 February 2012): e32688. https://doi.org/10.1371/journal.pone.0032688.

Fekete, B.M., Vörösmarty, C.J., Grabs, W., 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances. Glob. Biogeochem. Cycles 16, 15-1-15–10. https://doi.org/10.1029/1999GB001254

7.6 Motoshita et al 2011 (Human Health)

This method is based on the publication Motoshita et al (2011). The method is an endpoint indicator. It contains two different types of human health categories: one for infectious disease damage caused by domestic water scarcity and one for malnutrition damage caused by agricultural water scarcity.

For domestic water scarcity, the method assumes that water resource scarcity caused by water consumption will lead to a loss of access to safe water. The cause-effect chain modelling is based on hydrological and socio economic data. The water scarcity index used at the midpoint is Pfister et al 2009 (Water Scarcity). The level of economic development is considered through the parameter house connection to water supply.

The impacts of malnutrition caused by agricultural water deficit are modelled using the same data source for scarcity and distribution as above, multiplied by a socio-economic parameter describing the trade effect. This illustrates how food supply shortage in a country will spread to other countries through international food trade. Countries with low and middle incomes will be affected by the food shortage. This effect is quantified in DALY by using malnutrition-related DALYs in the importing countries (DALYs/kcal malnutrition).

The "HH, agricultural water scarcity" category is comparable with the "HH, marginal" category of Boulay et al 2011 (Human Health) and the "Human Health" category of the Pfister et al 2009 (Eco-indicator 99) and Pfister et al 2010 (ReCiPe) methods. The "HH, domestic water scarcity" category is complementary to the "HH, agricultural water scarcity" category.

The method provides country-based characterization factors in the context of both domestic and agricultural water scarcity, expressed in DALY per m3 of water consumed.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Motoshita, M., Itsubo, N., Inaba, A. (2011). Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. Int J LCA 16, 65-73.

Appendix 1: Superseded

Superseded methods

This section includes methods which have been updated or replaced by a newer version. We recommend therefore not using these but instead the methods presented in previous sections.

1 CML 1992

This classification method is based on the method published by CML of the University of Leiden in October 1992[14].

PRé has modified the method: the depletion and energy classes were separated and the classes for smell and biotic exhaustion were excluded.

This v2 version is adapted for SimaPro 8. All characterization factors in this method are entered for the 'unspecified' sub-compartment of each compartment (Raw materials, air, water, soil) and thus applicable on all sub-compartments.

This method is NOT fully adapted for inventory data from the Ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

1.1 Characterization

Grouped substances or sum parameters have been defined in a number of classes. This has been done because the emissions are not always specified separately in the data sources for the processes concerned. Emissions are often specified under a collective name, e.g. aromatic hydrocarbons. Since the different substances within such a group can have considerable variation in their environmental impact, the resulting effect score may not be completely reliable.

The main classes are: 1. Exhaustion of raw materials and energy, and 2. Pollution.

1. Exhaustion of raw materials and energy

<u>Abiotic</u>

This term refers to energy sources and a number of scarce metals. In the CML 92 method, all the energy sources were grouped into a separate class called Energy.

The effect score for exhaustion is calculated on the following basis:

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[14] R. Heijungs et al, *Environmental life cycle assessment of products, Guide, October 1992* CML, Leiden, The Netherlands, NOH report 9266.

Exhaustion = (amount consumed (kg) x {1/resources (kg)}) [15]

Biotic

This category is intended for rare animals and plants. This score is as yet very rudimentary and has therefore not been used.

2. Pollution

Greenhouse effect

The Global Warming Potential (GWP) is the potential contribution of a substance to the greenhouse effect. This value has been calculated for a number of substances over periods of 20, 100 and 500 years because it is clear that certain substances gradually decompose and will become inactive in the long run. For the CML 92 method, we have taken the GWP over a 100-year period because this is the most common choice.

We have added values for CFC (hard) and for CFC (soft) to the CML (1992) method, since it is not always known which CFC is released. The GWP for this category of substances has been equated to that of CFCs frequently used in industrial mass and series production; for CFC (hard) this is the value for CFC-12, and for CFC (soft) it is the value for HCFC-22.

The effect score for the greenhouse effect is calculated per substance as follows:

Greenhouse effect (kg) = (GWP 100 x airborne emission (kg)) [16]

Ozone layer depletion

Ozone Depletion Potential (ODP) values have been established mainly for hydrocarbons containing combined bromine, fluorine and chlorine, or CFCs. Here too, one of the substances (CFC-11) has been adopted as a reference. As for the greenhouse effect, we have added values for CFC (hard) and CFC (soft). The ODP equivalents for these groups are again those of CFC-12 and HCFC-22 respectively.

The effect score for ozone layer depletion is calculated as follows:

Ozone layer depletion (kg) = (ODP x airborne emission (kg)) [17]

Human toxicity

Criticism of the use of MAC values in the CML 1990 method led to the development of a fairly long list of substances that are poisonous to human beings. A notable feature is that human toxicity combines a score for emissions to air, water and soil. The following values have been established for most substances:

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[15] World Institute, *World Resources 1990-1991,* Oxford University Press, New York/Oxford.

[16] Houghton, Callender & Varney, *Climate Change 1992. The supplementary report to the IPCC scientific assessment*, Cambridge University Press, Cambridge, UK, 1992.

[17] World Meteorological Organization, *Scientific assessment of ozone depletion 1991*, Global Ozone Research and Monitoring Project - Report no. 25, 1991.

- Human-toxicological classification value for air (HCA)
- Human-toxicological classification value for water (HCW)
- Human-toxicological classification values for soil (HCS).

We have not included soil emissions in this because the program does not have an impact category for substances emitted to soil. The number of characterization factors from soil is very limited. Moreover, it may be assumed that emissions that initially enter the soil will ultimately appear in the groundwater and hence can be dealt with as emissions to water.

We have added a number of values for groups to this class: metallic ions and various groups of hydrocarbons. Metallic ions have been given a value equal to that of iron. The values of the hydrocarbons are given in Table 6. An equivalent has also been selected for most other values that were not defined; e.g. for chlorine, the equivalent value of bromine has been used.

	equivalents			
Substances	**human toxicity**	**human toxicity**	**ecotoxicity**	**smog**
	air	**water**	**water**	**air**
CxHy	isopropanol	isopropanol	crude oil	aliphatics average
CxHy aliphatic	isopropanol	isopropanol	crude oil	aliphatics average
CxHy aromatic	benzene	benzene	benzene	aromatics average
CxHy chloro	1,2, dichloroethane	1,2, dichloroethane	1,2, dichloroethan e	average chlorinated org. compounds
PAH	benzo(a)pyrene	benzo(a)pyrene	benzo(a)pyren e	aromatics average

Table 6: Substances from which HCA/HCW, ECA and POCP values for hydrocarbons are taken.

The human toxicity effect score is calculated as follows:

Human toxicity (kg) = (HCA (kg.kg-1) x emission to air (kg) +

HCW (kg.kg-1) x emission to water (kg)) [18]

[18] Vermeire, T.G et al., *Voorstel voor de humaan-toxicologische onderbouwing van C - (toetsings)waarden* [Proposal for the human-toxicological basis of test values], RIVM, Bilthoven, The Netherlands, 1991.

Ecotoxicity

Substances in this class are given values for toxicity to flora and fauna. The main substances are heavy metals. Values have been established for emissions to water and to soil, i.e.:

- Aquatic ecotoxicity (ECA)
- Terrestrial ecotoxicity (ECT)

Only the ECA values have been included in the CML 92 method because emissions to soil eventually appear in the groundwater and are thus already covered.

We have added a number of values for groups of hydrocarbons to this class. Values for the hydrocarbons are shown in Table 6. An equivalent has been selected for most other values that were not defined. The effect score for ecotoxicity is calculated as follows:

Ecotoxicity (m^3) = (ECA (m^3. kg-1) x waterborne emission (kg))[19]

Smog

The photochemical ozone creation potential (POCP) indicates the potential capacity of a volatile organic substance to produce ozone. Values have been published for a wide range of volatile organic substances. The value for ethene has been set at 1. The values for most other substances are less than this. The POCP of these sum-parameters such as alcohols, ketones, aldehydes and various groups of hydrocarbons groups is the average of all the relevant substances in the CML (1992) list. The values for the hydrocarbon groups are given in Table 6. NOx is omitted in the CML 92 methodThe effect score for smog is calculated as follows:

Smog (kg) = (POCP x airborne emission (kg))[20]

Acidification

The Acidification Potential (AP) is expressed relative to the acidifying effect of SO2. Other known acidifying substances are nitrogen oxides and ammonia. SOx has been added, with the same value as SO2.

Acidification effect scores are calculated as follows:

Acidification (kg) = (AP x airborne emission (kg))

Note that the results of the acidification classes from CML (1990) and CML (1992) are not calculated in the same way.

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[19] Slooff, W., *Maximum tolerable concentrations, eco-toxicological effect assessment*, RIVM no. 719102018, Bilthoven, The Netherlands.

[20] Protocol to the convention on long-range transboundary air pollution concerning the control of emissions of volatile organic compounds or their transboundary fluxes, United Nations - Economic Commission for Europe (UNECE), Geneva, Switzerland, 1991.

Eutrophication

The Nutrification Potential (NP) is set at 1 for phosphate (PO4). Other emissions also influence eutrophication, notably nitrogen oxides and ammonium.

The eutrophication effect score is calculated as follows:

Eutrophication (kg) = (NP x airborne emission (kg))

Odour

Weighting factors for stench have been developed, although their use is unusual in LCAs. In these, ammonia is given the value 1.

This class is not included in the CML 92 method because it is a highly localized environmental effect, and the degree of stench nuisance depends largely on local circumstances.

Solids

This class is not included in the original CML 1992 classification. We have added the solids class to the method because solid emissions form an important environmental problem in their own right. The weight of the waste emission is used for calculation, and no weighting factors are involved.

Solids (kg) = (solid emission output (kg))

1.2 Normalization

The first and probably most widely used normalization set was published in 1993 by Guinée from the CML. This set was compiled by extrapolating 1988 data from the Dutch Emission Registration. Most of the data was simply multiplied by a factor 100, to extrapolate them to the world level, as The Netherlands contribute about 1% to the Gross National Product figures in the World. An exception was made for greenhouse and ozone depleting emissions. These were taken directly from IPCC. The figures are supposed to reflect the world emissions. In order to make the figures more manageable, we have divided them by the world population of 6.000.000.000. A very recent project executed by IVAM-ER, NWS (University of Utrecht) and PRé, under commission from VROM and RIZA, in the Netherlands has resulted in three new sets of normalization figures. They are for a large part based on the Emission registration (base year 1994), and several other sources. The results of this project have been peer reviewed by Guinée.

The normalization levels are:

- Dutch territory. All emissions registered emitted within the Netherlands and all raw materials consumed by the Dutch economy.
- Dutch consumer. The effect of imports have been added, the effects of exports have been subtracted. The calculation was performed using the Dutch input-output matrix.
- European territory (EC, Switzerland, Austria and Norway). Most data are from original European data. In some cases data was extrapolated from Dutch and Swiss data. The energy consumption within a region was taken as a basis for extrapolation.

1.3 Evaluation

Although several organizations have developed evaluation factors using panel methods, there is no generally recognized method to evaluate the results obtained with the CML method.

2 Eco-indicator 95

Eco-indicator 95 is adapted for SimaPro 8. All characterization factors in this method are entered for the 'unspecified' sub-compartment of each compartment (Raw materials, air, water, soil) and thus applicable on all sub-compartments.

This method is NOT fully adapted for inventory data from the Ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

Due to continual adjustments of the method and/or inventory data sets the Eco-indicator 95 in SimaPro 8 will not give the same result as the original printed version.

2.1 Characterization

The only difference between the characterizations in the SimaPro 2 CML and SimaPro 3 Eco-indicator 95 methods is in the ecotoxicity and human toxicity effect definition. Both toxicity scores have been replaced by:

- Summer smog (already available in the SimaPro 2 CML method)
- Winter smog
- Carcinogens
- Heavy metals to air and water
- Pesticides

The characterization values are based on the following data:

Effect score of persistent toxic substances in air and water

This effect score relates in particular to heavy metals because long-term exposure at low levels brings clear health risks. The risks relate particularly to the nervous system and the liver and can be assessed for toxicity to both human beings and ecosystems. It is assumed in general (Globe, Air Quality Guidelines) that human toxicity is the most important limiting factor. The Air Quality Guidelines specify the following admissible air concentrations for annual exposure to humans (Table 7).

	Maximum concentration (μg/m³)	Weighting factor	Main health effect
Cadmium	0.02	50	Kidneys
Lead	1	1	Blood biosynthesis, nervous system and blood pressure
Manganese	7	0.14	Lungs and nervous system (shortage cause skin complaints)
Mercury	1	1	Brain: sensory and co-ordination functions

Table 7: Air Quality Guidelines admissible air concentrations for annual exposure to humans

Chromium and nickel are regarded as carcinogens because the risk of cancer is greater than the toxicological effect. Based on this concentration a weighting factor can be determined which is equal to the inverse of the admissible concentration. This agrees with the critical volume approximation that used to be applied with the MAC value. We have expressed the effect score as a lead equivalent.

The WHO 'Quality guidelines for drinking water' specify a number of values for persistent substances based on long-term, low-level exposure. These criteria have been drawn up to evaluate drinking water, based on established health effects. In table 8, a selection of substances that are persistent to a greater or lesser extent and that therefore accumulate in the environment.

Substance	Norm (mg/liter)	Weighting factor	Effect
Antimony	0.005	2	Glucose and cholesterol content of blood
Arsenic	0.01	1	Probability of skin cancer $6*10^{-4}$
Barium	0.07	0.14	Blood pressure and blood vessels
Boron	0.3	0.03	Fertility
Cadmium	0.003	3	Kidneys
Chromium (all)	0.05	0.2	Heredity (carcinogenity only applicable in event of inhalation)
Copper	2	0.005	Generally no problems, sometimes liver abnormalities
Lead	0.01	1	Blood biosynthesis, nervous system and blood pressure
Manganese	0.5	0.02	Nervous system
Mercury	0.001	10	Kidneys, nervous system (methyl mercury)
Molybdenum	0.07	0.14	No clear description
Nickel	0.02	0.5	Weight loss, great uncertainty

Table 8: WHO based substances that are persistent

With this effect score the weighting factor is determined in order to be able to calculate the lead equivalent. SimaPro merges the scores for water and air. This is possible because they are both expressed as a lead equivalent and because the target reductions for air and water are the same. We have combined the two scores for heavy metals. This was possible since they are both expressed as a lead equivalent and since the weighting factors are identical.

*Heavy metal to air (kg lead eq.) = (AQG (lead)/AQG (substance) * emission)*

Heavy metal to water (kg lead eq.) = (GDWQ (lead)/GDWQ (substance) emission)*

Carcinogenic substances

The 'Air Quality Guidelines' do not specify acceptable levels, but calculate the probability of cancer at a level of 1 μg/m³. In Table 9 this probability is expressed as the number of people from a group of 1 million who will develop cancer with the stated exposure.

	Probability of cancer at 1 µg/m³	Weighting factor for PAH equivalent	Type of cancer
Arsenic	0.004	0.044	General, also mutagenic effects
Benzene	0.000001	$1.1 * 10^{-5}$	Leukemia
Nickel	0.04	0.44	Lung and larynx
Chromium (VI)	0.04	0.44	Lung, among others, and mutagenic effects
PAHs (benzo(a)pyrene)	0.09	1	Lung cancer but also other types of cancer

Table 9: Number of people from a group of 1 million who will develop cancer with the stated exposure.

It is worth considering whether to include asbestos in this list. The difficulty with this is that asbestos emissions cannot be expressed meaningfully in a unit of weight. The number and type of fibers is the determining factor.

It is not entirely clear whether these numbers can be used directly as a weighting factor in order to calculate, for example, a PAH equivalent. This is because it is not known exactly whether a linear correlation may be assumed between probability and exposure. At present we assume that this is so.

Heavy metal to air (kg lead eq.) = (AQG (lead)/AQG (substance))

Winter smog

Only dust (SPM) and SO2 are factors in this problem. For both substances the 'Air Quality Guidelines' specify a level of 50 µg/m³. The weighting factors are thus both 1.

Winter smog (SO2 or SPM eq.) = SO2 emission + SPM emission

Pesticides

The Globe report describes pesticides as a problem for two reasons:

- Groundwater becomes too toxic for human consumption.
- Biological activity in the soil is impaired, as a result of which vegetation is damaged.

This means that account must be taken in the effect score weighting of both ecotoxicity (soil) and human toxicity (water). The target reduction is based on human toxicity. Globe distinguishes between

- disinfectants
- fungicides

- herbicides
- insecticides

Within these groups all the different sorts are listed, based on their active ingredient content. We propose also doing this for this effect score and shall also list the various mutual categories.

Pesticides (kg) = (active ingredients)

2.2 Normalization

The normalization values are based on average European (excluding the former USSR) data from different sources. The reference year is 1990. In many cases we had to extrapolate data from one or more individual countries to the European level. As an extrapolation basis we used the energy consumption of the countries. In order to make the figures more manageable we divided the figures by the population of Europe: 497,000,000.

2.3 Evaluation

In the SimaPro 3 and the ecopoints methods the distance-to-target principle is used to calculate evaluation values. The basic assumption is that the seriousness of an impact can be judged by the difference between the current and a target level.

In the SimaPro 3 method the target is derived from real environmental data for Europe (excluding the former USSR), compiled by the RIVM. In the text below this report is referred to as Globe (The Environment in Europe: A Global Perspective).

The targets are set according to the following criteria:

- At target level the effect will cause 1 excess death per million per year
- At target level the effect will disrupt fewer than 5% of the ecosystems in Europe
- At target level the occurrence of smog periods is extremely unlikely

Greenhouse effect

At present, temperatures are rising by 0.2% every ten years. Under the current policy this rate will increase to 0.3% every ten years. The consequence will be a large temperature change by 2050. In Northern and Eastern Europe the winters will be more than 5°C warmer, and in Southern Europe the summers will be 4°C warmer. Areas in particular that have no other systems in their vicinity that can exist in such climatic conditions will suffer serious damage. This will affect approximately 20% of Europe.

The Globe report indicates that fewer than 5% of the ecosystems will be impaired if the greenhouse effect is reduced by a factor of 2.5.

Ozone layer depletion

In accordance with the Montreal Protocol and its London amendment all CFC emissions must be reduced to zero. For the less persistent HCFCs it has been agreed that the contribution to the effect in 1989 may not exceed 2.6% of the total adverse effect of CFCs. After this, the use of these substances too is to be reduced gradually by 2015.

If that happens the annual total of fatalities per million inhabitants in Europe will first rise from approximately 1 to 2 and then fall to 1 death per year per million inhabitants. It does not yet seem directly necessary to reduce all HCFC emissions to zero because the norm (2 ppbv) is going to be achieved, even if after 2100. For these gases the target reduction is linked to the greenhouse effect[21].

Based on this reduction for greenhouse gases, we therefore assume, for the moment, that the target reduction for HCFCs is of the order of 60%. Based on the premise that the HCFCs presently cause 2.6% of ozone layer depletion it can be estimated that this reduction will cause ozone layer depletion to fall to 1% of its present level. The reduction factor is thus 100. There is a great deal of uncertainty about this figure.

Acidification

There is a great variety in Europe in the ability of ecosystems to withstand acidification. In Scandinavia, for example, problems can occur with deposits of 100 eq/ha.yr, while in some places in the Netherlands and Germany the soil can withstand a deposit of more than 2000 eq/ha.yr.

Actual deposition appears to reach its highest level in Central Europe, particularly as a result of the use of lignite.

If the deposition and ability to withstand acidification are combined with each other, it seems that major problems are occurring particularly in England, the Benelux countries, Germany, Poland, the Czech Republic and Slovakia.

A provisional estimate based on the RAINS computer model shows that the reduction must be of the order of a factor of 10 to 20 to keep damage to the ecosystem below 5%.

Eutrophication

Eutrophication is seen in the Globe report particularly as the problem of excessive use of fertilizers by agriculture, as a result of which nitrates leach out and poison groundwater supplies. The problem is at its greatest in the Benelux countries, North-Rhine Westphalia (Germany) and Italy's Po valley plain (approx. 200 kg/ha).

In the CML classification Eutrophication refers mainly to air and water emissions. These rarely contribute more than 10% of the amount of fertilizer applied by farmers. In uncultivated biotopes, however, that are low in nutrients this eutrophication can have a serious adverse effect on biodiversity.

In describing the level of eutrophication in rivers and lakes it is estimated that the critical value for phosphates is 0.15 mg/l and for nitrates 2.2 mg/l. At these levels there are no problems with

[21] By contrast, the elimination of CFCs will also result in a significant reduction in the greenhouse effect. CFCs are responsible for 24% of this effect. Eliminating the CFCs will therefore yield a 24% reduction in the greenhouse effect.

eutrophication. In the rivers Rhine, Schelde, Elbe, Mersey and Ebro, however, these figures have been exceeded more than 5 times. This means that the emissions must be reduced by a factor 5.

Summer smog

A hundred years ago the ozone concentration averaged over the whole year was approximately 10 ppb. At present it is 25 ppb. This is approximately the maximum acceptable level; above 30 ppb, for example, crop damage can occur.

The major problem is not determined by the average figures but by the summer peaks which can reach more than 300 ppb. To reduce this type of dangerous peak by 90% it is necessary to reduce VOCs and NOx by 60 to 70%.

Heavy metals

In Central Europe lead concentrations are very high, particularly in the soil and water. The air concentration is also high in towns and cities, particularly because of the use of leaded petrol. For adults the Air Quality Guideline specifies a limit in the air of 0.5 to 1 μg/m³. According to Globe this value is often exceeded by a number of times. Globe notes in passing (and without backing it up) that average lead concentrations in Poland are 20 μg/m³.

Eating locally grown vegetables would result in a blood lead level that is ten times too high. Lead levels in children's blood of 150 to 400 μg/l have been found. Such readings also occurred in the West 30 years ago, but not anymore. The figures are five to ten times lower now. There is thought not to be a no-effect-level for exposure for children. Above 100 μg/l clear reductions in learning ability can be measured.

Thus although it is plausible that this pollution has a clearly measurable effect on human health, it is not easy to calculate a general reduction percentage for lead. The best estimate is a reduction by a factor of 5 to 10. We have taken a figure of 5 for heavy metal emissions to air.

Agriculture (fertilizer) is the major source of cadmium deposition. The average deposition rate is 0.6 to 0.67 g/ha on grassland and 3.4 to 6.8 g/ha for arable land. The Southern Netherlands holds the record with a deposition rate of 7.5 to 8.5 g/ha. Furthermore, approximately 14% is distributed via the air (see winter smog).

This leaching is calculated in the Globe report for the Rhine. A detailed calculation makes a convincing case for the necessity to reduce cadmium emissions by 80 to 85%. In some other rivers such as the Elbe cadmium contamination is substantially greater, and the required target will perhaps have to be set even higher. For the moment we are continuing with a target reduction of a factor of 5 for heavy metals in water.

Winter smog

The most important sources of this problem which occurs mainly in Eastern Europe are SO2 and SPM (suspended particle matter, or small dust and soot particles). NOx, organic substances and CO are also involved to a lesser extent. The dust particles can also contain heavy metals.

This form of smog achieved notoriety in 1952 when it caused an estimated 4000 deaths in London. The SO2 and SPM concentrations reached values of 5000 micrograms per cubic meter. In Southern Poland and Eastern Germany average readings of 200μg/m³ still occur repeatedly.

The Air Quality Guidelines specify a limit of 50µg/m³ for long-term exposure to both SPM and SO2. Based on this, a reduction of 75% would be necessary.

Globe estimates that a reduction in SO2 emissions of more than 80% is necessary to eliminate by and large the occurrence of occasional smog periods. No target is proposed for SPM because it is not well a defined or well measured[22] pollutant.

We are continuing to use a factor of 5 as a target.

Carcinogenic substances

Globe also provides some data on the distribution of carcinogenic substances. The main substances involved are polyaromatic hydrocarbons (PAHs), of which benzo[a]pyrene in particular is an important example. This occurs, among other places, in coke furnaces and in (diesel) motors. In fact, the problem is only relevant in urban areas.

Globe specifies a value of 0.8 to 5 ng/m³ for Northern European towns and cities. The Air Quality Guideline specifies a value of 1 ng/m³ in American cities without coke furnaces in the vicinity and 1 to 5 ng/m³ in cities with coke furnaces. In European towns and cities in the 60s, when open coal fires were still very much in use, the average concentrations were in excess of 100 ng/m³. In Eastern Europe the values are still high because of the use of coal-fired heating systems. As a point of comparison, a room in which a lot of smoking takes place can contain 20 ng/m³.

The Air Quality Guideline specifies a threshold concentration of 0.01 ng/m³ at which 1 cancer case per million inhabitants per year will still occur. This criterion cannot be compared straightforwardly with the criterion for ozone layer depletion because not all the cancer cases are terminal. In addition, only about 1/3 of the population of Europe lives in towns or cities[23]. If we assume that one in every three cancer cases is terminal and if we only take the urban population the risk of death is about ten times lower. Based on this, there would be one death per million inhabitants per year at a concentration of 0.1 ng/m³.

Based on a background concentration of 1 ng/m³ in towns and cities without coke furnaces (West European towns and cities in particular) a reduction by a factor of 10 could be estimated.

Pesticides

Leaching of pesticides threatens groundwater sources throughout the EU. The groundwater is contaminated in 65% of the EU above the EU norm (0.5 µg/liter). The norm is exceeded tenfold in 25% of the EU. This occurs in 20% of the land area of Eastern Europe. A reduction by a factor of 25 is necessary to ensure that the norm is exceeded in less than 10% of Europe.

Exhaustion of raw materials and solid waste

We have not defined any percentage reductions for exhaust of raw materials. There are two reasons for this:

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[22] A major shortcoming of the CML classification system is the lack of a weighting factor for particulate matter in calculating human toxicity. According to the Globe report, SPM is one of the most injurious substances to health.

[23] Eurostat, estimate based on data for 6 EU member states

No people die and no ecosystems are impaired as a result of the depletion of raw materials. It mainly causes economic and social problems.

Exhaustion is difficult to quantify because there are alternatives for most materials. For example, copper has already been replaced on a very wide scale by glass-fiber (communications) and aluminum (electricity-conducting medium). There are also good prospects for substituting materials in energy generation if the market is prepared to pay more for energy. In fact, the problem with energy is not the depletion of fossil fuels but the environmental impacts of combustion. Explicit account is taken of these in the indicator. In other words, you need not think that all the oil reserves that are presently known have actually been used. That would be an environmental disaster.

We have not defined any percentage reduction for waste. A similar reason applies to waste as to energy. No people die and only very small sections of ecosystems are threatened by the use of space for waste (apart from litter or fly-tipped waste). Emissions from incineration, the decomposition of waste and the leaching of, for example, heavy metals are major problems. These emissions are properly specified in a good LCA. Waste is thus included in similar fashion, but it is assessed in terms of its emissions.

We do not have any score for ecotoxicity and human toxicity, as is usually the case. Instead we have a score for carcinogenic substances, heavy metals, winter smog and pesticides. The reason for this is that we could not find any reduction target for such a vague concept. We therefore opted to specify the term "toxicity" in individual problems.

As a result of these changes, the Eco-indicator can be viewed as an indicator for emissions, and raw materials exhaustion and the use of space for waste must be assessed individually for the moment. Despite this limitation we feel that the indicator is a powerful tool. Emissions will be our greatest concern if we wish to protect health and ecosystems.

2.4 Summary of weighting factors

Table 10 summarizes the values and the criteria used in determining them. The choice of these criteria is very important because there is a direct correlation with the reduction factors. If 5% ecosystem damage is compared with ten deaths per year rather than one, then all reduction factors based on the number of deaths criterion will fall by a factor of ten, assuming there is a linear correlation between an effect and the number of deaths.

Table 10 gives you an opportunity to calculate other weightings for yourself if you wish to use different criteria.

	Characterization	Reduction factor	Criterion
Greenhouse	CML (IPCC)	2.5	0.1° per decade, 95th percentile?
Ozone layer	CML (IPCC)	100	Probability of 1 death per year per million inhabitants
Acidification	CML	10	95th percentile
Eutrophication	CML	5	Rivers and lakes damage to an unknown number of aquatic ecosystems? (95th percentile?)
Summer smog	CML	2.5	Prevent smog periods, health complaints, particularly amongst asthma patients and the elderly
Winter smog	Air Quality Guidelines	5	Prevent smog periods, health complaints, particularly amongst asthma patients and the elderly
Pesticide	Active ingredient	25	95th percentile ecosystems
Heavy metals in air	Air Quality Guidelines	5	Lead content in blood of children, limited life expectancy and learning performance in an unknown number of people
Heavy metals in water	Quality Guidelines for water	5	Cadmium content in rivers, ultimately also has an effect on people (see air)
Carcinogenic substances	Air Quality Guidelines	10	Probability of 1 death per year per million inhabitants

Table 10: Background weighting factors.

3 Eco-indicator 99

Eco-indicator 99 is the successor of Eco-indicator 95. Both methods use the damage-oriented approach. The development of the Eco-indicator 99 methodology started with the design of the weighting procedure. Traditionally in LCA the emissions and resource extractions are expressed as 10 or more different impact categories, like acidification, ozone layer depletion, ecotoxicity and resource extraction. For a panel of experts or non-experts it is very difficult to give meaningful weighting factors for such a large number and rather abstract impact categories. It was concluded that the panel should not be asked to weight the impact categories but the different types of damage that are caused by these impact categories. The other improvement was to limit the number of items that are to be assessed. As a result the panel, consisting of 365 persons from a Swiss LCA interest group, was asked to assess the seriousness of three damage categories:

1. Damage to Human Health, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World bank and WHO.

2. Damage to Ecosystem Quality, express as the loss of species over an certain area, during a certain time
3. Damage to Resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels.

In order to be able to use the weights for the three damage categories a series of complex damage models had to be developed. In Figure 4 these models are represented in a schematic way.

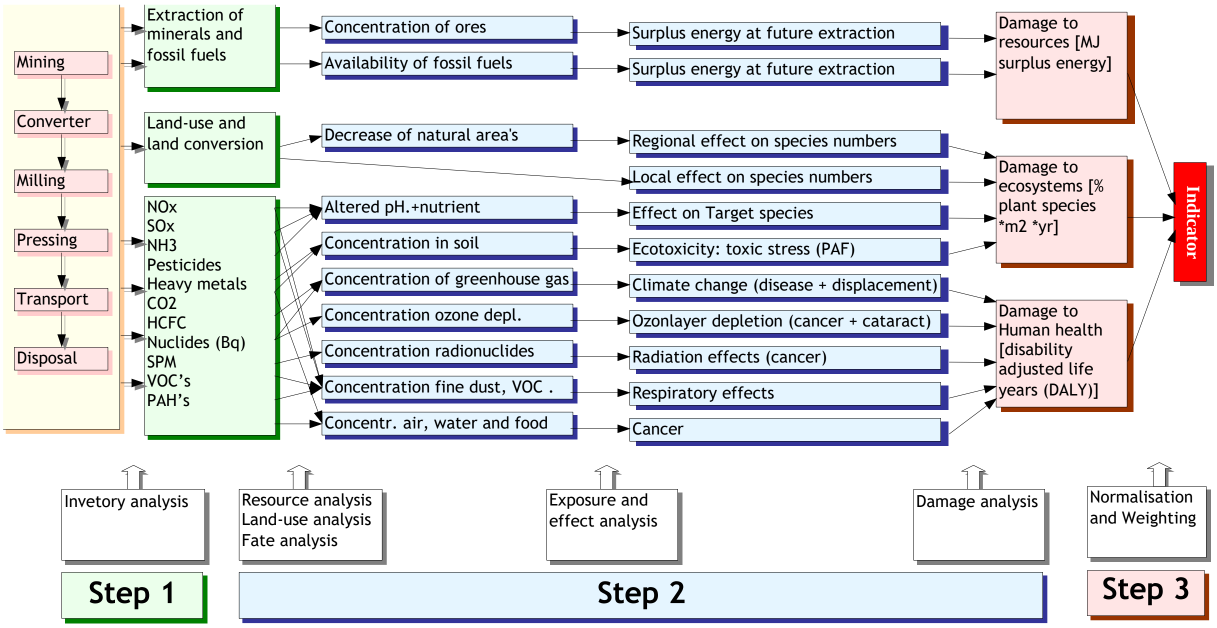

Figure 5: Detailed representation of the damage model

In general, the factors used in SimaPro do not deviate from the ones in the (updated) report. In case the report contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names in the database are used. A distinction is made for emissions to agricultural soil and industrial soil, indicated with respectively (agr.) or (ind.) behind substance names emitted to soil.

3.1 Characterization

Emissions

Characterization is factors are calculated at end-point level (damage). The damage model for emissions includes fate analysis, exposure, effects analysis and damage analysis.

This model is applied for the following impact categories:

Carcinogens

Carcinogenic affects due to emissions of carcinogenic substances to air, water and soil. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.

Respiratory organics

Respiratory effects resulting from summer smog, due to emissions of organic substances to air, causing respiratory effects. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.

Respiratory inorganics

Respiratory effects resulting from winter smog caused by emissions of dust, sulphur and nitrogen oxides to air. Damage is expressed in Disability adjusted Life Years (DALY) / kg emission.

Climate change

Damage, expressed in DALY/kg emission, resulting from an increase of diseases and death caused by climate change.

Radiation

Damage, expressed in DALY/kg emission, resulting from radioactive radiation

Ozone layer

Damage, expressed in DALY/kg emission, due to increased UV radiation as a result of emission of ozone depleting substances to air.

Ecotoxicity

Damage to ecosystem quality, as a result of emission of ecotoxic substances to air, water and soil. Damage is expressed in Potentially Affected Fraction (PAF)*m2*year/kg emission.

Acidification/ Eutrophication

Damage to ecosystem quality, as a result of emission of acidifying substances to air. Damage is expressed in Potentially Disappeared Fraction (PDF)* m2*year/kg emission.

Land use

Land use (in manmade systems) has impact on species diversity. Based on field observations, a scale is developed expressing species diversity per type of land use. Species diversity depends on the type of land use and the size of the area. Both regional effects and local effects are taken into account in the impact category:

Damage as a result of either conversion of land or occupation of land. Damage is expressed in Potentially Disappeared Fraction (PDF)* m^2*year/ m^2 or m2a.

Resource depletion

Mankind will always extract the best resources first, leaving the lower quality resources for future extraction. The damage of resources will be experienced by future generations, as they will have to use more effort to extract remaining resources. This extra effort is expressed as “surplus energy”.

Minerals

Surplus energy per kg mineral or ore, as a result of decreasing ore grades.

Fossil fuels

Surplus energy per extracted MJ, kg or m3 fossil fuel, as a result of lower quality resources.

3.2 Uncertainties

Of course it is very important to pay attention to the uncertainties in the methodology that is used to calculate the indicators. Two types are distinguished:

1. Uncertainties about the correctness of the models used
2. Data uncertainties

Data uncertainties are specified for most damage factors as squared geometric standard deviation in the original reports, but not in the method in SimaPro. It is not useful to express the uncertainties of the model as a distribution. Uncertainties about the model are related to subjective choices in the model. In order to deal with them we developed three different versions of the methodology, using the archetypes specified in Cultural Theory. The three versions of Eco-indicator 99 are:

1. the egalitarian perspective
2. the hierarchist perspective
3. the individualist perspective

Hierarchist perspective

In the hierarchist perspective the chosen time perspective is long-term, substances are included if there is consensus regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a and 2b are included, while class 3 has deliberately been excluded. In the hierarchist perspective damages are assumed to be avoidable by good management. For instance the danger people have to flee from rising water levels is not included. In the case of fossil fuels the assumption is made that fossil fuels cannot easily be substituted. Oil and gas are to be replaced by shale, while coal is replaced by brown coal. In the DALY calculations age weighting is not included.

Egalitarian perspective

In the egalitarian perspective the chosen time perspective is extremely long-term, Substances are included if there is just an indication regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a, 2b and 3 are included, as far as information was available. In the egalitarian perspective, damages cannot be avoided and may lead to catastrophic events. In the case of fossil fuels the assumption is made that fossil fuels cannot be substituted. Oil, coal and gas are to be replaced by a future mix of brown coal and shale. In the DALY calculations age weighting is not included.

Individualist perspective

In the individualist perspective the chosen time perspective is short-term (100 years or less). Substances are included if there is complete proof regarding their effect. For instance only carcinogenic substances in IARC class 1 included, while class 2a, 2b and 3 have deliberately been excluded. In the individualist perspective damages are assumed to be recoverable by technological and economic development. In the case of fossil fuels the assumption is made that fossil fuels cannot really be depleted. Therefore they are left out. In the DALY calculations age weighting is included.

3.3 Damage assessment

Damages of the impact categories result in three types of damages:

1. Damage to Human Health, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and the WHO.
2. Damage to Ecosystem Quality, express as the loss of species over an certain area, during a certain time
3. Damage to Resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels.

3.4 Normalization

Normalization is performed on damage category level. Normalization data is calculated on European level, mostly based on 1993 as base years, with some updates for the most important emissions.

3.5 Weighting

In this method weighting is performed at damage category level (endpoint level in ISO). A panel performed weighting of the three damage categories. For each perspective, a specific weighting set is available. The average result of the panel assessment is available as weighting set.

The hierarchist version of Eco-indicator 99 with average weighting is chosen as default. In general, value choices made in the hierarchist version are scientifically and politically accepted.

4 Ecological Footprint

The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption.

4.1 Characterization

In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use:

$$EF = EF_{direct} + EF_{CO2} + EF_{nuclear}$$

4.2 Normalization and weighting

Normalization is not a part of the method. To get a footprint, each impact category is given the weighting factor 1.

References

Frischknecht, R.; Jungbluth, N.; Althaus. H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

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5 Ecological scarcity 2006

The “ecological scarcity” method (also called Ecopoints or Umweltbelastungspunkte method) is a follow up of the Ecological scarcity 1997 method (see section 7.4), named Ecopoints 97 (CH) in the SimaPro method library.

The ecological scarcity method weights environmental impacts - pollutant emissions and resource consumption - by applying "eco-factors". The eco-factor of a substance is derived from environmental law or corresponding political targets. The more the current level of emissions or consumption of resources exceeds the environmental protection target set, the greater the eco-factor becomes, expressed in eco-points (EP). An eco-factor is essentially derived from three elements (in accordance with ISO Standard 14044): characterization, normalization and weighting.

5.1 Characterization, normalization and weighting

Characterization captures the relative harmfulness of a pollutant emission or resource extraction vis-à-vis a reference substance within a given impact category (global warming potential, acidification potential, radioactivity etc.). Normalization quantifies the contribution of a unit of pollutant or resource use to the total current load/pressure in a region (in this case the whole of Switzerland) per year. Weighting expresses the relationship between the current pollutant emission or resource consumption (current flow) and the politically determined emission or consumption target (critical flow).

The Ecoinvent implementation contains seven specific impact categories, with for each substance a final UBP (environmental loading points) score as characterization factor which compile the characterization, normalization and distance-to-target weighting. The impact categories considered by this method are not defined as an impact indicator but rather as type of emission or resource:

- Emissions into air
- Emissions into surface water

- Emissions into ground water
- Emissions into top soil
- Energy resources
- Natural resources
- Deposited waste

References

Frischknecht, R.; Steiner, R.; Jungbluth, N. 2008. Methode der ökologischen Knappheit - Ökofaktoren 2006. Öbu SR No. 28/2008, Bundesamt für Umwelt (BAFU), ÖBU Schweizerische Vereinigung für ökologisch bewusste Unternehmungsführung, Zürich und Bern.

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Frischknecht, R.; Steiner, R.; Braunschweig, A.; Egli, N.; Hildesheimer, G. 2006. Swiss Ecological Scarcity Method: The New Version 2006. Available at http://www.esu-services.ch/fileadmin/download/Frischknecht-2006-EcologicalScarcity-Paper.pdf.

6 Ecological Scarcity 2006 (Water Scarcity)

This method is taken from http://www.esu-services.ch/projects/ubp06/ (23-May 2008), with adaptations by PRé as described below. The characterization factors have first been implemented by ESU-services Ltd. All files are provided without liability. Contact info: http://www.esu-services.ch/address/

Ecological Scarcity 2006 is a follow up of the Ecological scarcity 1997 method, which is called Ecopoints 97 (CH) in the SimaPro method library (superseded). The ecoinvent implementation contains seven specific impact categories, with for each substance a final UBP (environmental loading points) score as characterization factor. This method only contains the impact category Natural resources containing only water resources. The complete method can be found in the European methods category.

7 Ecopoints 97

The Swiss Ministry of the Environment (BUWAL) has developed the Ecopoint system, based on actual pollution and on critical targets that are derived from Swiss policy. It is one of the earliest systems for impact assessment with a single score. Like the Eco-indicator 95 method, described above, it is based on the distance-to-target method. The Swiss Ecopoints 1997 (also called Swiss ecoscarcity) is an update of the 1990 method.

There are three important differences:

1. The Ecopoint system does not use a classification. It assesses impacts individually. Although this allows for a detailed and very substance-specific method, it has the disadvantage that only a few impacts are assessed.
2. The Ecopoint system uses a different normalization principle. It uses target values rather than current values.
3. The Ecopoint system is based on Swiss policy levels instead of sustainability levels. Policy levels are usually a compromise between political and environmental considerations.

The following data are necessary in calculating a score in ecopoints for a given product:

4. quantified impacts of a product;
5. total environmental load for each impact type in a particular geographical area;
6. maximum acceptable environmental load for each impact type in that particular geographical area.

7.1 Normalization

In SimaPro you will find 3 normalization sets: Target; Actual; and Ecopoints.

1. Normalization on Target Value or Critical Emission (N=Target)

   The original formula is used to calculate the Ecopoints:

$$\text{Ecofactor} = \frac{1}{Fk} \times \frac{F}{Fk} \times Const$$

$$\frac{1}{Fk} = \textit{normalization factor}$$

$$\frac{F}{Fk} \times Const = \textit{evaluation factor}$$

2. Normalization based on Actual Emission (N= Actual)

   The adapted formula is used to calculate the Ecopoints so that normalization based on actual emissions can be done:

$$\text{Ecofactor} = \frac{1}{F} \times \frac{F}{Fk} \times \frac{F}{Fk} \times Const$$

$$\frac{1}{F} = \text{normalization factor}$$

$$\frac{F}{Fk} \times \frac{F}{Fk} Const = \textit{evaluation factor}$$

F =*Actual Swiss emission per year*

Fk =Critical Swiss emission per year Const.=10^{12}/year

3. Ecopoints

   Ecofactors given in the evaluation step, normalization factors=1.

7.2 Weighting

Ecopoints (weighting factors) are calculated using the following formula:

$$f = \frac{1}{Fk} \times \frac{F}{Fk} \times 10^{12} = \frac{F}{Fk^2} \times 10^{12}$$

f: ecofactor	*F: actual total current load*
Fk: target norm for total load	*10^{12} constant*

The first term (1/Fk) expresses the relative contribution of the load to the exceeding of the target norm. It is the normalization step. The second term (F/Fk) expresses the extent to which the target norm is already being exceeded.

Please note that not all sum parameters such as (heavy) metals, AOX contributants, are included in the method.

References

Braunschweig A. et al. 1998. Bewertung in Ökobilanzen mit der Methode der ökologischen Knappheit. Ökofaktoren, Methodik Für Oekobilanzen, Buwal Schriftenreihe Umwelt Nr 297.

8 Ecosystem Damage Potential

The Ecosystem Damage Potential (EDP) is a life cycle impact assessment methodology for the characterization of land occupation and transformation developed by the Swiss Federal Institute of Technology (ETH), Zürich. It is based on impact assessment of land use on species diversity.

8.1 Characterization

This method was created using empirical information on species diversity from Central Europe. With information about species diversity on 5581 sample plots, Characterization factors for 53 land use types and six intensity classes were calculated. The typology is based on the CORINE Plus classification.

Linear transformations of the relative species numbers are linearly transformed into ecosystem damage potentials. The damage potential calculated is endpoint oriented.

The impact factor for the unknown reference land use type (ref) before or after the land transformation is chosen as EDP(ref) = 0.80. This represents the maximum EDP, i.e. the land use type with the most negative impact.

The different impact categories implemented in SimaPro are:

- "land transformation" as a result of the addition of "transformation, from land use type I" and "transformation, to land use type I"
- "land occupation"

Normalization is not a part of this method.

Because the two impact categories are expressed in the same unit (points), PRé added a weighting step. Each impact category is given the weighting factor 1.

References

Koellner, T.; Scholz, R. 2007. Assessment of land use impact on the natural environment: Part 1: An Analytical Framework for Pure Land Occupation and Land Use Change. Int J LCA 12 (1): 16-23.

9 EDIP 2003

EDIP 2003 is a Danish LCA methodology that is presented as an update of the EDIP 97 methodology. The main innovation of EDIP2003 lies in the consistent attempt to include exposure in the characterization modelling of the main non-global impact categories. EDIP2003 can originally be used both with and without spatial differentiation. Only characterization factors for site-generic effects, which does not take spatial variation into account, are implemented in SimaPro 8.

9.1 Characterization

The EDIP 2003 methodology represents 19 different impact categories. Some of them are updated versions of EDIP 97, whereas others are modelled totally differently. Table 1 gives an overview of the EDIP 2003 impact categories. The choices made for implementing the methodology into SimaPro 8, are summed up for each impact category.

Impact categories	Implemented in original form	Choices made during implementation
Global warming		**Time horizon of 100y is used (IPPC, 2007)**
Ozone depletion	**x**	
Acidification	**x**	

Terrestrial eutrophication	**x**	
Aquatic eutrophication (N-eq)		**Only emissions to inland waters only are included. Emissions to air included**
Aquatic eutrophication (P-eq)		
Ozone formation (human)	**x**	**Extended with extra factors from EI 2.0**
Ozone formation (vegetation)	**x**	**Extended with extra factors from EI 2.0**
Human toxicity (exposure route via air)		**Release height of 25m**
Human toxicity (exposure route via water)	**x**	
Human toxicity (exposure route via soil)	**x**	
Ecotoxicity (water acute)	**x**	
Ecotoxicity (water chronic)	**x**	
Ecotoxicity (soil chronic)	**x**	
Hazardous waste	**Directly taken from EDIP 97 (update 2004)**	
Slags/ashes	**Directly taken from EDIP 97(update 2004)**	
Bulk waste	**Directly taken from EDIP 97(update 2004)**	
Radioactive waste	**Directly taken from EDIP 97(update 2004)**	
Resources	**Directly taken from EDIP 97(update 2004)**	

Table 1: Overview of the different impact categories in EDIP2003, and the changes made for implementation.

In the EDIP 2003 method, characterization factors for aquatic eutrophication are developed for two impact categories: aquatic eutrophication (N-eq) and aquatic eutrophication (P-eq). In each impact category, characterization factors for emissions effecting inland waters and emissions effecting marine waters are developed. This double set of characterization factors reflects the fact that, in general, eutrophication is limited by nitrate in fresh waters, and phosphate in marine waters.

In order to avoid double counting, that would occur if both emission types are implemented simultaneously, only the characterization factors for inland water are implemented in SimaPro. When characterization factors for marine water are needed, the following list can be used and implemented in the EDIP 2003 method:

Substances	CAS no.	Impact category			
Emission to marine water		**Aquatic eutrophication**		**Aquatic eutrophication**	
Compartment		Soil	Water	Water	Soil
Nitric acid	7697-37-2	1,24E-01	1,61E-01	0,00E+00	0,00E+00
Nitrite	14797-65-0	1,62E-01	2,10E-01	0,00E+00	0,00E+00
Cyanide	57-12-5	2,92E-01	3,78E-01	0,00E+00	0,00E+00
Nitrogen, total		5,40E-01	7,00E-01	0,00E+00	0,00E+00
Phosphate	14265-44-2	0,00E+00	0,00E+00	3,30E-01	1,98E-02
Pyrophosphate	7722-88-5	0,00E+00	0,00E+00	3,50E-01	2,10E-02
Phosphorus, total		0,00E+00	0,00E+00	1,00E+00	6,00E-02

Table 2: Characterization factors for emissions to marine water in aquatic eutrophication. Emission compartment soil corresponds with the source category waste water while water corresponds with the source category agriculture.

The emission to soil only takes into account the effects after plant uptake. For this impact category the topsoil is part of the technosphere. Emissions to air are also included in the model. The data needed for this compartment is not present in the guideline, but is received from Michael Hauschild.

The EDIP2003 characterization factors for human toxicity, exposure route via air, are enhanced. The new exposure factors are established for:

- Two different kinds of substances: short-living (hydrogen chloride) and long-living (benzene)
- Actual variation in regional and local population densities: added for each substance
- Different release heights: 1m, 25m and 100m.

The release height of 25m is presented as default in EDIP2003 and is used in SimaPro.

9.2 Normalization

There are normalization factors provided for Europe in the reference year 2004 (Laurent et al. 2011).

9.3 Weighting

Until the EDIP weighting factors have been updated to an EDIP2003 version, the weighting factors of EDIP97 (according to the update issued in 2004), are also used in EDIP2003. Because ecotoxicity has no normalization factors, also for weighting the value is set at zero. For resources, normalization and weighing are already included in the characterization factor and therefore set at zero.

References

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Hauschild, M.; Potting, J. 2003. Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

Laurent, A.; Lautier, A.; Rosenbaum, R.K.; Olsen, S.I.; Hauschild, M.Z. 2011. Normalization in EDIP97 and EDIP2003: updated European inventory for 2004 and guidance towards a consistent use in practice. Int J LCA 16 (8): 728-738.

10 EDIP/UMIP 97

The EDIP method (Environmental Design of Industrial Products, in Danish UMIP) was developed in 1996.

In 2004 the characterization factors for resources, the normalization and weighting factors for all impact categories were updated. Excluded in this version of the method in SimaPro are working environment and emissions to waste water treatment plants (WWTP).

The method is adapted for SimaPro. All characterization factors in this method are entered for the 'unspecified' sub-compartment of each compartment (raw, air, water, soil) and thus applicable on all sub-compartments, where no specific characterization value is specified.

10.1 Characterization

Global warming is based on the IPCC 1994 Status report. Is SimaPro GWP 100 is used. Stratospheric ozone depletion potentials are based on the status reports (1992/1995) of the Global Ozone Research Project (infinite time period used in SimaPro). Photochemical ozone creation potentials (POCP) were taken from UNECE reports (1990/1992). POCP values depend on the background concentration of NOx, in SimaPro we have chosen to use the POCPs for high background concentrations. Acidification is based on the number of hydrogen ions (H+) that can be released. Eutrophication potential is based on N and P content in organisms. Waste streams are divided in 4 categories, bulk waste (not hazardous), hazardous waste, radioactive waste and slags and ashes. All wastes are reported on a mass basis.

Ecotoxicity is based on a chemical hazard screening method, which looks at toxicity, persistency and bio-concentration. Fate or the distribution of substances into various environmental compartments is also taken account. Ecotoxicity potentials are calculated for acute and chronic ecotoxicity to water and chronic ecotoxicity for soil. As fate is included, an emission to water may lead not only to chronic and acute ecotoxicity for water, but also to soil. Similarly an emission to air gives ecotoxicity for water and soil. This is the reason you will find emissions to various compartments in each ecotoxicity category.

Human toxicity is based on a chemical hazard screening method, which looks at toxicity, persistency and bio-concentration. Fate or the distribution of substances into various environmental compartments is also taken account. Human toxicity potentials are calculated for exposure via air, soil, and surface water. As fate is included, an emission to water may lead not only to toxicity via water, but also via soil. Similarly an emission to air gives human toxicity via water and soil. This is the reason you will find emissions to various compartments in each human toxicity category.

As resources use a different method of weighting, it cannot be compared with the other impact categories, for which reason the weighting factor is set at zero. Resources should be handled with great care when analyzing results, the characterization and normalization results cannot be compared with the other impact categories.

To give the user some information in a useful way all resources have been added into one impact category. As equivalency factor the result of the individual normalization and weighting scores have been used, i.e. the resulting score per kg if they would have been calculated individually.

For detailed information on resources, including normalization and weighting, choose the "EDIP/UMIP resources only" method.

EDIP v2.0 resources only

In the "EDIP/UMIP resources only" method only resources are reported. Opposite to the default EDIP/UMIP method, resources are given in individual impact categories, on a mass basis of the pure resource (i.e. 100% metal in ore, rather than ore). Normalization is based on global production per world citizen, derived from World Resources 1992. Weighting of non-renewables is based on the supply-horizon (World Reserves Life Index), which specifies the period for which known reserves will last at current rates of consumption. If no normalization data are known for an individual impact category, the normalization value is set at one and the calculation of the weighting factor is adjusted so that the final result is still consistent. However this may give strange looking graphs in the normalization step.

10.2 Normalization

The normalization value is based on person equivalents for 1994 (according to the update issued in 2004). For resources, normalization and weighing are already included in the characterization factor and therefore set at zero.

10.3 Weighting

The weighting factors are set to the politically set target emissions per person in the year 2004 (according to the update issued in 2004), the weighted result are expressed except for resources which is based on the proven reserves per person in 1994. For resources, normalization and weighing are already included in the characterization factor and therefore set at zero.

Note:

Presenting the EDIP method as a single score (addition) is allowed, however it is not recommended by the authors. Note that due to a different weighting method for resources (based on reserves rather than political targets), resources may never be included in a single score. This is the reason that the weighting factor for resources is set at zero.

References

Hauschild, M.; Wenzel, H. 1998. Environmental Assessment of Products. Volume 2: Scientific background. Chapman and Hall. See http://www.wkap.nl/book.htm/0-412-80810-2.

Wenzel, H.; Hauschild, M.; Alting, L. 1997. Environmental Assessment of Products. Volume 1: Methodology, tools and case studies in product development. Chapman and Hall. See http://www.wkap.nl/book.htm/0-7923-7859-8.

11 EF Method (adapted)

EF method is the impact assessment method of Environmental Footprint (EF), initiative introduced by the European Commission. The EF method 2.0 was the one to be used in Product Environmental Footprint Category Rules (PEFCRs) and Organisation Footprint Sector Rules (OEFSRs) of the EF pilot phase. Its validity has ended in December 2021. The method included in the SimaPro Professional database includes a number of adaptations, which make the EF method compatible with the data libraries provided in SimaPro.

Since the method was modified, it is not suitable for conducting the EF-compliant studies but can be used for other assessments. The original version of the method will be distributed in the dedicated SimaPro EF database.

The implementation is based on EF method with the following modifications:

- It does not include any substances, which would be new to SimaPro, e.g. regionalized land use flows;
- Additional substances have been included as they are extensively used by the background databases and their synonyms are part of the original EF method:
    - Resource use, energy carriers - flows expressed in mass units (not only in net calorific value as in EF); characterization factor corresponds to the lower heating values of given fuel;
    - Resource use, mineral and metals - additional flows for already characterized mineral and metals;
    - Water use - flows representing geographies not covered in the original EF method; global factor was applied;
    - Climate change - carbon dioxide (emission to air) is added with factor of carbon dioxide, fossil; carbon dioxide, to soil or biomass stock is added with factor -1 (this flow is necessary for the correct modeling of land use in ecoinvent).

11.1.1 Characterization

Impact category	Recommended default LCIA method	Indicator
Climate change	Baseline model of the IPCC 2013, including the carbon feedbacks for different substances. *IPCC 2013 supplementary material chap. 8 tab 8SM15* https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/supplementary/WG1AR5_Ch08SM_FINAL.pdf	Global Warming Potential 100 years
Ozone depletion	Steady-state ODPs *Scientific Assessment of Ozone Depletion: 1998. Global Ozone Research and Monitoring Project - Report No. 44,* ISBN 92-807-1722-7, Geneva. Undefined Report no. 4 by WMO (1999)	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years
Human toxicity, cancer	USEtox consensus model Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., Van de Meent, D., Hauschild, M.Z., 2008, *USEtox™, the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment.* Int J Life Cycle Assess 13 (7): 532-546	Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).
Human toxicity, non-cancer	USEtox consensus model Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., Van de Meent, D., Hauschild, M.Z., 2008, *USEtox™, the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment.* Int J Life Cycle Assess 13 (7): 532-546	Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogram).
Respiratory inorganics	PM method recommendaed by UNEP Fantke, P., Evans, J., Hodas, N., Apte, J., Jantunen, M., Jolliet, O., McKone, T.E. (2016). *Health impacts of fine particulate matter. In: Frischknecht, R., Jolliet, O. (Eds.), Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative, Paris, pp. 76-99*	Disease incidence due to kg of PM2.5 emitted
Ionising radiation, human health	Human health effect model as developed by Dreicer et al. 1995 Frischknecht, R., Braunschweig, A., Hofstetter P., Suter P. (2000), *Modelling human health effects of radioactive releases in Life Cycle Impact Assessment. Environmental Impact Assessment Review, Volume 20, Number 2, April 2000, pp. 159-189*	Ionizing Radiation Potentials: Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235
Photochemical ozone formation, human health	LOTOS-EUROS model Van Zelm, R., Huijbregts, M.A.J., Den Hollander, H.A., Van Jaarsveld, H.A., Sauter, F.J., Struijs, J., Van Wijnen, H.J., Van de Meent, D. (2008). *European characterization factors for human health damage of PM10 and ozone in life cycle impact assessment.* Atmospheric Environment 42, 441-453	Photochemical ozone creation potential (POCP): Expression of the potential contribution to photochemical ozone formation
Acidification	Accumulated Exceedance Seppälä, J., M. Posch, M. Johansson and J. P. Hettelingh (2006). *Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator*. International Journal of	Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive

	Life Cycle Assessment 11(6): 403-416 Posch, M., J. Seppälä, J. P. Hettelingh, M. Johansson, M. Margni and O. Jolliet (2008). *The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterization factors for acidifying and eutrophying emissions in LCIA.* International Journal of Life Cycle Assessment 13(6): 477-486	area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit.
Terrestrial eutrophication	Accumulated Exceedance Seppälä, J., M. Posch, M. Johansson and J. P. Hettelingh (2006). *Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator*. International Journal of Life Cycle Assessment 11(6): 403-416 Posch, M., J. Seppälä, J. P. Hettelingh, M. Johansson, M. Margni and O. Jolliet (2008). *The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterization factors for acidifying and eutrophying emissions in LCIA*. International Journal of Life Cycle Assessment 13(6): 477-486	Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which eutrophying substances deposit
Freshwater eutrophication	EUTREND model Struijs, J., Beusen, A., van Jaarsveld, H. and Huijbregts, M.A.J. (2008b). Aquatic Eutrophication. Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (2008). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition. Chapter in anthology Chapter on aquatic eutrophication in the ReCiPe report (report I: characterization factors, 2008).*	Phosphorus equivalents: Expression of the degree to which the emitted nutrients reaches the freshwater end compartment (phosphorus considered as limiting factor in freshwater).
Marine eutrophication	EUTREND model Struijs, J., Beusen, A., van Jaarsveld, H. and Huijbregts, M.A.J. (2008b). Aquatic Eutrophication. Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (2008). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition. In press. Chapter in anthology Chapter on aquatic eutrophication in the ReCiPe report (report I: characterization factors, 2008)*	Nitrogen equivalents: Expression of the degree to which the emitted nutrients reaches the marine end compartment (nitrogen considered as limiting factor in marine water)
Land use	CFs set re-calculated by JRC starting from LANCA® v 2.2 as baseline model. Bos U., Horn R., Beck T., Lindner J.P., Fischer M. (2016). *LANCA® Characterization Factors for Life Cycle Impact Assessment. Version 2.* Franhofer Verlag, Stuttgart, DE. http://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-3793106.pdf	Soil quality index
Ecotoxicity freshwater	USEtox consensus model Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., Van de Meent, D., Hauschild, M.Z., 2008, *USEtox™, the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment*. Int J Life Cycle Assess 13 (7): 532-546	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg)
Water scarcity	Available WAter REmaining (AWARE) as recommended by UNEP Boulay A.M., Bare J., Benini L., Berger M., Lathuillière M.J., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A.V., Ridoutt B., Oki T., Worbe S., Pfister S. (2016). *The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE)*	m3 water eq. deprived
Resource use, energy carriers	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). van Oers, L, Koning, A, Guinée, JB, Huppes, G (2002) *Abiotic resource depletion in*	Abiotic resource depletion fossil fuels (ADP-fossil); based on lower heating

	LCA. Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam http://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf	value
Resource use, mineral and metals	ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). van Oers, L, Koning, A, Guinée, JB, Huppes, G (2002) *Abiotic resource depletion in LCA.* Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam http://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf	Abiotic resource depletion (ADP ultimate reserve)

11.1.2 Normalization and weighting

Global normalization set for a reference year 2010 is part of the EF method.

The EF 2.0 method includes two versions of the weighting factors – including and excluding three toxicity-related impact categories. Currently, those impact categories are "not seen as sufficiently robust to be included in external communications or in a weighted result". The EF 3.0 method only has a single weighting set, which includes toxicity.

After an evaluation of existing weighting methods, three weighting sets were developed: i) panel based approach - general public survey; ii) panel based approach - LCA experts' survey; iii) hybrid evidence-and judgement-based approach. Those three weighting sets were then aggregated by first averaging the sets based on panel based approach.

References

Fazio, S. Castellani, V. Sala, S., Schau, EM. Secchi, M. Zampori, L., *Supporting information to the characterization factors of recommended EF Life Cycle Impact Assessment methods*, EUR 28888 EN, European Commission, Ispra, 2018, ISBN 978-92-79-76742-5, doi:10.2760/671368, JRC109369.

Normalization and weighting factors: *Annex A of the Product Environmental Footprint Category Rules Guidance v6.3*, May 2018. http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf.

Sala S., Cerutti A.K., Pant R., *Development of a weighting approach for the Environmental Footprint*, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-68042-7, EUR 28562, doi 10.2760/945290.

12 EPD (2008)

This method is to be used for the creation of Environmental Product Declarations or (EPDs), as published on the website Swedish Environmental Management Council (SEMC). The last update of this method is mainly based on the EPD document version 1.0 dated 2008-02-29.

12.1 Characterization

In the standard EPDs one only has to report on the following impact categories:

Original names	**Names in SP**
• Gross Calorific Values (GVC) (referred to as "Higher Heating Values")	Non renewable, fossil
• Greenhouse gases	Global warming (GWP100)
• Ozone-depleting gases	Ozone layer depletion (ODP)
• Acidifying compounds	Acidification
• Gases creating ground-level ozone (Photochemical Ozone creation)	Photochemical oxidation
• Eutrophying compounds	Eutrophication

Specific product category guidelines may require extra information.

12.2 Non renewable, fossil

The values as used for the calculation of the non renewable, fossil impact category are taken from the Cumulative energy demand LCIA method (v 1.05) as implemented in SimaPro. The values from IPPC (2007) are used as recommended on the EPD website. The characterization for biogenic methane has been corrected for the CO2 sequestration.

12.3 Ozone layer depletion (ODP), Photochemical oxidation, Acidification and Eutrophication

The values as used by the EPD document are used.

12.4 Normalization and weighting

Normalization and weighting are not a part of this method.

References

"Revision of the EPD® system into an International EPD®": www.environdec.com/Documents/GPI/EPD_annexes_080229.pdf

We thank Leo Breedveld from 2B (www.to-be.it) for his advice and support.

13 EPD (2013)

This method is the successor of EPD (2008) and is to be used for the creation of Environmental Product Declarations (EPDs), as published on the website of the Swedish Environmental Management Council (SEMC). An EPD is always created according to a Product Category Rule. This method is especially important for everybody who is reporting a Product Category Rule (PCR) published by Environdec.

13.1 Characterization

In the standard EPDs one only has to report on the following impact categories:

Original names	**Names in SimaPro**
Acidification potential	acidification (fate not included)
Eutrophication potential	eutrophication
Global warming potential	global warming'
Photochemical oxidant creation potential	photochemical oxidation'

Additional indicators:

Original names	**Names in SimaPro**
Ozone-depleting gases (expressed as the sum of ozone-depleting potential in mass of CFC 11-equivalents, 20 years)	ozone layer depletion (ODP) (optional)
Abiotic resource depletion	Abiotic depletion (optional)
Abiotic depletion (fossil fuels)	Abiotic depletion, fossil fuels (opt.)

All impact categories are taken directly from the CML-IA baseline method (eutrophication, global warming and photochemical oxidation) and CML-IA non baseline method (acification). These two methods can be found in SimaPro as well.

13.2 Normalization and weighting

Normalization and weighting are not a part of this method.

References

General programme instructions for the international EPD® system, 2.01. 18 September 2013. Download at

http://www.environdec.com/Documents/GPI/General_programme_instructions_2_01_20130918.pdf

14 EPS 2000

The EPS 2000 default methodology (Environmental Priority Strategies in product design) is a damage oriented method. In the EPS system, willingness to pay to restore changes in the safe guard subjects is chosen as the monetary measurement. The indicator unit is ELU (Environmental Load Unit), which includes characterization, normalization and weighting.

The top-down development of the EPS system has led to an outspoken hierarchy among its principles and rules. The general principles of its development are:

- The top-down principle (highest priority is given to the usefulness of the system);
- The index principle (ready-made indices represent weighted and aggregated impacts)
- The default principle (an operative method as default is required)
- The uncertainty principle (uncertainty of input data has to be estimated)
- Choice of default data and models to determine them

The EPS system is mainly aimed to be a tool for a company's internal product development process. The system is developed to assist designers and product developers in finding which one of two product concepts has the least impact on the environment. The models and data in EPS are intended to improve environmental performance of products. The choice and design of the models and data are made from an anticipated utility perspective of a product developer. They are, for instance not intended to be used as a basis for environmental protection strategies for single substances, or as a sole basis for environmental product declarations. In most of those cases additional site-specific information and modelling is necessary.

The EPS 2000 default method is an update of the 1996 version. The impact categories are identified from five safe guard subjects: human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational values.

This V2 version is adapted for SimaPro. All characterization factors in this method are entered for the 'unspecified' sub-compartment of each compartment (Raw materials, air, water, soil) and thus applicable on all sub-compartments, where no specific characterization value is specified.

This method is NOT fully adapted for inventory data from the Ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

14.1 Classification and characterization

Emissions and resources are assigned to impact categories when actual effects are likely to occur in the environment, based on likely exposure. Empirical, equivalency and mechanistic models are used to calculate default characterization values.

Human Health

In EPS weighting factors for damage to human health are included for the following indictors:

- Life expectancy, expressed in Years of life lost (person year)
- Severe morbidity and suffering, in person year, including starvation
- Morbidity, in person year, like cold or flue
- Severe nuisance, in person year, which would normally cause a reaction to avoid the nuisance
- Nuisance, in person year, irritating, but not causing any direct action

Ecosystem production capacity

The default impact categories of production capacity of ecosystems are:

- Crop production capacity, in kg weight at harvest
- Wood production capacity, in kg dry weight
- Fish and meat production capacity, in kg full weight of animals
- Base cat-ion capacity, in H+ mole equivalents (used only when models including the other indicators are not available)
- Production capacity of (irrigation) water, in kg which is acceptable for irrigation, with respect to persistent toxic substances
- Production capacity of (drinking) water, in kg of water fulfilling WHO criteria on drinking water.

Abiotic stock resources

Abiotic stock resource indicators are depletion of elemental or mineral reserves and depletion of fossil reserves. Some classification factors are defined 0 (zero).

In SimaPro, characterization values for abiotic depletion result from both the impact of depletion and impacts due to extraction of the element/mineral or resource.

Biodiversity

Default impact category for biodiversity is extinction of species, expressed in Normalized Extinction of species (NEX).

Cultural and recreational values

Changes in cultural and recreational values are difficult to describe by general indicators as they are highly specific and qualitative in nature. Indicators should be defined when needed, and thus are not included in the default methodology in SimaPro.

14.2 Normalization/Weighting

In the EPS default method, normalization/weighting is made through valuation. Normalization/weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

References

Steen B. 1999. A systematic approach to environmental strategies in product development (EPS). Version 2000 - General system characteristics. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:4.

15 Greenhouse Gas Protocol

The Greenhouse Gas Protocol (GHG Protocol), developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), is an accounting standard of greenhouse gas emissions. This method is based on the draft report on Product Life Cycle Accounting and Reporting Standard.

15.1 Characterization

To calculate carbon dioxide equivalents (CO2eq) of all non-CO2 gases (CH4, N2O, SF6, HFCs, CFCs) the company shall use and report the most recent 100-year IPCC global warming potentials (GWP). The 100–year GWP is a metric used to describe the time-integrated radiative characteristics of well mixed greenhouse gases over a 100-year time horizon.

The total GHG emissions for a product inventory shall be calculated as the sum of GHG emissions, in CO2eq, of all foreground processes and significant background processes within the system boundary. A distinction is made between:

- GHG emissions from fossil sources
- Biogenic carbon emissions
- Carbon storage
- Emissions from land transformation

According to the draft standard on product accounting, fossil and biogenic emissions must be reported independently. The reporting of the emissions from carbon storage and land transformation is optional.

15.2 Normalization and weighting

Normalization and weighting are not a part of this method.

References

WBCSD & WRI. 2009. Product Life Cycle Accounting and Reporting Standard. Review Draft for Stakeholder Advisory Group. The Greenhouse Gas Protocol Initiative. November 2009.

16 ILCD 2011 Midpoint+

This is the corrected and updated method of the ILCD 2011 Midpoint (without the +) which can still be found in the Superseded folder. For this new version, the normalization factors were added as provided in "Normalisation method and data for Environmental Footprints; 2014; Lorenzo Benini, et al.; Report EUR 26842 EN". The characterization factors in the Land use category are updated based on "ERRATA CORRIGE to ILCD - LCIA Characterization Factors" - Version06_02_2015(v. 1.0.6) - "List of changes to CFs for land use from v 1 0 5 to v 1 0 6_REVISED.xlsx".

Characterization factors for long term emissions are set to zero, because this was an implicit requirement from the European Commission. Weighting factors were added with equal weights for each of the recommended categories as indicated by the guidance document.

The full title of this method is: ILCD recommendations for LCIA in the European context. The European Commission (EC-JRC–IES, 2011) analyzed several methodologies for LCIA and made some effort towards harmonization. Starting from the first pre-selection of existing methods and the definition of criteria, a list of recommended methods for each impact category at both midpoint and endpoint was produced.

The endpoint methods, however, are not included here, because the list is far from complete. Recommendations are given for the impact categories of climate change, ozone depletion, human toxicity, particulate matter/respiratory inorganics, photochemical ozone formation, ionizing radiation impacts, acidification, eutrophication, ecotoxicity, land use and resource depletion (Table 3).

Research needs are identified for each impact category and differentiated according to their priority. No method development took place in the development of the ILCD recommendations. The intention was to identify and promote current best practice. These recommendations do not provide recommendations for weighting across impact categories, nor for normalization within a given category relative to impacts in a given region.

Impact category	Recommended default LCIA method	Indicator	Classification*
Climate change	Baseline model of 100 years of the IPCC	Radiative forcing as Global Warming Potential (GWP100)	I
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment	Ozone Depletion Potential (ODP)	I
Human toxicity, cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTUh)	II/III

Human toxicity, non- cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTUh)	II/III
Particulate matter/Respiratory inorganics	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	Intake fraction for fine particles (kg PM2.5-eq/kg)	I
Ionising radiation, human health	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	Human exposure efficiency relative to U235	II
Ionising radiation, ecosystems	No methods recommended		
Photochemical ozone formation	LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe	Tropospheric ozone concentration increase	II
Acidification	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	II
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	II
Eutrophication, aquatic	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe	Fraction of nutrients reaching freshwater end compartment (P)/ marine end compartment (N)	II
Ecotoxicity (freshwater)	USEtox model, (Rosenbaum et al, 2008)	Comparative Toxic Unit for ecosystems (CTUe)	II/III
Ecotoxicity (terrestrial and marine)	No methods recommended		
Land use	Model based on Soil Organic Matter (SOM) (Milà i Canals et al, 2007b)	Soil Organic Matter	III
Resource depletion, water	Model for water consumption as in Swiss Ecoscarcity (Frischknecht et al, 2008)	Water use related to local scarcity of water	III
Resource depletion, mineral, fossil and renewable**	CML 2002 (Guinée et al., 2002)	Scarcity	II

Table 3: Recommended methods and their classification at midpoint (ILCD 2011).

* Levels: “I” (recommended and satisfactory), level “II” (recommended but in need of some improvements) or level “III” (recommended, but to be applied with caution); “interim” indicates that a method was considered the best among the analyzed methods for the impact category, but still immature to be recommended.

** Depletion of renewable resources is included in the analysis but none of the analyzed methods is mature for recommendation

References

European Commission - Joint Research Centre. 2011. *International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context.* First edition November 2011. EUR 24571 EN. Luxemburg. Publications Office of the European Union; 2011

LCIA characterization factors release in February 2012 with errata from March 2012 can be downloaded from http://lct.jrc.ec.europa.eu/assessment/projects.

17 Impact 2002+

IMPACT 2002+, acronym of IMPact Assessment of Chemical Toxics, is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology - Lausanne (EPFL), with current developments carried out by the same team of researchers now under the name of Ecointesys-life cycle systems (Lausanne). The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories (Figure 1).

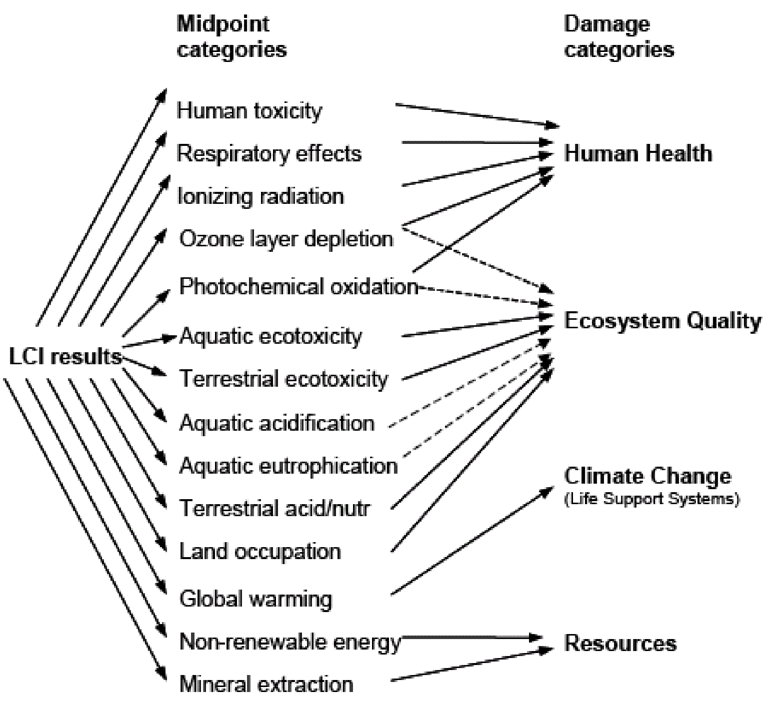

Figure 2: Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories. Based on Jolliet et al. (2003a)

In SimaPro, only the characterization factors at endpoint level are provided.

17.1 Characterization

The characterization factors for human toxicity and aquatic and terrestrial ecotoxicity are taken from the methodology IMPACT 2002+. The characterization factors for other categories are adapted from existing characterizing methods, i.e. Eco-indicator 99, CML 2001, IPCC and the Cumulative Energy Demand.

The IMPACT 2002+ method (version 2.1) presently provides characterization factors for almost 1500 different LCI-results. In SimaPro, 15 different impact categories are presented, as human toxicity is split up in 'Carcinogens' and 'Non-carcinogens'.

17.2 Normalization

The damage factor reported in ecoinvent are normalized by dividing the impact per unit of emission by the total impact of all substances of the specific category for which characterization factors exist, per person per year (for Europe). The unit of all normalized midpoint/damage factors is therefore [pers*year/unitemission], i.e. the number of equivalent persons affected during one year per unit of emission.

17.3 Weighting

The authors of IMPACT2002+ suggest to analyze normalized scores at damage level considering the four-damage oriented impact categories human health, ecosystem quality, climate change, and resources or, alternatively, the 14 midpoint indicators separately for the interpretation phase of LCA. However, if aggregation is needed, one could use self-determined weighting factors or a default weighting factor of one, unless other social weighting values are available.

PRé added an extra weighting step. Each damage category is given the weighting factor 1.

References

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. *Implementation of Life Cycle Impact Assessment Methods: Data v2.0.* ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Jolliet, O.; Margni, M.; Charles, R.; Humbert, S.; Payet, J.; Rebitzer, G.; Rosenbaum, R. 2003. *IMPACT 2002+: A New Life Cycle Impact Assessment Methodology*. Int J LCA 8 (6): 324 – 330.

18 IPCC 2001 GWP

IPCC 2001 is a method developed by the International Panel on Climate Change.

This method lists the climate change factors of IPCC with a timeframe of 20, 100 and 500 years. The method from the ecoinvent 1.01 database was expanded with other characterization factors for emissions available in the SimaPro database.

18.1 Characterization

The IPCC characterization factors for the direct global warming potential of air emissions. They are:

- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere.
- not considering the range of indirect effects given by IPCC.
- including CO2 formation from CO emissions.
- considering biogenic CO2 uptake as negative impact.

18.2 Normalization and weighting

Normalization and weighting are not a part of this method.

References

Intergovernmental Panel on Climate Change (IPCC). 2001. IPCC Third Assessment Report. The Scientific Basis. http://www.grida.no/climate/ipcc_tar/

19 IPCC 2007

IPCC 2007 is an update of the method IPCC 2001 developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20, 100 and 500 years.

19.1 Characterization

IPCC characterization factors for the direct (except CH4) global warming potential of air emissions.

They are:

- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere.

- not considering the range of indirect effects given by IPCC.
- not including CO2 formation from CO emissions.
- If only a minimum or maximum value of a substance is reported this minimum or maximum value is used.
- The substances that do not have a common name but only a formula are not included in the method.
- NOT considering biogenic CO2 uptake and emission, but only considering the biogenic methane release.

19.2 Normalization and weighting

Normalization and weighting are not a part of this method.

References

Intergovernmental Panel on Climate Change. 2007. IPCC Fourth Assessment Report. The Physical Science Basis. http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

Intergovernmental Panel on Climate Change. 2007. IPCC Fourth Assessment Report. The Physical Science Basis. Errata. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Errata_2008-08-05.pdf

20 IPCC 2013

IPCC 2013 is an update of the method IPCC 2007 developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20 and 100 years.

20.1 Characterization

IPCC characterization factors for the direct (except CH4) global warming potential of air emissions. They are:

- not including indirect formation of dinitrogen monoxide from nitrogen emissions.
- not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere.
- not considering the range of indirect effects given by IPCC.
- not including CO2 formation from CO emissions.

20.2 Normalization and weighting

Normalization and weighting are not a part of this method.

References

Intergovernmental Panel on Climate Change. 2013. IPCC Fifth Assessment Report. The Physical Science Basis. http://www.ipcc.ch/report/ar5/wg1/.

21 Pfister et al 2009 (Eco-indicator 99)

This method is based on the publication Pfister et al (2009). The method is based on the same endpoint categories as in the Eco-indicator 99 method.

Human health is obtained by modelling the cause-effect chain of water deprivation for agricultural users (lack of irrigation water) leading to malnutrition. It builds on the midpoint scarcity indicator [Pfister et al 2009 (Water Scarcity)] and models the cause-effect chain by multiplying it by:

- the agricultural users' share of water use from Vorosmarty,
- a socio-economic parameter defined as a human development factor for malnutrition, which relates the Human Development Index and
- two values independent of location combined in an effect factor that describes the DALY/m3 of water deprived for agriculture: the per-capita water requirements to prevent malnutrition (in m3/(yr•capita)) and the damage factor denoting the damage caused by malnutrition (DALY/(yr•capita)).

Ecosystem quality is obtained by modelling the cause-effect chain of freshwater consumption on terrestrial ecosystem quality and assessed following the Eco-indicator 99 method, with units of potentially disappeared fraction of species (PDF). The fraction of net primary productivity (NPP) which is limited by water availability represents the water-shortage vulnerability of an ecosystem, and is used as a proxy for PDF.

Resources is obtained by modelling the cause -effect chain of freshwater consumption on water resource depletion. The back-up technology concept is used following the Eco-indicator 99 method. The damage to resources resulting from water consumption is calculated by multiplying the energy demand for desalination by the fraction of water consumption contributing to freshwater depletion, which is dependent on the withdrawal to availability (WTA) ratio. The unit is expressed in surplus energy (MJ).

The "Human Health" category is comparable with the "HH, marginal" category in the Boulay et al 2011 (Human Health) method the "HH, agricultural water scarcity" category in the Motoshita et al 2010 (Human Health) method.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Pfister, S.; Koehler, A.; Hellweg, S. (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43(11), 4098–4104; DOI: 10.1021/es802423e (download: http://pubs.acs.org/doi/full/10.1021/es802423e)

22 Pfister et al 2009 (Water Scarcity)

This method is based on the publication Pfister et al (2009). This water scarcity indicator (WSI) is based on a withdrawal to availability (WTA) ratio and modelled using a logistic function (S-curve) in order to fit the resulting indicator to values between 0.01 and 1 m3 deprived/m3 consumed. The curve is tuned using OECD water stress thresholds, which define moderate and severe water stress as 20% and 40% of withdrawals, respectively. The indicator is applied to the consumed water volume and assesses consumptive water use only.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

Please note that starting from SimaPro 9.2 Pfister Water Scarcity 2009 method will no longer be updated.

References

Pfister, S.; Koehler, A.; Hellweg, S. (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43(11), 4098–4104; DOI: 10.1021/es802423e (download: http://pubs.acs.org/doi/full/10.1021/es802423e)

23 Pfister et al 2010 (ReCiPe)

This method is based on the publication Pfister et al (2010). The method is based on the same endpoint categories as in the ReCiPe method.

Human health is expressed in DALY and is obtained by modelling the cause-effect chain of water deprivation for agricultural users (lack of irrigation water) leading to malnutrition. The cause-effect chain modelling is based on hydrological and socioeconomic data. The water scarcity index is used at the midpoint [Pfister et al 2009 (Water Scarcity)]. The level of economic development is considered though the parameter Human Development Index.

Ecosystem quality is obtained by modelling the cause-effect chain of freshwater consumption on terrestrial ecosystem quality and assessed following ReCiPe, with units of disappeared species per year.

Resources is obtained by modelling the cause-effect chain of freshwater consumption on water resource depletion following ReCiPe, with units of surplus cost to extract an additional cubic meter of water.

The "Human Health" category is comparable with the "HH, marginal" category in the Boulay et al 2011 (Human Health) method the "HH, agricultural water scarcity" category in the Motoshita et al 2010 (Human Health) method.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute (http://www.worldwater.org/data.html) [old data – 2014 – check for new data].

After calculating your results we recommend you view the 'Checks' tab to see if there are any significant flows omitted due to the incomplete list of characterization factors for some countries.

References

Pfister, Stephan; Saner, Dominik; Koehler, Annette (2010). The environmental relevance of freshwater consumption in global power production. The International Journal of Life Cycle Assessment 2011, 16, 580-591.

24 ReCiPe 2008

ReCiPe is the successor of the methods Eco-indicator 99 and CML-IA. The purpose at the start of the development was to integrate the 'problem oriented approach' of CML-IA and the 'damage oriented approach' of Eco-indicator 99. The 'problem oriented approach' defines the impact categories at a midpoint level. The uncertainty of the results at this point is relatively low. The drawback of this solution is that it leads to many different impact categories which makes the drawing of conclusions with the obtained results complex. The damage oriented approach of Eco-indicator 99 results in only three impact categories, which makes the interpretation of the results easier. However, the uncertainty in the results is higher. ReCiPe implements both strategies and has both midpoint (problem oriented) and endpoint (damage oriented) impact categories. The midpoint characterization factors are multiplied by damage factors, to obtain the endpoint characterization values.

ReCiPe comprises two sets of impact categories with associated sets of characterization factors. At the midpoint level, 18 impact categories are addressed:

1. Ozone depletion
2. Human toxicity
3. Ionizing radiation
4. Photochemical oxidant formation
5. Particulate matter formation
6. Terrestrial acidification
7. Climate change
8. Terrestrial ecotoxicity
9. Agricultural land occupation
10. Urban land occupation
11. Natural land transformation
12. Marine ecotoxicity
13. Marine eutrophication
14. Fresh water eutrophication

15. Fresh water ecotoxicity
16. Fossil fuel depletion
17. Minerals depletion
18. Fresh water depletion

At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories:

- Human health
- Ecosystems
- Resource surplus costs

The three endpoint categories are normalized, weighted, and aggregated into a single score. Figure 2 sketches the relations between lifecycle inventory (LCI) parameters (left side), the 18 midpoint categories (middle), and the 3 endpoint categories, including the single score (right side).

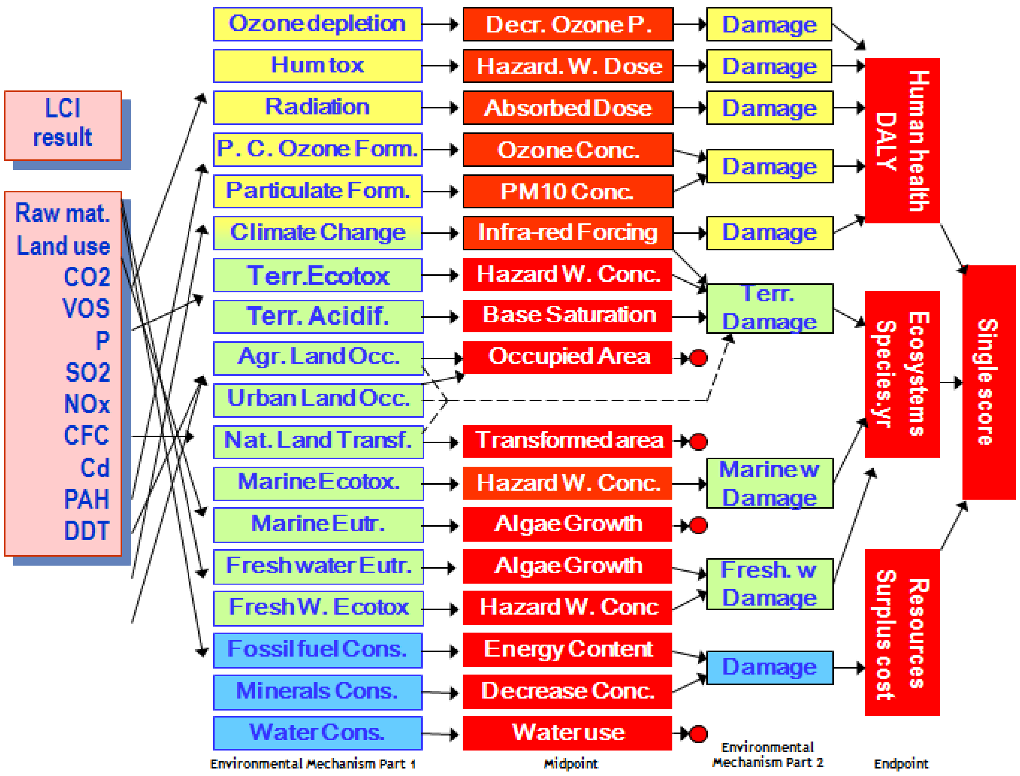

Figure 6: Representation of the relations between the inventory and the midpoint categories (environmental mechanisms) and the endpoint categories, including the single score (damage model).

24.1 Value choices

It is obvious that the environmental mechanisms and damage models are sources of uncertainty: the relationships modelled reflect state of the art knowledge of the environmental mechanisms that has a certain level of incompleteness and uncertainty. In ReCiPe, like in Eco-indicator 99, it was decided to group different sources of uncertainty and different (value) choices into a limited number of perspectives or scenarios, according to the “Cultural Theory” by Thompson 1990.

Three perspectives are discerned: individualist (I), hierarchist (H), and egalitarian (E). These perspectives do not claim to represent archetypes of human behaviour, but they are merely used to group similar types of assumptions and choices. For instance:

4. Perspective I is based on the short-term interest, impact types that are undisputed, technological optimism as regards human adaptation.
5. Perspective H is based on the most common policy principles with regards to time-frame and other issues.
6. Perspective E is the most precautionary perspective, taking into account the longest time-frame, impact types that are not yet fully established but for which some indication is available.

24.2 Characterization at midpoint level

Ozone depletion

The characterization factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). The unit is yr/kg CFC-11 equivalents.

Human toxicity and ecotoxicity

The characterization factor of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The unit is yr/kg 1,4-dichlorobenzeen (14DCB).

Radiation

The characterization factor of ionizing radiation accounts for the level of exposure. The unit is yr/kg Uranium 235 equivalents.

Photochemical oxidant formation

The characterization factor of photochemical oxidant formation is defined as the marginal change in the 24h-average European concentration of ozone (dCO3 in kg·m–3) due to a marginal change in emission of substance x (dMx in kg·year–1). The unit is yr/kg NMVOC.

Particulate matter formation

The characterization factor of particulate matter formation is the intake fraction of PM_{10}. The unit is yr/kg PM_{10} equivalents.

Climate change

The characterization factor of climate change is the global warming potential. The unit is yr/kg CO_2 equivalents.

Agricultural and urban land occupation

The amount of either agricultural land or urban land occupied for a certain time. The unit is m^2*yr.

Natural land transformation

The amount of natural land transformed and occupied for a certain time. The unit is m^2*yr.

Marine eutrophication

The characterization factor of marine eutrophication accounts for the environmental persistence (fate) of the emission of N containing nutrients. The unit is yr/kg N to freshwater equivalents.

Freshwater eutrophication

The characterization factor of freshwater eutrophication accounts for the environmental persistence (fate) of the emission of P containing nutrients. The unit is yr/kg P to freshwater equivalents.

Fossil fuel and minerals depletion

The characterization factor of fossil depletion is the amount of extracted fossil fuel extracted, based on the lower heating value. The unit is kg oil equivalent (1 kg of oil equivalent has a lower heating value of 42 MJ).

Minerals depletion

The characterization factor for minerals depletion is the decrease in grade. The unit is kg Iron (Fe) equivalents.

Freshwater depletion

The factor for the freshwater depletion is the amount of fresh water consumption. The unit is m^3.

24.3 Damage assessment

The endpoint characterization factors used in ReCiPe can be described as follows:

4. Human Health, expressed as the number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and WHO. The unit is years.
5. Ecosystems, expressed as the loss of species over a certain area, during a certain time. The unit is years.
6. Resources surplus costs, expressed as the surplus costs of future resource production over an infinitive timeframe (assuming constant annual production), considering a 3% discount rate. The unit is 2000US$.

24.4 Normalization

The normalization is based on the report of Sleeswijk et al. (2007). The normalization figures used in SimaPro are recalculated per citizen. The used population of EU25+3 is 464,036,294 citizens and the world has 6,055,000,000 citizens. Mineral use and the natural land transformation were not part of this project. Mineral use is based on data from USGS (2000). The source of the land transformation was FAO using the changes between 2000 and 2005.

24.5 Weighting

In this method, weighting is performed at damage category level (endpoint level in ISO terms). A panel performed weighting of the three damage categories. For each perspective, a specific weighting set is available. The average result of the panel assessment is available as weighting set.

The hierarchist version of ReCiPe with average weighting is chosen as default. In general, value choices made in the hierarchist version are scientifically and politically accepted.

References

Goedkoop, M.J.; Heijungs, R.; Huijbregts, M.A.J.; De Schryver, A.M.; Struijs, J.; Van Zelm, R. 2009. ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation. 6 January 2009, http://www.lcia-recipe.net.

Sleeswijk, A.W.; van Oers, L.F.; Guinée, J.B.; Huijbregts, M.A.J. 2007. Normalization in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. Sci Total Environ 390 (1):227-240.