Implementation of Life Cycle Impact Assessment Methods in the ecoinvent Database v3.12

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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. Files containing such a mapping per method are available on GitHub[1] in ecoinvent' s LCIA method mapped format[2]. Furthermore, the full LCIA implementation file containing all CFs implemented is available in the "Files" section on ecoQuery in the "ecoinvent 3.11_LCIA implementation.7z" file.

[1] https://github.com/ecoinvent/lcia

[2] https://github.com/ecoinvent/lcia/blob/master/data_formats/ecoinvent_lcia_method_mapped_format.md

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 flows (EF, also known as elementary exchange)
- The same EF name bears a different meaning in the database and the different methods
- The database does not provide the necessary EF 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 of 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 provides a short description of methods, specific assumptions, and exceptions to overarching assumptions. This part of the report starts with the IPCC method (section 7) as it is widely used, and its implementation comes with several assumptions. The other methods (sections 8ff.) follow in alphabetical order. Table 1 gives an overview of where to find information in ecoinvent reports about method implementation.

3 Currently Implemented Methods

Table 1 shows the currently implemented methods. There are three changes for v3.12. First, a version of the IPCC 2021 method including biogenic carbon dioxide was introduced ("IPCC 2021 (incl. biogenic CO2)"). Second, methods, categories, and indicators for EN15804 were renamed to better align with the standard, which will make it easier for users to find the indicator and score they are looking for. Third, the "IMPACT World+, footprint version" method was updated from v2.0.1 to v2.1.

Table 1 Implemented methods in ecoinvent v3.12; status "superseded" means that a newer version of the method is available as well.

Method	Status	Method Version	ecoinvent Report
CML v4.8 2016	current	v4.8	v3.12
Crustal Scarcity Indicator 2020	current	2020	v3.12
Cumulative Energy Demand (CED)	current	2021	v3.12 / v2.2[3]
Cumulative Exergy Demand (CExD)	current	2021	v3.12 / v2.2
Ecological Footprint	current	2008	v3.12 / v2.2
Ecological Scarcity 2021	current	2021	v3.12
Ecosystem Damage Potential	current	2007	v3.12 / v2.2
EF v3.0	superseded	v3.0	v3.12
EF v3.1	current	v3.1	v3.12
EN15804	current		v3.11 and dedicated report
EPS 2020d	current	2020d	v3.12
IMPACT World+ v2.1, footprint version	current	v2.1	v3.12
Inventory results and indicators	current	v3.12	v3.12
IPCC 2013	superseded	2013	v3.12
IPCC 2021	current	2021	v3.12
IPCC 2021 (incl. biogenic CO2)	current	2021	V3.12
ReCiPe 2016 v1.03	current	2016 v1.03 (SimaPro)	v3.12
TRACI v2.1	current	v2.1	v3.12
USEtox	current	v2.13	v3.12

[3] https://db.ecoinvent.org/reports/03_LCIA-Implementation-v2.2.pdf

4 Implementation Procedure

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

4.1 Main Procedure

The main steps performed in the method implementation are:

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

4.2 Formatted Method Files

The ecoinvent website 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 developer's website or obtained via e-mail. Data sources are given in each method's section.

ecoinvent has developed an ecoinvent LCIA method input format[4]. A "formatted" file is produced for each method. It contains information on the EFs, 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 the impact category names show the CFs for each EF. 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_formatted.xlsx".

[4] https://github.com/ecoinvent/lcia/blob/master/data_formats/ecoinvent_lcia_method_input_format.md

4.3 Mapping Files

An explicit mapping between ecoinvent's EF nomenclature and the method's nomenclature is established using a mapping algorithm. The algorithm uses EF 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

Emissions in the ecoinvent database are emitted in various compartments like air, water, soil, etc. Each compartment is further subdivided into sub-compartments that better describe the release path of each emission. All compartments and sub-compartments used for the mapping in the database are presented in **Table 2** below (not shown are compartments not in use or not used for the mapping, such as "economic" or "social").

Table 2. Compartments and sub-compartments in ecoinvent, used for the compartment mapping.

Compartment	Sub-compartment	Definition / Application
Emissions		
air	low population density, long-term	Emission taking place in the future, >100 years after the start of the activity e.g. emissions from uranium mill tailings
air	lower stratosphere + upper troposphere	Emissions from airplanes e.g. air transport, cruising
air	non-urban air or from high stacks	Emission in areas with a population density below 400 persons per km2 or from stacks higher than 100 m. Resource extraction, forestry, agriculture, hydro energy, wind power, coal and nuclear power plants, municipal landfills, wastewater treatment, long-distance transports, shipping
air	urban air close to ground	Emission below 100 meters in areas with a population density above 400 persons per km2. Industry, oil and gas power plants, manufacturing, households, municipal waste incineration, local traffic, construction activities
air	unspecified	Only used if no specific information available.
soil	agricultural	Emission to soil that is used for/or is suitable to produce agricultural products that enter the human food chain e.g. agriculture, agricultural biomass production
soil	forestry	Emission to soil that is used for plant production (wood, renewable raw materials), but which is not used or suitable for production of agricultural products that enter the human food chain (permanent forest land, marginal lands)
soil	industrial	Emission to soil used for industry, manufacturing, waste management and infrastructure. Industry, landfarming of wastes, built-up land.
soil	unspecified	Only used if no specific information available
water	surface water	Rivers and lakes usually from discharge of effluents from wastewater treatment facilities
water	ground-	Groundwater which will get in contact with the biosphere after some time
water	ground-, long-term	Emissions which take place in the future, 100 years after the start of the activity e.g. long-term emissions from landfills
water	fossil well	Emissions to deep underground wells, normally in the context of fossil fuel extraction
water	ocean	Ocean, sea, and salty lakes such as for offshore works, overseas ship transports
water	unspecified	Only used if no specific information available

Compartment	Sub-compartment	Definition / Application
Resources		
natural resource	biotic	Biogenic resource, e.g. wood
natural resource	in air	Natural resources in air, e.g. argon, carbon dioxide. Used for carbon uptake in biomass and gases produced by air separation
natural resource	in ground	Natural resource in soil e.g. ores; landfill volume
natural resource	in water	Natural resource in water, e.g. magnesium, water
natural resource	fossil well	Resource usually infiltrated millennia ago, often under climatic conditions different from the present, and have been stored in deep underground since
natural resource	land	Land occupation and transformation

The nomenclature of these compartments and sub-compartments may vary, depending on each LCIA method. Therefore, 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 for 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 formatted file to produce the final "mapped" file containing all available CFs for ecoinvent EFs per impact category of the method ("{method name}_mapped_3.X.xlsx", see **Figure 3**). These files are available on GitHub[5] in ecoinvent's LCIA method mapped format[6].

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

[5] https://github.com/ecoinvent/lcia

[6] https://github.com/ecoinvent/lcia/blob/master/data_formats/ecoinvent_lcia_method_mapped_format.md

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 EF and/or the category differed between 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, average 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 commonly used impact categories are:

- Acidification
- Climate change
- Ecotoxicity
- Energy resources
- Eutrophication
- Human toxicity
- Ionising radiation
- Land use
- Material resources
- Ozone depletion
- Particulate matter formation
- Photochemical oxidant formation
- Water use

Sub-categories are attached to 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 flows (EFs) 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 with 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 needs 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 is the 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 from 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.”[7] Some further examples are listed in **Table 3** or discussed below.

Table 3 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
Gamma-cyhalothrin	Cyhalothrin		

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

Cyhalothrin

Most methods do not include Gamma-cyhalothrin. Following IMPACT World+, where CFs for Cyhalothrin and Gamma-cyhalothrin are the same[8], Cyhalothrin is used as a proxy for Gamma-cyhalothrin. This also meant to overwrite a mapping in the EF methods where Gamma-cyhalothrin had much higher CFs than Cyhalothrin. Since methods agree that Lambda-cyhalothrin has higher CFs than Cyhalothrin, Lambda-cyhalothrin is not used as a proxy for Cyhalothrin (or Gamma-cyhalothrin).

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 a 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 EF.

6.3 Assessment of 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 a 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.

[8] https://zenodo.org/record/8200703/files/impact_world_plus_2.0.1_expert_version_ecoinvent_v39.xlsx?download=1

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 CO2, CO, and Methane Emissions in Global Warming Methods

To understand the choice of CFs for CO_2, CO, and methane, it is necessary to know how their fossil and non-fossil uptake and release are modeled in the database.

6.4.1.1 Biogenic Carbon Dioxide

Even if original datasets are carbon balanced, LCIs might not be 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 agricultural and wood products. Therefore, for introducing a -1 / +1 characterization for biogenic carbon dioxide in some methods, carbon allocation corrections are applied. To give an example: if we assume an activity producing logs and wood chips is 50:50, but carbon uptake is allocated 90:10 because logs are nine times the price of wood chips, there will be too much carbon uptake in the allocated logs activity and too little in the allocated wood chips activity. The EF “Carbon dioxide, non-fossil, resource correction” corrects the difference of the distorted result to the amount before allocation (**Figure 5**).

mass	carbon	allocation factor	CO2 uptake allocated	correction	CO2 uptake corrected
1 kg	0.5 kg	0.9	3.30 kg	-1.47 kg	1.83
1 kg	0.5 kg	0.1	0.37 kg	+1.47 kg	1.83

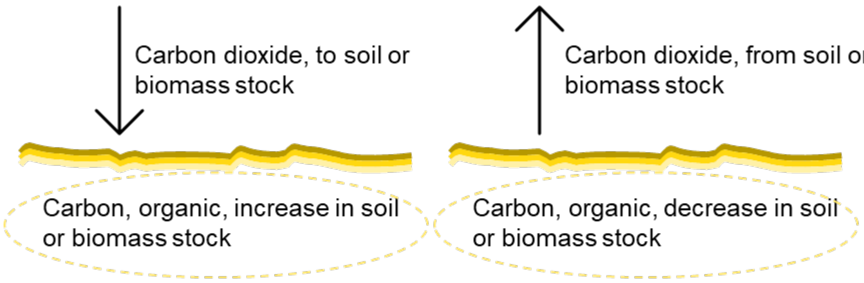
Figure 5 Example of biogenic carbon allocation correction

To implement this -1 / +1 characterization approach and carbon allocation correction in “IPCC 2021 (incl. biogenic CO2)” (Section 7.3) and “EN15804” (Section 15.3.2), we revised and harmonized biogenic carbon properties, uptake, and balances in the database to ensure accurate carbon accounting in inventories.

IMPORTANT NOTE: Scores for categories including biogenic carbon dioxide need to be handled with care, as there remains a risk of overestimating carbon uptake. For example, the difference between the score excluding and including biogenic CO_2 can be compared to the carbon dioxide in the reference product (based on its carbon content), as—in theory—they should be equal.

6.4.1.2 Biogenic Carbon in Land Use

The fixation of CO_2 by plants through photosynthesis is considered 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. To balance land tenure datasets, a source and an emission are given for overall carbon uptake or overall carbon release in these datasets:



flow	direction	CF
Carbon dioxide, to soil or biomass stock	input	-1
Carbon, organic, increase in soil or biomass stock	output	0

exchange	direction	CF
Carbon, organic, decrease in soil or biomass stock	input	0
Carbon dioxide, from soil or biomass stock	output	1

Figure 6 Carbon uptake and release modeling in land tenure datasets.

Emissions from soil or biomass stocks occur in agricultural and 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.

Table **4** gives an overview of relevant carbon EFs and how they are mapped to IPCC characterization factors (CFs).

Table 4 General assumptions for carbon sources and sinks.

Exchange Name	Mapping Rule
Carbon dioxide, fossil	Mapped with carbon dioxide fossil CF
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
Biogenic carbon dioxide	
Carbon dioxide, non-fossil	Zero except in methods including biogenic carbon dioxide (then mapped with carbon dioxide fossil CF)
Carbon dioxide, in air	Zero except in methods including biogenic carbon dioxide (then mapped with carbon dioxide fossil CF with a negative sign)
Carbon dioxide, non-fossil, resource correction	Correction for “Carbon dioxide, in air”, so mapped with carbon dioxide fossil CF, the sign depends on the correction
Land Use-related	
Carbon, organic, decrease in soil or biomass stock	Zero (this is a balancing flow for “Carbon dioxide, from soil or biomass stock)
Carbon dioxide, from soil or biomass stock	Mapped with carbon dioxide fossil CF
Carbon, organic, increase in soil or biomass stock	Zero (this is a balancing flow for “Carbon dioxide, to soil or biomass stock)
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

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 as “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[9] which was used for implementing EF methods (see section 15) contains such mappings.

6.4.3 Waste

Waste is not an elementary flow in ecoinvent. Wastes are sent to waste treatment activities, which in turn have emissions to the environment, depending on the nature of the input and the treatment. These emissions will be characterized by the methods, but since wastes do

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

not appear in the list of elementary flows 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.

6.5 Natural Resources

6.5.1 Energy Resources

Energy resources can be classified as 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 5)**.

Table 5 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 6** lists these values for fossil energy carriers). The Cumulative Energy Demand (CED) method implemented in ecoinvent version 1.01 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 (in CED, for example). 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 6 Higher Heating Values (HHV) and Lower Heating Values (LHV) for fossil energy carriers.

Exchange	Unit	HHV [MJ / Unit]	LHV [MJ / Unit]	Sources
Coal, brown	kg	9.9	9.41	[1] / [2] d
Coal, hard, unspecified	kg	19.1	18.01	[1] / [2] a, bituminous
Gas, mine, off-gas, process, coal mining	Sm3	40	36	[3] / [3]
Gas, natural	Sm3	40	36	[3] / [3]
Oil, crude	kg	46	43.4	[3] / [3]
Peat	kg	9.9	9.76	[1] / [2] b, peat

[1] Hischier et al. (2010)
[2] https://www.openlca.org/wp-content/uploads/2017/10/Calculation-of-energy-indicators-in-MJ-LHVs.pdf
[3] Meili et al. (2021)

Since the energy contents were updated, the Cumulative Exergy Demand (CExD) method's CFs also required an update. This was done using the energy-to-exergy ratio as provided in Bösch et al. (2007) (**Table 7**).

Table 7 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 distinguishes between land transformation (quantified in m^2) and land occupation (quantified in m^2*year). Datasets using land (typically, infrastructure) report what the land type was 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 …" EF will be lower, and the net sum will be positive (a damage).

6.5.3 Water Use

Water use is modeled 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 in 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 flow outputs are, when appropriate, modeled 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 consumption 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 EFs and hence no regionalized, but only global CFs are implemented.

IMPORTANT NOTE: Implementation of global CFs can affect results a lot, and regionalized results using a software allowing this should be used for studies where impact categories with regional differences, such as land and water use, are important.

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 straightforward 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 method 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

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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 favoring 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 of different emissions on climate change 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 the 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-year 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 subject 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 with CFs for GTP20). The recommendations regarding time horizons are:

- Using GWP 100 as the indicator for the shorter-term climate change impact category.
- Using GTP100 as a 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).

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 sulfur oxides (SOx) in their recommendations. In the IPCC

2013 implementation (Section 7.5), VOC, CO, and NO were characterized. Accordingly, these CFs (GWP 100) were used in a "…incl. SLCFs…" impact categories, which are meant to be used for sensitivity analysis. Furthermore, a CF of 11.6 (GWP 100) for hydrogen was added following Sand et al. (2023).

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 the 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[10], except for the values of methane (fossil and non-fossil) and nitrous oxide available in Table 7.15 (main report).

7.3.2 Differences to AR5

Carbon cycle responses (or carbon-climate feedback, see Section 7.5.3) are included in all the metrics.

7.3.3 Non-fossil Emissions and Emissions from Land Use Change

7.3.3.1 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 in Table 7.15 (**Table 8**). CO is not considered in the report.

7.3.3.2 Emissions from Direct Land Use Change (from soil or biomass stock)

See also Section 6.4.1.2.

Agriculture, forestry, land transformation, and hydropower datasets also report emissions of carbon through the elementary flows “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 8**). 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 is reported through the elementary flow “Carbon dioxide, to soil or biomass stock”, which gets -1 as a CF (**Table 8**).

Table 8 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, 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

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

7.3.4 Differences to Version 3.11

Previous implementations were based on the preliminary report and material available on GitHub[11]. The changes are negligible except for sulfur hexafluoride, as shown in **Table 9** ((e)-hex-2-en-1-ol is not used in ecoinvent currently).

Table 9 CFs updated from v3.11 to v3.12.

	v3.11					v3.12				
Elementary Flow	**GWP 20**	**GWP 100**	**GWP 500**	**GTP 50**	**GTP 100**	**GWP 20**	**GWP 100**	**GWP 500**	**GTP 50**	**GTP 100**
HFC-32	2690					2693				
HFC-134a	4140	1530				4144	1526			
CFC-11	8320	6230	2090	6350	3540	8321	6226	2093	6351	3536
PFC-14	5300		10600		9050	5301		10587		9055
(e)-hex-2-en-1-ol		0.003					0.002			
CFC-12			5710					5700		
Sulfur hexafluoride	18300	25200	34100	26200	30600	18200	24300	29000	25400	28800

7.3.5 Available Impact Categories and Indicators

The indicator that is most often used is global warming potential 100 (GWP100). Most impact categories offered are quantified for this indicator (**Table 10**, **Figure 7**). The main impact category is "climate change", but sub-categories group impacts as follows:

- Total (all relevant elementary flows assessed)
- Fossil (fossil elementary flows assessed)
  - Aircraft emissions (fossil aircraft emissions assessed)
- Direct land use change (land use change-related elementary flows assessed)
- Biogenic (biogenic/non-fossil elementary flows assessed)

Additionally, emissions and removals are given separately for "direct land use change" and "biogenic" sub-categories. Furthermore, it is made explicit in impact categories that biogenic carbon dioxide is excluded ("excl. biogenic CO2") where relevant ("fossil" by definition excludes "biogenic" and land use change-related carbon dioxide flows are separated from biogenic ones in modeling). Finally, for the main sub-categories, there are impact categories available that include short-lived climate forcers (SLCFs). These are carbon monoxide, nitric oxide, and volatile organic compounds (VOCs). AR6 does not provide metrics for these anymore, which is why CFs from the IPCC 2013 implementation are used here (see Section 7.2.3).

Other indicators than GWP100 are only offered for the "total" sub-category. These indicators are global warming potential 20 and 500 (GWP20 and GWP500) and global temperature potential 50 and 100 (GTP50 and GTP100).

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

Table 10 IPCC 2021 impact categories in v3.12 and v3.10.

Impact Category	Impact Category in v3.10	Indicator
climate change: total (excl. biogenic CO2)	**climate change**	**GWP100**
climate change: fossil	climate change: fossil	GWP100
climate change: fossil (excl. aircraft emissions)		GWP100
climate change: aircraft emissions		GWP100
climate change: direct land use change	climate change: land use	GWP100
climate change: emissions from direct land use change		GWP100
climate change: removals from direct land use change		GWP100
climate change: biogenic (excl. CO2)	climate change: biogenic	GWP100
climate change: total (excl. biogenic CO2, incl. SLCFs)	climate change: including SLCFs	GWP100
climate change: fossil (excl. biogenic CO2, incl. SLCFs)	climate change: fossil, including SLCFs	GWP100
climate change: direct land use change (incl. SLCFs)	climate change: land use, including SLCFs	GWP100
climate change: biogenic (excl. CO2, incl. SLCFs)	climate change: biogenic, including SLCFs	GWP100
climate change: total (excl. biogenic CO2)	climate change	GWP20
climate change: total (excl. biogenic CO2)	climate change	GWP500
climate change: total (excl. biogenic CO2)	climate change	GTP50
climate change: total (excl. biogenic CO2)	climate change	GTP100

7.4 IPCC 2021 (incl. biogenic CO2)

Several standards and guidelines exist in carbon footprinting. They have differences regarding the consideration of biogenic carbon flows. In the ecoinvent database, the main flows related to biogenic carbon are the elementary exchanges “Carbon dioxide, in air”, which represents the carbon dioxide uptake by biomass growth, and “Carbon dioxide, non-fossil”, which accounts for biogenic releases. So far, these flows were not characterized (0/0) for the impact assessment. However, some standards (like ISO 14067 and EN 15804) demand characterizing these flows with -1 / +1. Following what is described in Section 6.4.1.1, we have introduced “IPCC 2021 (incl. biogenic CO2)”, which is complementary to “IPCC 2021” (**Figure 7**).

Because carbon dioxide uptake and release are characterized with -1 / +1, the CF for biogenic methane and (when including SLCFs) carbon monoxide emissions need to be adjusted (Muñoz & Schmidt 2016). IPCC CFs are lower for biogenic emissions because a) oxidation (decay into carbon dioxide) replaces carbon dioxide that has been removed from the atmosphere, and b) “for biogenic methane the soil uptake and removal of partially oxidized products is equivalent to a sink of atmospheric CO2” (Forster et al. 2021). Furthermore, the assessment of biogenic carbon dioxide requires allocation correction as done with the exchange “Carbon dioxide, non-fossil, resource correction” (see section 6.4.1.1). **Table 11** shows a comparison of CFs for carbon dioxide, carbon monoxide, and methane in the IPCC implementations, excluding and including biogenic CO2.

Table 11 Characterization of carbon dioxide, carbon monoxide, and methane in the IPCC implementations, excluding and including biogenic CO2.

Name	Compartment	Excl. Biogenic CO2	Incl. Biogenic CO2	Excl. Biogenic CO2, Incl. SLCFs	Incl. Biogenic CO2, Incl. SLCFs
Carbon dioxide, fossil	air	1	1	1	1
Carbon dioxide, from soil or biomass stock	air	1	1	1	1
Carbon dioxide, non-fossil	air	0	1	0	1
Carbon dioxide, non-fossil, resource correction	natural resource		-1		-1
Carbon dioxide, in air	natural resource	0	-1	0	-1
Carbon dioxide, to soil or biomass stock	soil	-1	-1	-1	-1
Carbon monoxide, fossil	air			4.0624	4.0624
Carbon monoxide, from soil or biomass stock	air			4.0624	4.0624
Carbon monoxide, non-fossil	air			2.491	4.0624
Methane, fossil	air	29.8	29.8	29.8	29.8
Methane, from soil or biomass stock	air	29.8	29.8	29.8	29.8
Methane, non-fossil	air	27	29.8	27	29.8

The additional impact categories for “IPCC 2021 (incl. biogenic CO2)” are “climate change: total” without and with SLCFs, and “climate change: biogenic” including biogenic carbon dioxide for the total as well as the emissions and removals separately to provide more information and transparency.

7.4.1 Recommendations Regarding Biogenic Carbon Dioxide and Standards and Guidelines

First and foremost, we recommend using “IPCC 2021” where biogenic carbon dioxide is characterized with 0/0 whenever possible. However, some standards and guidelines demand a -1 / +1 characterization. For this, impact categories from “IPCC 2021” and “IPCC 2021 (incl. biogenic CO2)” can be mapped to standards and guidelines (**Figure 7**). Further carbon information, like the carbon content of products, might be needed to comply with standards and guidelines, but this information does not come from LCIA methods. We provide a list with the carbon contents of all products in the “Files” section in ecoQuery.

Scores including biogenic carbon dioxide are subject to potential distortions by allocation, and there is the risk of overestimating uptake. They should be handled with care, especially if they are negative, and they should never be used as a stand-alone score. Another approach to assess biogenic uptake is to simply check biogenic dioxide bound in the product based on its non-fossil carbon content. This can be compared to the difference of the scores excluding and including biogenic carbon dioxide as—in theory—they should be equal.

Users assume full responsibility for their application and interpretation.

IMPORTANT NOTE: We recommend using “IPCC 2021” where biogenic carbon dioxide is characterized with 0/0 whenever possible. Scores including biogenic carbon dioxide are subject to potential distortions by allocation, and there is the risk of overestimating uptake. They should be handled with care, especially if they are negative, and they should never be used as a stand-alone score.

Users assume full responsibility for their application and interpretation.

Impact category	Indicator	ID	method/standard/guideline: handling of biogenic CO2	IPCC 2021: 0/0 for biogenic CO2	IPCC 2021 (incl. biogenic CO2): -1/+1 for biogenic CO2	ISO 14067: -1/+1 for biogenic CO2	EN 15804: -1/+1 for biogenic CO2	flow / type	Methane, non-fossil (biogenic)	Carbon dioxide, non-fossil (biogenic)	Carbon dioxide, in air (biogenic, removal)	Carbon dioxide, non-fossil, resource correction (biogenic, removal)	Methane, from soil or biomass stock (land use)	Carbon dioxide, from soil or biomass stock (land use)	Carbon dioxide, to soil or biomass stock (land use, removal)	Carbon monoxide, fossil (SLCF)	Nitric oxide (SLCF)	VOC, volatile organic compounds (SLCF)	Carbon monoxide, non-fossil (SLCF, biogenic)	Carbon monoxide, from soil or biomass stock (SLCF, land use)	other GHGs (other)
climate change: total (excl. biogenic CO2)	**GWP100**	A		x		(x)	(x)		x				x	x	x						x
climate change: total (incl. biogenic CO2)	GWP100	B			x	x	x		x	x	x	x	x	x	x						x
climate change: fossil	GWP100	C		x (= D + E)		x (= D + E)	x														x
climate change: fossil (excl. aircraft emissions)	GWP100	D		x		(x)															x
climate change: aircraft emissions	GWP100	E		x		x															x
climate change: direct land use change	GWP100	F		x (= G + H)		x (= G + H)	x (= G + H)						x	x	x						
climate change: emissions from direct land use change	GWP100	G		x		(x)	(x)						x	x							
climate change: removals from direct land use change	GWP100	H		x		(x)	(x)								x						
climate change: biogenic (excl. CO2)	GWP100	H		x					x												
climate change: biogenic (incl. CO2)	GWP100	I			x (= J + K)	x (= J + K)	x (= J + K)		x	x	x	x									
climate change: biogenic emissions (incl. CO2)	GWP100	J			x	(x)	(x)		x	x											
climate change: biogenic removals (incl. CO2)	GWP100	K			x	(x)	(x)				x	x									
climate change: total (excl. biogenic CO2, incl. SLCFs)	GWP100			x		(x)	(x)		x				x	x	x	x	x	x	x	x	x
climate change: total (incl. biogenic CO2, incl. SLCFs)	GWP100				x	(x)	(x)		x	x	x	x	x	x	x	x	x	x	x	x	x
climate change: fossil (excl. biogenic CO2, incl. SLCFs)	GWP100			x		(x)	(x)									x	x	x			x
climate change: direct land use change (incl. SLCFs)	GWP100			x		(x)	(x)						x	x	x					x	
climate change: biogenic (excl. CO2, incl. SLCFs)	GWP100			x		(x)	(x)		x										x		
climate change: total (excl. biogenic CO2)	GWP20			x					x				x	x	x	x	x	x	x	x	x
climate change: total (excl. biogenic CO2)	GWP500			x					x				x	x	x	x	x	x	x	x	x
climate change: total (excl. biogenic CO2)	GTP50			x					x				x	x	x	x	x	x	x	x	x
climate change: total (excl. biogenic CO2)	GTP100			x					x				x	x	x	x	x	x	x	x	x

Figure 7 Available impact categories and indicators and mapping to standards; (x) = not explicitly mentioned in the standard but recommended to be included in the analysis.

7.5 IPCC 2013 (Assessment Report 5)

7.5.1 Source Tables for GWP and GTP

The IPCC only supplies values for air emissions, without specifying the 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 12 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.

7.5.2 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 horizons are implemented.

7.5.3 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 takes 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.

7.5.4 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 NOx 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.

7.5.5 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 horizons, 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 problem. **Figure 8** 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 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 in 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 SO_2 and NOx decreasing the score. If both effects are taken into account simultaneously, the median of the net effect is close to zero (see **Figure 8**). The assumption of sooth proportion in particulate matter is somewhat arbitrary and could vary greatly 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 a sooth parameter is impossible, including only one or the other results in a less accurate model than including none of them. It was therefore decided to exclude both effects until all relevant information about BC is integrated with the database.

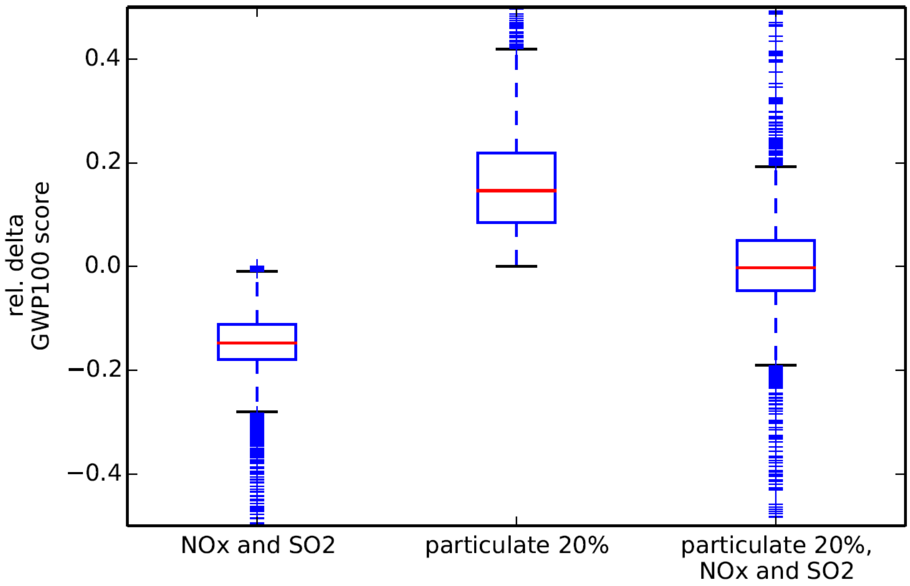

Figure 8 Effect of NOx, SO_2, and particulate on GWP100 scores.

Table 13 Effect of NO_x, SO_2, and particulate on GWP100 scores.

Percentile	Relative Delta, NOx, and SO_2	Relative Delta, Particulate 20%	Relative Delta, Particulate 20%, NOx, and SO_2
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

7.5.6 Non-fossil Emissions

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.

7.5.6.1 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 in 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.

7.5.6.2 Methane

The AR5 reports CFs for methane, non-fossil at Table 8.SM.17. The values for fossil methane are presented, rounded, in 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 in **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 in 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 14 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

7.5.6.3 Emissions From Soil or Biomass Stock

See Section 7.3.3.2.

7.6 Limitations

If agricultural, forestry, or land use dominate the climate change score in an LCA, a careful foreground and background modeling 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 the time of sequestration and the 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.

7.7 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.

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, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054. http://dx.doi.org/10.1017/9781009157896.009.

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

Muñoz, I., & Schmidt, J. H. (2016). Methane oxidation, biogenic carbon, and the IPCC's emission metrics. Proposal for a consistent greenhouse-gas accounting. International Journal of Life Cycle Assessment, 21(8), 1069–1075. https://doi.org/10.1007/s11367-016-1091-z

Sand et al. (2023). A multi-model assessment of the Global Warming Potential of hydrogen. Communications Earth & Environment 4, 203. https://doi.org/10.1038/s43247-023-00857-8

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 by 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 the 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 straightforward as method developers provided the method with ecoinvent naming.

10 Cumulative Energy Demand (CED)

10.1 General Information

Method Versions	2021
Method Description	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf
Source of the CFs	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf https://esu-services.ch/fileadmin/download/publicLCI/meili-2021-LCI for the oil and gas extraction.pdf / Table 6

10.2 Introduction

Cumulative Energy Demand (CED) is based on the method published by ecoinvent for version 1.01 in 1997. It "assesses primary energy usage, as it aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g., construction materials or raw materials".

10.3 Implementation

For version 3.9, the characterization factors for oil and gas were updated according to the higher heating values based on Meili et al. (2021) (see **Table 6**). Furthermore, the impact categories were regrouped and renamed as shown in **Table 15**. More information can be found in the ecoinvent v2.2 method implementation report (Hischier et al., 2010).

Table 15 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	

10.4 References

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf. Available at: https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

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

11 Cumulative Exergy Demand (CExD)

11.1 General Information

Method Versions	2021
Method Description	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf
Source of the CFs	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf Table 7

11.2 Introduction

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."

11.3 Implementation

The characterization factors for oil and gas were updated according to **Table 7**. Furthermore, the impact categories were regrouped and renamed as shown in **Table 16**. More information on the method implementation can be found in the ecoinvent v2.2 method implementation report (Hischier et al., 2010).

Table 16 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	

11.4 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.

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf. Available at: https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

12 Ecological Footprint

12.1 General Information

Method Versions	2008
Method Description	https://www.platformdse.org/wp-content/uploads/life-cycle-assessment.pdf https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf
Source of the CFs	https://www.platformdse.org/wp-content/uploads/life-cycle-assessment.pdf https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

12.2 Introduction

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 2008, and it assesses the direct land occupation as well as the indirect land occupation related to the sequestration of CO_2 emissions and nuclear energy use in the unit of “global hectares”.

12.3 Implementation

For fossil emissions and emissions from land transformation, the factor for CO_2 is applied. For uranium, an assumed energy content of 560,000 MJ per kg of uranium is used. Factors for land occupation are applied to all similar categories of land occupation. The categories “..., benthos” are approximated with “fisheries” with a factor of 0.36 m^2 year. The category “Occupation, unknown” is assigned a factor of 1 m^2 year, which represents the average of all the bio productive area on earth. More information on the method implementation can be found in the ecoinvent v2.2 method implementation report (Hischier et al., 2010) and in the paper published by Huijbregts et al. (2008).

12.4 References

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf. Available at: https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

Huijbregts M. A. J., Hellweg S., Frischknecht R., Hungerbühler K. and Hendriks A. J. (2008). Ecological Footprint Accounting in the Life Cycle Assessment of Products. In: Ecological Economics, 64 (4), pp 798-807. Available at: https://www.platformdse.org/wp-content/uploads/life-cycle-assessment.pdf

13 Ecosystem Damage Potential (EDP)

13.1 General Information

Method Versions	**2007**
Method Description	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf
Source of the CFs	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

13.2 Introduction

This method was published for the first time in 2007 for v2.2 by ecoinvent, and it was based on Koellner and Scholz (2007). The method assesses the impact of land use by taking into account **fifty-three** land use types and **six** intensity classes. The classification was based on CORINE land cover categories (see Hischier et al. 2010).

13.3 Implementation

The implementation of this method is also based on the factors published by Koellner and Scholz (2007). Only the factors based on a linear model are implemented.

For sea and ocean water surface no factor is available. Factors for the transformation of tropical rain forest (primary forest) were not available, because only land use types in Middle Europe are investigated. The factor for semi-natural coniferous forests above 800m and a restoration time of 1000 years is assumed. The process of calculating CFs for land transformation is meticulously explained in the ecoinvent v2.2 method implementation report (Hischier et al., 2010).

13.4 References

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf. Available at: https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

Koellner T. and Scholz R. (2007) Assessment of land use impact on the natural environment: Part 1: An Analytical Framework for Pure Land Occupation and Land Use Change. In: Int J LCA, 12(1), pp. 16-23, Available at: http://dx.doi.org/10.1065/lca2006.12.292.1.

14 Ecological Scarcity

14.1 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)

14.2 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.

14.3 Implementation

CFs were taken directly from the Excel file provided by method developers for the 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 EFs assessed in the “Noise” category are not present in ecoinvent.

14.3.1 Sub-compartment Mapping

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

14.3.2 Energy Resources

Since heating values of oil and gas EFs 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.

14.3.3 Metals/Minerals

For some metals, no elementary flows with the pure element are available, but only elementary flows 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 the 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 150,000 UPB / kg Sb eq and rounding them to two digits (**Table 17**).

Table 17 Additional characterization factors calculated for elements/minerals.

Name	Formula	van Oers et al. 2020 kg Sb eq/kg	Element Share -	As in Method 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

14.3.4 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[12] 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 were compared for a suggestion of a final CF (**Table 18**). An official documentation is not yet available, but is expected.

IMPORTANT NOTE: Implementation of global CFs can affect results a lot, and regionalized results using a software allowing this should be used for studies where impact categories with regional differences, such as land and water use, are important.

Table 18 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

[12] www.sinum.com

14.4 References

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.

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.

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.

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.

15 EF (Environmental Footprint)

15.1 General Information

Method Versions	**v3.0** **v3.1**
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
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

15.2 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, and both are implemented.

15.3 Implementation

The implementation of EF methods is based on the mapping between the ecoinvent EFs list and the EF method EFs list resulting from the GLAD project[13], in particular from the work of the nomenclature group[14]. Some adjustments were made to increase the coverage of ecoinvent EFs with EF method CFs.

For the 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 for mineral resources, as calculated for the EN15804 implementation, were added (Section 15.3.2).

15.3.1 IPCC Updates

Minor updates to climate change CFs were done as described in Section 7.3.4 and shown **Table 19** for EF v3.1. The changes are negligible except for sulfur hexafluoride. The CF for Sulfuryl fluoride was added following IPCC 2021.

Table 19 CFs updated from v3.11 to v3.12.

Elementary Flow	v3.11 **GWP 100**	v3.12 **GWP 100**
HFC-134a	1530	1526
CFC-11	6230	6226
Sulfur hexafluoride	25200	24300
Sulfuryl fluoride		4630

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

14 https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad-2/

15.3.2 Additional CFs for Minerals

In addition to the CFs provided by the method developers, CFs for the minerals and aggregates listed in **Table 20** were calculated by weighting CFs for contained elements with mass shares. They were implemented in EF v3.0, EF v3.1, and the EN15804 versions (Section 16). This was updated and extended for v3.12. Compositions of aggregates were taken from the Crustal Scarcity Indicator (Section 9).

Table 20 CFs for minerals and aggregates calculated by weighting CFs for contained elements with mass shares.

Mineral	Formula	CF
Anhydrite	CaSO4	4.55E-05
Borax	B4H20Na2O17	4.84E-04
Calcite	CaCO3	0.00E+00
Carnallite	Cl3H12KMgO6	1.04E-05
Chrysotile	H4Mg3O9Si2	5.34E-10
Cinnabar	HgS	7.95E-02
Colemanite	Ca2B6H10O16	6.74E-04
Dolomite	C2CaMgO6	2.66E-10
Fluorspar	CaF2	0.00E+00
Gypsum	CaH4O6S	3.59E-05
Kaolinite	Al2H4O9Si2	2.31E-10
Kieserite	H2MgO5S	4.47E-05
Magnesite	MgCO3	5.82E-10
Pyrite	FeS2	1.03E-04
Pyrolusite	MnO2	1.61E-06
Silicon dioxide	SiO2	6.54E-12
Sodium chloride	NaCl	1.65E-05
Sodium nitrate	NaNO3	1.49E-08
Sodium sulfate	Na2SO4	4.36E-05
Spodumene	AlLiO6Si2	4.33E-07
Stibnite	Sb2S3	7.17E-01
Sylvite	KCl	1.29E-05
Talc	H2Mg3O12Si4	3.93E-10
Ulexite	B5CaH16NaO17	5.70E-04
Zirconia, as baddeleyite	ZrO2	4.03E-06
Aggregate		**CF**
Basalt		2.34E-09
Clay, bentonite		1.72E-09
Diatomite		6.58E-12
Feldspar		3.65E-09
Granite		1.65E-09
Laterite		9.47E-09
Olivine		8.17E-09
Perlite		2.66E-09
Pumice		3.28E-09
Steatite		3.88E-10
Vermiculite		5.67E-09

16 EN15804

16.1 General Information

Method Versions	**Based on** EF v3.0 EN15804 EF v3.1 EN15804 **Additional EN15804 Inventory Indicators**
Method Descriptions	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 EN15804: https://eplca.jrc.ec.europa.eu/permalink/EN_15804.xlsx v3.1 EN15804: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

16.2 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. Furthermore, there is an EF v3.0 implementation for the EN 15804 standard, which differs in CFs for biogenic CO_2.

16.3 Implementation

The implementation of EF methods is based on the mapping between the ecoinvent EFs list and the EF method EFs list resulting from the GLAD project[15], in particular from the work of the nomenclature group[16]. Some adjustments were made to increase the coverage of ecoinvent EFs with EF method CFs.

For the 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 15.3.2).

16.3.1 A Separate System Model

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.

Further documentation about the ‘Allocation, cut-off, EN15804’ system model and impact assessment can be found in a dedicated report (Ioannidou et al. 2021).

IMPORTANT NOTE: The EN15804 impact assessment methods are meant to be used only with the EN15804 system model.

[15] https://github.com/UNEP-Economy-Division/GLAD-ElementaryFlowResources/tree/master/Mapping/Output/Mapped_files
[16] https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad-2/

16.3.2 Impact Assessment Methods and Indicators

Previously, four impact assessment methods were 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 U.S., 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 for users. For version 3.11, impact categories and indicators, as in the EF methods and inventory indicators, were rearranged with a new method and impact category names to better align with the standard and help users find what they are looking for. Thereby, a distinction between EF v3.0 and EF v3.1 is only made where relevant (climate change, ecotoxicity: freshwater, and human toxicity: non-carcinogenic) (**Table 21**).

Table 21 Method and category names for EN15804 in v3.12 and v3.10.

Method in v3.12 Category in v3.12	**Method in v3.10** Category in v3.10
EN15804+A2 - Core Impact Categories and Indicators	**EF v3.0 EN15804 or EF v3.1 EN15804**
climate change: total (EF v3.0 - IPCC 2013)	climate change
climate change: fossil (EF v3.0 - IPCC 2013)	climate change: fossil
climate change: biogenic (EF v3.0 - IPCC 2013)	climate change: biogenic
climate change: land use and land use change (EF v3.0 - IPCC 2013)	climate change: land use and land use change
ozone depletion	ozone depletion
acidification	acidification
eutrophication: freshwater	eutrophication: freshwater
eutrophication: marine	eutrophication: marine
eutrophication: terrestrial	eutrophication: terrestrial
photochemical oxidant formation: human health	photochemical oxidant formation: human health
material resources: metals/minerals	material resources: metals/minerals
energy resources: non-renewable	energy resources: non-renewable
water use	water use
climate change: total (EF v3.1 - IPCC 2021)	climate change
climate change: fossil (EF v3.1 - IPCC 2021)	climate change: fossil
climate change: biogenic (EF v3.1 - IPCC 2021)	climate change: biogenic
climate change: land use and land use change (EF v3.1 - IPCC 2021)	climate change: land use and land use change
EN15804+A2 - Additional Impact Categories and Indicators	
particulate matter formation	particulate matter formation
ionising radiation: human health	ionising radiation: human health
ecotoxicity: freshwater (EF v3.0)	ecotoxicity: freshwater
human toxicity: carcinogenic	human toxicity: carcinogenic
human toxicity: non-carcinogenic (EF v3.0)	human toxicity: non-carcinogenic
land use	land use
ecotoxicity: freshwater (EF v3.1)	ecotoxicity: freshwater
human toxicity: non-carcinogenic (EF v3.1)	human toxicity: non-carcinogenic

Since the inventory indicators do not correspond to common impact categories (see Section 5), "category" and "indicator" were used to provide a description and an acronym of the indicators (**Table 22**). Two indicators were added, but their value is 0 by default for now: "use of non-renewable secondary fuels" and "component for reuse".

Table 22 Method, category, and indicator names for EN15804 inventory indicators in v3.12 and v3.10.

Method in v3.12/ Category in v3.12	Indicator in v3.12	**Method - Category in v3.10** Indicator in v3.10
EN15804+A2 - Indicators Describing Resource Use		**EN15804 - Inventory Indicators ISO21930**
use of renewable primary energy excluding renewable primary energy resources used as raw materials	PERE	PERE
use of renewable primary energy resources used as raw materials	PERM	PERM
total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	PERT	Cumulative Energy Demand - renewable energy resources
use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	PENRE	PENRE
use of non-renewable primary energy resources used as raw materials	PENRM	PENRM
total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)	PENRT	Cumulative Energy Demand - non-renewable energy resources
use of secondary material	SM	use of secondary material
use of renewable secondary fuels	RSF	use of renewable secondary fuels
use of non-renewable secondary fuels	NRSF	
net use of fresh water	FW	use of net fresh water
EN15804+A2 - Indicators Describing Waste Categories		
hazardous waste disposed	HWD	hazardous waste disposed
non-hazardous waste disposed	NHWD	non-hazardous waste disposed
high-level radioactive waste disposed	HLRW	high-level radioactive waste disposed
intermediate and low-level radioactive waste disposed	ILLRW	intermediate and low-level radioactive waste disposed
EN15804+A2 - Indicators Describing Output Flows		
component for re-use	CRU	
materials for recycling	MFR	materials for recycling
materials for energy recovery	MER	materials for energy recovery
exported energy	EE	recovered energy
exported energy - electricity	EEE	exported energy - electricity
exported energy - heat	EET	exported energy - heat
EN15804+A2 - Indicators Describing Biogenic Carbon Content at Factory Gate		
biogenic carbon content in product	BCCP	biogenic carbon content in product
biogenic carbon content in accompanying packaging	BCCAP	biogenic carbon content in accompanying packaging

16.3.3 IPCC Updates

Minor updates to climate change CFs were done as described in Section 7.3.4 and shown in **Table 20** for EF v3.1. The changes are negligible except for sulfur hexafluoride. The CF for sulfuryl fluoride was added following IPCC 2021.

Table 23 CFs updated from v3.11 to v3.12.

Elementary Flow	v3.11 GWP 100	v3.12 GWP 100
HFC-134a	1530	1526
CFC-11	6230	6226
Sulfur hexafluoride	25200	24300
Sulfuryl fluoride		4630

16.3.4 Biogenic Emissions

(See also Section 7.4) The differences between EF v3.x and EF v3.x EN15804 methods are the CFs for biogenic carbon dioxide and—following this—biogenic methane and carbon monoxide emissions. Because carbon dioxide uptake and release are characterized with -1 / +1, the CF for biogenic methane and (for EF v3.0 EN15804) carbon monoxide emissions need to be adjusted (Muñoz & Schmidt 2016). IPCC CFs are lower for biogenic emissions because a) oxidation (decay into carbon dioxide) replaces carbon dioxide that has been removed from the atmosphere and b) “for biogenic methane the soil uptake and removal of partially oxidized products is equivalent to a sink of atmospheric CO2” (Forster et al. 2021). Furthermore, the assessment of biogenic carbon dioxide requires allocation correction as done with the exchange “Carbon dioxide, non-fossil, resource correction” (see Section 6.4.1.1). **Table 24** shows a comparison of CFs for carbon dioxide, carbon monoxide, and methane in EF v3.x and EF v3.x EN15804 methods.

Table 24 Characterization of carbon dioxide, carbon monoxide, and methane in EF v3.x and EF v3.x EN15804.

Name	Compartment	EF v3.1	EF v3.1 EN15804	EF v3.0	EF v3.0 EN15804
Carbon dioxide, fossil	air	1	1	1	1
Carbon dioxide, from soil or biomass stock	air	1	1	1	1
Carbon dioxide, non-fossil	air	0	1	0	1
Carbon dioxide, non-fossil, resource correction	natural resource		-1		-1
Carbon dioxide, in air	natural resource	0	-1	0	-1
Carbon dioxide, to soil or biomass stock	soil	-1	-1	-1	-1
Carbon monoxide, fossil	air			1.57	1.57
Carbon monoxide, from soil or biomass stock	air			1.57	1.57
Carbon monoxide, non-fossil	air			0	1.57
Methane, fossil	air	29.8	29.8	36.8	36.8*
Methane, from soil or biomass stock	air	29.8	29.8	36.8	36.8*
Methane, non-fossil	air	27	29.8	34	36.8*

* These values are 36.75 in the original file but were aligned with EFv 3.0 and, for methane, also adjusted for the difference reported in Forster et al. 2021 and described above.

16.4 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.

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, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054. http://dx.doi.org/10.1017/9781009157896.009.

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.

Muñoz, I., & Schmidt, J. H. (2016). Methane oxidation, biogenic carbon, and the IPCC's emission metrics. Proposal for a consistent greenhouse-gas accounting. International Journal of Life Cycle Assessment, 21(8), 1069–1075. https://doi.org/10.1007/s11367-016-1091-z

17 EPS

17.1 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

17.2 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.

17.3 Implementation

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

17.3.1 Land Use

The implementation of land use CFs is not straightforward, as the method makes assumptions about the land potential on which urban land use happens. The implementation is based on a worst-case assumption (arable land), as shown in **Table 25**. Furthermore, since a CF for unspecified land use was missing, it was calculated as the average of all CFs used in the implementation (Table 26).

Table 25 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

ecoinvent Name	Method Name	Comment
Occupation, field margin/hedgerow	Annual&perennial non-timber crops	
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 26 Calculation of the characterization 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

18 IMPACT World+

18.1 General Information

Method Versions	v2.1
Method Description	https://www.impactworldplus.org/version-2-0-1/
Source of the CFs	Provided by the method developers (generally available at https://zenodo.org/records/8200703)

18.2 Introduction

IMPACT World+ is developed by several institutions: CIRAIG, University of Michigan, Quantis International, Technical University of Denmark (DTU), and école Polytechnique de Lausanne (EPFL).[17] It is a globally regionalized LCIA method, “integrating multiple state-of-the-art developments as well as damages on water and carbon areas of concern within a consistent LCIA framework. Most of the regional impact categories have been spatially differentiated, and all long-term impact categories have been subdivided into shorter-term damage (the first 100 years after the emission) and long-term damage categories.”[18]

18.3 Implementation

Since ecoinvent does not yet provide regionalized inventories, only a reduced “footprint” version of the method is implemented, following the suggestion of the method developers. Characterization factors for version 2.1 were provided by the method developers already mapped to ecoinvent elementary flows. The method is described as follows on their website[19]:

“This version simplifies the interpretation of IW+ to 5 categories:

- "Carbon footprint": A carbon footprint indicator, based on the "Climate change, short term" midpoint indicator of IW+.
- "Water scarcity footprint": A water scarcity footprint indicator, based on the "Water scarcity" midpoint indicator of IW+.
- "Fossil and nuclear energy use": An indicator focusing on the use of fossil and nuclear resources, based on the "Fossil and nuclear energy use" midpoint indicator of IW+.
- "Remaining Human health damage": The Human health Area of Protection from which the impacts of Climate change and of Water availability were removed, as these two indicators are covered separately. In addition, all long terms impact categories and emissions are excluded.
- "Remaining Ecosystem quality damage": The Ecosystem quality Area of Protection from which the impacts of Climate change and of Water availability were removed, as these two indicators are covered separately. In addition, all long terms impact categories and emissions are excluded.”

[17] https://www.impactworldplus.org/team; last accessed 2024-11-15.
[18] https://www.impactworldplus.org; last accessed 2024-11-15.
[19] https://zenodo.org/record/8200703; last accessed 2024-11-15.

For the creation of the final mapped CF file, the CFs for oil and gas were overwritten with the higher heating values, as shown in **Table 6**, and water assessment was implemented as described in Section 6.5.3.

18.3.1 Implementation in v3.12

The method developers were still working on v2.2 while we were finishing v3.12. Because of this overlap in workflows, we missed updating the v2.1 implementation for new elementary flows. This means that the list of added elementary flows in **Table 27** was not mapped to the method, so even if CFs for these exist, they are currently not considered in the calculation of scores.

Table 27 Added elementary flows for v3.12.

Name	Compartment	Sub-compartment
1,1,2,2-Tetrafluoroethene	air	unspecified
1,1,2-Trichloroethane	water	unspecified
2-Ethyl hexyl acrylate	water	unspecified
2-Ethyl-2-hexenal	water	unspecified
2-Ethylhexanal	water	unspecified
2-Ethylhexanol	water	unspecified
2-Methylbutanal	air	unspecified
2-Methylbutanal	water	unspecified
Allyl alcohol	air	unspecified
Allyl alcohol	water	unspecified
Allyl chloride	air	unspecified
Bromide	natural resource	in water
Butadiene	water	unspecified
Butatriene	air	unspecified
Butyraldehyde	air	unspecified
Butyraldehyde	water	unspecified
Calcium acetate	water	unspecified
Calcium II	natural resource	in water
Chloride	natural resource	in water
Cobalt oxide	water	unspecified
Cyclopropene	water	unspecified
Dehydrolinalool	water	unspecified
Diethyl ketone	water	unspecified
Ethyl propionate	air	unspecified
Ethyl propionate	water	unspecified
Ethylene glycol dimethyl ether	air	unspecified
Ethylene glycol dimethyl ether	water	unspecified
Glycidol	water	unspecified
Isobutane	air	unspecified
Linalool	water	unspecified
Manganese carbonate	water	unspecified
Manganese II	natural resource	in water

Name	Compartment	Sub-compartment
Mesityl oxide	water	unspecified
Methyl isopropyl ketone	air	unspecified
Methyl isopropyl ketone	water	unspecified
Methyl propionate	air	unspecified
Methyl propionate	water	unspecified
Methyl vinyl ether	air	unspecified
Methyl vinyl ketone	water	unspecified
Methylbutenol	air	unspecified
Methylbutenol	water	unspecified
Methylbutynol	water	unspecified
Methylheptenone	water	unspecified
Pentanal	water	unspecified
Potassium acetate	water	unspecified
Potassium I	natural resource	in water
Propyl propionate	water	unspecified
Propylene carbonate	water	unspecified
Propylene glycol	water	unspecified
Sodium I	natural resource	in water
Succinonitrile	water	unspecified
tert-Butanol	air	urban air close to ground
tert-Butanol	water	surface water
Vinylidene chloride	air	unspecified
Vinylidene fluoride	air	unspecified

19 ReCiPe

19.1 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

19.2 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 the endpoint level.

19.3 Implementation

The implementation is based on a SimaPro export (method version 1.03), which was readily available in the ecoinvent LCIA method input format (see section 4.2). For the 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.

19.3.1 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 9** 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 9 Land transformations identified for characterization in Huijbregts et al. (2016).

19.4 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

20 TRACI

20.1 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

20.2 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.

20.3 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 ecoinvent LCIA method input 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 the same substances with different CAS numbers (**Table 28**). For all these exchanges, the higher CF was applied.

Table 28 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

21 USEtox

21.1 General Information

Method Versions	v2.13
Method Description	https://usetox.org/model/documentation
Source of the CFs	https://usetox.org/model/download

21.2 Introduction

“The USEtox model is an environmental model for characterization of human toxicological. and ecotoxicological life cycle impacts in LCA”. It was developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative. Its main goal is to improve the assessment and management of chemicals in the global environment by describing their fate, exposure, and effects.

21.3 Implementation

The implementation of this method was carried out based on the most recent version 2.13 of USEtox, as it was published in March 2023. The method publishes different indicators for organic and inorganic chemical substances, covering both the categories of human toxicity and ecotoxicity.

21.4 References

Fantke, P., Bijster, M., Guignard, C., Hauschild, M., Huijbregts, M., Jolliet, O., Kounina, A., Magaud, V., Margni, M., McKone, T.E., Posthuma, L., Rosenbaum, R.K., van de Meent, D., van Zelm, R., 2017. USEtox® 2.0 Documentation (Version 1) Available at: https://usetox.org/sites/default/files/assets/USEtox_Documentation.pdf

22 Inventory Results and Indicators

22.1 General Information

Method Versions	v3.12
Method Description	This report
Source of the CFs	No “real” CFs, results are a summary or aggregation of results (including some conversions)

22.2 Introduction

“Inventory results and indicators” builds on what was introduced in v2.0 as “selected LCI results” and “selected LCI results, additional”. Some “results” or “indicators” were kept, some added, some deleted. The calculation is not based on CFs but mainly summarizes or aggregates LCI values, and hence, “Inventory results and indicators” is not a “real” impact assessment method. Besides resource consumption and emissions, waste is added as a third category.

Sometimes, the “impact categories” and “indicators” chosen correspond to categories in policies and reporting schemes. The EU, for example, lists some “Main Air Pollutants”[20] and the U.S. EPA lists some “Criteria Air Pollutants”[21]. Both include, for example, sulfur oxides, which are included in the category “emissions to air” and the indicator “SOx”. In some cases, the sum of kg for such an indicator might be used as such, for example, kg Particulate Matter emissions to air; in other cases, the mapping of ecoinvent EFs to these indicators[22] might be of more use as it helps in identifying, for example, all ecoinvent EFs contained in the list of “Hazardous Air Pollutants” (HAP) by the US EPA[23] (included in the category “emissions to air” and the indicator “HAPs”). The ecoinvent EF list does not contain all HAPs.

22.3 Implementation

Table 29 shows the categories and indicators for “Inventory results and indicators”. Higher level indicators that sum up other indicators usually start with “total” to indicate this.

[20] https://www.eea.europa.eu/ims/emissions-of-the-main-air
[21] https://www.epa.gov/criteria-air-pollutants
[22] available on GitHub: https://github.com/ecoinvent/lcia/tree/master
[23] https://www.epa.gov/haps

Table 29 Categories and indicators for “Inventory results and indicators”.

Category	Indicator	Unit	Description
Resources			
resources	total surface occupation	m2a	Summation of surface occupation including the different land occupations and seabed occupation.
resources	land occupation	m2a	
resources	land occupation by flooding	m2a	
resources	seabed occupation	m2a	
resources	total water extraction	m3	Summation of water extractions from water bodies, excluding water used for cooling and in turbines.
resources	total freshwater extraction	m3	Summation of water extractions from surface water and groundwater
resources	freshwater extraction, surface water	m3	river and lake
resources	freshwater extraction, groundwater	m3	groundwater, well in ground, fossil well
resources	water extraction, saltwater	m3	ocean and sole
resources	water extraction, undefined	m3	
Emissions			
emissions to air	total particulate matter	kg	Summation of all particulate matter emissions to air.
emissions to air	particulate matter, < 2.5 um	kg	
emissions to air	particulate matter, >2.5 um and <10	kg	
emissions to air	particulate matter >10 um	kg	
emissions to air	total carbon dioxide, fossil and land use	kg	Summation of carbon dioxide emissions to air from fossil sources and due to land use (“to” and “from soil or biomass stock”)
emissions to air	total carbon monoxide	kg	Summation of carbon monoxide emissions to air
emissions to air	total methane	kg	Summation of methane emissions to air
emissions to air	carbon, non-fossil, fixed	kg	Biogenic carbon extracted from air (“negative emissions”) minus releases of biogenic carbon emitted with CO2, CO and CH4. A positive value indicates that a certain amount of the biogenic carbon is fixed in the product at issue. Products based on renewable sources are expected to have a levelled-out balance (carbon, non-fossil, fixed = zero) in case the incineration of the product is included. Carbon fixation in the soil is not included.
emissions to air	NMVOCs	kg	Summation of NMVOC emissions to air
emissions to air	N2O	kg	Summation of N2O emissions to air
emissions to air	NOx	kg	Summation of NOx emissions to air
emissions to air	SOx	kg	Summation of SOx emissions to air
emissions to air	ammonia	kg	Summation of ammonia emissions to air
emissions to air	lead	kg	Summation of lead emissions to air
emissions to air	photochemical oxidants (including ozone)	kg	Summation of all emissions to air characterized as photochemical oxidants in any of the implemented LCIA methods
emissions to air	HAPs	kg	Summation of all emissions listed in the US EPA list of Hazardous Air Pollutants
emissions to air	total radioactive emissions	kBq	Summation of radioactive emissions to air
emissions to water	total radioactive emissions	kBq	Summation of radioactive emissions to water

Category	Indicator	Unit	Description
Waste			
waste disposal	total area for dump sites	m2	Summation of area needed to deposit waste in dump sites
waste disposal	total volume of underground deposits	m3	Summation of volume needed to deposit waste in underground deposits including radioactive waste
waste disposal	total volume of radioactive waste	m3	Summation of volume of radioactive waste
waste disposal	total mass of waste	kg	Summation of mass deposited in dumb sites and underground deposits including radioactive waste
waste disposal	total mass for dump sites	kg	Summation of mass of waste deposited in dump sites
waste disposal	total mass for underground deposits	kg	Summation of mass needed to deposit waste in underground deposits including radioactive waste
waste disposal	total mass of radioactive waste	kg	Summation of mass of radioactive waste

22.3.1 NMVOCs

Non-Methane Volatile Organic Compounds (NMVOCs) are implemented following v2.2. To amend and check some random samples of the v2.2 implementation, the definition of a VOC was chosen as any organic compound having a boiling point less than or equal to 250°C measured at a standard pressure of 101,3 kPa, following European legislation.[24]

22.3.2 Waste

Waste flows for dump sites coming from models in ecoinvent are usually in kg (Doka, 2003), and waste densities are used to calculate EFs in m2. For waste deposited underground, waste densities can also be found in ecoinvent reports, see the implementation of the EDIP 2003 and 1997 methodologies according to Hischier et al. (2010). These waste densities are shown in **Table 30** and were used to back-calculate from EFs to indicators in kg, as listed in **Table 29**.

Table 30 Elementary flows and waste densities.

Elementary Flow	Flow Unit	Waste Density [kg/flow unit]	Source
Transformation, to dump site	m2	20 000	Doka (2003) / Hischier et al. (2010)
Transformation, to dump site, inert material landfill	m2	22 500	Doka (2003) / Hischier et al. (2010)
Transformation, to dump site, residual material landfill	m2	16 000	Doka (2003) / Hischier et al. (2010)
Transformation, to dump site, sanitary landfill	m2	20 000	Doka (2003) / Hischier et al. (2010)
Transformation, to dump site, slag compartment	m2	22 500	Doka (2003) / Hischier et al. (2010)
Volume occupied, underground deposit	m3	1600	Hischier et al. (2010)
Volume occupied, final repository for low-active radioactive waste	m3	2500	Hischier et al. (2010
Volume occupied, final repository for radioactive waste	m3	5400	Hischier et al. (2010

[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0042; last accessed 2023-10-23.

22.4 References

Doka, G. (2003). Life Cycle Inventories of Waste Treatment Services. ecoinvent report No. 13, Swiss Centre for Life Cycle Inventories, Dübendorf, December 2003. Available from https://db.ecoinvent.org/reports/13-III_Landfills_v2.1.pdf.

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf. Available from https://db.ecoinvent.org/reports/03_LCIA-Implementation-v2.2.pdf