SimaPro database manual

Methods library

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About SimaPro

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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Fact-based sustainability

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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 adapting 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 (see Figure 1) is:

1. Characterization (also referred to as 'midpoint')
2. Damage assessment (also referred to as 'endpoint')
3. Normalization
4. Weighting
5. Addition (often referred to as 'single score')

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.

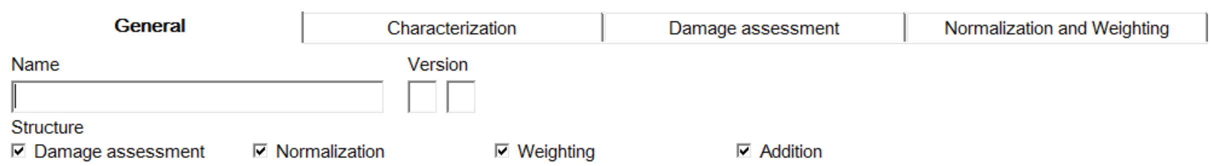

Figure 1: Steps to be selected in a method in SimaPro

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 is equal to 1, while the characterization factor of dinitrogen monoxide can be 273. This means the release of 1 kg dinitrogen monoxide causes the same amount of climate change as 273 kg CO_2, or put differently: dinitrogen monoxide is 273 times more powerful in causing climate change than carbon dioxide. The total result is expressed in a reference unit, in this example it would become kg CO_2 equivalents.

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.

When the sub-compartment in which a substance occurs is defined but the chosen impact assessment method has no specific characterization factor defined for that, SimaPro will adopt the characterization factor included for the “unspecified” sub-compartment.

Some impacts depend on where an emission of resource use takes place. Impact assessment methods often also consider this. For that reason, in SimaPro some substances are regionalized, e.g. water, and impact assessment methods may include different characterization factors per region for the same substance.

Currently, SimaPro supports various substances at country and continental level. More granular spatial variability like watersheds, ecoregions, etc. are not provided in SimaPro desktop. However, in case you can collect this data and the impact assessment method provides CFs for it, users can add the respective substances and add them to their method of choice.

2.2 Damage assessment

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). Damage assessment is added for methods with a midpoint-endpoint framework, such as IMPACT World+ method.

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.

Some methods don’t have actual damage assessment, i.e. mid-to endpoint factors, but Damage in SimaPro might be selected to group various indicators at Characterization step in the Damage step. SimaPro also includes methods that already include characterization factors at endpoint in the Characterization step, e.g. ReCiPe 2016 endpoint methods and LC-IMPACT.

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. 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 Addition

Addition is the final option available for impact assessment methods in SimaPro. It allows the addition of separate indicators in previous steps of the method into a single score.

2.6 Checking impact assessment results

Although impact assessment methods become very complete 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* anywhere in the method are shown under 'Checks' in the result window.

Further, under 'Inventory results' you can choose to see the impact assessment results per substance. If a substance is not defined in the selected method, a dash (-) instead of a value is shown.

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 Categorization of methods in SimaPro

Currently, in SimaPro we include six categories of methods:

- **European:** which include comprehensive LCIA methods that are focused on the European context and, therefore, mostly useful when doing LCA studies in Europe.
- **Global:** which include comprehensive LCIA methods with a global scope, i.e. ideal to apply in studies with a global value chain.
- **North American:** which include methods developed for the North American region.
- **Single issue:** which cover methods which focus on one single metric or environmental impact area, except for those focused on water. Water footprint methods are included in a separate category.
- **Water footprint:** which include methods to assess only water related impacts.
- **Superseded:** which include methods that are outdated and no longer supported by PRé. We strongly discourage users to select these. These are kept and continue to be distributed though because existing SimaPro users might use them. Further details on Superseded methods can be found here.

The methods which are currently provided in SimaPro and still supported are further documented below.

4 European methods

4.1 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 version with 10 'obligatory' impact categories; and an extended version with 'all impact categories' including additional 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.

4.1.1 Different levels of operability

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.

4.1.2 Characterization

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 the multimedia model 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.

Freshwater aquatic ecotoxicity

This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil resulting in Freshwater Aquatic Ecotoxicity Potentials (FAETP). Similar to HTP, 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 and of this method. 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)
- Freshwater 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

4.1.3 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.

4.2 Ecological scarcity 2021

The “Ecological scarcity” method (also called Ecopoints or Umweltbelastungspunkte method) is a follow up of the Ecological scarcity 2013, the Ecological scarcity 2006, and the Ecological scarcity 1997 method which was named Ecopoints 97 (CH) in the SimaPro method library. These are now provided in SimaPro in the category for Superseded methods.

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 the last update of the method are as follows:

- Global warming: A reduction target of 87.5% until 2040 compared to 1990 has been set for CO2 and other greenhouse gases. This falls within the range of the reduction required to achieve the 1.5°C target.
- Energy resources: To assess energy resource use, the Swiss federal government's long-term target (2,000 W per capita) is interpolated to the time frame set out in the legislation, which is 2040.
- Heavy metals: In this version, heavy metals are characterized according to USEtox version 2 and the weighting factor is derived for the entire group of metals, instead of for individual metals.
- Mineral resources: Available reserves are now measured as ultimate reserves instead of economically exploitable resources.
- Non-radioactive waste: New eco-factors are introduced for micro and macro plastic emissions into soil and water.
- Pesticides into soil: Pesticides are now characterized with USEtox, both in terms of human and ecotoxicity. Also, a more ambitious target of the Swiss federal government to reduce pesticide emissions, namely a 50% reduction of the impact of pesticide emissions compared to 2012-2015, is applied for weighting.
- Biotic resources: New eco-factors are provided for marine fish resource use. The eco-factors are derived based on the ratio of annual catch amount to current fish population and intrinsic annual growth rate.
- Water resources: Eco-factors for freshwater are now derived based on the AWARE method, which measures the relative remaining water per area in a watershed after the needs of people and ecosystems have been met.
- New eco-factors are introduced for persistent organic pollutants into water, water pollutants, carcinogenic substances into air and land use in various biomes.

4.2.1 Characterization, normalization and weighting

The Ecological scarcity 2021 method contains 20 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:

1. Water resources, net balance
2. Energy resources
3. Mineral resources
4. Land use
5. Global warming
6. Ozone layer depletion
7. Main air pollutants and particulates
8. Carcinogenic substances into air
9. Heavy metals into air
10. Water pollutants
11. Persistent organic pollutants 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 Waste, non radioactive
19 Radioactive waste to deposit
20 Biotic Resources

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.

The implementation of the Ecological Scarcity 2021 method in SimaPro is only compatible for use with databases provided by PRé Sustainability in SimaPro, and is for instance not suitable for use with the UVEK LCA database. In case you would like to use the UVEK LCA data DQRv2:2022, which is provided by the Swiss Federal government, in combination with the Ecological Scarcity 2021 method, please reach out to Rolf Frischknecht from treeze Ltd., fair life cycle thinking.

References

Frischknecht, R., Krebs, L., Dinkel, F., Kägi, T., Stettler, C., Zschokke, M., Braunschweig, A., Ahmadi, M., Itten, R. & Stucki, M. (2021). Ökofaktoren Schweiz 2021 gemäss der Methode der ökologischen Knappheit. Methodische Grundlagen und Anwendung auf die Schweiz. Umwelt-Wissen no. 2121. Bundesamt für Umwelt BAFU, Öbu. www.bafu.admin.ch/uw-2121-d

4.3 Environmental Footprint 3.1 (adapted)

This constitutes the impact assessment method developed by the European Commission to be used in the context of the Environmental Footprint (EF) initiative. The Environmental Footprint 3.1 method is the latest version available and 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.

The differences between the Environmental Footprint 3.0 and the Environmental Footprint 3.1 methods are the updated climate change, acidification, photochemical ozone formation, human toxicity and ecotoxicity impact categories.

> We speak about 'adapted' because the method included in the SimaPro Professional database includes a number of adaptations, which make the Environmental Footprint 3.1 method compatible with the data libraries provided in SimaPro. Since the method was modified, it is not suitable for conducting EF-compliant studies, but it can be used for other assessments. The original version of the method is distributed in the dedicated SimaPro EF 3.1 database.

4.3.1 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 2021, including the carbon feedbacks for different substances. References: *IPCC 2021 chapter 7 table 7.15* https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf *IPCC 2021 supplementary material chapter 7 table 7.SM.7* https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.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 kilogram).
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).

Particulate matter	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 (AE) characterizing the change in critical load exceedance of the sensitive

	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	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 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 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 –*	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated

	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	over time and volume per unit mass of a chemical emitted (PAF m3 day/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 http://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf	Abiotic resource depletion fossil fuels (ADP-fossil); based on lower heating value
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)

4.3.2 Normalization

Global normalization set for a reference year 2010 is part of the Environmental Footprint 3.1 method. Methodological details are available in Crenna et al. (2019).

4.3.3 Weighting

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 a panel based approach.

4.3.4 Adaptations by PRé Sustainability

The implementation is based on the Environmental Footprint 3.1 impact assessment method and with the following modifications:

- It does not include any regionalized EF substances which would be new to SimaPro, nor does it include the raw material flows 'Carbon dioxide, in air, biogenic', 'Carbon dioxide, in air, fossil', and 'Carbon dioxide, in air, land transformation' as these are not used by data libraries. Specific sub-compartments that are not supported in SimaPro (such as close to ground, low stack, high stack or very high stack) and that are not used by background datasets have been omitted as well.
- Synonymous/duplicate EF substances have been mapped to one sole substance by combining characterization factors of both synonyms/duplicates and, in case of conflicting factors, keeping only the higher one.
- SimaPro substances that may not be directly mapped to EF elementary flows have been included as they are extensively used by the background databases and their synonyms are part of the original Environmental Footprint 3.1 method:
    - Flows representing geographies not covered in the original Environmental Footprint 3.1 method inherited the factor of other geographies as follows: Sub-regions and electricity grids of individual countries inherited the factor of the country (e.g. BR-GO and SERC inherited the factor of BR, respectively US). Other geographies not covered in the original Environmental Footprint 3.1 method as well as island states received the factor of the unspecified region.
    - 'Methane' and 'Carbon dioxide' (emissions to air) were added with the factor of 'Methane, fossil' and 'Carbon dioxide, fossil', respectively; 'Methane, peat oxidation', 'Carbon dioxide, peat oxidation' and 'Dinitrogen monoxide, peat oxidation' (emissions to air) were added with the factor of 'Methane, fossil', 'Carbon dioxide, fossil' and 'Dinitrogen monoxide, fossil' respectively; 'Carbon dioxide, in air' and 'Carbon dioxide, non-fossil, resource correction' (raw materials) were added with the factor of 'Carbon dioxide, in air, biogenic'; 'Chromium (IV)' (emission to air) was added with the factor of 'Chromium, ion'.
    - Climate change: 'Carbon dioxide, to soil or biomass stock' was added with a characterization factor of -1 kg CO2 eq/kg (this flow is necessary for the correct modeling of land use in ecoinvent).

- Resource use, fossil fuels: flows expressed in mass units (not only in net calorific value as in EF) were added; characterization factor corresponds to the lower heating values of the given fuel.
- Resource use, mineral and metals: additional flows for already characterized minerals and metals.
- Eutrophication, freshwater: 'Fertiliser, applied (P component)' and 'Manure, applied (P component)' were added with the factor of Phosphorus, total.
- Ionising radiation: 'Plutonium-alpha' (emissions to air and water) were added with the same factor as 'Plutonium'.
- Particulate matter: additional flows for already characterized particulates.
- Land use and water use: additional flows for already characterized land and water use substances.

References

Andreasi Bassi, S., Biganzoli, F., Ferrara, N., Amadei, A., Valente, A., Sala, S. and Ardente, F., *Updated characterisation and normalisation factors for the Environmental Footprint 3.1 method*, EUR 31414 EN, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-76-99069-7, doi:10.2760/798894, JRC130796.

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. and Diaconu, E., *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: https://eplca.jrc.ec.europa.eu/permalink/EF3_1/Normalisation_Weighting_Factors_EF_3.1.xlsx

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.

4.4 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. In LCA context environmental prices are used as weighting sets, which allows calculation of single score results. This method includes characterization and weighting.

The previous version of this method can be found in the category of Superseded methods.

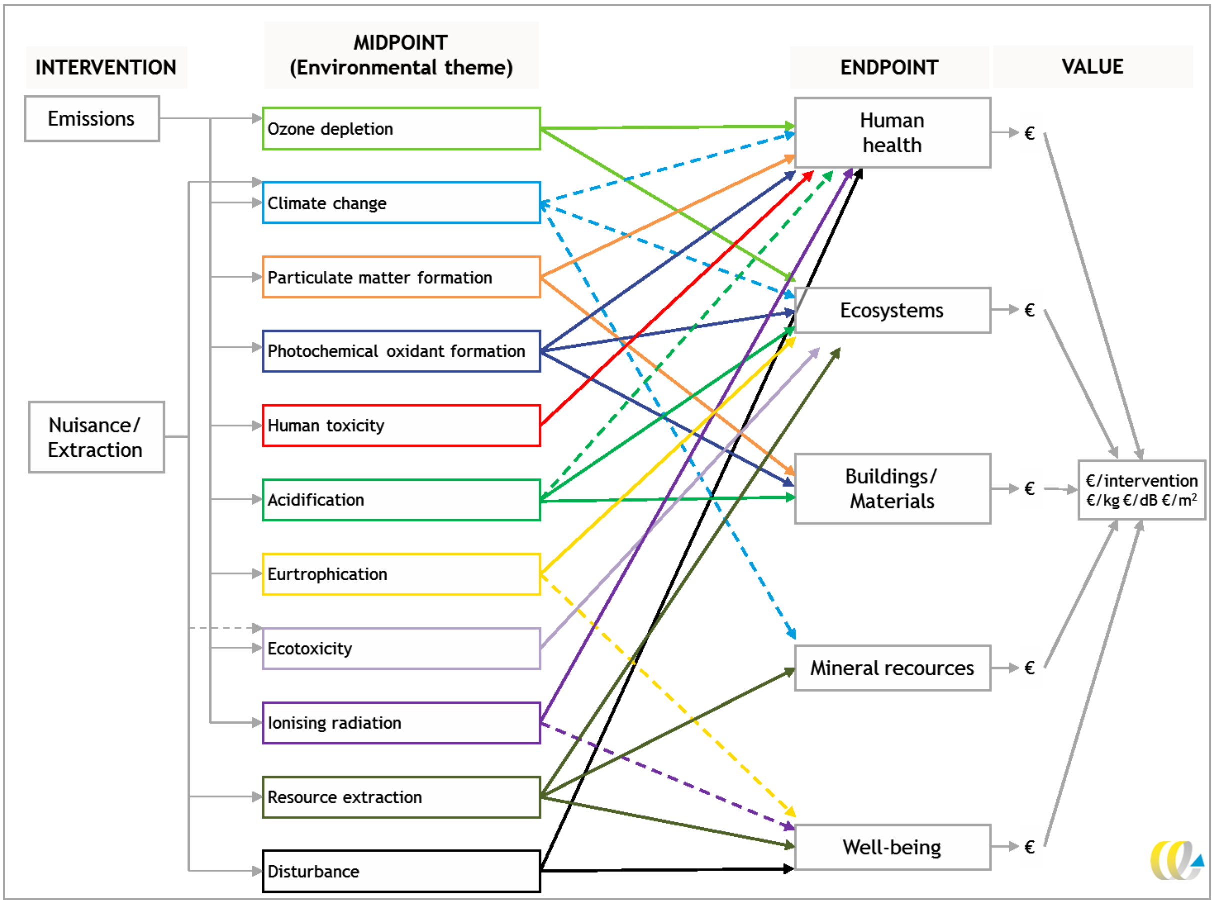

Figure 2. The relationships mapped in the Environmental Prices Handbook (de Bruyn, et al. 2017)

In SimaPro methods, three versions of Environmental Prices are available, namely

- Environmental Prices (E)
- Environmental Prices (I)
- Environmental Prices (H)

4.4.1 Characterization

Environmental Prices (E)

The characterization step is a copy of ReCiPe (2016) Midpoint, egalitarian. An overview is provided in section 5.3.2.

Environmental Prices (I)

The characterization step is a copy of ReCiPe (2016) Midpoint, individualist perspective. An overview is provided in section 5.3.2

Environmental Prices (H)

The characterization step is a copy of ReCiPe (2016) Midpoint, hierarchist perspective. An overview is provided in section 5.3.2

4.4.2 Weighting

In SimaPro, these methods utilize midpoint-level prices. This means that the prices of environmental themes are combined in a weighting set. Two groups of weighting sets are provided by the developers at CE Delft:

- Dutch Environmental Prices (2023) based on average emissions in the Netherlands in 2023
- European Environmental Prices (2023) based on average emissions in the EU27 area in 2023

Environmental prices are unavailable for the following impact categories: i) natural land transformation, ii) Water, iii) Metal, iv) Fossil depletion. The published weighting set also contains data for a new impact category, NO_2 addition. This impact category was not implemented in these methods in SimaPro.

References

CE Delft, 2023. S. de Bruyn, J. de Vries, D. Juijn, M. Bijleveld, C. van der Giesen, M. Korteland, W. van Santen, S. Pápai, Handboek Milieuprijzen 2023: Methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieu-impacts.

4.5 EN 15804 + A2 Method (adapted)

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 Environmental Footprint 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. Accounting for temporary and permanent carbon storage is not allowed. Therefore the EN 15804 standard provides a set of requirements to prevent this accounting.

Thus, this method is identical to the Environmental Footprint 3.1 (adapted) method above, except for a few characterization factors in both the Climate Change and Climate Change – Biogenic impact categories.

Table 2. Differences between EN 15804 + A2 (adapted) method compared to the Environmental Footprint 3.1 (adapted) method

Substance	Compartment	CF EN 15804 +A2	CF Environmental Footprint 3.1
Carbon dioxide (biogenic)	Emission	1	0
Methane (biogenic)	Emission	29.8	27
Carbon dioxide (biogenic)	Resource	-1	0

The difference to the former EN15804 + A2 method is the adoption of the new EN15804 reference package based on the EF 3.1 reference package instead of on the EF 3.0 reference package.

References

European Commission – Joint Research Centre (2023). EN 15804 reference package based on EF 3.1 reference package. https://eplca.jrc.ec.europa.eu/LCDN/EN15804.xhtml

5 Global

5.1 IMPACT World+

IMPACT World+ is a life cycle impact assessment method which characterizes thousands of substances spanning across various compartments and sub-compartments of the environment. It differentiates 19 impact categories at midpoint level and 34 impact categories at damage level. The v2.1 update is the biggest update of the IMPACT World+ method in many years as it introduces new impact categories and updates many models with the latest available research. IMPACT World+ version 2 comes in three interpretation levels: midpoint, expert and footprint.

The implementation in SimaPro is based on version 2.1 released November 2024 and includes:

- Only CFs with carbon neutrality approach
- Partial regionalization – some unsupported regionalized flows 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.

The Fisheries impact category from the expert version is currently excluded from SimaPro Craft.

The relationship between midpoint and endpoint indicators and areas of protection is presented in Figure 3 while the new footprint version is illustrated in Figure 4.

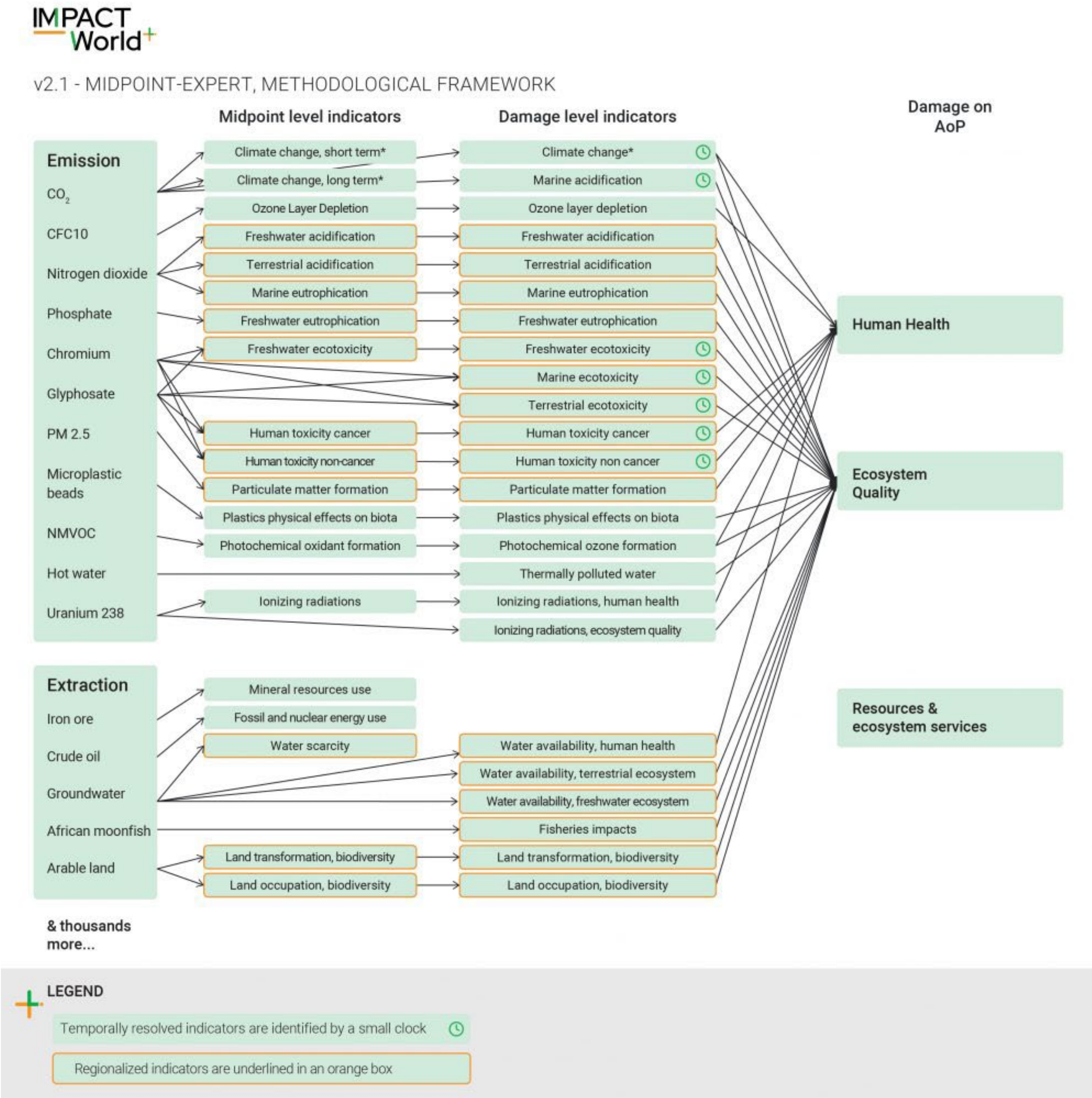

Figure 3. Representation of the relations between the impact categories midpoint and the damage on areas of protection (expert) in Impact World + 2.1 (retrieved from http://www.impactworldplus.org/)

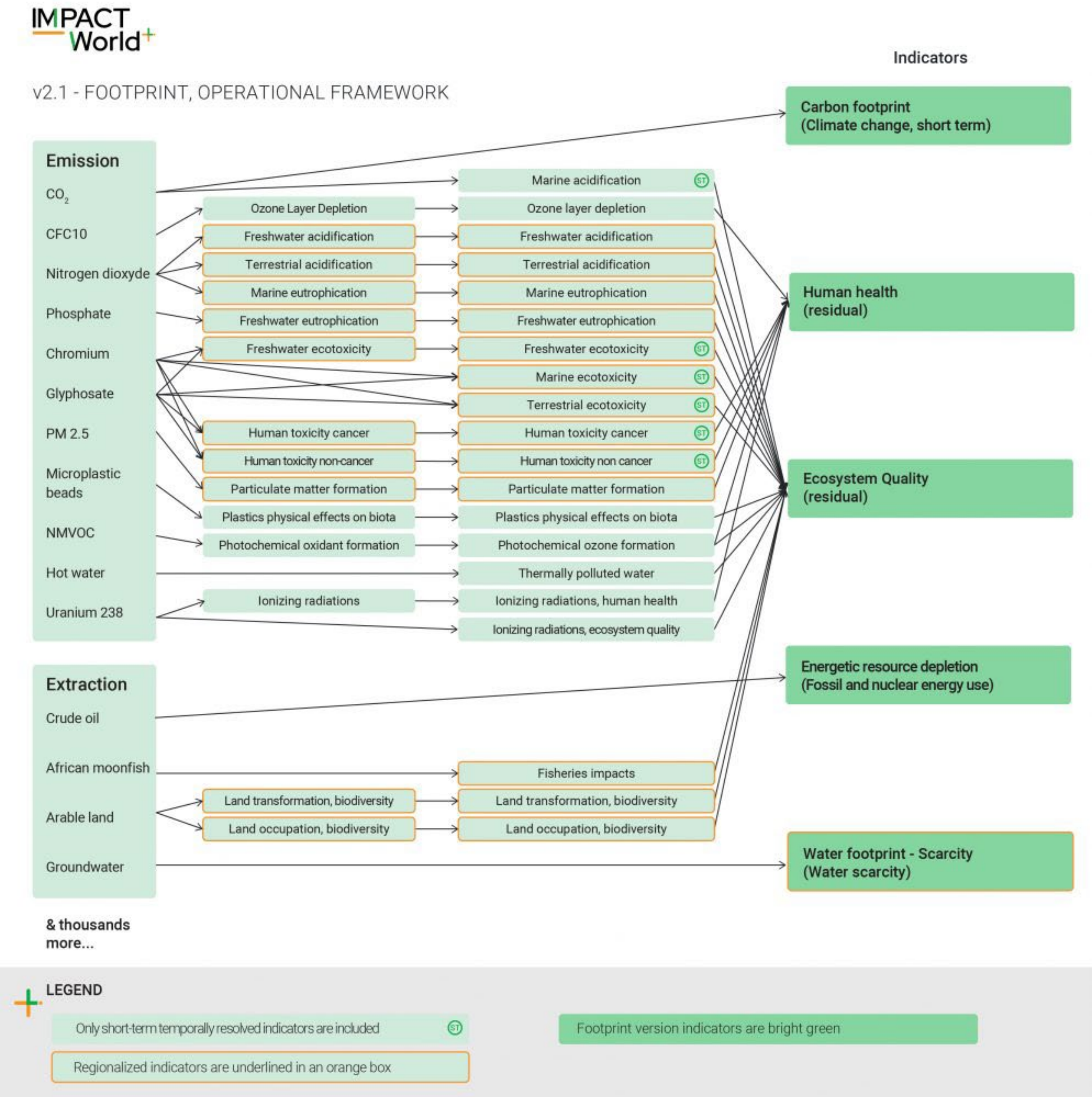

Figure 4. Footprint version displaying indicators of general interest in decision-making along with indicators ensuring comprehensiveness with respect to all the environmental issues considered in the Expert version (retrieved from http://www.impactworldplus.org/)

5.1.1 Characterization

Climate change short- and long-term

The midpoint climate change, short term (GWP100) and climate change, long term (GTP100) indicators directly come from the values of the IPCC AR6 report.

A value for the substance carbon monoxide was added, based on the molecular mass of carbon between CO and CO2, thus giving a 1.57 kgCO2eq/kgCO characterization factor.

The expert damage indicator is based on the multiplication of a Fate factor (FF) and an Effect factor (EF) (and sometimes also a severity factor (SF)).

Fossil and nuclear energy use

The fossil and nuclear energy use come from the Higher Heating Values (HHV) of different feedstocks. These HHVs were taken from the ecoinvent database. You can find these HHVs in this ecoinvent report in Table 5.1.

The fossil and nuclear energy use has no directly associated damage indicators.

Mineral resources use

This indicator is based on the approach proposed by De Bruille, V. (2014). *Impact de l'utilisation des ressources minérales et métalliques dans un contexte cycle de vie : une approche fonctionnelle* (https://publications.polymtl.ca/1591/). It defines the fraction of users unable to adapt to depletion of reserves before reaching reserve base depletion time. The adaptation time for users is defined as a function of the substitutability of the resource (value between 0 and 1; 1 for a non-substitutable resource and 0 for an easily substitutable resource in each technology) in all of the technologies in which it is used. If an important share of users is able to adapt quickly, the depletion time increase and let more time to users facing challenges to adapt, to indeed adapt and substitute the resource by another one in each technology. The unit of CFs is kg deficit per kg dissipated.

The mineral resource use indicator has no directly associated damage indicators.

Ionizing radiation

The Ionizing radiations midpoint and Human health damage indicators come from the Table 6 of Frischknecht et al. (2000) [https://doi.org/10.1016/S0195-9255(99)00042-6] following the Egalitarian/Hierarchist perspective.

The Ionizing radiations damage indicator on Ecosystem quality comes from Garnier-Laplace et al. (2009) [https://doi.org/10.1051/radiopro/20095161]. Table 1 provides the PAF values. Severity factors from Usetox are then applied to get to PDF.m2.yr values.

Photochemical ozone formation

The Photochemical ozone formation midpoint indicator is a copy from the ReCiPe2016 LCIA methodology. However, IW+ does not wish to see a distinction between human health and ecosystem quality at the midpoint indicator (like what is done within ReCiPe). As a result, the midpoint indicator of IW+ is based solely on the midpoint human health indicator of ReCiPe.

The Photochemical ozone formation damage indicator is a copy from the ReCiPe2016 LCIA methodology. However, ReCiPe operates in species.yr for their ecosystem quality indicator while IW+ operates in PDF.m2.yr. The ecosystem quality damage indicator values were thus divided by the species density provided by the ReCiPe methodology (1.48e-8 species/m2).

Ozone layer depletion

The midpoint indicator in based on the Ozone Depletion Potential values (ODP) provided by the World Meteorological Organization in their latest report (2022) in Table A-5 [https://ozone.unep.org/sites/default/files/2023-02/Scientific-Assessment-of-Ozone-Depletion-2022.pdf]. These ODPs are at an infinite time horizon. Other LCIA methodologies like ReCiPe limit this potential to different time horizons, but IW+ took the decision to keep the infinite time horizon values.

To go from midpoint to damage we use the conversion factor from the ReCiPe2016 LCIA methodology. Since the midpoint indicator in IW+ has an infinite time horizon, we use the egalitarian midpoint-to-damage-conversion factor which is 1.34e-3 DALY/kg CFC-11 eq.

Ecotoxicity and human toxicity

The Freshwater ecotoxicity and Human toxicity midpoint indicator values are based on the Usetox model v2.02.

The different ecotoxicity and Human toxicity damage indicators values are based on the Usetox model v2.02. Usetox provides values in PDF.m3.yr. The depth of the environment compartment is used to arrive to values in PDF.m2.yr. The time horizon for long term impacts is infinite.

Terrestrial and freshwater acidification

The freshwater acidification midpoint and damage indicator values come from Roy et al. (2014) [https://doi.org/10.1016/j.scitotenv.2014.08.099]

Marine acidification

The marine acidification category depends on the GWP100 midpoint indicator.

The marine acidification damage indicator values come from the SSDs curves of Azevedo et al. (2015) Figure 1 [https://doi.org/10.1021/es505485m]

Freshwater eutrophication

The Freshwater eutrophication midpoint indicator values come from Helmes et al. (2012) [https://doi.org/10.1007/s11367-012-0382-2]

The Freshwater eutrophication damage indicator values are just the midpoint values multiplied by an effect factor. The latter was determined by calculating the hypoxia rate in 3 environments (Gulf of Mexico, Chesapeake Bay and the Baltic sea) over different periods [https://d38c6ppuviqmfp.cloudfront.net/content/publications/cbp_34915.pdf], [https://gulfhypoxia.net/Research/Shelfwide%20Cruises/#Size].

The base data covers one pollutant: phosphate. The factors for other pollutants assessed in IW+ were estimated based on stoichiometric ratios.

Marine eutrophication

The marine eutrophication midpoint indicator values come from Roy et al. (2012) [https://doi.org/10.1016/j.atmosenv.2012.07.069] for emissions in the air. For emissions in water, 70% of the N containing substances discharged is assumed to reach the coastal zone as done in ReCiPe and EDIP (Goedkoop et al. 2013; Hauschild and Potting 2005; Hauschild and Wenzel 1998). This reflects the fact that elimination due to denitrification in anaerobic zones in freshwater is treated as a constant with a generic removal of 30 % in the CARMEN European model used in both LCIA methods. Hence, 70 % of the nitrogen input transports to sea.

The marine eutrophication damage indicator values come from Roy et al. (2012) [https://doi.org/10.1016/j.atmosenv.2012.07.069] for air and the same approximation for water emissions as for the midpoint. The effect factor was determined by calculating the hypoxia rate in 3 environments (Gulf of Mexico, Chesapeake Bay and the Baltic sea) over different periods [https://d38c6ppuviqmfp.cloudfront.net/content/publications/cbp_34915.pdf], [https://gulfhypoxia.net/Research/Shelfwide%20Cruises/#Size]

Particulate matter formation

The midpoint indicator is the normalization of the damage indicator using the Particulates, < 2.5 um, global value for normalization.

The damage indicator mainly comes from the work of Fantke, et al. (http://dx.doi.org/10.1021/acs.est.7b02589 / http://dx.doi.org/10.1021/acs.est.9b01800), which describes the intake fraction and effect factors for primary "Particulates, < 2.5 um" in cities of above 100,000 population. They also provide these values for rural contexts (implicitly < 100,000 population). The CFs were aggregated at the country (e.g., CA), region (e.g., CA-QC), continent (e.g., North America) and global levels. This is thus a fully regionalized impact category. The aggregation is based on the population in the given geography. The Particulates, < 10 um values are calculated from the estimated ratio of PM2.5 in PM10 (~60% of PM2.5 within PM10), coming from the Table S2 of Humbert, et al. (https://doi.org/10.1021/es103563z). This value also corroborates with other research, e.g., see Figure 4 of Fan, et al.(https://doi.org/10.3389/fenvs.2021.692440). For secondary PMs (e.g., SO2, NOx and NH3), the intake fractions come from Table 3 of Humbert, et al. (https://pubs.acs.org/doi/10.1021/es103563z). However, they could be updated in subsequent IW+ updates with the values from Figure 5/6 of Parvez, et al. (https://doi.org/10.1016/j.atmosenv.2017.06.011) and new secondary PM pollutants could be added through that publication.

Land occupation and transformation

The Land occupation/transformation midpoint indicators are based on the ratio of the corresponding damage indicators over the damage indicator of the reference value. In other words, if the value for the occupation of artificial areas in Canada is 0.4 and that the reference value (i.e., occupation of annual crops global) is 0.7 then the midpoint will be 0.4 / 0.7.

For land transformation, we used the recovery times per taxa provided in Chaudhary et al. (2015). These can be found in table "SI - Land use - recovery times". The previously obtained CFs are multiplied by these recovery times and then divided by two, thus yielding the CFs for land transformation.

Water scarcity

The water scarcity midpoint indicator is based on the AWARE 2.0 methodology (https://doi.org/10.5281/zenodo.14205922). For more information, see Seitfudem, et al. (2025): https://doi.org/10.1111/jiec.70023.

Water availability freshwater ecosystem

The Water availability, freshwater ecosystem damage indicator comes from Hanafiah et al. (2011) [https://doi.org/10.1021/es1039634]. The CF values from the table S4 (Supplementary information) are converted from PDF.m3.yr/m3 to PDF.m2.yr/m3 by assuming a global average depth of river of 2.5m (same number as in Usetox). This indicator was not regionalized, and only the median value of all CFs was taken and globally applied.

Water availability human health

The Water availability, human health has no directly associated midpoint indicator.

The Water availability, human health damage indicator comes from Debarre et al. (2022) https://doi.org/10.1007/s11367-024-02395-7.

Water availability terrestrial ecosystem

The Water availability, terrestrial ecosystem has no directly associated midpoint indicator.

The Water availability, terrestrial ecosystem damage indicator comes from van Zelm et al. (2011) [https://doi.org/10.1021/es102383v]. The article estimates to 0.21 PDF.m2.yr/m3 (Figure 4 hierarchist value) the impact of consuming groundwater on terrestrial ecosystems. However, the authors note that this value depends on the depth of the groundwater. The depth of groundwater is determined with this article from Jasechko et al. (2021) [https://doi.org/10.1126/science.abc2755]. By reading directly on the Figure 2 of the article, we extract the % of shallow well compared to deep well in 40 countries. We take the most recent values (2000-2015, in blue diamonds on the graph). Note that we consider that the proportion of water drawn from surface aquifers is the same as the proportion of the surface area of the countries where these surface wells are found. The article also provides a global value of 1 out 5 wells that are shallow. The global default value was thus 20% of shallow wells in each country not covered. This proportion is then multiplied by the 0.21 PDF.m2.yr/m3 factor of van Zelm et al. We also add the value of 0.21 for Netherlands which was directly given in van Zelm et al.

Plastic physical effect on biota

The plastic physical effect on biota midpoint and damage indicators come from the CF of the MariLCA group, taken from https://marilca.org/characterization-factors/

Thermally polluted water

The thermally polluted water category has no directly associated midpoint indicator.

The thermally polluted water damage indicator is based on Verones, et al. (2010) [https://doi.org/10.1021/es102260c]. To derive an average global CF from th article, IW+ assumed a 3m deep river with a 4°C temperature increase as the average case. It resulted in a 4.11e-05 PDF.m2.yr/m3 CF.

Fisheries impact (excluded)

There is no midpoint indicator for this impact category.

The damage indicator for this impact category is based on the work of Stanford-Clark, et al. (2024) (https://doi.org/10.3390/su16093870). These CFs are not in IMPACT World+ ready format as they are provided by default in species/yr. They were converted to PDF.m2.yr by dividing by estimates of species richness per FAO fishing region, obtained from the database "WORMS". Then, we divide by the surface of each FAO zone. Surface data is taken from "Aquamaps".

5.1.2 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.

5.1.3 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.

5.1.4 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

5.2 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.

No normalization or weighting are provided in LC-IMPACT.

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.

5.2.1 Characterization

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
    - PDF·m^3·d (Potentially Disappeared Fraction of species in a cubic meter during one day) for all ecotoxicity impacts,
    - PDF·year (Potentially Disappeared Fraction of species during one year) for all other impacts on ecosystems.
- Mineral scarcity, expressed in potential kg ore surplus

The LC-IMPACT method 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 differentiation	Both available[1]
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.,

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

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.

5.3 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. At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories. Figure 5 illustrates the relations between the 18 midpoint impact categories and the three endpoint categories.

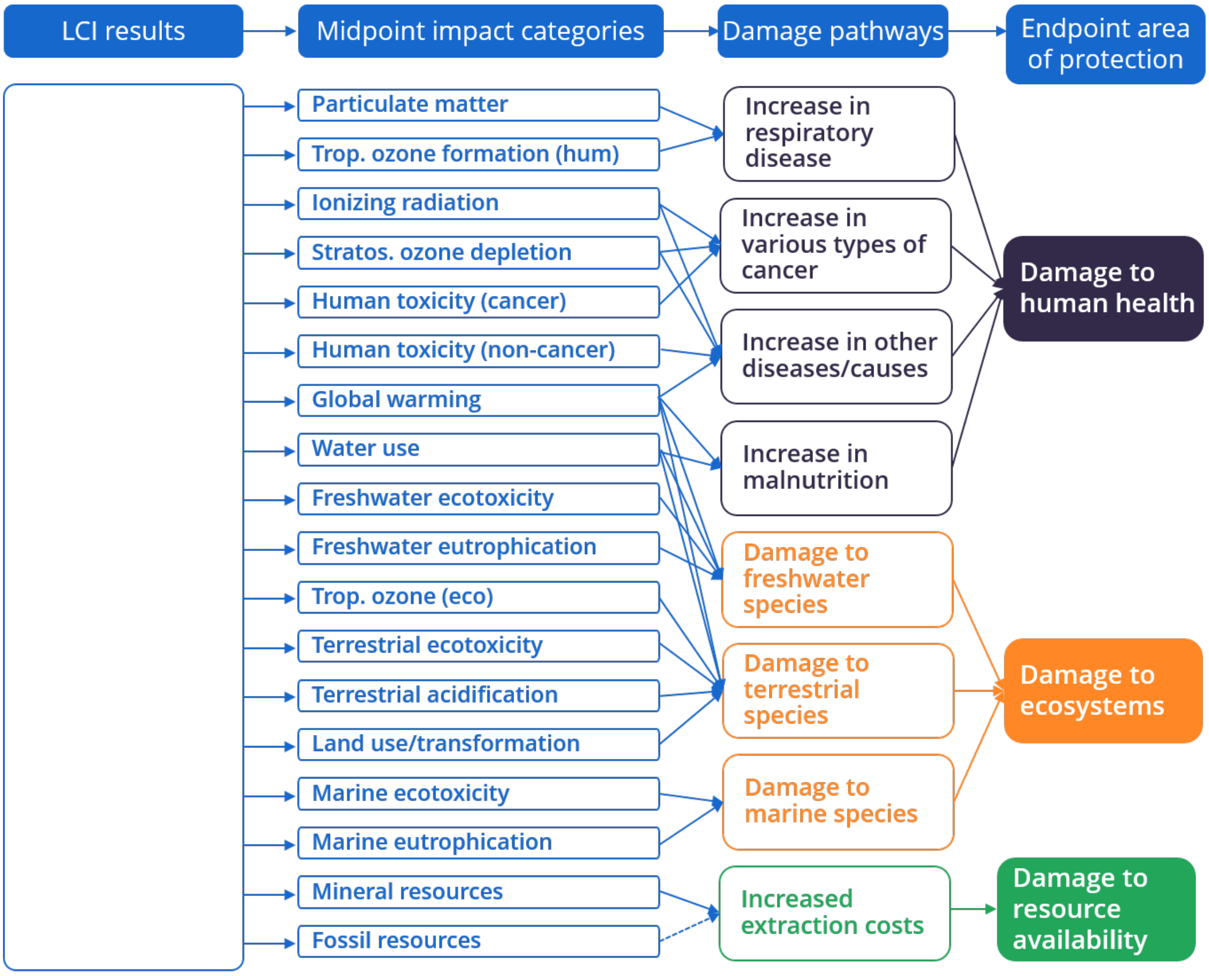

Figure 5: Representation of the relations between the impact categories midpoint and the areas of production (endpoint) in ReCiPe 2016. Source: Adapted from Huijbregts MAJ et al.(2017) Department of Environmental Science, Radbound University Nijmegen.

5.3.1 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.

5.3.2 Characterization

ReCiPe 2016 exists in SimaPro with characterization factors at midpoint or at endpoint level. The impact categories below are supported, some of which relate to more than one Are of Protection.

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.

5.3.3 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.

Damage assessment in SimaPro is only provided for the three ReCiPe 2016 Endpoint methods, one for each perspective. Since for these, characterization factors are already provided at endpoint level, damage assessment simply combines various impact categories into one damage category.

5.3.4 Normalization

Global normalization factors for reference year 2010 are included since version 1.03 of ReCiPe 2016 (https://www.rivm.nl/en/documenten/normalization-scores-recipe-2016).

5.3.5 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.

5.3.6 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

6 North American

6.1 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 6. 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.

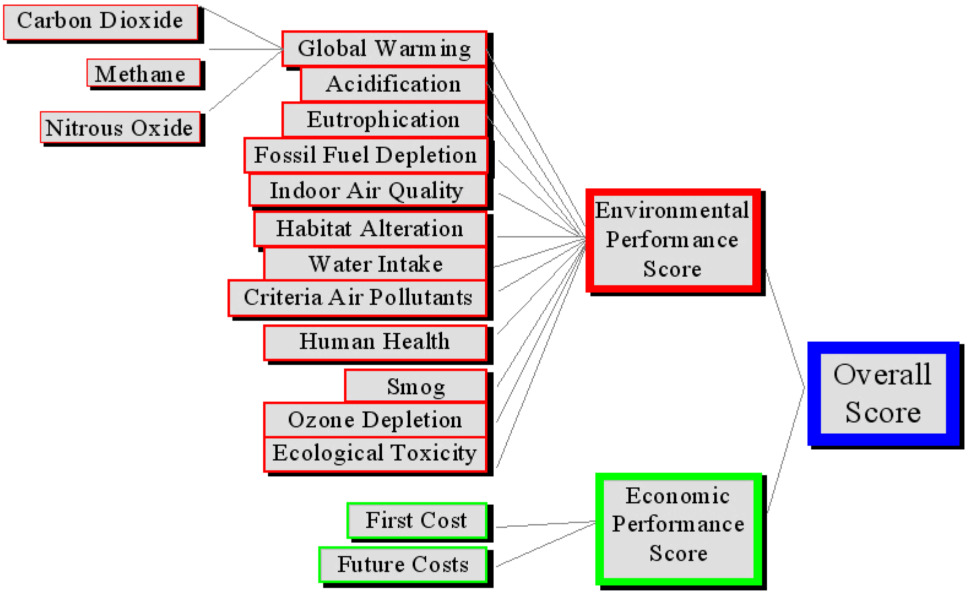

Figure 6: Structure of the BEES 4.0 methodology

6.1.1 Characterization

The following twelve life cycle assessment impact categories are used by BEES:

1. Global Warming
2. Acidification
3. Eutrophication
4. Fossil Fuel Depletion
5. Indoor Air Quality
6. Habitat Alteration
7. Water Intake
8. Criteria Air Pollutants
9. Smog
10. Ecological Toxicity

11. Ozone Depletion
12. Human Health

In SimaPro we distinguish two subcategories for human health: cancer and non-cancer.

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).

6.1.2 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.

6.2 TRACI 2.2

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency specifically for the US using input parameters consistent with US locations.

TRACI 2.2 facilitates the characterization of environmental stressors that have potential effects, including ozone depletion, global warming, tropospheric ozone (smog) formation, acidification, human health cancer effects, human health non-cancer effects, respiratory effects, ecotoxicity, freshwater eutrophication and marine eutrophication. The method includes characterization and normalization.

The previous version of this method can be found in SimaPro in the category for Superseded methods.

6.2.1 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 2.2 is a midpoint oriented LCIA method including the following impact categories:

- Ozone depletion
- Global warming
- Smog

- Acidification
- Carcinogenics
- Non carcinogenics
- Respiratory effects
- Ecotoxicity
- Freshwater eutrophication
- Marine eutrophication

The only airborne emissions covered in the marine eutrophication category are Ammonia and Nitrogen oxides. In the vast majority of cases, these substances will make up most of the nitrogen-related airborne emissions. Users are encouraged however to check if other nitrogen-related airborne emissions account for a significant portion of the inventory, which needs to be considered when interpreting results.

6.2.2 Normalization

Normalization factors for Canada (2005), USA (2008), and USA + Canada (2008) were re-calculated based on the same inventories as used for TRACI 2.1. References of the inventories can be found in Ryberg et al. (2014).

References

Bare, J.C., Norris, G.A., Pennington, D.W., and McKone, T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology.

Henderson, A.D., Niblick, B., Golden, H.E., and Bare, J.C. (2021). Modeling spatially resolved characterization factors for eutrophication potential in life cycle assessment. International Journal of Life Cycle Assessment 26, 1832 – 1846.

https://www.epa.gov/system/files/documents/2024-01/traci_2_2.xlsx

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

7 Single issue

7.1 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.

7.1.1 Characterization

Characterization factors are given for the energy resources divided in five 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.

7.2 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).

7.2.1 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.

7.3 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.

7.3.1 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

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.

7.4 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 phosphorus or even solely nitrogen-limited.

7.4.1 Characterization

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.

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 mostly 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·mol^{-1}/g·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).

Spatial 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.

7.4.2 Damage assessment

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.

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.

7.5 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

Normalization and weighting are not a part of this method.

7.5.1 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.

7.5.2 Characterization

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).

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 land transformation	fossil biogenic emissions land transformation

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.

[2] This impact category is only in the methods including CO_2 uptake.

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.

7.6 Land use impacts on biodiversity (Chaudhary et al. 2015)

Chaudhary et al. (2015) is the global consensus method recommended by the Life cycle Initiative for assessing land use impacts on biodiversity (Frischknecht & Jolliet, 2016). The indicator is expressed as Potential Species Loss (PSL) and it measures the potential effect of land occupation displacing entirely or reducing the species which would otherwise exist on that land.

The developers published the characterization factors in the supplementary information of their peer-reviewed publication (Chaudhary et al., 2015). However, the characterization factors were updated in the supplementary information of the subsequent report of Frischknecht & Jolliet (2016). The latter have been implemented in SimaPro.

Habitat degradation and subsequent biodiversity damage take place due to land occupation and transformation. The method for assessing land use impacts on biodiversity, developed by Chaudhary et al. (2015), uses the countryside Species-Area Relationship (SAR) to quantify regional species loss due to land occupation and transformation for five taxa (mammals, reptiles, fish, amphibians, and birds) and six land use types (annual crops, permanent crops, extensive forestry, intensive forestry, pasture, and urban) in 804 terrestrial ecoregions (according to the World Wildlife Fund). Further, it calculates vulnerability scores for each ecoregion based on the fraction of each species' geographic range (endemic richness) hosted by the ecoregion and the International Union for Conservation of Nature (IUCN) assigned threat level of each species. Vulnerability scores are multiplied with SAR-predicted regional species loss to estimate potential global extinctions per unit of land use. This method considers natural undisturbed habitat in the same region as the reference state[3], it the relative abundance of those species within the ecoregion, and the overall global threat level for the affected species.

7.6.1 Characterization

The method characterizes the impact at endpoint. The characterization factors in this method represent the potential disappeared fraction of species in a year (PDF*year) due to land occupation and land transformation according to the Potential Species Loss (PSL) method, aggregated for all

[3] Reference state is a baseline used as a starting point to which to quantitatively compare another situation. A reference state refers to a time period and space.

five included taxa. Chaudhary et al. (2015) also calculated specific CFs per taxa but these were not implemented in SimaPro.

There are two different versions of this method:

- As a regional indicator – PSLreg - where changes in relative species abundance within the ecoregion is included;
- As a global indicator – PSLglo - where the threat level of the species on a global scale is included.

In SimaPro, the occupation and transformation components are implemented for both the Global and Regional methods in separate impact categories, but can be aggregated for the Global and Regional models in two separate damage categories. Note that the Global and Regional impact categories cannot be aggregated - they are separate methods.

Frischknecht & Jolliet (2016) is Volume 1 of the UNEP-GLAM (United Nations Environmental Programme - Global Life Cycle Impact Assessment Method) report recommending the method of Chaudhary et al. (2015) as follows:

- “As an *interim recommendation*, the **global** average characterization factors (CFs) based on the method developed by Chaudhary et al. (2015) are deemed suitable to assess impacts on biodiversity due to land use and land use change as hotspot analysis in LCA only.”
- “The interim recommendation is to use the **regional** CFs as suitable to provide *additional insights* to the practitioner/environmental manager in further investigating identified potential hotspots.“

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 mostly relevant for regionalized inventory data.

Since data libraries included in SimaPro do not 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, i.e. occupation and transformation flows for “annual crop”, “forest, extensive”, “forest, intensive”, “grassland/pasture/meadow”, “permanent crop”, and “urban” (i.e. the same published by Chaudhary et al., 2015).

Spatial scale

Chaudhary et al. (2015) and the update in Frischknecht & Jolliet (2016) provided CFs calculated at ecoregion, country, continent and global scale. The country average CFs were provided based on the share of each ecoregion within a country for each land use type. The regionalized substances included in SimaPro include **country, continental and global scale**. The method developers also provided CFs per ecoregion, however these are not included in SimaPro. However, we encourage users to add these and to add them to the method using the ecoregion-specific CFs published.

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. Characterization factors for ecoregions are soon to be available in SimaPro online (apps.simapro.com). In case your model includes flows at ecoregion level, you might see differences in the results calculated with SimaPro desktop and SimaPro online.

References

Chaudhary, A., Verones, F., De Baan, L., & Hellweg, S. (2015). Quantifying land use impacts on biodiversity: combining species–area models and vulnerability indicators. Environmental science & technology, 49(16), 9987-9995.

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

7.7 MarILCA

The MarILCA method developed by Corella-Puertas et al. offers a framework for quantifying the environmental impact of microplastic emissions in aquatic ecosystems. It integrates data on micro- and nanoplastic toxicity to aquatic organisms and introduces fate factors for various polymer types, shapes, and sizes. This methodology updates the life cycle assessment approach by addressing gaps in understanding the physical effects of microplastics on marine biota. It is designed as a practical tool for environmental decision-makers to assess the sustainability of plastic use and alternatives

The impact assessment in the MarILCA framework measures microplastic effects using two key metrics: exposure and effect factors (EEF) and fate factors (FF). The EEF is expressed in terms of impacts per unit mass of microplastic (kg), and FF evaluates the likelihood of particles reaching aquatic environments based on polymer degradation rates and transport pathways. These units allow practitioners to estimate how much damage a given amount of microplastic can cause to aquatic life, based on real-world environmental behaviour.

For the damage assessment, the model calculates physical impacts like ingestion rates and mortality, translating these into risk factors for specific organisms and ecosystems. By modeling microplastic interactions with species over time, the MarILCA framework predicts broader ecological consequences, linking microplastic quantities to ecosystem damage.

7.7.1 Characterization

This method characterizes 9 polymers, of 3 shapes, in 4 sizes, at the midpoint level. The impact category for this method is Physical effects on biota, expressed in Potentially Affected Fraction of species (PAF) in an area in one day, i.e., PAF*m3*day.

Quantified Polymers:

- HDPE (High-density polyethylene)
- LDPE (Low-density polyethylene)
- Nylon (PA)
- PET (Polyethylene terephthalate)
- PHA (Polyhydroxyalkanoates)
- PLA (Polylactic acid)
- PP (Polypropylene)
- PS (Polystyrene)
- PVC (Polyvinyl chloride)

Quantified Shapes:

- Microplastic beads
- Fragments
- Fibers

Quantified Sizes:

- 1 µm
- 10 µm
- 100 µm
- 1000 µm

7.7.2 Damage assessment

The endpoint characterization factors used in this method can be described in terms of ecosystem quality, which gives endpoint characterization factors expressed in Potentially Displaced Fraction of species (PDF) over time in an area, i.e., PDF&m2*year.

References

Corella-Puertas, E., Hajjar, C., Lavoie, J., & Boulay, A.M. (2023). MarILCA characterization factors for microplastic impacts in life cycle assessment: Physical effects on biota from emissions to aquatic environments. Journal of Cleaner Production, Volume 418, 2023, 138197, ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2023.138197

7.8 Mineral resources dissipation (Poncelet et al. 2022)

Poncelet et al (2022) describes the dissipative flows for mineral resources, meaning minerals that become inaccessible for future use. This study expands upon previous works (Poncelet et al (2019)) and extends their coverage to provide characterization factors (CFs) for the average dissipation rate and lost potential service time for 61 metals.

The average dissipation rate (ADR) is calculated as the inverse of the average lifetime of metals in the economy. The CFs are given by the ratio of the average dissipation rate (ADR) of the metal in question, and the ADR of iron. Lost potential service time (LPST) is the difference between the optimal service time and actual service time of a given metal, for a given time horizon. As with ADR, the CFs for each metal are given by the ratio of the LPST of the metal in question, and the LPST of iron.

The socio-economic impacts due to dissipation of different mineral resources are evaluated by applying the market prices of metals to these midpoint methods thereby quantifying also CFs at endpoint level.

7.8.1 Value choices

The characterization factors for the indicators Lost potential service time and Lost potential value consider three time horizons: 25 years, 100 years, and 500 years.

7.8.2 Characterization

This method characterizes 61 metals at midpoint and endpoint level. The impact category indicators are:

- At midpoint level:
    - average dissipation rate (ADR)
    - lost potential service time (LPST)
- At endpoint level:
    - potential value loss rate (PVLR)
    - lost potential value (LPV)

At midpoint level, iron is used as a reference for the remaining metals; ADR and LPST are thus reported in Iron-equivalent kilograms per kilogram (kg Fe-eq/kg).

The endpoint methods Lost potential value (LPV) and Potential value loss rate (PVLR) apply the market value of the metals to the midpoint characterization factors for LPST and ADR, respectively. PVLR is measured in $US1998/kg·year, while the LPV is measured in $US1998/kg.

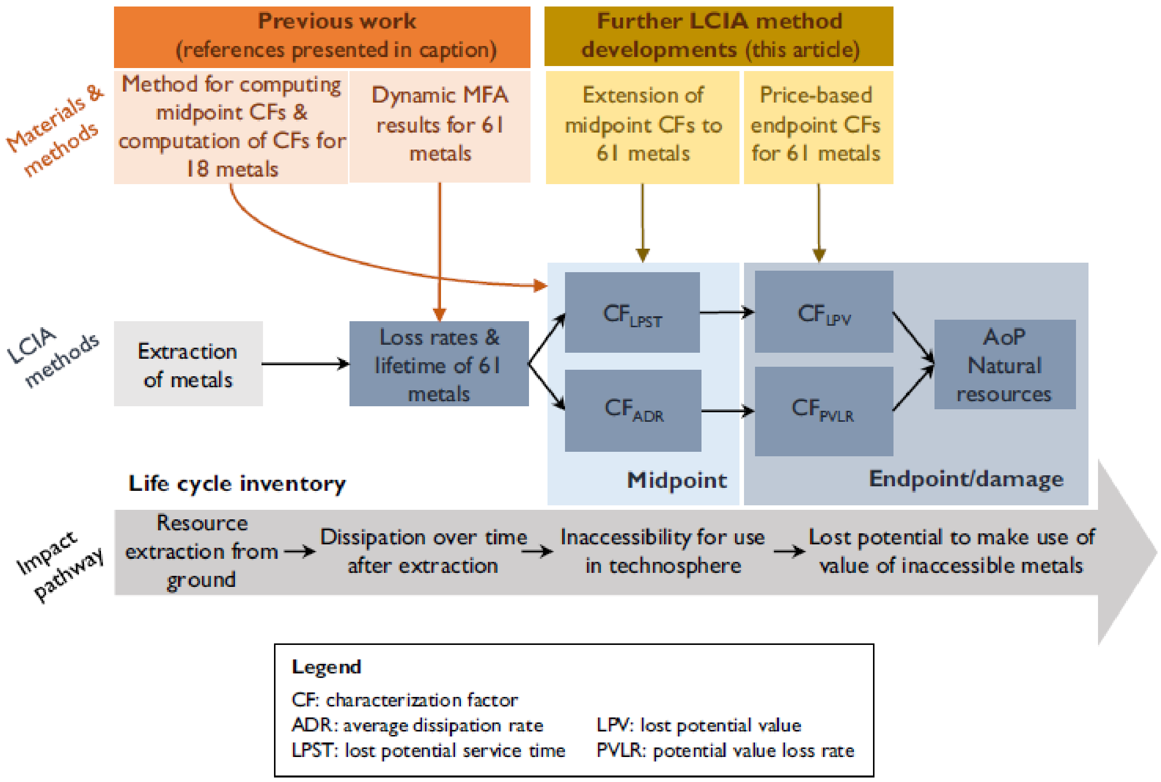

Figure 7: Overview of impact pathway and further development of the ADR and LPST methods based on previous work

In SimaPro, each method contains characterization factors for 129 substances.

To note: Characterization factors for titanium dioxide (TiO_2) are based on the mass balance of titanium in titanium dioxide.

References

Poncelet, A.C., Loubet, P., Helbig, C., Beylot, A., Muller, S., Villeneuve, J., Laratte, B., Thorenz, A., Tuma, A., & Sonnemann, G. (2022). Midpoint and endpoint characterization factors for mineral resource dissipation: Methods and application to 6000 data sets. The International Journal of Life Cycle Assessment, 27(9-11), 1180–1198. https://doi.org/10.1007/s11367-022-02093-2

Poncelet, A.C., Helbig, C., Loubet, P., Beylot, A., Muller, S., Villeneuve, J., Laratte, B., Thorenz, A., Tuma, A., & Sonnemann, G. (2021). Life cycle impact assessment methods for estimating the impacts of dissipative flows of metals. *Journal of Industrial Ecology*, *25*(5), 1177–1193. https://doi.org/10.1111/jiec.13136

7.9 Selected LCI results

The selected life cycle inventory indicators are, in most cases, the summation of selected substances emitted to all different sub-compartments. In some cases, different substances are added up to quantify frequently used parameters such as non-methane volatile organic carbon (NMVOC), selected radioactive species or particulate matter. According to ISO 14044 2006, clause 4.4.2.5, a set of elementary flow may be part of the results after characterization. This is the reason why the selected LCI indicators within the life cycle impact assessment methods section of the ecoinvent database is presented.

7.9.1 Characterization

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. 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.

Table 7: List of selected life cycle inventory indicators implemented in ecoinvent data v2.0.

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

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.

7.10 USEtox®

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) as the scientific consensus for toxicity-related impact categories. 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.

7.10.1 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 ecotoxicological 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.

Table 8. List of correspondence of SimaPro and USEtox sub-compartments.

	SimaPro compartments	USEtox compartments	
Air	(unspecified)	*50 Em.airU / 50 Em.airR*	50/50 urban/rural
Air	high. pop.	*Em.airU*	Urban air
Air	low. pop.	*Em.airR*	Rural air
Air	low. pop., long-term	*Em.airR*	Rural air
Air	stratosphere + troposphere	*Em.airR*	Rural air
Air	indoor	*Em.air*	Household indoor air
Water	(unspecified)	*Em.fr.waterC*	Freshwater
Water	river	*Em.fr.waterC*	Freshwater
Water	river, long-term	*Em.fr.waterC*	Freshwater
Water	lake	*Em.fr.waterC*	Freshwater
Water	ocean	*Em.sea waterC*	Sea water
Soil	agricultural	*Em.agr.soilC*	Agri. Soil
Soil	(unspecified)	*Em.nat.soilC*	Natural soil
Soil	forestry	*Em.nat.soilC*	Natural soil

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.

7.10.2 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*m^3*day (potentially disappeared fraction of species).

References

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

8 Water Footprint

8.1 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 (an international working group focusing on water use assessment and water footprinting taking the life cycle perspective) to assess water consumption impact assessment in LCA.

In 2025, AWARE2.0 was published (https://doi.org/10.1111/jiec.70023) in an effort to increase data transparency and consistency, while alleviating some general limitations of the previous characterization factor dataset. AWARE2.0 explicitly considers the special cases of river deltas, inland sinks, and subdivided river basins and furthermore benefits from an improved representation of basin area, increased responsiveness of environmental water requirements to seasonal flow patterns, and a more appropriate water consumption definition.

AWARE2.0 was created by a smaller team than AWARE, intending to remain within the limits of the initial consensus while increasing methodological consistency, timeliness, and input data transparency. In the final stage of the project, the remaining co-authors of the main AWARE publication were consulted for their feedback.

This version includes:

1. More recent input data: While AWARE was calculated from 51 years average water availability ending in 2010, with AWARE2.0, a 30 years long, more recent period is used.

2. Improved data consistency: While AWARE used two different models for calculating water availability and environmental water requirements, AWARE2.0 is entirely calculated from post-processed output of WaterGAP2.2e.

3. Several smaller improvements in the calculations: E.g., smoother environmental flow curves and more realistic basin areas.

These improvements together create a characterization factor dataset that better implements what the AWARE consensus aimed to represent: Characterization factors based on a watershed's available water remaining after human and ecosystem requirements have been met.

The current version implemented in SimaPro is AWARE2.0.

8.1.1 Characterization

AWARE is a midpoint indicator expressed in m^3 world-eq. Characterization factors (CFs) of AWARE quantify the relative water scarcity of an average m^3 of water withdrawn in a region, on a scale from 0.1 to 100, with a value of 1 corresponding to the world average[4]. A value of 10, for example, indicates a region where there is 10 times less available water remaining per area than the world average

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 = 0.0241 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).

Spatiotemporal scale

There is considerable seasonal variability, and variability based upon the end-use (agriculture or otherwise). In SimaPro desktop, AWARE contains CFs averaged across all types of water usage (i.e. agricultural, and non-agricultural), AND averaged across all months of the year, per country and other regions such as RER (Europe). Factors specific to the end-use of the water, agricultural or non-agricultural, and per month, or per watershed are currently not supported in SimaPro desktop. If data on season and/or use is available it is recommended to use the additional factors available at https://wulca-waterlca.org/aware/download-aware-factors/

Implementation of AWARE2.0 in SimaPro was adapted based on the water scarcity method in Impact World+ midpoint v2.1 method.

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

References

Seitfudem, G., Berger, M., Schmied, H. M., & Boulay, A.-M. (2025). The updated and improved method for water scarcity impact assessment in LCA, AWARE2.0. *Journal of Industrial Ecology*, 29, 891–907. https://doi.org/10.1111/jiec.70023

[4] It should be noted that a factor value of 1 is not equivalent to the factor for the average water consumption in the world, i.e. the world average factor to use when the location is not known. This value is calculated as the consumption-weighted average across all regions and months of the year.

8.2 Hoekstra et al 2012 (Water Scarcity)

This method is based on the publication Hoekstra et al (2012).

8.2.1 Characterization

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).

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