Implementation of life cycle impact assessment methods in the ecoinvent database v3.9
(2022.10.13)

Thomas Sonderegger, Nikolia Stoikou

Technoparkstrasse 1
8005 Zurich, Switzerland
+41 44 500 42 58
info@ecoinvent.org

ecoinvent.org

Table of Contents

Citation:

Sonderegger T., Stoikou N. (2022). Implementation of life cycle impact assessment methods in the ecoinvent database v3.9. ecoinvent Association, Zürich, Switzerland.

1 Executive summary

ecoinvent publishes the result of its own work as cumulative life cycle inventories (LCIs): an extensive list of emissions to the environment and natural resource consumption, resulting from human activities from the cradle to the grave of a product. In addition, life cycle impact assessment (LCIA) scores are calculated and published, with the help of characterization factors (CFs) provided by LCIA method developers.

This report documents the assumptions made by ecoinvent in the implementation of the LCIA methods concerning many aspects, for example, flow names, compartment and sub-compartment mapping choices, long-term and short-term emission treatment, fossil and non-fossil greenhouse gas emissions and natural resources. A brief description of the implemented methods is available, including specific assumptions applicable to each of them.

The result of the implementation is available in a series of spreadsheets, showing the explicit mapping between the nomenclature of the database and each LCIA method. Most relevant information is found in the spreadsheets, and only brief descriptions about what cannot be easily expressed in a spreadsheet are included in the written report. The complete set of files is available on request at support@ecoinvent.org.

2 Introduction

ecoinvent specializes in the life cycle inventory (LCI) phase of life cycle assessment (LCA). The data gathered is available as unit processes (direct emissions and resource consumption by a human activity, and its connection to other human activities) and as cumulative LCIs (sum of direct and indirect emissions and resource consumption by a human activity).

The life cycle impact assessment phase (LCIA) of an LCA depends on extensive knowledge in different areas of the natural and health sciences, depending on the cause-and-effect chain between emission and impact on the so-called damage categories or areas of protection (for example, human health or ecosystem quality). The development of an impact model requires input from meteorology, chemistry, hydrology, pedology, ecology, biology, geology, and many other specializations. ecoinvent uses the end-products of those models, the so-called characterization factors (CFs), to calculate impact scores of the cumulative LCI results of each dataset.

An LCIA score is calculated with the following equation:

$$h_i = \sum_k g_k \cdot CF_{i,k}$$

where $CF_{i,k}$ stands for the CF of substance k in the impact category i, g_k stands for the quantity of substance k emitted/consumed by the life cycle of the system considered, and h_i is the LCIA score for category i.

Mapping CFs from different methods to a database comes with several challenges, such as:

- Different naming conventions are used to refer to the same elementary exchanges (EEs)
- The same EE name bears different meaning in the database and the different methods
- The database does not provide the necessary EE for the full implementation of the methods

This report’s purpose is to communicate the choices made by ecoinvent in this context. The implementation made by ecoinvent may differ from implementations provided by LCA software, eco-design tools, case studies, etc.

Section 3 gives an overview on currently implemented LCIA methods. Section 4 describes the general implementation procedure and corresponding files. Section 5 introduces the ecoinvent nomenclature for impact categories. Section 6 describes overarching assumptions, applicable to every method unless explicitly contradicted. Sections 7 and following provide a short description of methods, specific assumptions, and exceptions to overarching assumptions. Thereby, the focus is on the IPCC method (as it is widely used, and its implementation comes with several assumptions) and on new methods. Details about other method implementations can be found in previous implementation reports as indicated in Table 1.

3 Currently implemented methods

Table 1 shows the currently implemented methods. For an explanation of the status, see below.

Table 1 Implemented methods in ecoinvent v3.9

Method	Status	Method Version	ecoinvent Report
CML v4.8 2016	current	v4.8	v3.9
Crustal Scarcity Indicator 2020	current	2020	v3.9
Cumulative Energy Demand (CED)	current	1997	v2.2
Cumulative Exergy Demand (CExD)	current	1997	v2.2
Ecological Footprint	current	2006	v2.2
Ecological Scarcity 2021	current	2021	v3.9
Ecosystem Damage Potential	current	1997	v2.2
EDIP 2003	legacy	2003	v2.2
EF v3.0	superseded	v3.0	v3.9
EF v3.0 EN15804	current	v3.0	v3.9
EN15804 inventory indicators ISO21930	current		dedicated report
EF v3.1	current	v3.1	v3.9
EF v3.1 EN15804	current	v3.1	v3.9
EPS 2020d	current	2020d	v3.9
IMPACT 2002+ (Endpoint)	legacy	v2.1	v2.2
IMPACT 2002+ (Midpoint)	legacy	v2.1	v2.2
IPCC 2013	superseded	2013	v3.9
IPCC 2021	current	2021	v3.9
ReCiPe 2016 v1.03 midpoint	current	2016 v1.03 (SimaPro)	v3.9
ReCiPe 2016 v1.03 endpoint	current	2016 v1.03 (SimaPro)	v3.9
selected LCI results	legacy		v2.2
selected LCI results, additional	legacy		v2.2
TRACI v2.1	current	v2.1	v3.9
USEtox	legacy	v1.0	v2.2

The implementation of methods with status “superseded” is up to date and valid. Legacy methods, on the other hand, are still published, but not maintained anymore. This means that a) if an error is reported, it will not be corrected; and b) if a new elementary exchange is added to ecoinvent, legacy methods will not be checked for a CF match with the new exchange. Information on these methods and their original implementation can be found in the v2.2 LCIA implementation report.

Except for EF v3.0, EF v3.0 EN15804, and IPCC 2013, superseded versions of methods for which an updated version is available are not published anymore. ecoinvent is keeping the old implementation files, so they could be re-introduced as legacy methods. Superseded methods are:

- CML 2001, v3.3
- ecological scarcity 2013
- EDIP 1997
- EF v2.0 2018
- EF v3.0 (still published)
- EF v3.0 EN15804 (still published)
- EPS 2000
- IPCC 2013 (still published)
- ReCiPe 2008 Endpoint, v1.0
- ReCiPe 2008 Midpoint, v1.13 (SimaPro)
- ReCiPe 2008 Midpoint, v1.0
- TRACI, 2007

Finally, some methods are old or have been updated more than once. These methods will not be maintained in any form. These methods are:

- eco-indicator 99
- ecological scarcity 1997
- ecological scarcity 2006
- EF1.0.8 midpoint
- IPCC 2001
- IPCC 2007

4 Implementation procedure

This section summarizes the implementation process including a description of produced supporting files and the nomenclature for impact categories and indicators.

4.1 Main procedure

The main steps performed in method implementation are

- Bringing the method to the ecoinvent standard format (see section 4.2)
- Mapping flow names of elementary exchanges excluding compartments and sub-compartments
- Mapping compartments and sub-compartments
- Mapping full elementary exchanges including flow names, compartments, and sub-compartments

4.2 Standard method files

The website of ecoinvent does not host the files provided by the method developers. Those are all presented in different formats (spreadsheet or xml files) and have been downloaded from the website of the developers or obtained via e-mail. Data sources are given in each method's section.

ecoinvent has developed a common "standard" spreadsheet format. A standard file is produced for each method. It contains information on the EEs such as name, CAS number, formula, synonyms, unit, compartment, and sub-compartment, and the name of each impact category, as published by the method developers (see Figure 1). The cells below impact category names show the CFs for each EE. An empty cell indicates no CF reported by the developers.

A	B	C	D	E	F	G	H	I	J	K	L	
name	casNumber	formula	synonym	unitName	direction	compartment	subcompartment	abiotic depletion (elements, ultimate ultimate reserves)	abiotic depletion (fossil fuels)	global warming (GWP100)	ozone layer depletion (ODP steady state)	hu tox (HT
-(CF2)4CH(OH)-	16621-87-7			kg	emission	air	unspecified			13		
(CF3)2CFOCH3	22052-84-2			kg	emission	air	unspecified			363		
(CF3)2CHOCH3	13171-18-1			kg	emission	air	unspecified			14		
(CF3)2CHOCHF2	26103-08-2			kg	emission	air	unspecified			2620		
(HFE-7100)	163702-07-6			kg	emission	air	unspecified			486		
1,1,1-trichloroethane	71-55-6			kg	emission	air	unspecified			160	0.12	16.
1,1,1-trichloroethane	71-55-6			kg	emission	soil	agricultural					16.
1,1,1-trichloroethane	71-55-6			kg	emission	soil	industrial					[illegible]
1,1,1-trichloroethane	71-55-6			kg	emission	water	ocean					9.

Figure 1 Screen capture of "CML v4.8 2016_standard.xlsx"

4.3 Mapping files

An explicit mapping between ecoinvent's EE nomenclature and the method's nomenclature is established using a mapping algorithm. The algorithm uses EE's names, CAS numbers, formulas, and synonyms. However, some manual mappings and overwrites are needed, which are all managed and documented in these mapping files.

4.4 Compartment and sub-compartment mapping file

The nomenclature of compartments and sub-compartments may vary, depending on the method. It was necessary to establish an explicit correspondence between ecoinvent's nomenclature and each method's nomenclature. This information is contained in the file "compartment_mapping_3.X.xlsx (see Figure 2).

Some methods do not provide CFs for specific sub-compartments, but the CFs from another sub-compartment would be appropriate. The compartment mapping file indicates the mapping algorithm in which proxy sub-compartment to look for a CF.

	A	B	C	D	E	F	G
1	method name in ecoinvent	compartment name in ecoinvent	subcompartment name in ecoinvent	compartment name in method	subcompartment name in method 1	subcompartment name in method 2	subcompartment name in method
140	IPCC 2013	air	urban air close to ground	air	unspecified	N/A	N/A
141	IPCC 2013	air	indoor	N/A	N/A	N/A	N/A
142	IPCC 2013	air	low population density, long-term	air	unspecified	N/A	N/A
143	IPCC 2013	air	unspecified	air	unspecified	N/A	N/A
144	IPCC 2013	air	non-urban air or from high stacks	air	unspecified	N/A	N/A
145	IPCC 2013	air	lower stratosphere + upper troposp	air	unspecified	N/A	N/A
146	IPCC 2013	direct human uptake	unspecified	N/A	N/A	N/A	N/A
147	IPCC 2013	economic	primary production factor	N/A	N/A	N/A	N/A
148	IPCC 2013	natural resource	in air	N/A	N/A	N/A	N/A
149	IPCC 2013	natural resource	land	N/A	N/A	N/A	N/A
150	IPCC 2013	natural resource	biotic	N/A	N/A	N/A	N/A

Figure 2 Screen capture of "compartment_mapping_3.5.xlsx"

4.5 Mapped files

The mapping algorithm uses, the mapping files, the compartment mapping file, and the method standard file to produce the final "mapped" file containing all available CFs for ecoinvent EEs per impact category of the method ("{method_name}_mapped_3.X.xlsx", see Figure 3). These files are available on request at support@ecoinvent.org

The column "status" contains "mapped" if a match has been established between ecoinvent and the method for the exchange, otherwise it says "ecoinvent orphan".

The column "conversion_factor" indicates the ratio of the CF as found in this file and as found in the original method file. This conversion was necessary in cases where the unit of the exchange and/or the category was different in the method and ecoinvent.

name	compartment	subcompartment	unit	conversion_factor	status	method_name	method_compartment	method_subcompartment	method_unit	human toxicity//human toxicity (HTP inf)	ecotoxicity: freshwater//freshwater aquatic ecotoxicity (FAETP inf)	ecotoxicity: marine//marine aquatic ecotoxicity (MAETP inf)	ecotoxicity: terrestrial//terrestrial ecotoxicity (TETP inf)	photochemical oxidant formation//photochemical oxidation (high NOx)	acidification//acidification (incl. fate, averag Europ
1-Pentene	air	low popul	kg	1	mapped	1-pentene	air	unspecifie	kg					0.977	
1-Pentene	air	lower stra	kg	1	mapped	1-pentene	air	unspecifie	kg					0.977	
1-Pentene	air	non-urbar	kg	1	mapped	1-pentene	air	unspecifie	kg					0.977	
1-Pentene	air	unspecifie	kg	1	mapped	1-pentene	air	unspecifie	kg					0.977	
1-Pentene	air	urban air (	kg	1	mapped	1-pentene	air	unspecifie	kg					0.977	
2,4-D	air	non-urbar	kg	1	mapped	2,4-d	air	unspecifie	kg	6.638457455	38.70264593	5.281333499	0.596861512		
2,4-D	soil	agricultur	kg	1	mapped	2,4-d	soil	agricultur	kg	46.95248552	29.49533085	0.166268447	1.57851244		

Figure 3 Screen capture of the file "CML v4.8 2016_mapped_3.8.xlsx"

5 ecoinvent nomenclature for impact categories

Impact categories and indicators can be the same for different methods, for example "climate change" with the indicator "global warming potential 100 years". However, they can come with different names, for example as "global warming" with the indicator "GWP100". To allow for easier comparison between methods, ecoinvent has introduced its own "standard" terminology for impact categories (and partly for indicators although there are many more than impact categories). The mapping between ecoinvent impact categories and method impact categories is provided in the category mapping file ("category_mapping_v3.X.xlsx", see Figure 4).

Method name in ecoinvent	Category name in ecoinvent	Category name in method
ReCiPe 2016 v1.03, midpoint (E)	acidification: terrestrial	Terrestrial acidification
ReCiPe 2016 v1.03, midpoint (E)	climate change	Climate change
ReCiPe 2016 v1.03, midpoint (E)	ecotoxicity: freshwater	Freshwater ecotoxicity
ReCiPe 2016 v1.03, midpoint (E)	ecotoxicity: marine	Marine ecotoxicity
ReCiPe 2016 v1.03, midpoint (E)	ecotoxicity: terrestrial	Terrestrial ecotoxicity
ReCiPe 2016 v1.03, midpoint (E)	energy resources: non-renewable, fossil	Fossil resource scarcity
ReCiPe 2016 v1.03, midpoint (E)	eutrophication: freshwater	Freshwater eutrophication
ReCiPe 2016 v1.03, midpoint (E)	eutrophication: marine	Marine eutrophication
ReCiPe 2016 v1.03, midpoint (E)	human toxicity: carcinogenic	Human toxicity: cancer
ReCiPe 2016 v1.03, midpoint (E)	human toxicity: non-carcinogenic	Human toxicity: non-cancer
ReCiPe 2016 v1.03, midpoint (E)	ionising radiation	Ionising radiation
ReCiPe 2016 v1.03, midpoint (E)	land use	Land use
ReCiPe 2016 v1.03, midpoint (E)	material resources: metals/minerals	Mineral resource scarcity
ReCiPe 2016 v1.03, midpoint (E)	ozone depletion	Ozone depletion
ReCiPe 2016 v1.03, midpoint (E)	particulate matter formation	Fine particulate matter formation
ReCiPe 2016 v1.03, midpoint (E)	photochemical oxidant formation: human health	Photochemical oxidant formation: human health
ReCiPe 2016 v1.03, midpoint (E)	photochemical oxidant formation: terrestrial ecosystems	Photochemical oxidant formation: terrestrial ecosystems
ReCiPe 2016 v1.03, midpoint (E)	water use	Water use

Figure 4 Screen capture of "category_mapping_3.9.xlsx"

The most common used impact categories are

- acidification
- climate change
- ecotoxicity
- eutrophication
- human toxicity
- ionising radiation
- ozone depletion
- particulate matter formation
- photochemical oxidant formation
- energy resources
- material resources
- land use
- water use

Sub-categories are attached in names using a colon after the main category, for example "energy resources: non-renewable", and are further separated by a comma, for example "energy resources: non-renewable, fossil".

6 General assumptions

Elementary exchanges (EEs) in ecoinvent are identified by a flow name for the material, energy, or space that “flows” from or to biosphere (for example, “Carbon dioxide, fossil”, always starting with a capital letter), as well as by a compartment and a sub-compartment (for example, “air” and “urban air close to ground”).

6.1 Flows

6.1.1 Oxidation states

Metal emissions in ecoinvent are usually given including their oxidation states (for example, Cadmium II). However, where this is not the case or where it explicitly states “ion” as it could refer to two different oxidation states (for example, Copper I or Copper II), a decision for mapping this flow name to the method’s flow names need to be made. Where two CFs were available for one ecoinvent flow, we went with a precautionary approach and applied the larger CF. This is the simpler of the two approaches suggested in Sanyé-Mengual et al. (2022) as no average CF needs to be calculated.

6.1.2 Common proxy mappings and conversions

Some flows are almost the same and hence a proxy mapping is possible. One example are volatile organic compounds (VOCs) including or not including methane (NMVOCs): “Essentially, NMVOCs are identical to volatile organic compounds (VOCs), but with methane excluded. Methane is excluded in air-pollution contexts because it is not toxic. It is however a very potent greenhouse gas, with low reactivity and thus a long lifetime in the atmosphere.”[1] Some further examples are listed in Table 2.

Table 2 Examples of flow proxy mappings applied

ecoinvent flow	Proxy flow(s)	Flow-to-proxy relationship	
VOC	NMVOC	>	includes more than proxy
NMVOC	VOC	<	includes more than proxy
particulates, > 2.5 um, and < 10um	PM10	<	includes less than proxy
Beta-cyfluthrin	Cyfluthrin	<	includes less than proxy
Nitric oxide	NOx	<	includes less than proxy
Nitrogen dioxide	NOx	<	includes less than proxy

[1] https://en.wikipedia.org/wiki/Non-methane_volatile_organic_compound

6.2 Compartments

As described in section 4.4, there is no general rule for sub-compartment mapping between ecoinvent and the different methods. The mapping algorithm follows the instructions documented in the compartment mapping file. For each ecoinvent sub-compartment, there might be a matching sub-compartment and one (or two) proxy sub-compartments. If a CF for a flow is not found for the matching sub-compartment, the algorithm looks for a CF in the proxy sub-compartments. Usually, “unspecified” is used as the proxy sub-compartment. For the “unspecified” sub-compartment, on the other hand, a specific sub-compartment, for example, “freshwater”, is used as proxy.

Because fate and exposure of emissions are highly dependent on the compartment of an emission, it is not appropriate to use the CFs of another compartment to characterize an exchange.

6.3 Assessment for long-term emissions

Long-term emissions are defined as emissions that will be transferred from the technosphere to the environment more than 100 years after the use of the process in the considered life cycle. This is different from long-term impacts that would be caused, for example, by the bioaccumulation of a pesticide in the food chain. This impact is taken into account if the LCIA method developers judged it was relevant to include them and had the available data to do so. An emission is classified as “long-term” in ecoinvent based on the moment where it is released in the environment, not the moment where it causes its impact. LCIA methods often discount impacts happening many decades after emission by using different perspectives: “hierarchist”, “egalitarian” and “individualist”, each integrating impacts over different time horizon.

LCA experts have not yet reached a consensus about the inclusion or exclusion of long-term emissions. Until the debate is settled, long-term emissions are reported separately via sub-compartments explicitly labelled “long-term”, allowing practitioners to test the influence of their inclusion/exclusion. ecoinvent provides some methods with and without CFs for long-term emissions. However, not all methods provide the distinction between the two types of emission. In this case, two options are possible:

- Attribute the same CF to both short term and long-term emissions, leading to an over-estimation of the impacts
- Attribute no CF to the long-term emission, leading to an under-estimation of the impacts.

The first option has been retained and those methods for which this was applied are also available without long-term emissions, labelled as “{method name}, no LT”. It is strongly recommended, in the interpretation phase of an LCA, to test the sensitivity of conclusions to the two scenarios.

6.4 Emissions

6.4.1 Fossil and non-fossil CO_2, CO, and methane emissions in global warming methods

To understand the choice of CFs for CO, CO_2, and methane, it is necessary to know how their fossil and non-fossil emissions/uptakes are modelled in the database. The table below shows the list of exchanges to untangle, and the solution retained for them.

Table 3 General assumptions for carbon sources and sinks

Exchange name	Mapping rule
Carbon dioxide, fossil	Mapped with carbon dioxide fossil CF
Carbon dioxide, non-fossil	Should be zero
Carbon monoxide, fossil	Mapped with carbon monoxide fossil CF
Carbon monoxide, non-fossil	Could be larger than zero if enough information is provided
Methane, fossil	Mapped with methane fossil CF
Methane, non-fossil	Could be larger than zero if enough information is provided
land use related	
Carbon, organic, in soil or biomass stock	Should be zero
Carbon dioxide, from soil or biomass stock	Mapped with carbon dioxide fossil CF
Carbon dioxide, in air	Should be zero
Carbon dioxide, to soil or biomass stock	Mapped with carbon dioxide fossil CF, with a negative sign
Carbon monoxide, from soil or biomass stock	Mapped with carbon monoxide fossil CF
Methane, from soil or biomass stock	Mapped with methane fossil CF
allocation correction	
Carbon dioxide, non-fossil, resource correction	Correction for “Carbon dioxide, in air”

Even if original datasets are carbon balanced, LCIs are rarely carbon balanced due to the unavoidable distortions introduced by allocation. In these conditions, using negative CFs for carbon uptakes and positive CFs for non-fossil carbon emissions would lead to unreliable GWP scores, particularly for agriculture and wood products. Carbon allocation corrections are applied for activities in the wood and paper sector for the cut-off and the EN15804 system models. Furthermore, the “EF v3.0 EN15804” method considers carbon capture and non-fossil carbon emissions (see section 11.4.1).

Fossil emissions essentially originate from combustion processes, where it is known that the fuels are fossil or not. Often, furnaces use a mix of fuels to produce electricity and/or heat. This mix may include organic material like wood residues or oil residues from plants. In this case, the dataset will emit both fossil and non-fossil emissions. Non-fossil emissions also occur as transportation loss of bio-methane, animal exploitation, organic chemical production, flooding of reservoirs in hydroelectricity production and waste treatment operations.

The fixation of CO_2 by plants through photosynthesis is considered as long-term carbon capture in land tenure datasets. It is assumed that this carbon will stay in the soil for a much longer period than a typical LCA time frame and hence is considered permanently removed from the atmosphere. In order to balance land tenure datasets, a source and an emission are given for overall carbon uptake or overall carbon release in these datasets:

Overall carbon uptake:

- Source: Carbon dioxide, in air (source, no CF)
- Emission: Carbon dioxide, to soil or biomass stock (negative emission, CF = -1)

Overall carbon release:

- Source: Carbon, organic, in soil or biomass stock (source, no CF)
- Emission: Carbon dioxide, from soil or biomass stock (emission, CF = 1)

Emissions from soil or biomass stocks occur in agricultural forestry operations, flooding of reservoirs in hydroelectricity production and some land transformation datasets. These atoms of carbon would not have been emitted if not for the perturbation caused by human activities, so they are equivalent to fossil emissions in terms of impacts.

6.4.2 Group emissions

The term “group emissions” as used in Sanyé-Mengual et al. (2022) refers to flow names that represent a group of flows such as “hydrocarbons” or “pesticides”. In ecoinvent, these can get an “unspecified” extension or be further classified such “Hydrocarbons, unspecified” or “Hydrocarbons, chlorinated”. It would be possible to map specific flows to these generic flows if known to which groups they belong. However, such a grouping system is not (yet) in place. Therefore, this is not being done with two exceptions: 1) if such mappings were used in previous implementations of methods, they were maintained for consistency reasons; 2) the GLAD mapping[2] which was used for implementing EF methods (see section 11) contains such mappings.

6.4.3 Waste

Waste is not an elementary exchange in ecoinvent. Wastes are sent to waste treatment activities, who in turn have emissions to environment depending on the nature of the input and the treatment. These emissions will be characterized by the methods, but since wastes do not appear in the list of elementary exchanges in ecoinvent, if a method reports CF for wastes, they won’t be taken into account in the implementation.

6.4.4 Noise

CFs for noise are not implemented in version 3.9 of ecoinvent.

[2] https://github.com/UNEP-Economy-Division/GLAD-ElementaryFlowResources/tree/master/Mapping/Output/Mapped_files

6.5 Natural resources

6.5.1 Energy resources

Energy resources can be classified into renewable and non-renewable energy resources. Non-renewables can further be classified into fossil energy carriers, nuclear energy carriers (uranium), and biomass (primary forest). For renewable energy resources there is again biomass, and there is water, solar, wind, and geothermal Table 4.

Table 4 Energy resources in ecoinvent

		Name	**Compartment / sub-compartment**		**Unit**
non-renewable	fossil	Coal, brown	natural resource	in ground	kg
		Coal, hard, unspecified		in ground	kg
		Gas, natural		in ground	Sm3
		Gas, mine, off-gas, process, coal mining		in ground	Sm3
		Oil, crude		in ground	kg
		Peat		biotic	kg
	nuclear	Uranium		in ground	kg
	biomass	Energy, gross calorific value, in biomass, primary forest		biotic	MJ
renewable		Energy, gross calorific value, in biomass		biotic	MJ
	water	Energy, potential (in hydropower reservoir), converted		in water	MJ
	solar	Energy, solar, converted		in air	MJ
	wind	Energy, kinetic (in wind), converted		in air	MJ
	geothermal	Energy, geothermal, converted		in ground	MJ

The assessment of energy resources is often based on energy content, meaning higher and lower heating values (HHV and LHV), also called gross and net calorific values (Table 5 lists these values for fossil energy carriers). The Cumulative Energy Demand (CED) method implemented since a long time in ecoinvent is based on HHVs. The standard EN 15804:2012+A2:2019 (CEN/TC 350 2019) implemented in the EF v3.0 EN15804 method, on the other hand, uses LHVs for the calculation of CFs. Following the latter, LHVs are implemented in methods assessing energy resources if no other CFs are given (as for example in CED). The values for oil and gas were updated for v3.9 according to Meili et al. (2021), which was the basis for updates of oil and gas datasets.

Table 5 Higher Heating Values (HHV) and Lower Heating Values (LHV) for fossil energy carriers

Exchange	Unit	HHV [MJ / Unit]	LHV [MJ / Unit]	Source
Coal, brown	kg	9.9	9.41	[1] d
Coal, hard, unspecified	kg	19.1	18.01	[1] a, bituminous
Gas, mine, off-gas, process, coal mining	Sm3	40	36	[2]
Gas, natural	Sm3	40	36	[2]
Oil, crude	kg	46	43.4	[2]
Peat	kg	9.9	9.76	[1] b, peat

[1] https://www.openlca.org/wp-content/uploads/2017/10/Calculation-of-energy-indicators-in-MJ-LHVs.pdf
[2] Meili et al. (2021)

Since the energy contents were updated, also the Cumulative Exergy Demand (CExD) method's CFs needed to be updated. This was done using the energy-to-exergy ratio as provided in Bösch et al. (2007) (Table 6).

Table 6 Exergy content for oil and gas calculated following Bösch et al. (2007)

Exchange	Unit	HHV [MJ / Unit]	energy-to-exergy ratio	Exergy [MJ / Unit]
Gas, natural	Sm3	40	0.94	37.6
Gas, mine, off-gas, process, coal mining	Sm3	40	0.94	37.6
Oil, crude	kg	46	1.015	46.7

6.5.2 Land transformation and occupation

ecoinvent makes the distinction between land transformation (quantified in m^2) and land occupation (quantified in m^2*year). Datasets using land (typically, infrastructure) report what was the land type before the land use (EE with name "Transformation, from …"), and the intended state of the land after the life of the infrastructure (EE with name "Transformation, to …"). The CFs for the former are positive (a damage) and the CFs for the latter are negative (a credit). Land use is balanced within datasets (the difference of "land transformed to" and "land transformed from" is zero). If a dataset returns the land to the same state as it was before, the transformation impact will be zero. If a dataset returns the land to a lesser quality, the negative CFs for the "Transformation, to …" EE will be lower, and the net sum will be positive (a damage).

6.5.3 Water use

Water use is modelled using water from the natural resource compartment and emitting water to compartments "water" or "air". Some datasets are intentionally not water balanced, for example cement production, where the water chemically reacts with the other components and is not released under the form of water after its use. Note that most datasets do not consume water from the biosphere but display an input of tap water. Water flows outputs are, when appropriate, modelled to flow to a wastewater treatment process.

The issue with water is similar to the carbon imbalance: allocation distorts the balance and simply applying positive CFs to water consumptions and negative CFs to water emission back to water would lead to unreliable water scores. However, ecoinvent rigorously reports water evaporation to air. This quantity represents the water that leaves the ecosystem without being available for its usual function, so the general approach is to apply (positive) CFs only to those EE.

6.6 Regionalization

ecoinvent does not yet consider regionalized EES and hence no regionalized, but only global CFs are implemented.

6.7 Normalization and weighting

ecoinvent implements the CF up to the endpoint reported by LCIA method developers. Transforming endpoint impact scores to normalized and weighted scores is a straight-forward operation, involving only multiplying or dividing scores by the normalization and weighting factors provided by the method developers. This task is left to the users, allowing them to choose the most appropriate sets and test the influence of this choice on the conclusions of their LCA.

6.8 Gaps and errors in methods

We usually do not touch the data provided by methods developers. Sometimes, we adapt a CF to ecoinvent needs or we fill gaps by calculating additional CFs. If so, this is described in the chapter for the specific method.

There are over 200 000 CFs in the actual implementation. Typos or mistakes are unavoidable when dealing with such a large amount of data. In case of suspected mistakes, check the known issue page on the ecoinvent website to see if the mistake has already been reported. If it is not the case, contact the ecoinvent team through support@ecoinvent.org.

6.9 References

Bösch M. E. et al. (2007). Applying Cumulative Exergy Demand (CExD) indicators to the ecoinvent database. International Journal of Life Cycle Assessment, 12 (3), 181–190. https://doi.org/10.1065/lca2006.11.282.

CEN/TC 350 (2019). CEN/TC 350 Sustainability of Construction Works - Environmental Product Declarations - Core Rules for the Product Category of Construction Products EN 15804:2012+A1:2013/A2:2019.

Meili C. et al. (2021). Life cycle inventories of crude oil and natural gas extraction. Retrieved from https://esu-services.ch/fileadmin/download/publicLCI/meili-2021-LCI for the oil and gas extraction.pdf.

Sanyé-Mengual E. et al. (2022). Linking inventories and impact assessment models for addressing biodiversity impacts: mapping rules and challenges. The International Journal of Life Cycle Assessment, 27 (6), 813–833. https://doi.org/10.1007/s11367-022-02049-6.

7 IPCC methods

7.1 General information

Method versions	**2021 (Assessment Report 6)** **2013 (Assessment Report 5)**
Sources of the CFs	Assessment Report 6: https://www.ipcc.ch/report/ar6/wg1/ (Chapter 7) https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_07_Supplementary_Material.pdf https://github.com/chrisroadmap/ar6/blob/main/data_output/7sm/metrics_supplement_cleaned.csv Assessment Report 5: https://www.ipcc.ch/report/ar5/wg1/ (Chapter 8) https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf https://www.ipcc.ch/site/assets/uploads/2018/07/WGI_AR5.Chap_.8_SM.pdf http://onlinelibrary.wiley.com/doi/10.1002/rog.20013/abstract
Revision of implementation	Annie Levasseur (for the 2013 version)

7.2 Introduction

The IPCC is the Intergovernmental Panel on Climate Change by the United Nations. The panel regularly releases Assessment Reports (ARs) containing emissions metrics for Global Warming Potential (GWP) and Global Temperature Change Potential (GTP). These numbers are implemented as CFs in the IPCC methods.

7.2.1 Radiative forcing and global warming potential

The planet receives heat from the sun and loses heat to space through radiation. The balance of these two forces keeps the Earth within a stable range of temperature. Emissions of greenhouse gases (GHGs) change this balance by favouring or hindering radiation, a phenomenon known as radiative forcing (RF), measured in W/m^2. Many gases increase the energy absorbed by the atmosphere (positive RF, global warming), but other gases decrease it (negative RF, global cooling).

The integral over a time horizon (H) of the RF curve following a pulse emission of 1 kg of a gas represents the energy (in W-yr/m^2) that has not escaped the atmosphere through radiation because of this emission. This quantity is known as the Absolute Global Warming Potential (AGWP). Dividing the AGWP of a gas by the AGWP of CO_2 for the same time horizon leads to the GWP of this gas, with units of kg CO_2 equivalents per kg of gas emitted. This metric is used to express the effects on climate change of different emissions on a common scale.

$$GWP_i(H) = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt} = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)}$$

The Global Temperature Potential (GTP) goes one step further in the cause-and-effect chain and is based on the change in global mean surface temperature (AGTP) at a chosen point in time after a pulse emission, relative to that of CO_2. The GTP considers more physical processes, like climate sensitivity and exchange of heat between the atmosphere and oceans. Values of GWP and GTP can be quite different, especially for shorter time horizons, for gases whose effect on climate happens mostly within the first decade after emission. This happens because GTP is an instantaneous metric that expresses the magnitude of the temperature increase at a given point in time, compared to GWP, a cumulative metric. Instantaneous metrics are more relevant to assess climate impacts related to an absolute temperature such as heat waves or extreme weather events, while cumulative metrics are more relevant to assess climate impacts related to cumulative warming such as sea level rise. Moreover, moving further along the cause-and-effect chain produces a more societally relevant, yet more uncertain metric.

The IPCC warns that both GWP and GTP are dependent on the arbitrary selected time horizon. Although 20, 100 or 500 years are traditionally reported, and the Kyoto Protocol has chosen to focus on the 100 years horizon, there is no scientific argument for selecting one over the other. Depending on the goal and scope of the LCA and the value choices of the sponsors, various aspects of climate change might be emphasized. This will determine the selection of the time horizon and of GWP or GTP as the metric of choice. This choice is value-based and subjective to the decision-makers. The selection of a shorter time horizon implicitly gives more importance to short-term effects and less to future generations.

7.2.2 Guidance by the Life Cycle Initiative

The Life Cycle Initiative hosted by UN Environment has published recommendations on greenhouse gas emissions and climate change impacts in their first global guidance for LCIA indicators report (UNEP/SETAC 2016). These recommendations relate to AR5/IPCC 2013 as this was the report available back then (without CFs for GWP500, but CFs for GTP20). The recommendations regarding time horizons are

- using GWP 100 as the indicator for the shorter-term climate change impact category.
- using of GTP100 as proxy for long-term impacts because it is an instantaneous indicator targeting potential temperature rise 100 years in the future (because GTP50 leads to similar conclusions as GWP100).

Furthermore, it is recommended to

- perform a sensitivity analysis including short-lived climate forcers (SLCFs, called near-term climate forcers NTCFs in AR5) and using GWP20 in addition to GWP100 (as for shorter-term impacts, GWP20 is the metric that represents the highest potential contribution from NTCFs).

7.2.3 Short-lived climate forcers (SLCFs)

Short-lived climate forcers (SLCFs) typically have atmospheric lifetimes shorter than two decades, and they can be classified as direct (exerting climate effects through their radiative forcing) and indirect (being precursors of direct climate forcers) (AR6, Chapter 6). Indirect SLCFs do not have emissions metrics in ARs. The life cycle initiative considers volatile organic compounds (VOCs), and carbon monoxide (CO), black carbon (BC), organic carbon (OC), nitrogen oxides (NOx), and sulphur oxides (SOx) in their recommendations. In the IPCC 2013 implementation (section 7.4), VOC, CO, and NO were characterized. According to the recommendations by the life cycle initiative (UNEP/SETAC 2016) and available CFs from the IPCC 2013 implementation, CFs for indicators GWP20, GWP100, and GTP100 are provided for VOC, CO, and NO in the impact category/indicator “climate change//{indicator, for example, GWP100}, SLCFs” for performing sensitivity analysis.

7.3 IPCC 2021 (Assessment Report 6)

7.3.1 Source tables for characterization factors

The IPCC only supplies values for air emissions, without specifying sub-compartment. The same CF is assigned to an exchange emitted to air for all the sub-compartments. The CFs for GWP and GTP are taken from Table 7.SM.7 (supplementary material) or – if there was a difference – the online update of it[3] except for those for which values are available in Table 7.15 (main report).

7.3.2 Differences to AR5

Carbon cycle responses (or carbon-climate feedback, see section 7.4.3) are included in all the metrics.

7.3.3 Implementation of non-fossil emissions and emissions from land use change

7.3.3.1 Carbon dioxide

Uptake of CO_2 by plants is accounted for in forestry and agriculture datasets by the elementary exchange “Carbon dioxide, in air”. This same carbon eventually goes back to the atmosphere under the form of methane, CO, and CO_2. Every dataset releasing these substances differentiates between the fossil and non-fossil origin of the carbon. The net null effect of capturing a carbon atom and releasing it later is modelled by attributing null CFs to resource elementary exchanges “Carbon dioxide, in air” and the emission elementary exchanges “Carbon dioxide, non-fossil” (Table 7).

7.3.3.2 Methane

Carbon atoms in CO_2 fixed by plants are sometimes released as CO or methane. These molecules eventually oxidize back to the more stable CO_2, but before that they will create a higher radiative forcing than CO_2. Therefore, the net impact of releasing non-fossil CO and methane is larger than zero. The AR6 reports CFs for fossil and non-fossil methane at table 7.15 (Table 7). CO is not considered in the report.

7.3.3.3 Emissions from land use change (from soil or biomass stock)

Agriculture, forestry, land transformation and hydropower datasets also report emissions of carbon through the elementary exchanges “Carbon dioxide, from soil or biomass stock”, “Carbon monoxide, from soil or biomass stock” and “Methane, from soil or biomass stock”. These emissions are treated as fossil emissions (Table 7). Their CFs are therefore the same as their fossil counterpart, as they came from the atmosphere to the stock much earlier than the scope of any LCA, like fossil carbon. If there is a net carbon uptake in these datasets, this

[3] https://github.com/chrisroadmap/ar6/blob/main/data_output/7sm/metrics_supplement_cleaned.csv

is reported through the elementary exchange "Carbon dioxide, to soil or biomass stock", which gets -1 as a CF (Table 7).

Table 7 CFs for fossil and non-fossil carbon emissions in the implementation of IPCC 2021

Substance name in ecoinvent	Substance name in IPCC	GWP100	Source table
Carbon dioxide, in air	Carbon dioxide	0	
Carbon dioxide, non-fossil	Carbon dioxide	0	
Carbon dioxide, fossil	Carbon dioxide	1	7.SM.7
Carbon dioxide, from soil or biomass stock	Carbon dioxide	1	7.SM.7
Carbon dioxide, to soil or biomass stock	Carbon dioxide	-1	7.SM.7
Methane, fossil	Methane, fossil	29.8	7.15
Methane, from soil or biomass stock	Methane, fossil	29.8	7.15
Methane, non-fossil	Methane, non-fossil	27	7.15

7.4 IPCC 2013 (Assessment Report 5)

7.4.1 Source tables for GWP and GTP

The IPCC only supplies values for air emissions, without specifying sub-compartment. The same CF is assigned to an exchange emitted to air for all the sub-compartments.

Values of GWP and GTP are scattered in many tables in the AR5 and the supplementary material. It is also clear from comparing the same CF, found in different tables, that some of them have been rounded. Table 5 shows the source for those metrics. Supporting spreadsheet "IPCC_mapped_3.5.xlsx" contains more detailed information about the source of CFs.

Table 8 Sources for GWP and GTP from AR5

Source table	Substances	Note
8.A.1	Carbon dioxide	See discussion below about fossil and non-fossil carbon dioxide, and from soil or biomass stock
8.A.4	Carbon monoxide	See discussion below about fossil and non-fossil carbon monoxide, and from soil or biomass stock
8.A.5	VOC	
8.SM.17	N2O and methane	See discussion about fossil and non-fossil methane below
Hodnebrog et al.	Halocarbons, nitrogen fluoride, sulfur hexafluoride	AR5 report uses rounded values of the Hodnebrog paper.

7.4.2 Time horizons

In the AR5, metrics for the 500-year horizon are considered too uncertain and have not been published. Although the necessary information is available to calculate GWP and GTPs for this time horizon (through the form of parameters for RF curves), the calculation was not performed. Only metrics for 20- and 100-year time horizon are implemented.

7.4.3 Carbon-climate feedback

The AR5 includes two sets of GWP and GTP, with and without carbon-climate feedback (CCFB) loops for non-CO_2 gases. CCFB take into account that a changing climate will in turn change the fluxes of CO_2 between atmosphere, land and oceans (Friedlingstein et al. 2006). The IPCC states that ideally, all indirect effects should be taken into account (AR5, section 8.7.1.4, p.713): "Though uncertainties in the carbon cycle are substantial, it is *likely* that including the climate–carbon feedback for non-CO_2 gases as well as for CO_2 provides a better estimate of the metric value than including it only for CO_2."

Unfortunately, the values of GWP and GTP with CCFB are not published for all gases. Only the values without CCFB are available for CO, NOx, SO_2, VOC and fossil methane. Until all CFs are available with CCFB, only the metrics without CCFB are implemented.

7.4.4 Well-mixed GHG and near-term climate forcers

Near-term climate forcers (NTCFs) have shorter lifetimes, relative to well-mixed GHGs (WMGHG). NTCFs include CO, HFCs, methane, VOCs, organic and black carbon, NOx and SO_2. Methane and HFCs are treated as WMGHGs because they have longer lifetimes compared to other NTCFs. They thus have enough time to get evenly distributed in the atmosphere and their impact does not depend on the location of emission. HFCs metrics are well agreed-upon, and their implementation is straightforward. Metrics are taken from Hodnebrog et al. (2013). VOC, CO and are ozone precursors. Ozone formation depends on other factors, which is why the amount of radiative forcing of those substances varies with the geographic location of emission. Table 8.A.4 and 8.A.5 of the AR5 show different values for different regions. ecoinvent does not have the possibility to implement regionalized impact assessment yet, so the global values have been selected.

7.4.5 Sulfur dioxide, nitrous oxides, and black carbon

The implementation of the CFs for SO_2, NOx and BC (black carbon, or sooth) is problematic in the context of ecoinvent. SO_2 and NOx CFs are negative for some time horizon, meaning that these emissions contribute to global cooling. On the other hand, the CFs for black carbon, or sooth, are positive and two orders of magnitude larger. Applying only the SO_2 and NOx CFs yields to an underestimation of the GWP scores, and sometimes, to a net negative GWP score. This is misleading and sends the message that the production of certain commodities, such as copper, is overall beneficial to the climate change problematic. Figure 5 shows the effect of the application of the SO_2 and NOx CFs. For each market activity of v3.2 allocation by cut-off classification, the GWP100 score was calculated with and without these CFs, and the ratio (with – without) / without is represented. For 95% of the cases, the GWP100 scores diminish between 2.3% and 74.3% (see table 6).

Application of CF for black carbon (BC) is currently impossible in ecoinvent, as the substance is not directly reported. However, the quantity of BC can be estimated as a percentage of the particulate matter smaller than 2.5 microns found reported in the inventory. For the rest of this analysis, it is assumed that 20% of these particulates are BC. Application of CF for BC would lead to an increase of the GWP100 scores between 1.4% and 57.3% for 95% of the cases. The magnitude of the effect is comparable to the one of the SO_2 and NOx. If both effects are taken into account simultaneously, the median of the net effect is close to zero. The assumption of proportion of sooth in particulate is somehow arbitrary and could greatly vary depending on the source of the emission. This issue should be addressed at the inventory level, not by a blanket assumption during impact assessment. However, applying only the NOx and SO_2 CFs, without the BC CFs would create a bias. This paradoxical effect, first described by economists in the 1950s, is known as the theory of the second best. In its original formulation, the theory states that when the optimal situation is impossible to attain, the second-best situation is not necessarily the closest situation to the optimal one. In the present context, this means that since the inclusion of both NOx, SO_2 and sooth parameter is impossible, including only one or the other results in a less accurate model than the inclusion including none of them. It was therefore decided to exclude both effects until all relevant information about BC is integrated in the database.

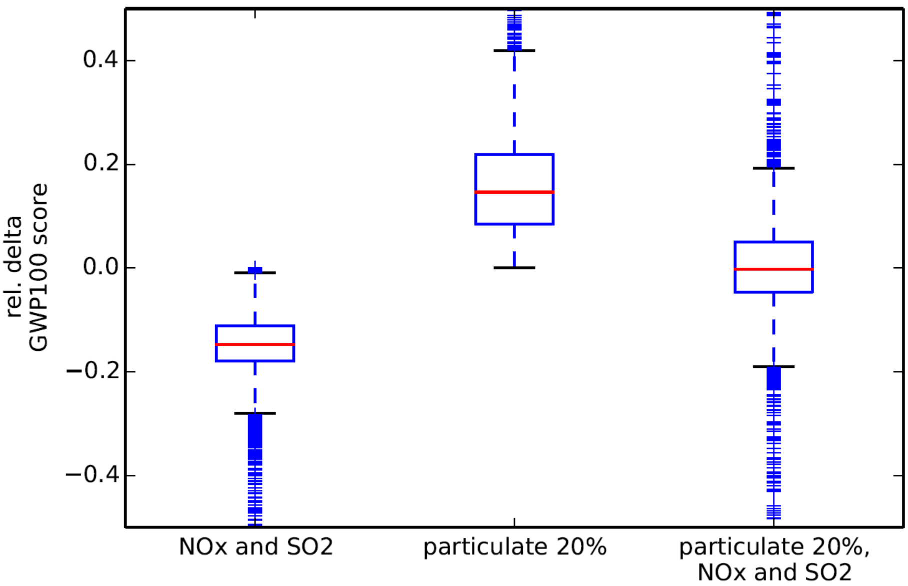

Figure 5 Effect of NOx, SO2 and particulate on GWP100 scores

Table 9 Effect of NO_x, SO_2 and particulate on GWP100 scores

Percentile	relative delta, NOx and SO2	relative delta, particulate 20%	relative delta, particulate 20%, NOx and SO2
2.5	-0.743	0.014	-0.517
25	-0.179	0.085	-0.046
50	-0.147	0.146	-0.002
75	-0.111	0.219	0.05
97.5	-0.023	0.573	0.377

7.4.6 Non-fossil emissions

7.4.6.1 Carbon dioxide

See section 7.3.3.122.

Carbon atoms in CO_2 fixed by plants are sometimes released as CO or methane. These molecules eventually oxidize back to the more stable CO_2, but before that they will create a higher radiative forcing than CO_2. Therefore, the net impact of releasing non-fossil CO and methane is larger than zero. The net impact of releasing non-fossil CO and methane is therefore larger than zero.

7.4.6.2 Carbon monoxide

The AR5 contains CFs only for non-fossil carbon monoxide, meaning the effect such emission has before it oxidizes to CO_2. To calculate the CF for fossil monoxide, the ratio of the molar masses of CO_2 and CO has been added to the CF found at table 8.A.4. The underlying assumption of this operation is that all molecules of CO oxidize to CO_2 and the half-life of CO in the atmosphere is much smaller than the half-life of CO_2.

7.4.6.3 Methane

The AR5 reports CFs for methane, non-fossil at table 8.SM.17. The values for fossil methane are presented, rounded, at table 8.A.1. The footnote of table 8.A.1 indicates that the difference between fossil and non-fossil methane is calculated by Boucher et al (2009). The values are found at table 1, in the column "Indirect CO_2-induced fossil source", and it is clear that the IPCC has chosen the lower bound to calculate the rounded CFs presented at table 8.A.1. Fossil methane CFs are calculated by adding the lower bound from Boucher et al. to the table 8.SM.17 values, without rounding.

Table 10 CFs for fossil and non-fossil carbon emissions in the implementation of IPCC2013

Substance name in ecoinvent	Source table	GWP20	GWP100	GTP20	GTP100
Carbon dioxide, in air	NA	0	0	0	0
Carbon dioxide, non-fossil	NA	0	0	0	0
Carbon dioxide, fossil	8.A.1	1	1	1	1
Carbon dioxide, from soil or biomass stock	8.A.1	1	1	1	1
Carbon dioxide, to soil or biomass stock	8.A.1	-1	-1	-1	-1
Carbon monoxide, fossil	8.A.4 + oxidation	9.2214 (7.65+1.5714)	4.0624 (2.491+1.5714)	6.4714 (4.9+1.5714)	1.9578 (0.3864+1.5714)
Carbon monoxide, from soil or biomass stock	8.A.4 + oxidation	9.2214 (7.65+1.5714)	4.0624 (2.491+1.5714)	6.4714 (4.9+1.5714)	1.9578 (0.3864+1.5714)
Carbon monoxide, non-fossil	8.A.4	7.65	2.491	4.9	0.3864
Methane, fossil	8.SM.17 + Boucher	84.6 (83.9+0.7)	29.7 (28.5+1.2)	68.5 (67.5+1)	5.7 (4.3+1.4)
Methane	8.SM.17 + Boucher	84.6 (83.9+0.7)	29.7 (28.5+1.2)	68.5 (67.5+1)	5.7 (4.3+1.4)
Methane, from soil or biomass stock	8.SM.17 + Boucher	84.6 (83.9+0.7)	29.7 (28.5+1.2)	68.5 (67.5+1)	5.7 (4.3+1.4)
Methane, non-fossil	8.SM.17	83.9	28.5	67.5	4.3

7.4.6.4 Emissions from soil or biomass stock

See section 7.3.3.3.

7.5 Limitations

If agricultural, forestry or land use dominate the climate change score in an LCA, a careful foreground and background modelling based on primary data collection is strongly recommended.

There is a growing interest in using “dynamic LCA”, where the effects of temporarily storing carbon and delaying emissions are considered. However, its application requires extensive knowledge of case-specific information like time of sequestration and temporal profile of emission. ecoinvent, a background database, cannot take into account all the possible cases arising in LCAs. If the inclusion of dynamic effects is suspected to cause significant changes in the LCIA scores and conclusions of an LCA, its goal and scope should describe how those effects are taken into account, and the CFs applied to the ecoinvent database should be adapted.

7.6 References

Boucher O., Friedlingstein P., Collins B., Shine K.P. (2009). The indirect global warming potential and global temperature change potential due to methane oxidation. Environmental Research Letters, 4 (4). http://dx.doi.org/10.1088/1748-9326/4/4/044007.

Friedlingstein et al. (2006). Climate-Carbon Cycle Feedback Analysis: Results from the C^4MIP Model Intercomparison. Journal of Climate, 19 (14), 3337–3353. http://dx.doi.org/10.1175/JCLI3800.1.

Hodnebrog et al. (2013). Global warming potential and radiative efficiencies of halocarbons and related compounds: A comprehensive review. Reviews of Geophysics, 51 (2), 300-378. http://dx.doi.org/10.1002/rog.20013

UNEP/SETAC (2016). Global guidance for life cycle impact assessment indicators - Volume 1. http://dx.doi.org/10.1146/annurev.nutr.22.120501.134539.

8 CML

8.1 General information

Method versions	**v4.8 2016**
Method description	https://www.universiteitleiden.nl/en/research/research-projects/science/cml-new-dutch-lca-guide
Source of the CFs	https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors

8.2 Introduction

The CML impact assessment method (CML-IA) is provided from the Institute of Environmental Sciences of the University of Leiden in the Netherlands. It was first developed in 1992 and updated to its current 4.8 version in 2016. It is a midpoint method assessing several impact categories

8.3 Implementation

For creation of the final mapped CF file, carbon exchanges were mapped as described in section 6.4.1 and lower heating values were used for energy carriers (section 6.5.1).

9 Crustal Scarcity Indicator

9.1 General information

Method versions	**2020**
Method description	https://doi.org/10.1007/s11367-020-01781-1
Source of the CFs	https://research.chalmers.se/publication/519861/file/519861_Fulltext.pdf also provided by e-mail

9.2 Introduction

The Crustal Scarcity Indicator was developed in 2020 by Rickard Arvidsson and colleagues at Chalmers University in Gothenburg, Sweden. The method assesses mineral resource use based on crustal concentrations, which is considered a proxy for long-term global elemental scarcity.

9.3 Implementation

The implementation was straight forward as method developers provided the method with ecoinvent naming.

10 Ecological scarcity

10.1 General information

Method versions	2021 (v1.5)
Method description	https://www.bafu.admin.ch/bafu/en/home/topics/economy-consumption/economy-and-consumption-publications/publications-economy-and-consumption/eco-factors-switzerland.html
Source of the CFs	provided by e-mail (they can also be found in the report under the link above, but there might be differences)

10.2 Introduction

The Ecological Scarcity method was developed for Switzerland by the Federal Office for the Environment (FOEN) in 1990 and it was updated to its current version in 2021. It is a "distance to target" method considering the current situation and political targets (concerning emissions and resource use) for Switzerland (or by international policies and supported by Switzerland). The method assesses several impact categories in eco-points (“Umweltbelastungspunkte” or UBP), which is why results can be summed into a total.

10.3 Implementation

CFs were taken directly from the Excel file provided by method developers to most part. The two impact categories “Water resources, net balance” and “Noise” are not used. For water, the category “Water resources, evaporated” was used as it corresponds to the ecoinvent approach (see section 6.5.3). The EEs assessed in the “Noise” category are not present in ecoinvent.

10.3.1 Sub-compartment mapping

In the “water” compartment, the sub-compartments “lake”, “river” and “river, long-term” all have the same CFs. They are all to mapped with the method sub-compartment “lake” to the EE sub-compartment “surface water”.

10.3.2 Energy resources

Since heating values of oil and gas EEs were updated (section 6.5.1), CFs in the method were checked and for “Gas, natural/m3”, the CF was changed to 330, calculated as 40 MJ/m3 * 8.3 UBP/MJ oil-eq.

10.3.3 Metals/minerals

For some metals, no elementary exchanges with the pure element are available, but only elementary exchanges like “Metal, *concentrations in ore*”. Since they all have the same CF, we randomly mapped to one of these. Furthermore, the method does not make full use of available raw data provided in the supplementary material to van Oers et al. (2020), which results in a lacking coverage of elements. For all elements/minerals not covered by the method, additional CFs were calculated following the approach of the method, meaning by multiplying CFs in van Oers et al. (2020) by 150000 UPB / kg Sb eq and rounding them to two digits (Table 11).

Table 11 Additional characterization factors calculated for elements/minerals

name	formula	van Oers et al. 2020	element share	as in method
		kg Sb eq/kg	-	UPB / kg
Actinium	Ac	0	1	0
Arsenic	As	0.002361424	1	350
Astatine	At	0	1	0
Barium	Ba	1.43827E-05	1	2.2
Beryllium	Be	7.92746E-05	1	12
Bismuth	Bi	0.295759095	1	44000
Boron	B	0.004979433	1	750
Caesium	Cs	0.00193218	1	290
Calcium	Ca	3.57556E-07	1	0.054
Dysprosium	Dy	4.8582E-05	1	7.3
Erbium	Er	7.533E-05	1	11
Germanium	Ge	7.00506E-05	1	11
Holmium	Ho	0.000132546	1	20
Iridium	Ir	192.0936519	1	29000000
Laterite		0		0
Lutetium	Lu	0.00069752	1	100
Mercury	Hg	2.705132718	1	410000
Niobium	Nb	0.000286687	1	43
Osmium	Os	72.67337933	1	11000000
Polonium	Po	0	1	0
Potassium	K	1.32256E-07	1	0.020
Protactinium	Pa	0	1	0
Radium	Ra	0	1	0
Rubidium	Rb	0	1	0
Ruthenium	Ru	366.0744397	1	55000000
Scandium	Sc	7.62267E-08	1	0.011
Selenium	Se	0.312252203	1	47000
Silicon	Si	8.1958E-10	1	0.00012
Sodium	Na	1.65101E-07	1	0.025
Sodium sulphate, various forms		0		0
Strontium	Sr	1.65855E-06	1	0.25
Sylvite	KCl	1.32E-07	0.5244	0.010
Sylvite, 25 % in sylvinite	KCl	1.32256E-07	0.5244	0.010
Terbium	Tb	0.000266059	1	40
Thallium	Tl	1.92708E-05	1	2.9
Thorium	Th	0	1	0
Thulium	Tm	0.000498486	1	75
Titanium	Ti	3.78996E-07	1	0.057
Tungsten	W	0.021018311	1	3200
Vanadium	V	6.57728E-06	1	0.99
Ytterbium	Yb	0.000100943	1	15

10.3.4 Land use

The file provided by method developers does not contain global CFs for land occupation although this is the expert recommendation to method developers (Mutel et al. 2019). Fortunately, Martin Kilga of sinum[4] has insisted on having this and calculated global CFs following the approach described in Verones et al. (2020) and using the data in the supplementary material to Chaudhary and Brooks (2018): Area weighted global averages of CFs for countries and ecoregions were calculated and the results of the two approaches compared for a suggestion of a final CF (Table 12). An official documentation is not yet available but expected.

Table 12 Additional global characterization factors for land occupation in UBP/m2-year.

UPB category	**GLOvalue_country**	**GLOvalue_ecoregion**	**GLOvalue**
UBP_clear_cut	1338	1339	**1340**
UBP_selective_logging	860	864	**860**
UBP_RIL	105	105	**100**
UBP_min_plantation	1449	1451	**1450**
UBP_Lt_plantation	1482	1485	**1480**
UBP_Int_plantation	1526	1530	**1530**
UBP_min_pasture	1379	1381	**1380**
UBP_Lt_pasture	1432	1434	**1430**
UBP_Int_pasture	1471	1473	**1470**
UBP_min_crop	1346	1348	**1350**
UBP_Lt_crop	1420	1422	**1420**
UBP_Int_crop	1432	1434	**1430**
UBP_min_urb	1245	1246	**1240**
UBP_Lt_urb	1461	1463	**1460**
UBP_Int_urb	1529	1530	**1530**

10.4 References

van Oers L., Guinée J.B., Heijungs R. (2020). Abiotic resource depletion potentials (ADPs) for elements revisited—updating ultimate reserve estimates and introducing time series for production data. The International Journal of Life Cycle Assessment, 25, 294-308. https://doi.org/10.1007/s11367-019-01683-x.

Mutel C., Liao X., Patouillard L., et al. (2019) Overview and recommendations for regionalized life cycle impact assessment. The International Journal of Life Cycle Assessment, 24, 856-865. https://doi.org/10.1007/s11367-018-1539-4.

Verones F., Hellweg S., Antón A., et al. (2020) LC-IMPACT: A regionalized life cycle damage assessment method. Journal of Industrial Ecology, 24, 1201-1219. https://doi.org/10.1111/jiec.13018.

Chaudhary A., Brooks T.M. (2018). Land Use Intensity-Specific Global Characterization Factors to Assess Product Biodiversity Footprints. Environmental Science & Technology 52 (9), 5094-5104. https://doi.org/10.1021/acs.est.7b05570.

[4] www.sinum.com

11 EF (Environmental Footprint)

11.1 General information

Method versions	**v3.0** **v3.1** **v3.0 EN15804 + EN15804 (inventory indicators ISO21930)** **v3.1 EN15804 + EN15804 (inventory indicators ISO21930)**
Method descriptions	v3.0: https://eplca.jrc.ec.europa.eu/LCDN/EF_archive.xhtml v3.1: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml v3.0 EN15804: https://eplca.jrc.ec.europa.eu/LCDN/EN15804.xhtml v3.0 EN15804: https://eplca.jrc.ec.europa.eu/LCDN/EN15804.xhtml
Sources of the CFs	v3.0: https://eplca.jrc.ec.europa.eu/LCDN/EF_archive.xhtml v3.1: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml v3.0 EN15804: https://eplca.jrc.ec.europa.eu/permalink/EN_15804.xlsx v3.1 EN15804: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

11.2 Introduction

EF stands for Environmental Footprint and the method is maintained by the European Commission. The method was updated from version 3.0 to version 3.1 in July 2022, both are implemented. Furthermore, there is an EF v3.0 implementation for the EN 15804 standard, which differs in CFs for biogenic CO_2.

11.3 Implementation

The implementation of EF methods is based on the mapping between the ecoinvent EEs list and the EF EEs list resulting from the GLAD project[5], in particular from the work of the nomenclature group[6]. Some adjustments were made to increase the coverage of ecoinvent EEs with EF CFs.

For creation of the final mapped CF file, all regionalized CFs were excluded, carbon exchanges were mapped as described in section 6.4.1, water assessment was implemented as described in section 6.5.3, lower heating values were used for energy carriers (section 6.5.1), and several additional CFs were calculated for mineral resources (section 11.4.2).

11.4 EN15804

ecoinvent has developed a system model called ‘Allocation, cut-off, EN15804’. The aim of this system model is a) to facilitate Environmental Product Declaration (EPD) practitioners to comply with the standard EN15804&A2:2019 (CEN/TC 350 2019), and b) to contribute to a harmonization in the calculation of the indicators of the standard.

Four impact assessment methods are provided for the ‘Allocation, cut-off, EN15804’ system model: the *EF v3.x EN15804* methods, which provide the LCIA scores based on the CFs for *EF v3.0* and *EF v3.1*, the *TRACI v2.1* method, which is used for EPDs in the US, and the *EN15804* (inventory indicators ISO21930) method, which provides the resource indicators required in EPDs. The latter are not impact assessment indicators but are included in an impact assessment method to be more easily accessible to the users. There is no official

[5] https://github.com/UNEP-Economy-Division/GLAD-ElementaryFlowResources/tree/master/Mapping/Output/Mapped_files

[6] https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad-2/

release of *EF v3.1 EN15804*, but since *EF v3.1* was released, we implemented the same changes as between *EF v3.0* and *EF v3.0 EN15804* (see section 11.4.1).

Further documentation about the 'Allocation, cut-off, EN15804' system model and the impact assessment methods can be found in a dedicated report (Ioannidou et al. 2021). Here we focus on differences between *EF v3.0* and *EF v3.0 EN15804* method and additional CFs for mineral resources.

IMPORTANT NOTE: THE EN15804 IMPACT ASSESSMENT METHODS ARE MEANT TO BE USED ONLY WITH THE EN15804 SYSTEM MODEL.

11.4.1 Biogenic CO_2

The difference between *EF v3.0* and *EF v3.0 EN15804* methods (which were transferred to *EF v3.1* and *EF v3.1 EN15804*) are the CFs for biogenic CO_2 emissions: "Compared to the EF reference package valid at the time when the amendment was related, the revised EN 15804 differs for the characterisation factors (CFs) of biogenic CO2 uptake and emissions, which were set in the standard as equal to "-1" (CO2 uptake) and "+1" (CO2 release)." (EPLCA 2021). Furthermore, the ecoinvent EE "Carbon dioxide, non-fossil, resource correction" corrects for allocation distortions and gets the same characterization factor as "Carbon dioxide, in air" (Table 13).

Table 13 Characterization of carbon dioxide in EF v3.x and EF v3.x EN15804

name	compartment	EF v3.x	EF v3.x EN15804
Carbon dioxide, in air	natural resource	0	-1
Carbon dioxide, fossil	air	1	1
Carbon dioxide, from soil or biomass stock	air	1	1
Carbon dioxide, non-fossil	air	0	1
Carbon dioxide, non-fossil, resource correction	natural resource		-1
Carbon dioxide, to soil or biomass stock	soil	-1	-1

Characterisation factors available in raw data have further differences for CO and Methane flows. However, since this is not mentioned as a difference, we assumed these to be mistakes and corrected the CFs accordingly (Table 14).

Table 14 Corrected characterization factors for EF v3.0 EN15804

name	compartment	original	corrected
Carbon monoxide, non-fossil	air	1.57	0
Methane, fossil	air	36.75	36.8
Methane, from soil or biomass stock	air	36.75	36.8
Methane, non-fossil	air	36.75	34

11.4.2 Additional CFs for minerals

In addition to CFs provided by the method developers, CFs for the minerals listed in Table 15 were calculated based on CFs for contained elements and the molecular weight. They were implemented in EF v3.0, EF v3.1, and EF v3.0 EN15804.

Table 15 Minerals for which additional CFs were calculated based on CFs for contained elements and the molecular weight

Mineral	Formula	CF
Anhydrite	$CaSO_4$	4.545213E-05
Borax	$Na_2[B_4O_5(OH)_4]\cdot 8H_2O$	0.000484152
Chrysotile	$Mg_3(Si_2O_5)(OH)_4$	5.34357E-10
Colemanite	$Ca_2B_6O_{11}\cdot 5H_2O$	0.000673718
Diatomite	$SiO_2.nH_2O$	6.54411E-12
Dolomite	$CaMg(CO_3)_2$	2.66249E-10
Gypsum	$CaSO_4\cdot 2H_2O$	3.594E-05
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.30892E-10
Kieserite	$MgSO_4\cdot H_2O$	4.47161E-05
Magnesite	$MgCO_3$	5.82308E-10
Pyrite	FeS_2	0.000103181
Sodium chloride	NaCl	1.64607E-05
Sodium nitrate	$NaNO_3$	1.48768E-08
Sodium sulphate, various forms	Na_2SO_4	4.35814E-05
Spodumene	$LiAlSi_2O_6$	4.29051E-07
Sylvite	KCl	1.28953E-05
Talc	$Mg_3Si_4O_{10}(OH)_2$	3.92505E-10
Ulexite	$NaCaB_5O_6(OH)_6\cdot 5H_2O$	0.000569542

11.5 References

CEN/TC 350 (2019). CEN/TC 350 Sustainability of Construction Works - Environmental Product Declarations - Core Rules for the Product Category of Construction Products EN 15804:2012+A1:2013/A2:2019.

Ioannidou D., Foster C., Symeonidis A., Müller J., Bourgault G., FitzGerald D., Moreno Ruiz E. (2021). Documentation for the 'Allocation, cut-off, EN15804' system model. ecoinvent Association, Zürich, Switzerland.

EPLCA (2021). EN 15804 reference package. Retrieved from https://eplca.jrc.ec.europa.eu/LCDN/EN15804.xhtml

12 EPS

12.1 General information

Method versions	2020d (d = default)
Method description	https://www.ivl.se/english/ivl/publications/publications/eps-weighting-factors---version-2020d.html
Source of the CFs	https://www.ivl.se/download/18.694ca0617a1de98f472f9c/1628415088657/FULLTEXT01.pdf

12.2 Introduction

EPS stands for Environmental Priority Strategies. The method was developed by the Swedish Energy Agency, FORMAS. It was first released in 1990 and updated to its current version in 2020. It is an endpoint method assessing economic damage caused by emissions as well as the use of energy and material resources and land, expressed in 2018 Euros.

12.3 Implementation

CFs were taken directly from the method`s report. The two impact categories “emissions of noise from car and truck transports” and “ecosystem services” are not implemented in ecoinvent.

12.3.1 Land use

The implementation of land use CFs is not straight forward as the method makes assumptions on the land potential on which urban land use happens. The implementation is based on a worst-case assumption (arable land) as shown in Table 16. Furthermore, since a CF for unspecified land use was missing, it was calculated as the average of all CFs used in the implementation (Table 17).

Table 16 Mapping of land use exchanges to the EPS 2020d method.

ecoinvent name	Method name	Comment
Occupation, annual crop	Annual&perennial non-timber crops	
Occupation, annual crop, flooded crop	Annual&perennial non-timber crops	
Occupation, annual crop, greenhouse	Annual&perennial non-timber crops	
Occupation, annual crop, irrigated	Annual&perennial non-timber crops	
Occupation, annual crop, irrigated, extensive	Annual&perennial non-timber crops	
Occupation, annual crop, irrigated, intensive	Annual&perennial non-timber crops	
Occupation, annual crop, non-irrigated	Annual&perennial non-timber crops	
Occupation, annual crop, non-irrigated, extensive	Annual&perennial non-timber crops	
Occupation, annual crop, non-irrigated, intensive	Annual&perennial non-timber crops	
Occupation, arable land, unspecified use	Annual&perennial non-timber crops	
Occupation, cropland fallow (non-use)	Annual&perennial non-timber crops	assumed to still be part of the farming system
Occupation, field margin/hedgerow	Annual&perennial non-timber crops	

ecoinvent name	Method name	Comment
Occupation, heterogeneous, agricultural	Annual&perennial non-timber crops	
Occupation, permanent crop	Annual&perennial non-timber crops	
Occupation, permanent crop, irrigated	Annual&perennial non-timber crops	
Occupation, permanent crop, irrigated, extensive	Annual&perennial non-timber crops	
Occupation, permanent crop, irrigated, intensive	Annual&perennial non-timber crops	
Occupation, permanent crop, non-irrigated	Annual&perennial non-timber crops	
Occupation, permanent crop, non-irrigated, extensive	Annual&perennial non-timber crops	
Occupation, permanent crop, non-irrigated, intensive	Annual&perennial non-timber crops	
Occupation, grassland, natural, for livestock grazing	Livestock farming and ranching	
Occupation, pasture, man made	Livestock farming and ranching	
Occupation, pasture, man made, extensive	Livestock farming and ranching	
Occupation, pasture, man made, intensive	Livestock farming and ranching	
Occupation, grassland, natural (non-use)	Livestock farming and ranching	assumed to still be part of the farming system
Occupation, forest, extensive	Logging and wood harvesting	
Occupation, urban/industrial fallow (non-use)	Commercial & industrial areas on arable land in cities < 0.5 million inhabitants	
Occupation, dump site	Commercial & industrial areas on arable land in cities < 0.5 million inhabitants	
Occupation, industrial area	Commercial & industrial areas on arable land in cities > 0.5 million inhabitants	
Occupation, construction site	Commercial & industrial areas on arable land in cities > 0.5 million inhabitants	
Occupation, shrub land, sclerophyllous	Commercial & industrial areas on arable land in cities > 0.5 million inhabitants	used in dump and treatment activities
Occupation, urban, discontinuously built	Housing and urban areas on arable land in cities < 0.5 million inhabitants	
Occupation, urban, green area	Housing and urban areas on arable land in cities < 0.5 million inhabitants	
Occupation, urban, continuously built	Housing and urban areas on arable land in cities > 0.5 million inhabitants	
Occupation, forest, unspecified	Housing and urban areas on forestland in cities > 0.5 million inhabitants	
Occupation, mineral extraction site	Mining and quarrying	
Occupation, traffic area, rail network	Roads and railroads	
Occupation, traffic area, rail/road embankment	Roads and railroads	
Occupation, traffic area, road network	Roads and railroads	
Occupation, forest, intensive	Wood & pulp plantations	

Table 17 Calculation of the characterisation factor (CF) for unspecified land use as average of CFs implemented

Method name	CF
Annual&perennial non-timber crops	0.000742
Commercial & industrial areas on arable land in cities > 0.5 million inhabitants	9.56
Commercial & industrial areas on arable land in cities < 0.5 million inhabitants	6.6
Housing and urban areas on arable land in cities < 0.5 million inhabitants	6.61
Housing and urban areas on arable land in cities > 0.5 million inhabitants	9.57
Livestock farming and ranching	0.000231
Logging and wood harvesting	0.00026
Mining and quarrying	0.568
Roads and railroads	0.959
Wood & pulp plantations	0.00138
Occupation, unspecified	**3.3869613**

13 ReCiPe

13.1 General information

Method versions	2016 (v1.03 SimaPro)
Method description	https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf
Source of the CFs	https://www.rivm.nl/documenten/recipe2016cfsv1120180117

13.2 Introduction

ReCiPe was developed by the Dutch research institute of RIVM (National Institute for Public Health and the Environment), Radboud University Nijmegen, Leiden University and PRé Consultants in 2008. It was updated to its current version in 2016. It is a midpoint and an endpoint method, and it considers three distinct cultural perspectives: Individualist (I), Hierarchist (H), and Egalitarian (E). The method assesses several midpoint impact categories and the three areas of protection human health, ecosystem quality, and natural resources at endpoint level.

13.3 Implementation

The implementation is based on a SimaPro export (method version 1.03), which was readily available in the ecoinvent standard format (see section 4.2). For creation of the final mapped CF file, carbon exchanges were mapped as described in section 6.4.1 and water assessment was implemented as described in section 6.5.3.

13.3.1 Land use

The ReCiPe report (Huijbregts et al. 2016) gives instructions on how to implement land transformation: "Only natural land transformation is included here, land that is transformed from one type of anthropogenic use to another is not taken into account. […] Transformation from this type of natural land constitutes an impact on the ecosystem while transformation to one of these land types has a benefit for the ecosystem (i.e., negative CFs). Note that transformation to primary forest is not possible." Figure 6 shows the transformations identified in the report. Additionally, the CF for transformation from and to "… unspecified, natural (non-use)" was set to 3.75 and -3.75, respectively.

Table S7.4. Midpoint CFs for transformation of natural land.

Name	**Midpoint CF (annual crop equivalents·yr)**
Transformation, from grassland, natural (non-use)	3.75
Transformation, from forest, primary (non-use)	36.75
Transformation, from forest, secondary (non-use)	36.75
Transformation, from shrub land, sclerophyllous	3.75
Transformation, from wetland, inland (non-use)	3.75
Transformation, to shrub land, sclerophyllous	-3.75
Transformation, to forest, secondary (non-use)	-36.75
Transformation, to wetland, inland (non-use)	-3.75
Transformation, to grassland, natural (non-use)	-3.75

Figure 6 Land transformations identified for characterization in Huijbregts et al. (2016).

13.4 References

Huijbregts M. et al. (2016). ReCiPe 2016. National Institute for Public Health and the Environment. https://doi.org/10.1007/s11367-016-1246-y

14 TRACI

14.1 General information

Method versions	v2.1 (2014)
Method description	https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci
Source of the CFs	https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci

14.2 Introduction

TRACI stands for Tool for the Reduction and Assessment of Chemical and other environmental Impacts and is a method published by the U.S. Environmental Protection Agency (US EPA). The original version of TRACI was released in 2002 and it was updated to v2.1 in 2012 (the method file that can be downloaded suggests an update in December 2014: “traci_2_1_2014_dec_10_0.xlsx”). TRACI is a midpoint method assessing several impact categories.

14.3 Implementation

In TRACI, compartments are part of impact categories (for example, Ecotox. CF [CTUeco/kg], Em.agr.soilC, freshwater or Eutrophication Water (kg N eq / kg substance)), so bringing the method to the standard ecoinvent format needed for implementation (see section 4.2) meant to introduce the compartments and sub-compartments to the substance flows and map CFs accordingly. For example, “Ecotox., Em.agr.soilC, freshwater” is mapped to the impact category “ecotoxicity, freshwater” for substance flows with the compartment “soil” and the sub-compartment “agricultural soil”.

Some of the resulting exchanges only have a CF for “air, undefined” (for example, for global warming), which is then missing for specific sub-compartments (“rural air" and "urban air"). In this case, the CF is copied from “air, undefined” to the exchanges with specific sub-compartments. Some of the flows only have specific sub-compartments (such as “rural air" and "urban air") but are missing a CF for “unspecified”. In these cases, the average of the specific compartments was calculated for “unspecified”. For water, the specific sub-compartment “freshwater” was mapped as the second option in compartment mapping (meaning if no “unspecified” exchange can be found) to catch the cases where only a CF for the specific sub-compartment is available.

Energy resources were not mapped as there are several TRACI exchanges per ecoinvent exchange and a mapping is not possible (for example, “Hard coal, open pit mining” and “Hard coal, underground mining” vs. “Coal, hard, unspecified”).

Five duplicates were identified, meaning same substances with different CAS numbers (Table 18). For all these exchanges, the higher CF was applied.

Table 18 Duplicate substances in TRACI

Method name	CAS Number
CHLORDANE	57-74-9
CHLORDANE	12789-03-6
CYPROCONAZOLE	113096-99-4
CYPROCONAZOLE	94361-06-5
DODINE	2439-10-3
DODINE	112-65-2
FENOXAPROP-ETHYL	71283-80-2
FENOXYCARB	79127-80-3
FENOXYCARB	72490-01-8
FENPROPATHRIN	39515-41-8
FENPROPATHRIN	64257-84-7
MECOPROP	93-65-2
MECOPROP	7085-19-0
METIRAM (=ZINEB)	9006-42-2
ZINEB (= METIRAM)	12122-67-7

15 Further method updates

Since the oil and gas update affects energy exchanges, energy related methods needed to be updated (see section 6.5.1). These are Cumulative Energy Demand (CED) and Cumulative Exergy Demand (CExD). Furthermore, the impact categories for these methods were updated.

For the Ecological Footprint method, some gaps in the characterization of carbon dioxide exchanges were closed.

15.1 CED

Cumulative Energy Demand (CED) is based on the method published by ecoinvent for version 1.01 in 1997. It assesses primary energy usage. More information can be found in the ecoinvent v2.2 method implementation report.

The characterization factors for oil and gas were updated according to the higher heating values in Table 5.

Furthermore, the impact categories were regrouped and renamed as shown in Table 19.

Table 19 Impact categories available for the Cumulative Energy Demand (CED) method

Main categories	Sub-categories
energy resources: non-renewable	energy resources: non-renewable, biomass
	energy resources: non-renewable, fossil
	energy resources: non-renewable, nuclear
energy resources: renewable	energy resources: renewable, biomass
	energy resources: renewable, geothermal
	energy resources: renewable, geothermal, solar, wind
	energy resources: renewable, solar
	energy resources: renewable, water
	energy resources: renewable, wind
total	

15.2 CExD

Cumulative Exergy Demand (CExD) is based on the publication by Bösch et al. (2007). It "assesses the quality of energy demand and includes the exergy of energy carriers as well as of non-energetic materials". Thereby, exergy "accounts for the minimal work necessary to form the resource or for the maximally obtainable amount of work when bringing the resource's components to their most common state in the natural environment."

The characterization factors for oil and gas were updated according to Table 6. More information on the method implementation can be found in the ecoinvent v2.2 method implementation report.

Furthermore, the impact categories were regrouped and renamed as shown in Table 20.

Table 20 Impact categories available for the Cumulative Exergy Demand (CExD) method

Main categories	**Sub-categories**
energy resources: non-renewable	energy resources: non-renewable, biomass
	energy resources: non-renewable, fossil
	energy resources: non-renewable, nuclear
energy resources: renewable	energy resources: renewable, biomass
	energy resources: renewable, solar
	energy resources: renewable, water
	energy resources: renewable, wind
material resources	material resources: metals
	material resources: minerals
	material resources: water
total	

15.3 Ecological Footprint

The Ecological Footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. The method was developed in 2006 and it assesses the direct land occupation as well as the indirect land occupation related to the sequestration of CO2 emissions and nuclear energy use in the unit of "global hectares". More information on the method implementation can be found in the ecoinvent v2.2 method implementation report.

In order to align the characterization of land use related carbon dioxide flows (see section 6.4.1), negative CFs for carbon dioxide flow to soil or biomass stock were added based on already implemented CFs (Table 21).

Table 21 Added characterisation factors for the Ecological Footprint method

Name	**Compartment**	**Sub-compartment**	**Unit**	**CF**
Carbon dioxide, to soil or biomass stock	soil	agricultural	kg	-2.6722
Carbon dioxide, to soil or biomass stock	soil	forestry	kg	-2.6722
Carbon dioxide, to soil or biomass stock	soil	industrial	kg	-2.6722
Carbon dioxide, to soil or biomass stock	soil	unspecified	kg	-2.6722

15.4 References

Bösch M.E., Hellweg S., Huijbregts M.A.J., Frischknecht R. (2007). Applying Cumulative Exergy Demand (CExD) indicators to the ecoinvent database. The International Journal of Life Cycle Assessment, 12, 181-190. https://doi.org/10.1065/lca2006.11.282.