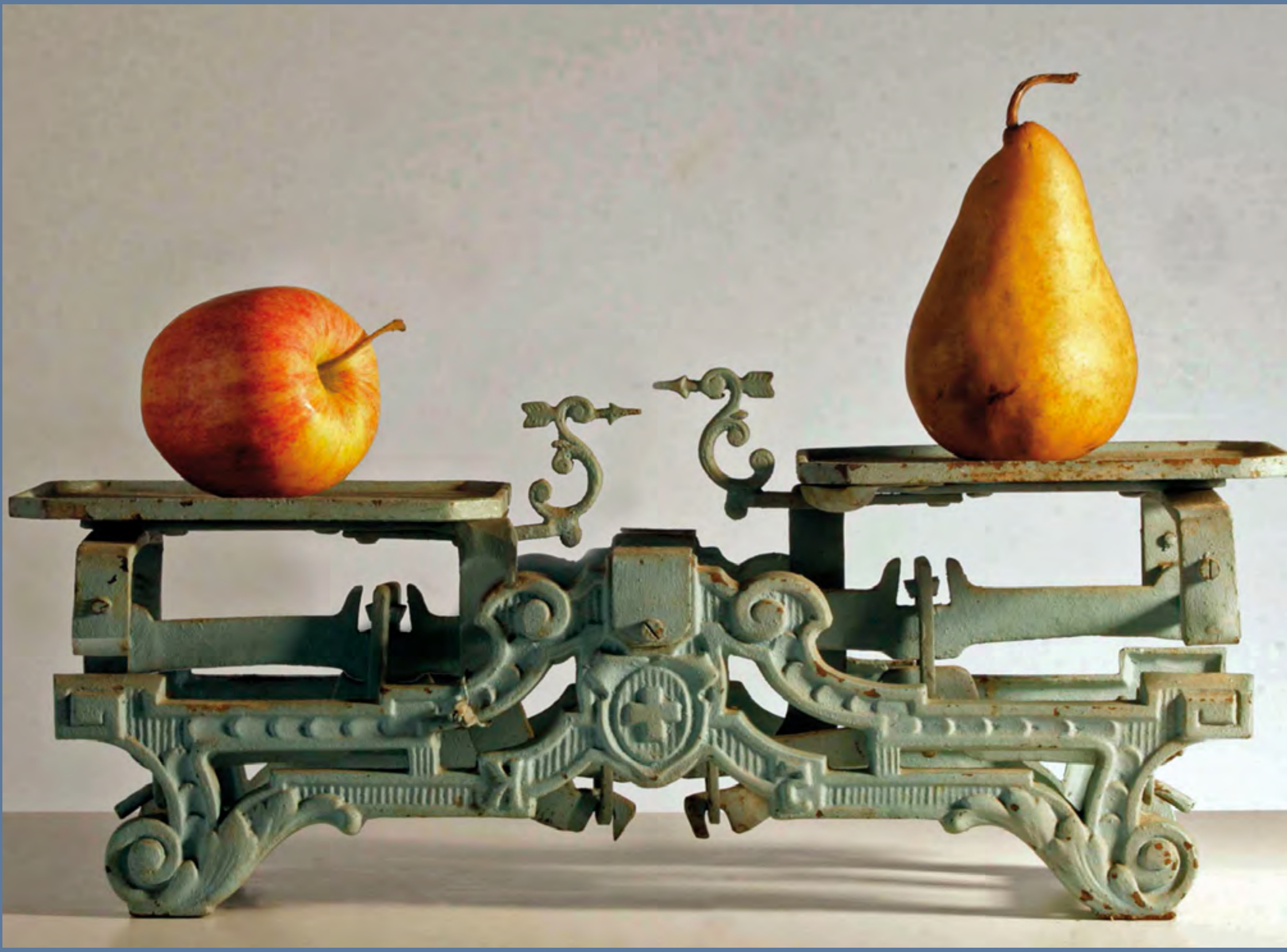
Swiss Eco-Factors 2021 according to the Ecological Scarcity Method

Methodological fundamentals and their application in Switzerland



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Abstracts

The ecological scarcity method makes it possible to assess the impact of emissions, the use of resources and waste as part of a life cycle assessment. The key metrics of this method are eco-factors, which measure the environmental damage in eco-points (UBP) per unit of quantity. This publication describes how Switzerland's eco-factors are derived on the basis of current emissions in relation to the targets set out in legislation. This fifth edition adds eco-factors for the use of marine fish resources to the set of existing eco-factors. The assessments of water use and biodiversity loss through land use are now based on internationally recommended approaches. The method itself remains unchanged.

Keywords:
LCA, eco-factors, assessment of impacts, ecological scarcity, eco-points

Die Methode der ökologischen Knappheit ermöglicht im Rahmen einer Ökobilanzierung die Wirkungsabschätzung von Emissionen, Ressourcennutzungen und Abfällen. Zentrale Grösse der Methode sind die Ökofaktoren, welche die Umweltbeeinträchtigung in Umweltbelastungspunkten (UBP) pro Mengeneinheit ausdrücken. Die Publikation beschreibt die Herleitung der Ökofaktoren für die Schweiz auf der Basis der aktuellen Emissionen im Verhältnis zu den gesetzlichen Zielen. In dieser fünften Ausgabe wird der Katalog von Ökofaktoren ergänzt durch solche für die Nutzung mariner Fischressourcen. Die Bewertungen der Wassernutzung und der Biodiversitätsverluste durch Landnutzung basieren neu auf international empfohlenen Ansätzen. Die Methode an sich bleibt unverändert.

Stichwörter:
Ökobilanz, Wirkungsabschätzung, Umweltbelastungspunkte (UBP), Ökologische Knappheit, Ökofaktor

La méthode de la saturation écologique permet, dans le cadre d’un écobilan, d’évaluer l’impact des émissions, de l’utilisation des ressources et des déchets. Les écofacteurs sont les variables centrales de cette méthode ; ils représentent l’atteinte à l’environnement, exprimée en unités de charge écologique (ou écopoints ; UCE=UBP) unité de mesure. La présente publication décrit comment les écofacteurs ont été obtenus pour la Suisse, par une comparaison entre les émissions actuelles et les objectifs ancrés dans la législation. Dans la présente cinquième version, de nouveaux écofacteurs pour les ressources halieutiques marines sont introduits. Les évaluations portant sur l’utilisation de l’eau ainsi que sur les pertes de biodiversité liées à l’utilisation du territoire se fondent désormais sur des approches recommandées à l’échelle internationale. La méthode en tant que telle reste inchangée.

Mots-clés :
écobilan, évaluation de l’impact, écopoint (UCE = UBP), saturation écologique, écofacteur

Nel quadro di un ecobilancio, il metodo della scarsità ecologica consente di valutare l’impatto sull’ambiente delle emissioni di inquinanti e del prelievo di risorse naturali. Gli ecofattori costituiscono gli elementi centrali di detto metodo: indicano il carico inquinante dovuto all’emissione di inquinanti o al prelievo di risorse naturali, che viene espresso in punti di impatto ambientale (PIA) per unità quantitativa. La pubblicazione descrive le modalità di determinazione degli ecofattori per la Svizzera in base al rapporto tra le emissioni attuali e gli obiettivi stabiliti dalla legge. In questa quinta versione, il catalogo degli ecofattori è integrato con quelli relativi all’utilizzo delle risorse ittiche marine. Le valutazioni dell’utilizzo dell’acqua e della perdita di biodiversità causata dall’utilizzo del suolo si basano ora su approcci raccomandati a livello internazionale. Il metodo rimane tuttavia invariato.

Parole chiave:
ecobilancio, valutazione dell'impatto, punti di impatto ambientale (PIA = UBP), scarsità ecologica, ecofattori

Foreword

In recent years, life cycle assessments have acquired a firm place in the public consciousness. Whenever topical issues such as climate change, nutrition or new energy carriers such as synthetic fuels or hydrogen are discussed, calls for a serious environmental impact evaluation almost automatically follow. The life cycle assessment has established itself in politics and business as a decision-supporting tool, for example in connection a tax relief for biofuels, in procurement (e.g. vehicles, paper) and in product development (e.g. use of recycled raw materials or non-scarce minerals in battery production).

In order for life cycle assessments to be credible as a basis for evaluation and decision-making, two requirements must be met. On the one hand, the process data on which the calculations are based must be of high quality. Vital, in this respect, are databases containing up-to-date, transparent and comprehensible background data, such as the Recommendation 2009/1 on life cycle assessment data in the construction sector of the Swiss Coordination Group for Construction and Property Services (KBOB) or UVEK LCI Data, i.e. the life cycle assessment data of the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

On the other hand, the method used for the assessment must be suitable for answering the questions at hand. It should represent the environmental burdens of the product under consideration as comprehensively as possible and in a way that allows them to be compared both individually and collectively. This is the only way to identify the relevant environmental impacts and their drivers.

The ecological scarcity method, also known as the eco-points method, is particularly well suited to evaluating Swiss conditions, first because it takes full account of the environmental impacts (use of resources, emissions, wastes) and second because the resulting assessment is based on the current environmental situation and Switzerland's statutory environmental targets and goals. Once again in in this publication, the assessment bases have been updated to reflect the current conditions in Switzerland. For this reason, experts should always use the eco-points method, in addition to other methods of impact assessment, for life cycle assessments relating to Switzerland.

The eco-points method has grown in importance well beyond Switzerland's borders. Thus, eco-factors based on the ecological scarcity method exist, for example, for the European Union, for individual EU countries, and for Japan.

In order to safeguard the quality of data and of the method, the FOEN has been supporting both data collection and further development of the eco-points method for more than 30 years. This publication is a further step on that path.

Karine Siegwart, Vice Director
Federal Office for the Environment (FOEN)

Summary

According to ISO standard 14040, life cycle assessments (LCAs) of products, processes, companies or entire national economies comprise four phases:

- goal and scope definition,
- inventory analysis,
- impact assessment, and
- interpretation.

In the ecological scarcity method, an impact assessment of life cycle inventories is performed according to the 'distance-to-target' principle. The key metrics of this method are eco-factors, which indicate the environmental burden of an emission, resource use or other substance flows in the form of eco-points (UBP) per unit of quantity. An eco-factor is derived by relating the current situation to the tolerated maximum emission or use. The ecological scarcity method, for convenience also referred to as the eco-points method, was first published in 1990.

As well as outlining the general method, this publication describes in detail how the eco-factors for Switzerland are derived. Acceptable, tolerated levels are based on statutory Swiss targets or on international targets supported by Switzerland. In the previous update (Frischknecht & Büsser Knöpfel 2013), new eco-factors were developed for various environmental impacts. These and the previous eco-factors have since been used by a wide range of experts carrying out LCAs on behalf of companies and authorities.

The ecological scarcity method is regularly revised on the basis of new scientific findings, new statutory and political targets, new international agreements, developments in international standardisation and experience gathered in practice. In this fourth update, the set of environmental pressures assessed has been further expanded. The data and information on which the existing eco-factors were based was checked and updated. The key changes compared to the 2013 update are:

- The eco-factor for **greenhouse gases** has doubled. This is due to the Federal Council's target from 2019 to reduce greenhouse gas emissions to net zero by 2050, and the increase of emissions since the 2013 edition.

- There is no longer a separate eco-factor for **diesel soot**, which is now covered by the subgroups PM10, PM2.5–10 and PM2.5. The eco-factor is equal for all subgroups.

- The environmental impact of **heavy metal emissions to air, water and soil** is now characterised based on the USEtox® model. Furthermore, the heavy metals are no longer assessed individually, but as a group. In the vast majority of cases, this results in significantly lower eco-factors than in the 2013 edition.

- The basic eco-factor for **plant protection products** has almost doubled compared to the 2013 edition. This is due to the new, more stringent target in the Plant Protection Products Action Plan. Together with the fact that individual substances are now characterised using USEtox®, eco-factors are clearly different from the 2013 edition, with some eco-factors being significantly higher and others significantly lower.

- For the first time, an eco-factor has been developed for **plastic entering the natural environment**. No distinction was made here between plastics entering the soil and those entering water, the two being considered as equivalent.

- The consumption of **primary energy carriers** is now weighted two-and-a-half times more heavily than in the 2013 edition. This is because current consumption is higher compared to the target for 2050 of 2,000 watts of continuous power.

- The eco-factor for **mineral and metal resources** is now based on the amount present in the earth's crust and no longer on the reserves deemed economically exploitable. Consequently, some resources have a much higher, others a much lower eco-factor.

- Characterisation of **freshwater use** is now based on the internationally recognised AWARE (Available WAter REmaining) method.

- For the first time, eco-factors for various **wild-caught marine fish** resources have been included. This makes

it possible to include (over)fishing of oceans in assessments.

- To take account of the space requirements and associated landscape changes caused by landfilled wastes (e.g. by filling valleys or pits), a new factor has been added for **landscape changes due to landfills**.

Table A

Overview of eco-factors 2021

The table shows the 2021 eco-factors for Switzerland. Factors for more substances determined by characterisation are listed in the annexes. The 'current flow' column states today's emission situation in Switzerland. The 'normalisation flow' column presents the reference quantity, which in most cases is identical to the current flow. The 'critical flow' column represents the legal target. If the critical flow is larger than the current flow, then today's situation is in accordance with the target. The column on the far right shows the eco-factor's percentage change compared with the 2013 edition.

	Normalisation flow (annual quantity)		Current flow (annual quantity)	Critical flow (annual quantity)		Eco-factor 2021		Eco-factor change since 2013 report
Emissions to air								
CO_2	61 826 000	t CO_2-eq.	61 826 000	7 829 000	t CO_2-eq.	1	UBP/g CO_2-eq.	+ 117 %
Ozone-depleting substances	95	t R11-eq.	95	61	t R11-eq.	25 000	UBP/g R11-eq.	+ 194 %
NMVOC	79 727	t	79 727	81 000	t	12	UBP/g	– 14 %
NOx	70 733	t	70 733	46 518	t	33	UBP/g	– 15 %
NH_3 (as N)	45 378	t	45 378	28 997	t	54	UBP/g NH_3-N	– 34 %
SO_2	5 208	t SO_2-eq.	5 208	25 000	t	8.3	UBP/g SO_2-eq.	– 60 %
PM10	14 994	t	14 994	9 639	t	160	UBP/g	+ 14 %
PM2.5–10	14 994	t	7 904	5 082	t	160	UBP/g	+ 14 %
PM2.5	14 994	t	7 089	4 558	t	160	UBP/g	+ 14 %
Carcinogenic substances (Benzene, Dioxins and Furans, PAHs)	4,71	CTUh	4.71	4,23	CTUh	$2.6 * 10^{11}$	UBP/CTUh	– 90 %
Heavy metals (ecotoxicity)	32 700	kg Cd-eq.		(see Heavy metals in the ground)		59 000	UBP/g Cd-eq.	(other derivation)
Radioactive emissions	0,91	TBq C-14-eq.	0.91	89,2	TBq C-14-eq.	110 000	UBP/GBq C-14-eq.	+ 13 650 %
Emissions to surface waters								
Nitrogen (as N)	64 000	t	44 364	29 113	t	36	UBP/g N	– 37 %
Phosphorus (as P)	1 490	t	–	–		970	UBP/g P	+ 9 %
COD	37 002	t	37 002	73 527	t	6.8	UBP/g	0 %
Heavy metals and arsenic (human toxicity)	14 700	kg As-eq.	14 700	48 900	kg As-eq.	6 200	UBP/g As-eq.	(other derivation)
Radioactive emissions to domestic waters	0.036	TBq U-235-eq.	0.036	35.38	TBq U-235-eq.	29 000	UBP/GBq U-235-eq.	– 87 %
Radioactive emissions to the Sea	4.02	TBq C14-eq.	36.5	46.6	TBq C14-eq.	150	UBP/kBq C14-eq.	+ 85 %
Oil emissions to the sea	5 467	t	9 377	7 403	t	290	UBP/g	+ 7 %
AOX (as $CHCl_3$-eq.)	370	t	0.97	28	t	3.2	UBP/g $CHCl_3$-eq.	(other derivation)
PAHs	744	kg	0.0119	0.1	µg/l	19 000	UBP/g	+ 36 %
Endocrine disruptors	3,1	kg E2-eq.	3,1	19	kg E2-eq.	8 700 000	UBP/g E2-eq.	+ 12 %
Persistent organic pollutants	306	t 2,4,6-T-eq.	306	72,2	t 2,4,6-T-eq.	59 000	UBP/g 2,4,6-T-eq.	+ 4 %

	Normalisation flow (annual quantity)		Current flow (annual quantity)	Critical flow (annual quantity)		Eco-factor 2021		Eco-factor change since 2013 report
Emissions to groundwater								
Nitrogen (as N)	34 000	t	34 000	17 000	t	120	UBP/g NO_3-N	0 %
Emissions to soil								
Heavy metals (human toxicity)	686 976	kg Zn-eq.	686 976	493 235	kg Zn-eq.	2 800	UBP/g Zn-eq.	(other derivation)
Plant protection products (human toxicity)	9 761	t glyphosate-eq.	9 761	5 854	t glyphosate-eq.	280	UBP/g glyphosate-eq.	+ 87 %
Plastic in the environment (ground or water)	16 285	t plastic	474	687	t plastic	29	UBP/g plastic	new
Resources								
Primary energy carriers	1 295	PJ oil-eq.	1 295	396	PJ	8.3	UBP/MJ oil-eq.	+ 150 %
Land use, settlement area	15 945	km^2.a SA-eq.	15 945	4 900	km^2.a SA-eq.	630	UBP/m^2.a SF-eq.	+ 110 %
Metal and mineral resources	6 733	t Sb-eq.	6 733	6 733	t Sb-eq.	150	UBP/g Sb-eq.	– 86 %
Gravel	36 000	1 000 t	36 000	36 000	1 000 t	0,028	UBP/g	– 7 %
Freshwater Switzerland	2.61	km^3 water-eq.	2,61	10,7	km^3 water-eq.	22	UBP/m^3 water-eq.	– 4 %
Marine fish resources	2 629 000	t PA-eq.	2 629 000	1 614 000	t PA-eq.	1	UBP/g PS-eq.	new
Wastes								
C to landfill	161 500	t	161 500	161 500	t	6.2	UBP/g C	+ 13 %
Hazardous wastes to underground disposal sites	31 682	t	31 682	14 939	t	142	UBP/g	+ 426 %
Landscape-changing landfilling	28.1 m	m^3 waste	28.1 m	28.1 m	m^3 waste	36 000	UBP/m^3 waste	new
High-level radioactive wastes	154.9	m^3 HLW-eq.	$1,37 * 10^{14}$	$4,70 * 10^{13}$	RTI/a	54 000	UBP/cm^3 HLW-eq.	+ 17 %
Noise								
Road noise	821 164	HAP	716 317	424 504	HAP	3 500 000	UBP/HAP	+ 3 %
· Passenger transportation						23	UBP/vkm	+ 10 %
· Transportation of goods						180	UBP/vkm	– 14 %
Railway noise	821 164	HAP	45 411	22 553	HAP	4 900 000	UBP/HAP	+ 14 %
· Passenger transportation						8	UBP/pkm	+ 54 %
· Transportation of goods						4,8	UBP/tkm	– 68 %
Aircraft noise	821 164	HAP	59 436	24 382	HAP	7 200 000	UBP/HAP	+ 76 %
· Passenger transportation						4	UBP/pkm	+ 186 %
· Transportation of goods						40	UBP/tkm	+ 186 %

User information

This publication 'Swiss Eco-Factors 2022 according to the Ecological Scarcity Method: Methodological fundamentals and their application in Switzerland' consists of three main parts:

- Part 1 is aimed at readers with a professional interest in the subject, especially those commissioning life cycle assessments in companies and administrations, as well as policymakers and media professionals. The first chapter, entitled 'Basic information about eco-points', gives a simple and concise explanation of the ecological scarcity (or eco-points) method and its characteristics. The second chapter, 'Questions and answers concerning life cycle assessments (FAQ)', provides more detailed information on life cycle assessments in general and the eco-points method in particular.

- Part 2 presents the ecological scarcity method in detail. The explanations are aimed at a professional audience of commissioning parties as well as experts in research and industry. The content focuses on the principles behind the method, the formulas used to derive the eco-factors and the thematic structure of the 2021 eco-factors.

- Part 3 provides a detailed description of how the eco-factors are derived. This is where specialists will find the scientific and environmental policy parameters underpinning the assessment of emissions, resource use and other substance flows according to the eco-points method.

Part 1

Life cycle assessments in brief

Part 1 explores the basic issues surrounding life cycle assessments in general and the eco-points method in particular. The text is aimed at readers with a professional interest in the subject who nonetheless are not experts in the field, especially commissioning parties, media professionals and policymakers.

1 Basic information about eco-points

Life cycle assessments (LCAs) can be used as a basis for environmental decision-making. A question that usually arises in this context is how different environmental burdens can be weighted against each other. The eco-points method is very helpful in this regard. It weights different environmental pressures by means of 'eco-points' (UBP): the fewer the eco-points, the smaller the environmental burden. The method bases this evaluation on legal environmental quality targets.

Is it possible to compare apples with pears? Yes, it is. Just as you compare the price of a kilo of apples with that of a kilo of pears in a shop, it is possible to determine whether less of a burden is placed on the environment by tomatoes grown in a field in Spain or those grown in a Swiss greenhouse. Similarly, the environmental impacts of a vegetarian menu can be weighed against one containing meat. You can even work out how much more environmentally damaging it is to drive to the shopping centre than to use a plastic bag for your vegetables – two things that have completely different functions, but can still be compared in terms of their environmental impacts.

Eco-points (abbreviated to UBP from the German Umweltbelastungspunkte) are a very useful unit of measurement for such comparisons. Used in an LCA, eco-points take into account the many aspects of environmental burden and impact – from resources and emissions (both substances and, for example, noise) through to wastes. This means that in many cases the eco-points method has an advantage over methods that use only one or just a few areas of environmental impact as a yardstick (infoboxes 1 and 2). Currently, for example, many studies consider only greenhouse gases (climate impact), thus ignoring all other environmental pressures.

The life cycle assessment of vehicle fuels, for example, illustrates what consequences this can have. If a study solely analyses greenhouse gas emissions, fuels from renewable raw materials often appear to be a good choice because they emit fewer greenhouse gases into the atmosphere than fossil fuels. However, such a comparison does not tell the whole story and is therefore unsuitable as a basis for decision-making. This is because it ignores the fact that renewable fuels burden the environment in other ways: growing and processing crops requires soil, energy and water, and fertilisers and plant protection products are often used as well. The eco-points method factors in these environmental impacts too, taking account of the conditions in the regions where the crops are grown. A fuel LCA applying UBP therefore presents a nuanced view: while some renewable fuels (notably those derived from algae or plant waste) are indeed more environmentally friendly than the fossil fuels petrol and diesel, others (e.g. those made from rapeseed or grain) have an even greater environmental impact than fossil fuels. The eco-points method thus gives a more reliable overall picture of the environmental issues involved.

Businesses, authorities and non-profit organisations use LCAs as a decision-making tool in many situations, as they allow them to better evaluate the environmental impact of products, processes, operations and locations.

LCAs show the environmental relevance of an activity, process or plant. An LCA using eco-points helps to gauge the environmental burden of processes and products, and to evaluate the outcomes of mitigation measures by means of a before-and-after comparison. An LCA using eco-points can also identify which measures are most cost-effective in terms of environmental impact reduction.

In this way, the purchasing department can consult life cycle assessments with UBP: An LCA using eco-points provides pertinent information about environmental impacts and hence informs the choice of consumables and capital goods. LCAs are also valuable in environmental management: for an organisation with an ISO 14001-certified environmental management system, a company LCA with eco-points can be useful, for example, for identifying the relevant environmental aspects and for continuous improvement, and also for the assessment of the organisation's environmental performance. Furthermore, LCAs using eco-points are used to raise awareness about environmental issues in business and industry, in education and training and among the public at large.

For all these areas of LCA application, the eco-points method is simple and practical. While it considers a comprehensive set of environmental pressures, it reduces these to a common denominator and expresses them as a single indicator, making the result comprehensible and useful even for inexperienced persons. In addition, the eco-points method can also be used to provide a clear breakdown of the environmental burden, as shown in Figure 1. This is a major advantage when it comes to communication.

Invobox 1: Comprehensive assessment of environmental pressures
The eco-points method assesses a wide range of resources, emissions and wastes. Those included in the eco-factors for Switzerland are listed here. Environmental pressures marked '[new]' are covered for the first time in this publication.
Resources: water resources, energy resources, primary mineral resources, land use (biodiversity loss), marine fish resources [new]
Emissions: climate change (e.g. CO_2, methane), ozone layer depletion (e.g. CFCs, halons), main air pollutants and particulate matter, carcinogenic substances to air, heavy metals to air, water pollutants (including endocrine disruptors), heavy metals to water, persistent organic pollutants to water, pesticides to soil, heavy metals to soil, radioactive substances to air, radioactive substances to water, noise (traffic noise), plastic to soil and water [new]
Wastes: waste in landfills (non-radioactive), radioactive waste in final repositories

When carrying out an LCA using the eco-points method, LCA practitioners and the commissioning party define the goal and scope of the study. They then compile the life cycle inventory by determining the quantities of resources and energy required as well as the emissions and wastes generated by all the processes considered. An example is the production of one kilo of tomatoes, comparing different cultivation methods and regions. The LCA includes the environmental impacts from cultivation all the way to the point of sale in Switzerland.

In order to estimate the impact with eco-points, life cycle practitioners multiply each environmental pressure by its respective 'eco-factor'. Each eco-factor gives a weight based on each environmental pressure and the environmental legislation or national and international environmental policy targets. The higher the current emissions or use of resources is in relation to the target, the heavier the weighting.

The commissioning parties then add up the eco-points of each environmental pressure to give a total number of points. This means that each item studied gets a single number expressing its environmental impact (see also Tab. 1 in Section 2.1.1).

If the items studied are equivalent products or services, the results may now be compared. When assessing companies or factories, the evolution over a certain time period can be evaluated. The final stage of a life cycle study lies in the interpretation of the results and, usually, recommendations for action within the scope of the initially defined study goals.

The eco-points method was co-developed by the Swiss Federal Office for the Environment (FOEN). In the Swiss version, the eco-factors are based on the environmental quality targets and limit values of the Swiss environmental legislation and international agreements. According to the FOEN, the eco-points method is a benchmark for LCAs which serve as a basis for decision-making in Swiss companies, authorities and non-profit organisations.

The eco-points method can also be applied to other countries. For example, eco-factors are available for Germany, the European Union as a whole, and Japan, based on their respective legal frameworks.

Answers to more detailed questions, including those on LCAs in general, can be found in Chapter 2, 'Questions and answers concerning life cycle assessments (FAQ)'.

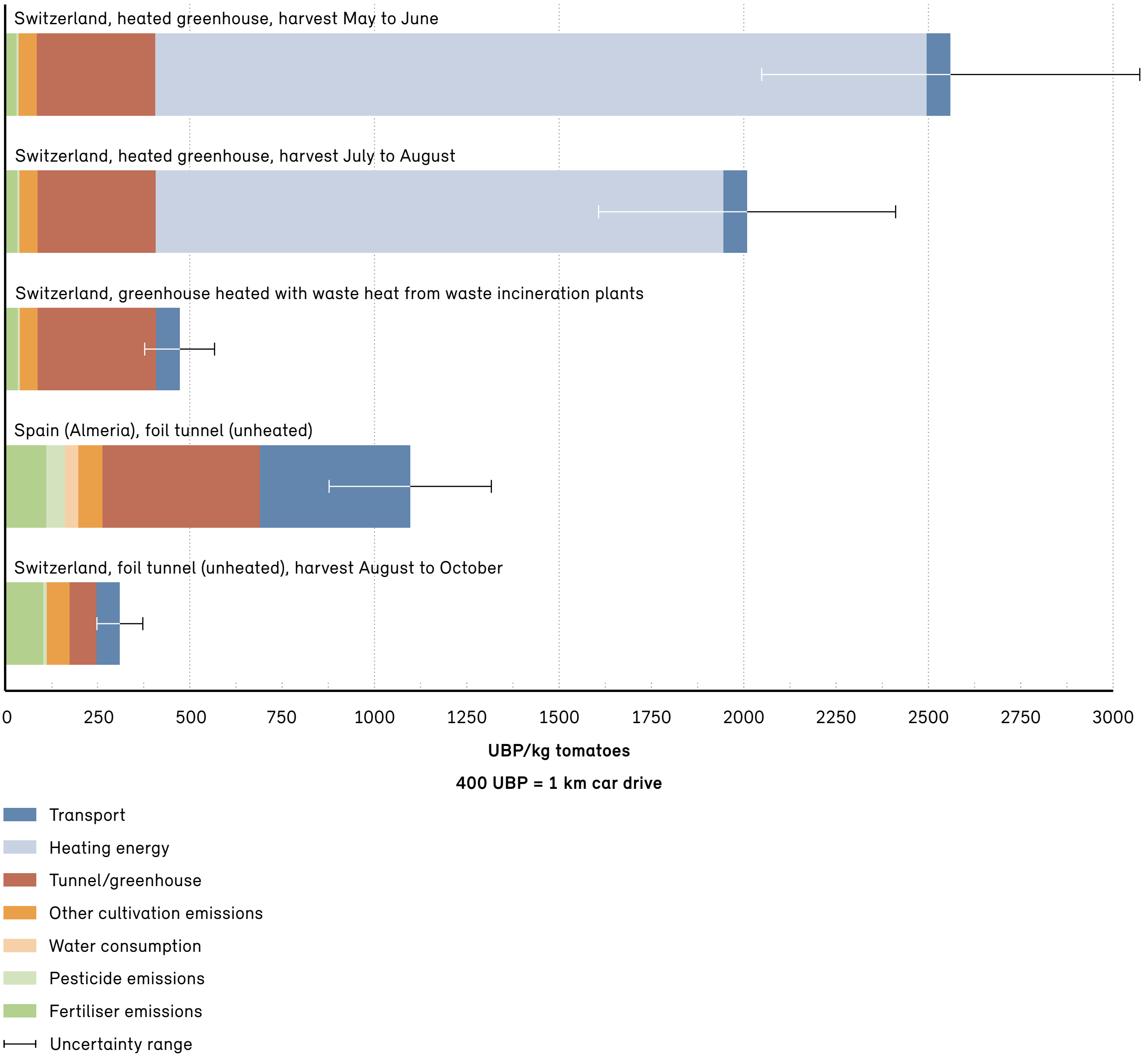
Infobox 2: Strengths of the eco-points method

- Encompasses numerous environmental impacts
- Delivers clear statements
- Provides transparent results
- Is weighting irrespective of the user
- Supports the decision-making of companies, authorities, policymakers, non-profit organisations and private individuals
- Is broadly based and trustworthy
- Enables country- and region-specific calculations
- Charts newly identified environmental pressures at an early stage
- Is practical to apply
- Can be easily updated

(see also Section 2.2.7)

Fig. 1: LCA for tomatoes using the 2021 eco-points method

The environmental impact of tomato cultivation varies according to the origin and season. In order to be able to harvest tomatoes as early as May to July, the greenhouses in Switzerland have to be heated, which is a major environmental drawback. However, if the heating energy comes from waste heat, for example from waste incineration or industrial plants, early tomatoes from Switzerland are barely any more environmentally damaging than seasonal tomatoes grown in a foil tunnel. In the case of tomtatoes from Spain, the long transport route substantially adds to the environmental impact. The life cycle assessment refers to one kilo of fresh tomatoes from cultivation to the point of sale in Switzerland.



Source: Carbotech, using 2021 eco-points method

2 Questions and answers concerning life cycle assessments (FAQ)

The questions and answers are divided into general questions on life cycle assessments, and specific questions about the eco-points method (ecological scarcity method).

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Abbreviations

DETEC
Federal Department of the Environment, Transport, Energy and Communications (the German abbreviation UVEK is also used in some source references)

EPD
Environmental Product Declaration

FOEN
Federal Office for the Environment (Swiss environment agency)

ISO
International Organization for Standardization

LCA
Life Cycle Assessment

ReCiPe
Damage-oriented assessment method for life cycle assessments; the capital letters stand for the organisations that originally developed the method.

UBP
Eco-point(s) (from the German Umweltbelastungspunkt(e))

WHO
World Health Organization

2.1 Life cycle assessments in general

2.1.1 How is a life cycle assessment conducted?

An LCA shows environmental impacts in numbers, providing a basis for a comprehensive comparison of different options. An LCA study takes place in four phases.

Keyword: Procedure

An LCA describes and evaluates the environmental pressures of a product, service, process or organisation. A brief outline of the eco-points method can be found in Chapter 1 above.

An LCA involves the following four phases:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

In practice, LCA practitioners often repeat these phases several times in order to refine the calculations (see Figure 1). New knowledge acquired and information obtained by research is integrated in each new round. This approach is in line with the → ISO standards.

Phase 1: The life cycle practitioners and commissioning parties jointly determine the goal (What questions does the LCA aim to answer?) and the scope of the study (What conditions should the LCA consider?). The assumptions made, the constraints imposed and the boundary of the system studied (→ system boundary) usually have a significant impact on the results.

Where several alternatives are compared, a study has to establish a uniform basis. To this end, a meaningful → functional unit is defined. For example, if comparing the environmental impact of passenger cars, a kilometre driven in a vehicle of a certain size class would make sense as a functional unit. If passenger cars are being compared with other means of transport such as bicycles, buses and trains, the functional unit must also take into account the number of people transported, e.g. one person travelling a distance of one kilometre, also known as a 'passenger-kilometre'.

Phase 2: In the inventory analysis, the life cycle practitioners measure the quantities of resources, materials and energy required for each individual process, as well as the emissions and wastes generated. They then link the processes to form 'product systems' in accordance with the system boundary defined in phase 1. The result of the inventory analysis includes all the resources required and the emissions and wastes generated throughout the system under consideration. Using the example of an electric vehicle, Tab. 1 shows a much-simplified inventory analysis with emission and use quantities, calculated for one passenger-kilometre. For cars, the statistically average vehicle occupancy of 1.6 people was assumed.

Such an inventory analysis requires detailed environmental data on products and services. Usually, some of these data are collected specially for the study and some are taken as 'background data' from LCA databases. Background data include, for example, standard processes and supply chains, such as the provision of petrol or steel. The FOEN mainly uses DETEC's 'UVEK LCI Data' for this purpose. This is based on version 2 of the *ecoinvent* data quality guidelines and is characterised by a high level of transparency and traceability.

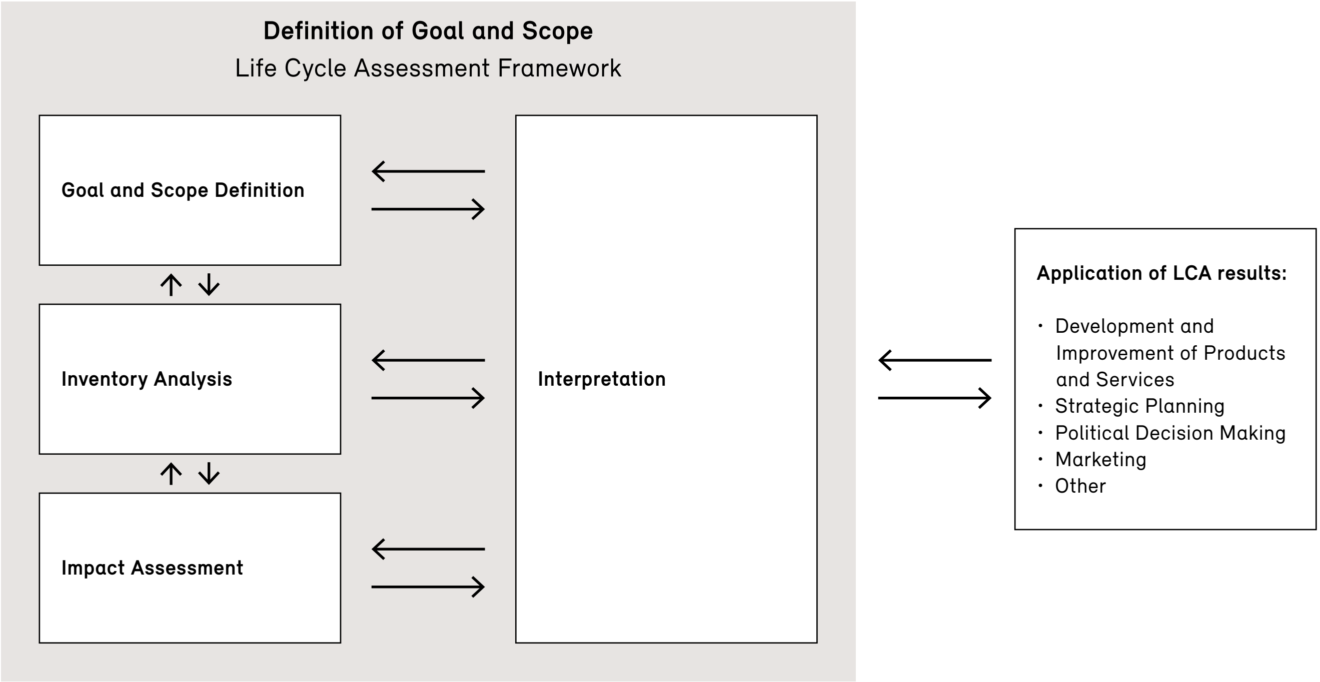
Phase 3: In the next step, the practitioners use the life cycle inventory analysis to determine the impacts on the environment and human health. They do this by classifying and characterising emissions and resource uses. Classification involves allocating emissions to specific impact categories. Examples of impact categories include climate change, acidification and over-fertilisation (eutrophication). In the characterisation process, substances with a similar impact are combined into a standard metric based on scientific knowledge. For instance, substances that contribute to climate change are referred to as greenhouse gases and characterised by their global warming potential. This is expressed in kilograms of CO_2-equivalents. Fossil methane, for example, has a warming effect on the climate and is therefore considered a greenhouse gas. Its climate impact per kilogram is 30 times greater than 1 kg of the most important greenhouse gas, carbon dioxide. One kilogram of fossil methane thus contributes 30 kg of CO_2-equivalents to climate change. Many impact categories have a reference metric of this kind, which serves as a common denominator. This enables life cycle practitioners to add up the contributions made by emissions or resource uses in relation to the same impact. Some environmental pressures are considered without characterisation.

Depending on the goal of the LCA, the various environmental pressures are combined into an overall evaluation. This raises an important question: how do you weight global warming potential, acidification potential, over-fertilisation and other → environmental impacts against one another? There are several ways to do this. Most methods fall into one of two basic categories: damage modelling or distance-to-target. Damage modelling uses models to calculate, for example, how many years of human life are lost or how many plant species disappear from a region if a specific quantity of pollutant contaminates the environment. The distance-to-target approach uses transparent – usually government-defined – environmental quality targets as its benchmark: the more the tolerated emission level or tolerated resource use is exceeded, the stronger the impact is weighted.

The ecological scarcity method discussed in this publication follows the second approach. It totals all of the environmental impacts using the metric of eco-points (UBP). More eco-points mean a higher environmental burden. The eco-points are calculated using → eco-factors. The eco-factors for Switzerland are based on statutory environmental targets in this country. Because of the unit of measurement, the method is also known as the eco-points method (or UBP method).

Phase 4: In the interpretation phase, the life cycle practitioners critically examine the results obtained. They ask themselves the following questions: Which phases of the life cycle, which activities, which resource uses, which emissions, etc. contribute most to the overall environmental impact? How do the assumptions made in the previous phases affect the results? How does the quality of the inventory analysis data influence the result? What are the effects of the → assessment methods used? The life cycle practitioners use an uncertainty analysis to calculate the extent to which the results may differ and assess which statements are justifiable from this point of view. If necessary, they also carry out a → sensitivity analysis.

Fig. 2: Four phases of a life cycle assessment (as in ISO 14040)



Bearing in mind the formulated goals and taking into account the constraints (derived from the uncertainty and sensitivity analyses), the life cycle practitioners formulate conclusions and, if necessary, recommendations. The study's recipients use these as a basis for their decisions, usually factoring in additional aspects such as economic, social and technical considerations.

2.1.2 What are the benefits of a life cycle assessment?

LCAs provide recipients with a basis for environmentally relevant decisions.

Keyword: Benefits

An LCA study can be used to evaluate a product, service or process with regard to its → environmental impacts or to compare different options on a uniform basis of assessment. Examples of what may be studied include:

- variants and alternatives for products, processes and organisations;
- the ecological relevance of operational areas and the associated optimisation potential;
- 'before' and 'after' situations in companies, sectors or entire economies;
- impacts of policy measures such as laws and regulations.

Since they emerged in the mid-1980s, LCAs have been able to correct many perceptions concerning environmental pressures by their comprehensive view of the associated impacts. Notable fields of application include electric vehicles and fuels made from renewable raw materials. The first generation of electric cars were promoted as zero-emission vehicles in Europe, based on the term zero emission used in Californian environmental legislation. This term might suggest that such vehicles put no pressure on the environment. In reality, it refers only to the absence of emissions from fuel combustion when the vehicle is being driven. LCAs, however, always consider the entire life cycle of a product from manufacture through to disposal or recycling (→ system boundary). For example, LCA studies show that the most significant environmental burdens associated with an electric vehicle are linked to battery production and electricity supply. In a bid to reduce the environmental pressures of electric vehicles, manufacturers and users are now turning their attention to these areas.

Example of a life cycle assessment calculation

The quantities determined in the inventory analysis are multiplied by their respective → eco-factor. For example: 1 UBP per gram of CO_2 or 30 UBP per gram of fossil CH_4. The UBP values of all assessed emissions and uses are then added up to calculate the total number of points. The sum of all the eco-points reflects the environmental burden

Tab. 1: Example of an LCA calculation using the eco-points method, based on an electric vehicle

Per passenger-kilometre (pkm) with an average vehicle load of 1.6 persons

Resource or emission	Inventory analysis Amount per pkm	Impact category	Eco-factor UBP per gram	Total UBP per pkm
Crude oil	7,27 g	Energy resources	0,38	2,7
Lithium	0,03 g	Primary mineral resources	3,8	0,1
Carbon dioxide (CO_2)	75,10 g	Greenhouse gas potential (global warming)	1	75,1
Methane (CH_4)	0,23 g	Greenhouse gas potential (global warming)	30	6,9
Other environmental pressures	(miscellaneous)	(miscellaneous)		173,5
Total				**255,6**

Similarly, when fuels made from renewable raw materials emerged, experts used LCAs to show that 'renewable' does not automatically mean 'environmentally friendly'. In this case, energy-intensive production processes and environmentally harmful intense cultivation of agricultural raw materials have a negative impact.

2.1.3 What cannot be assessed with an LCA?

LCAs assess environmental aspects. To evaluate economic, social and legal aspects as well as risks, additional instruments are needed.

Keyword: Boundaries

The LCA methodology as currently applied involves the evaluation of environmental relevance. It does not encompass economic, social and legal aspects. However, there are complementary approaches that enable social aspects to be taken into account. For example, supply chains can already be analysed for potential risks such as child labour or human rights violations, although a comprehensive evaluation of all socially important impacts is not yet possible.

Business and commercial aspects of a system are often calculated over its life cycle. This is known as 'life cycle costing'. The total commercial costs of a system over its life cycle are easier to calculate than an LCA, given that the costs of the upstream processes are covered by the purchase prices. Conversely, calculating the total (socio-)economic costs of products over their life cycle is more akin to a life cycle assessment. This is because an economic impact assessment uses factors (similar to → eco-factors) for the external costs, i.e. for the environmental and social costs not included in the market prices.

Legal issues are not covered by a life cycle assessment. Whether a project or product complies with the law must be clarified outside the context of an LCA. Life cycle practitioners generally assume that the legal requirements are being or will be complied with, i.e. they assess the legally permissible environmental pressures.

When it comes to risks, LCA practitioners consider the normal course of operations. They factor in ongoing and regular events, but not exceptional events with a low probability of occurrence and major impacts, such as accidents. For example, it is normal during gas pipeline and oil tanker operations for some of the transported energy carrier to enter the environment during cleaning and as a result of leaks. The → environmental impacts of these emissions are taken into account in the LCA. However, less common risks such as the explosion of a gas pipeline and oil emissions due to major shipping accidents are excluded. These risks are assessed by means of a separate risk analysis.

In general, life cycle practitioners answer only those questions raised in the study goals (phase 1, → procedure). The results may therefore be interpreted solely within the confines of the → questions and the scope defined in the study and not beyond that.

2.1.4 How is it possible to compare very different environmental burdens?

Comparisons are based on both scientific knowledge and the application of a measure of value.

Keyword: Basis of comparison

Reducing different environmental burdens such as climate change, air pollution and freshwater consumption to a common denominator is one of the main challenges involved in life cycle assessments. The process is known as 'weighting', and it is the final step in the impact assessment (phase 3, → procedure).

The impact assessment expresses the effects of a studied system on various environmental areas ('impact categories') such as the greenhouse effect, ozone formation, freshwater consumption or human health. This phase may also involve weighting the various impact categories in relation to each other, for example to determine how greenhouse gas emissions are assessed in comparison with acidifying emissions. There are two main principles of weighting (for other approaches, see → comparison).

In damage-oriented approaches such as ReCiPe 2016, harms to human health, ecosystem quality and resource availability are quantified. The eco-points method, as updated in this publication, is a distance-to-target approach, where the weighting is based on the environmental targets and the relationship ('distance') to the current situation. For example, the annual quantities of phosphorus emitted in Switzerland today are related to the legally tolerated quantity. The weighting factor of a substance places environmental legislation or corresponding policy targets in relation to the current environmental burden. The higher a current emission or resource use is in relation to the set maximum target, the greater the weighting factor. The weighting factor is an element in the calculation of the → eco-factor.

2.1.5 Is weighting actually necessary in a life cycle assessment?

If you want to derive recommendations for action from an LCA, a weighting of some kind – whether explicit or implicit – is unavoidable.

Keyword: Weighting

If the purpose of an LCA study is solely to identify the type and scope of environmental pressures caused by a product or process, then weighting is not required. In such a case, the result specifies the individual environmental pressures of the products examined, such as energy consumption or greenhouse gas emissions.

However, if the goal is to find out whether one product generally places more or less of a burden on the environment than another, the various environmental pressures need to be weighted. Even if you just want to know how much the individual environmental pressures of a product contribute to its overall → environmental impact or how relevant the different environmental pressures are, weighting is necessary.

This is because an unweighted interpretation is no help in making decisions (unless one option under consideration has the lowest environmental impact in all areas). When comparing fuels, for example, knowing that rapeseed-based diesel requires more land and emits more nitrate to groundwater, whereas petroleum diesel generates more CO_2 emissions and causes more marine pollution due to shipping, will not really help for decision making. Only a weighting will tell the commissioning party (and, in some cases, the public) which of the studied alternatives places the least burden on the environment and how big the differences between the alternatives are.

There are essentially three options for weighting environmental pressures:

- In many cases, only a single environmental impact is considered – today, this is often the emission of greenhouse gases. If this method is adopted, all other environmental impacts are implicitly considered equal to zero and therefore excluded.

- In other cases, life cycle practitioners rely on a methodological approach they have tailored to the respective study. If this is done, it is often difficult to determine the information and interests involved in the assessment. This usually makes it hard for third parties to understand the basis and measure of value for the statements. With such an approach, some LCA practicioners are even under the misapprehension that they have dispensed with weighting. Yet that is clearly not the case because whenever recommendations for action are derived from life cycle assessments, the environmental pressures have been weighted in one way or another. In some cases, however, this weighting is unclear or even implicit.
- The environmental pressures are weighted with a transparent method such as eco-points or ReCiPe. To obtain a reliable overall picture, it is a good idea to apply multiple → assessment methods to the same inventory analysis. This will highlight the effects of methodological features that influence the result.

Whichever approach is chosen, the conclusion may be drawn that any application-oriented interpretation of an inventory analysis will be based – implicitly or explicitly – on value judgements. Given the necessity of assessments, the FOEN recommends using comprehensive and explicit assessment methods and applying multiple methods in parallel if possible. Currently published approaches may not be perfect, but they are generally transparent, part of the scientific discussion, and user friendly (→ overview of methods).

2.1.6 What are the roles of scientific knowledge and of values in the assessment of environmental pressures?

Environmental sciences, environmental policy and societal values all play an important role in the assessment.

Keyword: Science

There is much discussion about whether LCAs enable a purely scientific evaluation. The answer is "No": science provides information, and this information has to be interpreted and weighted. Environmental policy performs a collective weighting, converting the different societal values on the environment into binding rules.

For example, the impact intensity of different greenhouse gases can be determined scientifically (global warming potential). This information is used in the characterisation stage (phase 3, → procedure) to relate the → environmental impacts of the various greenhouse gases to one another. This is actually a purely scientific matter. However, the calculation of global warming potentials is based on models that indicate the impacts for a specific time horizon. Consequently, the global warming potentials differ depending on the time horizon. The scientifically published factors relate to a period of 20 years on the one hand and 100 years on the other. Depending on the chosen time horizon, methane, for example, has a different impact intensity compared with CO_2. This could affect the evaluation of alternatives in an LCA. At present, the global warming potential over 100 years is generally used for greenhouse gas calculations. This premise is not scientifically 'right' (and neither), but a value-based specification derived for environmental policy. By choosing a time horizon, the short- and long-term effects of greenhouse gases are given a different weight.

Similarly, the risk to human health from substances is assessed using scientific, measurement-based models on the one hand and value-based premises on the other. For instance, in damage-based assessment methods, the risk to human health is expressed in terms of 'disability/disease-adjusted life years' (DALYs). This internationally used metric indicates how many years of life are 'lost' due to disease and disability, measured against a human being's average life expectancy. But even DALYs are not a purely scientific parameter. While most people would likely agree that an itchy skin rash is a lesser evil than a rapidly advancing terminal cancer, the weighting that one should have in relation to the other is a value-based and also a pragmatic decision. To address this, the method draws on extensive WHO surveys among doctors, who rate the various diseases on a scale. DALYs are extremely helpful because the assessment is broad-based, unrelated to individual cases and clearly described.

The weighting of different environmental impacts, which is ultimately necessary for a comprehensive assessment, is based on further value-based premises. In the eco-points method, these consist of a) the assumption that environmental pressures within the maximum permissible value are equivalent ('an eco-factor is assigned to each pollutant emission and each resource use'), and b) the design of the calculation formula. Both elements are value-based, but can be justified on the grounds of plausibility.

The assessment of environmental pressures thus requires and combines scientific knowledge and values.

2.1.7 Why are multiple assessment methods better than just one?

Because no one method can fully and consistently cover all ecological aspects.

Keyword: Assessment methods

If LCA practitioners use multiple assessment methods, they can check whether the results point in the same direction or ascertain the reasons for any differences. Discrepancies identified while a study is being carried out can also provide clues to any errors that may still be present in the inventory analysis data.

Differing trends in the results of different assessment methods are linked to different weighting approaches and reveal a method's blind spots. They thus provide life cycle practitioners with additional information they can use to interpret the results. The ReCiPe 2016 method, for example, weights climate change (global warming potential) heavily, but does not take radioactive waste and water use but does not take into account radioactive in the overall assessment. The 2021 eco-points method, meanwhile, weights climate change somewhat less heavily, but also factors in water use and radioactive waste. Consequently, an assessment of electricity from fossil, nuclear and renewable sources will turn out quite differently depending on the method used.

Depending on the goal and recipients of an LCA, it may therefore be helpful and important to apply several evaluations. The Swiss Federal Administration, for example, often uses three indicators – greenhouse effect, primary energy use and eco-points (UBP) – which gives an impression of the situation from three points of view. In an international or European context, on the other hand, the use of ReCiPe 2016, EU-specific UBP or the environmental footprint method would also be advisable. It is not yet possible to make a general recommendation, applicable worldwide, as to which assessment approaches should be used in which situations. An in-depth discussion on this at international level has only just begun, and the FOEN believes that a consensus needs to be sought.

2.1.8 Can a fully aggregating approach be dispensed with?

If you want to weigh up ecological advantages and disadvantages by means of an LCA, aggregation is always required. The FOEN recommends using a common, reproducible method for this purpose.

Keyword: Fully aggregating approach

The term 'fully aggregated' refers to the → weighting step within the impact assessment (→ procedure). If various → environmental impacts such as the greenhouse effect, acidification or hormonal impacts are separately accounted for in the impact assessment, burdens with similar impacts are aggregated but not all the impacts are 'fully aggregated' into a single metric. As long as the results of all environmental impacts in a comparative study point in the same direction, it is easy to see which alternative is less harmful to the environment. However, when there are differing trends in environmental impacts among the various alternatives, the question must be asked how the impacts should be evaluated in relation to each other. In this case, → weighting is necessary.

In this situation, the benefits of fully aggregating methods of impact assessment become abundantly clear (→ strengths). A quantity of points is generated for each considered effect on the environment and then added up to a total. As well as partial results for the various environmental impacts, this produces a single, fully aggregated number that expresses the overall burden placed on the environment by a studied alternative.

For all these reasons, the FOEN recommends using at least one common, fully aggregated assessment method such as the eco-points method in action-oriented LCAs.

2.1.9 Are there good and bad questions for life cycle assessments?

A precise question is a prerequisite for any meaningful life cycle assessment.

Keyword: Questions

Precise questions are indispensable for life cycle practitioners to ensure that the subject of the study is aligned with its goal and that the right data are processed. These challenges can be perfectly illustrated in an example. A study aims to answer the following everyday question: should I heat my building with oil, gas or wood? The life cycle practitioners must determine the following points, among others:

- Where is this taking place? The intensity of the heating season and the availability of raw materials will differ depending on whether the building is in Switzerland, Finland or Greece.
- Is it an early or a regular replacement investment? If the existing heating system is being replaced before it reaches the end of its life, it will be compared with new heating systems in order to determine the best time to replace it. However, if the current heating system has reached the end of its life, only new heating systems will be compared with each other.
- Where do the raw materials come from, and what is their quality? With wood, for example, it is important to know where it is sourced and how dry it is.
- Which qualities of heating systems should be compared? Inexpensive systems, the market average for each fuel type, or top-quality systems, which are more efficient and possibly more expensive to buy?

The above list leads to the conclusion that general questions are not usually suitable for life cycle studies that will be applied to a specific situation. The reverse is also true: specific questions (and the answers to them) cannot normally be transposed 'as is' to general situations.

2.1.10 Why is the functional unit so important?

The functional unit is the metric used to determine the benefits of a product and compare it with other products.

Keyword: Functional unit

The functional unit is a key element in any LCA. It describes the measurable benefit of the studied product or process and serves as a basis for comparing different products or processes that can be used for the same purpose. Examples of functional units are: '1 kWh of electricity at household voltage, from the grid in country XY', '1 kg of boiled beans on the dining table of a Swiss household', '1,000 litres of mineral water, bottled at a regional beverage facility' and '1 km driven in a lower mid-size car, built in or around 2021' (for comparing passenger cars) or 'transportation of one person over a distance of 1 km' (for comparing different means of transport).

The functional unit has a considerable influence on the result of the study because all resulting analyses are based on it. This can be illustrated, for example, by a comparison between passenger cars. If '1 kg of total weight moved' were to be taken as the functional unit, then the movement of the car per se would also be part of the benefit, whereas choosing '1 person moved' (plus possibly one item of luggage) as the functional unit gets very close to the actual benefit of a passenger vehicle.

2.1.11 How much does the system boundary affect the result?

The definition of the system boundary has a decisive influence on the results of a life cycle assessment.

Keyword: System boundary

There is no such thing as a 100% comprehensive LCA. In every study, the life cycle practitioners and commissioning parties have to exclude processes, otherwise the analysis would be endless. They must therefore establish a 'system boundary' to explicitly define which of the processes associated with the subject of study they will include and which they will ignore. To do this, they need to ascertain which aspects are actually important for the study. The decisions regarding the system boundary have a significant influence on the result of the LCA.

To ensure that the system boundary is not set in a completely arbitrary way, quality specifications are established. In general, the boundary should be reproducible and not exclude any essential factors. In this connection, ISO standard 14044 (ISO 2006b) notes that the exclusion of life cycle stages or unit processes and inputs and outputs is only allowed when this does not essentially change the general conclusions of the study. To evaluate this in practice, LCA practitioners draw on specialist knowledge and expertise. It is important that they clearly describe the criteria used to justify the exclusion.

The temporal system boundary chosen is also important. For example, emissions from landfills sometimes take a long time to manifest themselves. The life cycle practitioners must decide how to take account of such long-term future pressures. As with many other decisions, there is usually no 'right' or 'wrong' answer. The boundary of an analysis should be set in accordance with the questions being investigated, and the available budget is also a factor to consider.

Table 2 shows the importance of system boundaries using the example of an LCA of fuels.

Tab. 2: Influence of the system boundary using the example of fuels

System boundary	Fuel combustion *(life cycle from tank to wheel)*	Fuel supply and combustion *(life cycle from cradle to wheel)*
Functional unit	1 kilometre driven*	1 kilometre driven*
Result	Misleading comparison: fuel production is omitted.	Meaningful comparison: a comprehensive study of the life cycle gives a complete picture.
Reasons	Many environmental impacts of fuels made from renewable raw materials arise in the agricultural production and the processing of basic products. It is therefore not expedient to consider only the exhaust emissions.	A full life cycle assessment takes comprehensive account of resource use, emissions and wastes.

* As regards the → functional unit, both examples feature a suitable definition. Due to the different energy density of diesel, petrol and biodiesel, for example, '1 litre of fuel' would be unsuitable, whereas '1 kilometre driven' (as used above) gives meaningful results.

2.1.12 What is the significance of allocations?

In the case of production processes with multiple usable products, the proportion of expenditures and emissions attributed to each product is important for the life cycle assessment.

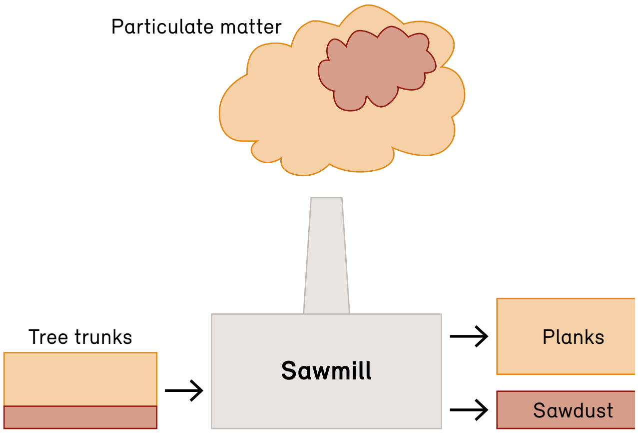
Keyword: Allocation

The processes studied in LCAs may have multiple benefits or uses. Allocation refers to the assignment of expenditures, resource uses and emissions to individual products. In some cases, some of these products may even lie outside the scope of the study. Cattle rearing, for example, often serves to produce both milk and meat. Leather products can be made from the animal skins, although that is not considered further here. If the environmental burden caused by cheese is being studied, the life cycle practitioners must determine in the allocation procedure what proportion of the environmental burden from cattle rearing is attributable to milk production and what proportion to meat production. There are various ways of doing this, based for example on physical or economic laws or principles. Depending on the breeding system (pure meat breeds or dairy cattle breeds), the production goals (more meat or more milk) and the allocation approach, the LCA for milk and beef will be different. Fig. 3 shows the allocation for a sawmill that produces two products from tree trunks: planks and sawdust. An allocation key is used to assign the sawmill's inputs and emissions to these two products.

Such an allocation is also necessary when it comes to recycling material. Given that, for example, it is not possible to produce recycled paper without new paper and without a collection system, the life cycle practitioners also have to make an allocation for recycling: they determine which proportions of the resource use and emissions remain with the previous use and which are attributed to the recycled material.

The choice of allocation approach often has a major impact on the LCA result. While ISO standard 14044 makes general recommendations on how to perform allocations (ISO 2006b), there is usually no simple 'right' or 'wrong' way of doing this. It is therefore up to the experts to select allocations that are appropriate and meaningful in light of

Fig. 3: Allocation using the example of a sawmill



the LCA questions. In a comparative study, it is vital that the allocation is consistent for all studied alternatives. That is why a quality control of allocations is a key step in the → critical review.

2.1.13 When is a sensitivity analysis needed?

A sensitivity analysis is particularly important in situations of uncertain and widely varying data and varying modelling. It serves to determine the impact of these factors on the results.

Keyword: Sensitivity analysis

Sensitivity analyses show how the assumptions that have to be made in a life cycle study affect a result. Sensitivity analyses are carried out, for example, if a raw material can come from different sources (e.g. metal from new production or from recycling), if no reliable data are available for a process that appears to be important, or if a product, say, can be used in different ways (e.g. a car can be driven in sport mode or eco mode).

LCA practitioners also use a sensitivity analysis in the interpretation phase (→ procedure) to examine the quality of the results. They do this by comparing the results with outcomes achieved using modified assumptions, methods or data. They then determine the sensitivity as the percentage change or the absolute deviation from the results of the baseline variant, which enables to ascertain how heavily the results and conclusions are influenced by the assumptions made and by uncertainties in the data.

If the sensitivity analysis reveals that the assumptions and uncertainties associated with the LCA study have little bearing on the result, this increases the stability of the results. If this is not the case, the practitioners must qualify the statements made or take additional factors into account in the interpretation.

Sensitivity analyses are especially important in situations of uncertain data, widely varying data or highly divergent models. This is the case, for example, where:

- different technologies are used to manufacture a product or technical developments are likely to occur (e.g. an increase in the efficiency of the batteries used in electric cars),
- several assumptions appear plausible (e.g. concerning the service life of a device or future disposal methods), or
- recycling can be modelled in different ways (→ allocation).

2.1.14 What kind of influence does the commissioning party have on the result?

The commissioning party can greatly influence the result of the study, especially since they define its goal.

Keyword: Commissioning party

The goal of an LCA study is defined by the commissioning parties, while the life cycle practitioners, in consultation with the commissioning party, determine the scope of the study, collect the data, specify the → allocations and make the interpretations. Together they select the → functional unit, → system boundary and → assessment methods. By helping to determine all these crucial parameters, the commissioning party can have a considerable influence over the results. This means that commissioning parties need to be aware of their responsiblity. It also means that outsiders to the study should question the potential interests of the commissioning party when interpreting the results and conclusions of LCAs.

Another factor to consider is the budget provided by the commissioning party for the life cycle study. This will significantly affect the quality of the study, as the scope of the study, the level of detail in the data collected, the type and number of assessment methods used and the nature of the → critical review are directly dependent on the financial framework.

2.1.15 What are the characteristics of a proper life cycle assessment?

Basically, a life cycle assessment should be comprehensive, transparent, traceable, fair and therefore reliable.

Keyword: Quality

The ISO 14040 series of standards (ISO 2006a) contains numerous specifications on quality assurance. The most important ones are as follows:

- The → functional unit should be objectively and convincingly defined.
- Data and assessment methods (→ assessment) should be appropriate to the subject of study.
- A (self-)critical scrutiny of the key assumptions should be made.
- The interpretation of the results should take into account the data quality as well as the constraints and boundaries of the study. This is particularly important in the case of LCA issues linked to significant financial and regulatory interests.
- The study should undergo a → critical review by external, independent and experienced experts.
- The practitioners tasked with carrying out the LCA should be independent and experienced, because often only versed specialists can identify the factors relevant to the study. They may also have to resist interference from their → commissioning party in order to safeguard their reputation.

2.1.16 Why is the critical review important?

The critical review can contribute significantly to the quality of a life cycle study. It involves independent experts checking whether the assumptions made and the questions addressed are appropriate.

Keyword: Critical review

The critical review is a key tool for ensuring the → quality and objectivity of an LCA study. It involves external, independent experts examining the assumptions, specifications and conclusions. According to ISO standards (ISO 2006b), the most important questions are:

- Do the methods comply with the ISO standard?
- Are the methods scientifically and technically reliable?
- Are the data used adequate in relation to the goal of the study?
- Is the interpretation of the results compatible with the scope and constraints of the study?
- Is the life cycle study transparent and consistent?

The critical review is intended to prevent the practitioners and/or commissioning parties from intentionally or unintentionally influencing the results in an objectively unjustified manner. In practice, just knowing that an external critical review is imminent often causes those involved in the LCA to produce more thorough and better-quality work, as no one wants to risk their reputation in professional circles. According to ISO 14040, the critical review report must be published together with the life cycle study.

There are essentially three types of critical review:

- internal review by experts who are not involved in the study but who work for the commissioning party's or appointed practitioners' company;
- external review by experts who are not associated with the office carrying out the study;
- panel review carried out by a group of at least three independent experts, which may include individuals from interested circles and LCA experts.

The type of critical review used depends on the scope and significance of the LCA study and on the requirements of → ISO standards 14040 and 14044.

2.1.17 What is the benefit of the ISO standards on life cycle assessment (14040/14044)?

ISO standards 14040 and 14044 define rules for the implementation and quality assurance of an LCA study. However, their provisions concerning the fully aggregating approach are no longer up to date.

Keyword: ISO standards

The LCA procedure with the above-mentioned four phases (→ procedure) is set out in two international standards: ISO 14040 describes the principles and general framework for the life cycle assessment of products and services, while ISO 14044 defines the requirements and provides practical instructions on the steps in the process (see ISO 2006a and 2006b). Of particular importance are the principles governing the particularly critical tasks, namely setting the → system boundary, defining the → functional unit, carrying out the → allocations and assessing impacts. In these areas, the ISO standards provide valuable guidance for a good LCA → quality. The standards have been instrumental in ensuring that LCAs are carried out in systematic, reproducible processes.

However, while the provisions of the ISO standards in these areas are reasonable and uncontested, their provisions regarding a → fully aggregating approach, in particular, are now disputed. According to the ISO standards, fully aggregating assessment methods are permissible only for internal, i.e. unpublished, LCA studies, whereas they are not allowed for public comparisons of products on the market. One of the reasons for this cautious approach is to prevent unjustified statements. These may occur if, for example, unproven → weighting methods are used.

Nowadays, however, transparent and reproducible methods are available for a fully aggregating weighting. Consequently, renowned LCA experts now consider this stipulation of the standard to be outdated. Published comparative studies with clear findings are important for companies, investors and private individuals as they provide guidance on purchasing decisions and recommended actions. Meanwhile, government regulations and procurement contracts – e.g. in the case of a tax relief for biofuels[1] – need to be based on clear and comprehensible information; indeed, such transparency is required by the freedom-of-information principle that is legally binding on Swiss authorities. For these reasons, the FOEN publishes the LCA studies carried out on its behalf.

The FOEN's practice deviates from the ISO standard with regard to two points. Firstly, it uses the → fully aggregating approach in comparative studies, too. Secondly, it does not always carry out a panel-based → critical review of such studies. This is because publication itself is a control mechanism.

2.1.18 Why is the 'true and fair view' principle so important?

A distorted presentation can lead to inappropriate conclusions. To ensure that the information presented chimes with the actual situation, the FOEN has established quality criteria for environmental information.

Keyword: True and fair view

The → ISO standards set out key requirements for robust LCAs. They state that the results must be presented to commissioning parties in a comprehensive, factually correct and impartial way (see ISO 2006b). The ISO standards for life cycle assessment also require – without actually using the term – a 'true and fair view'. To guide the implementation of this concept and its critical review, the FOEN recommends eight quality criteria for environmental information (see Schwegler et al. 2011):

1. Relevance for decisions
2. Focus on the overall picture
3. Reliability
4. Transparency
5. Clarity
6. Coherence and comparability
7. Availability of information
8. Up-to-date information

The first two criteria are essential for a true and fair view, while criteria 3 to 8 support this objective. The first criterion, 'relevance', for example, requires that no relevant information be left out and, if possible, no irrelevant information be brought to the fore. Here is an example: an assessment of engine technologies that looks only at their greenhouse gas performance ignores, among other things, the environmental pressures caused by extracting the raw materials needed to make batteries, meaning that it does not provide a true and fair view.

'Focus on the overall picture' means, among other things, that an uncertain but potentially important factor cannot simply be left out, but must be included along with estimates (and, if necessary, a → sensitivity analysis), on the grounds that it is "better to be approximately correct than exact yet misleading".

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[1] biofuels, biogenic fuels: fuels produced from biomass or other renewable energy sources [Mineral Oil Tax Act (MinöStG) 641.61]

These principles also apply to → assessment methods in life cycle assessments. According to Schwegler et al. (2011), the eco-points method fulfils seven of the eight criteria well and one satisfactorily. Such an appraisal is a first step in applying the → critical review approach, which the ISO standards on life cycle assessment currently require only for some LCA studies, to assessment methods as well. A transparent appraisal of assessment methods according to the 'true and fair view' principle also helps LCA practitioners in their choice of method. The FOEN deems important to have a constructive and critical discussion of the true and fair view in life cycle assessments because this principle helps to strengthen the relevance and effectiveness of LCAs as well as confidence in LCA results.

2.1.19 How do life cycle assessments differ from Environmental Product Declarations?

Unlike life cycle assessments in accordance with ISO 14040/14044, Environmental Product Declarations are based on inventory analyses that do not necessarily cover the entire life cycle of a product.

Keyword: Environmental Product Declaration (EPD)

Environmental Product Declarations (EPDs) are used to assess the environmental burden of products within the supply chain. For example, since April 2012, European standard EN 15804 has laid down the requirements for EPDs for construction materials, products and services. In the EPD, product manufacturers or associations indicate → environmental impacts such as resource use and greenhouse gases. For many product groups, there are specific rules for drawing up EPDs. In a number of areas (e.g. calculation methodology, impact indicators), the information is based on the same → ISO standards as LCAs. With EPDs, comparisons of environmental impacts within a product category (e.g. cement) and across products (e.g. concrete ceiling and wooden ceiling, or plastic floor and tile floor) are only meaningful if they have been drawn up using the same calculation rules, identical background data and equivalent usage scenarios. Ensuring this in individual cases is very time-consuming for users, since different rules can apply to different product groups and the standard does not make any specifications in this regard.

2.1.20 What questions does the 'eco-efficiency' indicator answer?

The aim of eco-efficiency is to identify the best possible solution, taking into account economic and environmental considerations. There are different ways of calculating this.

Keyword: Eco-efficiency

There are various definitions and approaches when it comes to eco-efficiency. Ecological-economic efficiency means minimising costs while maximising the reduction in environmental pressures. Ecological efficiency with regards to the technical benefit of a good means less environmental burden for the same performance or output. This can be achieved, for example, by replacing a conventional light bulb with a much more economical LED lamp (provided that the other environmental burdens of the LED lamp do not outweigh the energy saved).

Life cycle assessments are often about ecological-economic efficiency. While economic impacts are not considered in an LCA, they do play a role in a commissioning party's decision-making processes. An economic view can be added to the LCA's purely environmental perspective by relating the economic costs or benefits of a proposed action to its impact on the environment.

Experts select different approaches and methods of presentation depending on the subject of study and the questions being addressed. The portfolio matrix is often used (Figure 4). In this matrix, the costs of the studied alternatives are plotted downwards from left to right along the horizontal axis, while the environmental benefits of a measure are plotted upwards along the vertical axis. In the example, the result area is divided into four areas. The bottom-left area contains the least efficient alternatives, while the most eco-efficient options are in the top-right area. In this case, high eco-efficiency means the lowest possible → environmental impacts that can be achieved at the lowest possible cost.

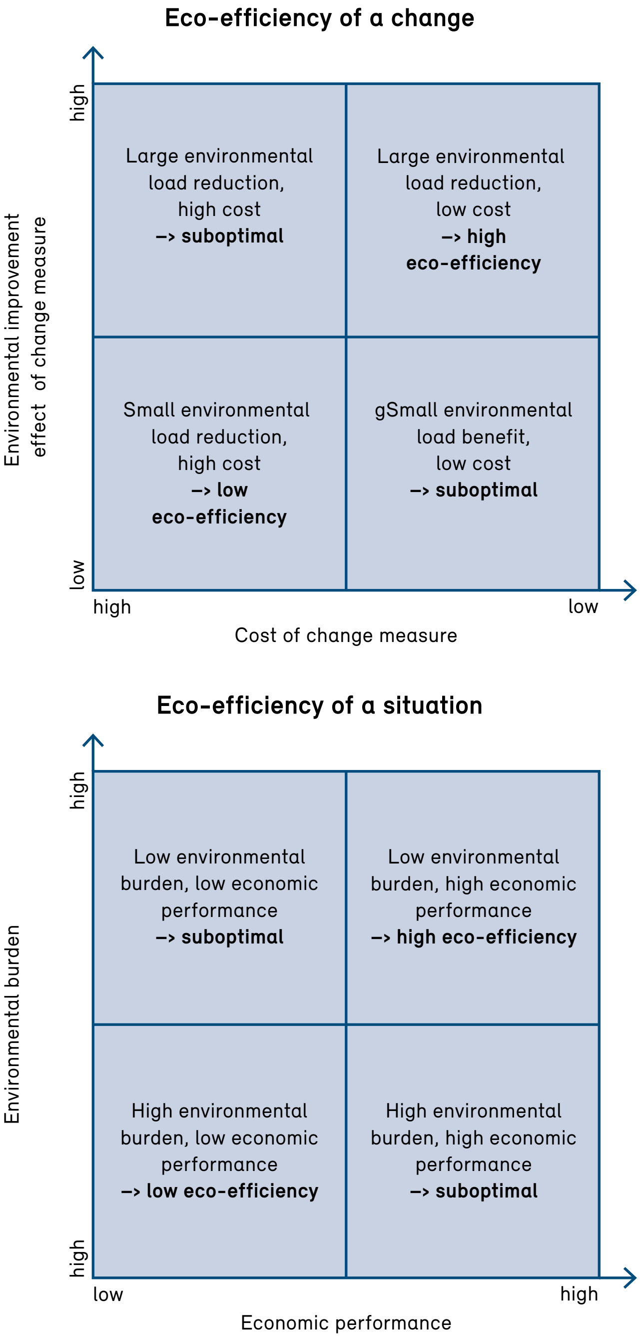
There are three aspects to consider when it comes to eco-efficiency:

1. When applied to projects, eco-efficiency approaches are used to optimise for low costs, meaning that the objective is either 'the least possible environmental burden per Swiss franc spent in purchasing' or 'the lowest possible cost per environmental burden unit' (Figure 4, Eco-efficiency of a change). This is how options are evaluated in a project to reduce environmental burdens, for example.
2. If, on the other hand, the aim is to evaluate an overall economic and ecological situation (as may be done by governments, industries or companies, for example), the designation of the horizontal axis changes from 'costs' to 'economic performance' (Figure 4, Eco-efficiency of a situation). In this case, a high value on the horizontal axis – expressed in Swiss francs, for instance – is positive, because here the objective is 'the highest possible economic performance with a low environmental burden'.
3. Increased eco-efficiency alone does not guarantee that a product is also economically viable. Indeed, if an eco-efficient product is not successful enough on the market, a company can go bankrupt. Eco-efficiency is therefore only a relative auxiliary parameter – both absolute ecological and absolute economic performance remain vital too, each in their own right.

Eco-efficiency can therefore be assessed very differently and lead to different recommendations, depending on the perspective.

Another factor to be considered in connection with eco-efficiency is the dynamics of rebound effects. A rebound effect is an increase in consumption triggered, for example, by an actual increase in efficiency or a subjectively perceived ecological improvement. An example of this would be if someone stops switching off an LED lamp on the pretext that it is hardly using any power anyway, or if carbon offsetting of air travel encourages people to take more flights than they would otherwise have done. In this way, efficiency gains can lead to increased consumption due to financial or moral incentives and thus, in the long term, reduce or even outweigh the environmental gains achieved.

Fig. 4: Portfolio matrix of ecological-economic efficiency



2.2 The eco-points method (ecological scarcity method)

2.2.1 Can an environmental burden be expressed in a single number?

The eco-points method factors in a range of environmental pressures, reduces them to a common denominator and expresses them as a single indicator, making the results comprehensible and useful even to inexperienced users.

Keyword: Eco-points (UBP)

The eco-points – or ecological scarcity – method uses eco-points (Umweltbelastungspunkte in German, abbreviated to UBP) as its basis of comparison. Eco-points allow different environmental burdens to be added up and compared. This can be likened to calculating the manufacturing costs of a product in Swiss francs. These costs are made up of various components such as raw material prices, wage costs and amortisation of the production facility. Similarly, very different environmental pressures such as crude oil consumption, greenhouse gas emissions and noise emissions can be expressed in UBP. Eco-points are just one of a number of ways of evaluating different → environmental impacts. Just as there are different currencies in the financial world, so there are different → assessment methods and associated measurement parameters in life cycle assessment.

The eco-points method considers a wide range of environmental burdens (→ Switzerland). The key metrics in this method are → eco-factors, which indicate the environmental burden of an emission, resource use or generated waste, in the form of eco-points (UBP) per unit of quantity. The eco-factors are calculated according to the distance-to-target principle: the greater the current emissions, resource uses or waste quantities in relation to the protection target, the higher the eco-factor. The results for the individual pressures are then added up and combined into a single key figure expressed in UBP.

Expressing a result as a single number has one obvious major advantage: it makes comparisons easier and the significance of decisions clearer (→ fully aggregating approach, → aggregated results). This is illustrated by the tomato example (Fig. 1). Another advantage of the eco-points method is that the contribution of processes to the overall burden becomes clear at a glance.

A brief outline of the eco-points method can be found in Chapter 1.

2.2.2 Is the eco-points method arbitrary or scientific?

This eco-points method is broadly based, legitimised by legal foundations and not very susceptible to being influenced by interested parties due to its system of controls.

Keyword: Separation of powers

In general, the following applies to the evaluation of environmental pressures: scientists state what consequences could arise from environmental pressures, while policymakers determine what situations we will aim for or tolerate. For the assessment of → environmental impacts, the eco-points method is underpinned by both scientific results and environmental policy goals and targets.

Scientific data are used to determine the current quantities of emissions and resource uses. The modes of action and relative environmental impact of substances in the same impact category (→ procedure, → eco-factor) are also evaluated based on scientific methods and/or assessments of specialised bodies. For example, the climate impact of gases is assessed based on the work of the Intergovernmental Panel on Climate Change (IPCC).

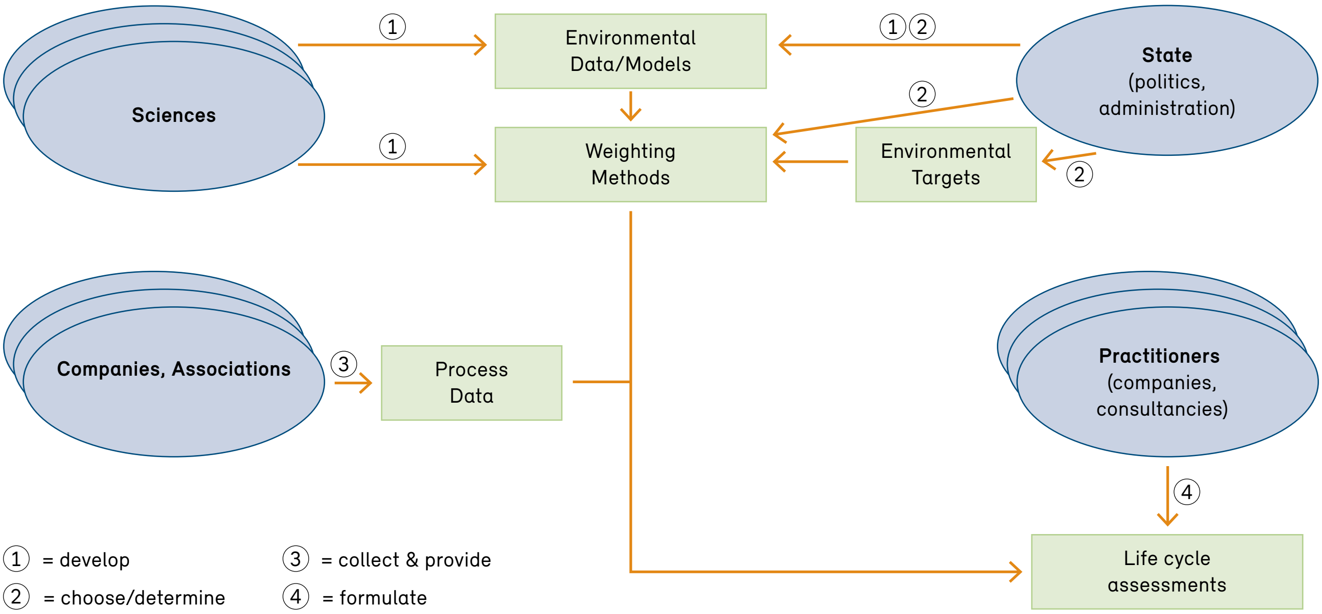
In addition, national or international regulations and limit values are used to define the tolerated target quantities. These may include targets set by Parliament or government, such as limit values, or intergovernmental agreements. In the case of climate gases, for example, the Federal Council's Sustainable Development Strategy and its decision to set a target of net zero by 2050 are used to derive the Swiss eco-factor (see Section 9.2).

The quality of the eco-points method is ensured by a system based on 'separation of powers' such as that governing a modern democratic state, meaning that the roles involved in determining eco-factors are divided up between different actors (see Fig. 5):

- Various **sciences** (physics, chemistry, biology, medicine, statistics) provide fundamental knowledge ('environmental models') about the environmental impacts, such as the toxicity of substances, the greenhouse effect of emitted gases or the health risk caused by noise. Scientific research also yields a lot of environmental data. In addition, the sciences develop assessment and weighting methods.
- The **state** – i.e. lawmakers, followed by the competent authorities – develops environmental quality targets based on this knowledge and so lays the foundations for the weighting criteria.
- **Companies** and business associations provide specific data on their activities and processes with regard to material and energy flows.
- **LCA practitioners** apply LCA methods (as well as process data) on behalf of industrial, commercial and consulting firms, authorities, other organisations and research entities. In general, this is done without changing the basis for the weighting.

What sets the eco-points method apart from other fully aggregating → assessment methods such as ReCiPe is the fact that it is broadly based and makes statements that are legitimised by law. With the eco-points method, the assessment of different environmental impacts in LCA studies is not very susceptible to the influence of interested parties.

Fig. 5: 'Separation of powers' in the eco-points method



Source: Own diagram based on Ahbe et al. (2014, p. 18)

2.2.3 Is the application of political appraisals in the eco-points method defensible from a scientific perspective?

The eco-points method assesses environmental impact based on both scientific evaluations and legal requirements. The latter emerge from political processes and reflect democratic processes.

Keyword: Evaluation

The eco-points method assesses environmental pressures such as resource use, emissions and wastes on the basis of statutory requirements. The maximum acceptable size of each environmental pressure is determined by experts in the particular field based on scientific knowledge of → environmental impacts, and set out by Parliament in laws or specified by the government in the form of environmental targets. Ultimately, therefore, the assessments made using the eco-points method are based on political decisions. This fact has led some to question the method's scientific credentials.

This criticism cannot simply be dismissed. However, the following should be taken into consideration:

- Fundamentally, evaluating an environmental burden is not a purely scientific process. For example, it is possible to make the scientific claim that phosphate causes algae to grow, oxygen to become scarce and fish to die. On the other hand, over thousands of years this process (accelerated by phosphate emissions) would create new mires, which are today protected by law. The fact that this process is still considered undesirable is an (environmental) political judgement.
- In democratically governed countries, environmental targets are a result of the opinion-forming process, in which all relevant actors can participate. For that reason, the targets enjoy broad legitimacy.
- The development of the scientific basis has a broad basis as well, since experts at work in the relevant authorities are familiar with the entire spectrum of scientific discussion in Switzerland, Europe and worldwide.
- A conclusive → weighting cannot be avoided in application-oriented life cycle assessments, as conflicts of objectives are often to be expected in comparative LCAs and decisions based on them. This begs the question of what would be the alternative to assessments based on legislation. In damage-oriented approaches such as ReCiPe 2016, a panel of experts determines the relative significance of the harm to human health, to the quality of ecosystems and to resources (→ harmfulness). Compared with such a specialised body, the assessment base applied by the eco-points method, with its broad political and therefore democratic underpinning, is more representative. Moreover, the eco-points method helps users to reduce their environmental burden based on the statutory targets.

2.2.4 Why is it advantageous to use the eco-points method in Switzerland?

The eco-points method, with its Switzerland-specific eco-factors, is based on the state of the Swiss environment and uses democratically legitimised environmental targets and goals as its yardstick.

Keyword: Switzerland

In the FOEN's view, the eco-points method using the Swiss eco-factors is a reference method for LCAs concerning Switzerland. Consequently, in studies relating to Switzerland, one of the assessments should always be carried out using the eco-points method. A study relates to Switzerland if it concerns products for the Swiss market, supports decision-making from a Swiss perspective or is used by Swiss companies, authorities and non-profit organisations to determine their environmental footprint. The most important reason for this is that the Swiss version of the eco-points method is based on the environmental quality targets and limit values anchored in Swiss legislation. These are also the relevant frame of reference for the commissioning party.

The eco-points method with the Swiss eco-factors reflects Switzerland's statutory environmental targets and, in the fifth version presented here, assesses a wide range of → environmental impacts. The environmental pressures marked '[new]' are included in this publication for the first time.

Resources:
- water resources (freshwater, according to regional scarcity)
- energy resources (renewable and non-renewable)
- primary mineral resources (extraction of metal ores, gravel, gypsum, etc.)
- land use (loss of biodiversity, differentiated by biomes)
- marine fish resources [new]

Emissions:
- climate change (caused by the emission of e.g. CO_2, methane, N_2O, SF_6)
- ozone layer depletion (caused by the emission of e.g. CFCs, halons)
- main air pollutants and particulate matter
- carcinogenic substances to air
- heavy metals to air
- water pollutants (including endocrine disruptors)
- heavy metals to water
- persistent organic pollutants to water
- pesticides to soil
- heavy metals to soil
- radioactive substances to air
- radioactive substances to water
- noise (traffic noise)
- plastic to soil and water [new]

Wastes:
- waste in landfills (non-radioactive)
- radioactive waste in final repositories

The eco-points method, and in particular the eco-points formula, is universally applicable. Eco-factors already exist for some countries other than Switzerland (→ international).

2.2.5 Can the eco-points method be applied in other countries and regions?

Yes, this method is universal, even though the assessment criteria must be adapted.

Keyword: International

The eco-points method is based on a basic principle and assessment criteria. While the basic principle of the method – the method of calculating ecological scarcity – is universal, the assessment criteria, i.e. the → eco-factors, are based on nationally binding environmental policy targets. For that reason, the eco-points method can be applied around the world. Prerequisites are environmental targets set out in the legislation of the country or region concerned and knowledge of the current state of emissions and resource use. Accordingly, eco-factors can be derived for each country, just like the eco-factors used for Switzerland that are described in this publication. For example, versions of the eco-points method have been published for the European Union as a whole and its member states as well as Japan, based on their respective relevant environmental legislation (→ other countries).

Because it can be adapted for different countries and regions, specific statements are possible. For example, an emission is weighted higher in countries where a limit value is exceeded compared to countries where this is not the case. However, eco-factors for different regions cannot be directly compared with one another. They behave like independent 'environmental currencies', which have to be converted for direct comparisons (→ abroad).

2.2.6 Are national eco-factors a useful yardstick for processes abroad?

Yes, because this is a means to counteract environmental dumping.

Keyword: Abroad

In principle, the eco-points method assesses the burdens on the environment abroad as if they were caused domestically. So if, for example, a factory in rural China produces batteries for the Swiss market, its particulate emissions are assessed as if they were produced in Switzerland. This results in a partly stricter weighting than when regionally or nationally-adapted metrics are used. This prevents downplay of the environmental burdens that occur abroad due to domestic demand. Otherwise, the exporting of environmental burdens would be rewarded. This rule of the eco-points method implements the principle 'Do not do unto others what you would not have them do unto you'.

However, there are situations in which ecosystems abroad are more severely affected by resource use or emissions than would be the case domestically. In this case, the eco-points method gives too low a rating for the environmental burden abroad. If the Swiss version is used as the basis, such situations arise, for example, in connection with water consumption in regions with severe water scarcity, or intensive agricultural and industrial land use in areas with originally very high levels of → biodiversity, such as tropical rainforest. For this reason, weighting should ideally be regionalised in cases where local ecological scarcity is greater abroad than domestically. Regionally differentiated → eco-factors already exist for the examples mentioned above. In this way, products and processes can be assessed with a regionally differentiated characterisation, and a normalisation and weighting based on domestic conditions. For example, given the scarcity of water in Morocco, the current eco-factor characterises one litre of water used in Morocco as if almost 100 litres of water were used in Switzerland. Accordingly, it is possible to assess the regional scarcity situation of a resource or an emission so that it can be compared with the assessment of the same resource or emission based on Switzerland's environmental situation. In the example of Moroccan tomatoes, this approach can be used to add up the eco-points of agricultural production in North Africa and food production in Switzerland.

When the eco-factors are updated, a review is made to determine whether further regionalisations are necessary and expedient in order to avoid underestimating environmental burdens abroad. When preparing this edition, for example, sulphur dioxide pollution in Switzerland was compared with that in European countries such as Germany, the UK and France. The result was a significantly lower weighting factor for Switzerland. Regionalisation would therefore be indicated in this case. However, since the currently published European eco-factors, unlike the Swiss ones, did not undergo an explicit approval process by the relevant environmental authorities, and there is also a lack of regionalised inventory analysis data, this has not been done.

2.2.7 What are the strengths of the eco-points method?

The eco-points method is comprehensive, transparent, easy to understand and user-friendly.

Keyword: Strengths

The strengths of the eco-points method can be described as follows:

- **It encompasses many environmental impacts.** The eco-points method gives an overall picture of the environmental burden, as it considers a wide range of relevant → environmental impacts and avoids → multiple assessment of impacts. These are key aspects of ensuring a → true and fair view.
- **It delivers clear statements.** The results are easy to understand and interpret, even for inexperienced users and the general public (→ fully aggregating approach).
- **It provides transparent results irrespective of the user.** The eco-points method is a reproducible metric. The derivations can be checked and all the documentation is publicly available (cf. this publication). Thus, manipulating the results is virtually impossible (→ separation of powers, → transparency).
- **It supports the decision-making** of companies, authorities, policymakers, non-profit organisations and private individuals. The fact that the eco-points method makes assessments based on statutory environmental quality targets means that it is easier to incorporate environmental arguments into commissioning parties' decisions. Decision-makers have certainty that they are orienting themselves on the relevant national environmental legislation.
- **Its basis is broad and trustworthy.** With the eco-points method, ecological sustainability is evaluated by the authorities and not by the actors involved in an LCA. As a result, the assessment is independent of the interests of the method developers, the commissioning parties or the practitioners. Furthermore, statutory environmental quality targets take into account not only the protection of the environment and human health, but also technical and financial feasibility and social acceptance. The data and models used enjoy broad scientific support (→ separation of powers).

- **It enables country- and region-specific calculations.** The eco-points method can deliver results tailored to the environmental situation and targets of the country concerned (→ Switzerland, → international).
- **It charts newly identified environmental pressures at an early stage.** The → precautionary principle in Swiss environmental law means that the limits of an environmental burden can be anchored in legislation even if not all the information about impacts and damages is available yet. It is therefore possible to include in the eco-points method environmental pressures that cannot yet be assessed using damage-oriented methods.
- **It is practical to apply.** Despite its comprehensive approach, the method is easy and cost-effective to apply, especially when inventory databases and LCA software are used which link emissions with eco-factors.
- **It can be easily updated.** The basis behind the eco-points method is independent of the assessment criteria and generally remains constant. New data on environmental pressures, as well as any adaptations in the characterisation models, can easily be incorporated into the eco-factor formula (→ eco-factor). Emissions which are to be added to the impact assessment can easily be integrated into the existing system (→ adaptation).

2.2.8 What are the gaps and weaknesses of the eco-points method?

The eco-points method is based on differentiated legal targets and must be adapted to countries' specific circumstances.

Keyword: Gaps and weaknesses

Like all methods, the eco-points method has gaps and weaknesses. These include the following:

- **Gaps in the law mean gaps in the assessment.** As the eco-points method is based on limit values and quantitative environmental targets, it does not directly illustrate the damage potential, in contrast to other methods. While scientifically established → harmfulness plays a role in setting limit values, so do political factors. Legal requirements being necessary can potentially delay the inclusion of substances newly identified as problematic or substances that are increasingly prevalent into the eco-points method. This is currently the case with nanoparticles, for instance, with their variety of impacts. This delay is the downside of its otherwise broad legitimacy. Emissions and resource uses that are not subject to environmental policy targets are therefore generally not taken into account, unless the → precautionary principle can be applied.
- **Non-ecological influences can affect environmental policy goals and targets.** The environmental policy goals and targets formulated by the political system are influenced by different interests and may even be contradictory.
- **No provision of an overall picture of the state of the environment.** The eco-points method does as yet not allow to determine whether the environmental pressure of an examined system is sustainable. This would ideally require regionalised eco-factors for all major environmental pressures, with a calculation of the corresponding 'impact budgets'. However, the LCA of Switzerland's total consumption between 1996 and 2015 (Frischknecht et al. 2018) based on the eco-points method is a first step in evaluating the sustainability of that consumption. There are also approaches that evaluate ecological sustainability from a global perspective, e.g. per capita rights based on the → planetary boundaries or the ecological footprint (→ overview of methods). However, these methods do not cover as many environmental pressures as the eco-points method.
- **The assessment is not 'true' – but it is reproducible and transparent.** An → assessment method can never produce the 'truth', but it can create trust by being transparent (→ strengths).
- **National or regional adjustments are necessary.** While the eco-points method in principle can be used anywhere in the world, the weighting factors must be adapted to the environmental situation and the statutory environmental targets of a country or a larger region. To this end, legal requirements and statistics about the current impact situation must be available. More or less comprehensive national eco-factor sets can therefore be calculated depending on the situation regarding environmental data and targets (→ international).
- **Regionalised assessment requires regionalised inventory analysis data.** In its current form, the eco-points method can be used to assess regionally varying environmental burdens such as freshwater use and land

use (→ biodiversity). While the method covers relevant regionalisations, the challenge for LCA practitioners is to collect robust and representative regionalised inventory data and have them available in background databases.

2.2.9 How is an eco-factor created?

An eco-factor measures the burden on the environment from an emission or resource use based on the relationship between the current situation and the targets set out in legislation.

Keyword: Eco-factor

The eco-points method uses eco-factors to weight environmental pressures – emissions of pollutants and noise as well as resource use and other substance flows – and expresses them in eco-points (UBP). Examples: The emission of one kilogram of CO_2 produces 1,000 UBP, the emission of one kilogram of phosphate to a body of water bring about 970,000 UBP and the extraction of one kilogram of gravel 2.8 UBP. Each quantity of an environmental pressure determined in the inventory analysis is multiplied by its eco-factor and the resulting points are totalled (→ procedure).

An eco-factor is essentially derived from three elements: characterisation, normalisation and weighting.

Characterisation quantifies the relative harmfulness of an environmental pressure compared with a reference substance. This occurs within a specific category of pollutants (such as greenhouse gases, plant protection products, primary energy consumption or radioactive isotopes) or non-substance emissions (such as noise). The numbers used to express these relations are based on scientific knowledge. According to information from the IPCC (IPCC 2013a), the climate impact of 1 kg of methane (CH_4), for example, is around 30 times higher than that of 1 kg of carbon dioxide (CO_2), while for 1 kg of sulphur hexafluoride (SF_6) it is even 23,500 times higher. The characterised quantity is normally expressed in kilograms of 'reference substance equivalents'. In the case of greenhouse gases, this metric is kilograms of CO_2-equivalents (kg CO_2-eq.). The emission of one kilogram of methane has the same impact as the emission of around 30 kilograms of CO_2, which is why the characterisation factor – and hence also the eco-factor – of methane is 30 times greater.

Normalisation measures the contribution of an environmental pressure in the subject of study to the total quantity of this category of environmental pressure in a region (in this case Switzerland) per year. If 100,000 tonnes of a substance are released in Switzerland every year, then a contribution of 10 grams is small, whereas if a total of only 70 grams are released every year nationwide, then the contribution of 10 grams is very large. In the first case, the 10 grams are measured against the 100,000 tonnes, in the second case against the 70 grams. The contribution to the environmental pressure will be assessed as weaker or stronger accordingly.

Weighting expresses the relationship between the current quantity of an environmental pressure and the tolerated target quantity set out in environmental legislation. The weighting factor is squared. This means that if the current quantity of an environmental pressure is greater than the tolerated target amount, this is clearly noticeable in the result.

The eco-factor formula is:

$$\text{Eco-factor} = \underbrace{K}_{\substack{\text{Characterisation}\\ \text{(optional)}}} \times \underbrace{\frac{1\ \text{UBP}}{F_n}}_{\text{Normalisation}} \times \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \times \underbrace{c}_{\text{constant}}$$

K = Characterisation factor of an emission or a resource
F_n = Normalisation quantity (technical term: normalisation flow): current annual quantity (emission or consumption), with Switzerland as the system boundary
F = Current quantity (technical term: current flow): current annual quantity (emission or consumption) in the reference area
F_k = Tolerated target quantity (technical term: critical flow): statutory limit value in the reference region
c = Constant ($10^{12}/a$): serves to obtain easily representable numerical quantities
UBP = Eco-point: the unit of environmental impact assessed

Example: Eco-factor for methane (CH_4)
The tolerated target quantity for greenhouse gases is derived from the Federal Council's climate targets. Based on the target of net zero by 2050, the authors of this report, in consultation with the FOEN, have defined a reduction target of 7.6 million tonnes of CO_2-equivalents by the year 2040, which corresponds to a reduction in annual emissions of 87.5% compared with the reference year 1990. The current emissions were based on the average for the years 2016–18, i.e. just under 62 million tonnes of CO_2-equivalents. From this, the eco-factor for greenhouse gases (CO_2-eq.) can be calculated (see Section 9.2). Since fossil methane has a climate impact 30 times greater than the reference substance CO_2, the formula is prefixed with the characterisation factor 30. The result is an eco-factor of 30 UBP per gram of fossil methane.

$$\text{Eco-factor for methane}$$
$$= 30 \times \frac{1\ \text{UBP}}{61\,826\,000\ \text{t}\ CO_2\text{-eq/a}} \times \left(\frac{61\,826\,000\ \text{t}\ CO_2\text{-eq/a}}{7\,829\,000\ \text{t}\ CO_2\text{-eq/a}}\right)^2 \times 10^{12}/\text{a}$$
$$= 30\ \text{UBP/g}$$

2.2.10 Why are the assessment criteria regularly adjusted?

The environmental situation and environmental policy targets change over time. Consequently, the eco-factors have to be redefined from time to time.

Keywords: Adjustments

The eco-points method is subject to a thorough review every few years. Over time, both the emission and consumption quantities and – if environmental policy requirements change – the tolerated target quantities evolve. Therefore, when the method is revised, the → eco-factors change. For example, the eco-factors for Switzerland in the areas of greenhouse gases, non-renewable energy carriers and plant protection products have risen compared to the previous edition, in some cases significantly. This reflects the fact that lawmakers have set much tougher reduction targets. In addition, new scientific knowledge has been incorporated into the assessment. This aligns the approaches with the international state of debate (e.g. the characterisation of freshwater use in this edition) or includes additional environmental pressures in the assessment and assigns them an eco-factor for the first time (e.g. wild-caught marine fish in this edition).

These adjustments are necessary and ensure that the eco-points method remains up to date. Being up to date is an important principle underpinning a → true and fair view. A disadvantage of these updates is that they seem to limit comparability over the years and create uncertainty for planning. With long-term time series, therefore, earlier inventory analysis data must be recalculated using the current assessment method when transitioning to a new version of the eco-points method. Essentially, the results of different studies can only be meaningfully compared if they were obtained using the eco-points method from the same year (e.g. UBP 2022).

2.2.11 How are substances assessed that are subject to several different targets set out in legislation?

Double counting is avoided both in the inventory analysis and in the eco-points assessment.

Keyword: Multiple assessment of impacts

The same pollutant can cause different → environmental impacts. For example, when fossil fuels are burned, nitrogen oxides (NO_x) are released. These pollutants promote the formation of ground-level ozone, contribute to over-fertilisation and acidification of soil, harm plants and can cause respiratory diseases. The challenge for an LCA is to record environmental pressures such as emissions, resource uses and other substance flows as comprehensively as possible, while avoiding double counting.

Damage-oriented assessment methods such as ReCiPe 2016 assess multiple impacts separately. This way, the potentials harms are comprehensively evaluated. By contrast, the eco-points method relates the weighting to the current usage or emission situation. Consequently, where there are multiple impacts subject to multiple statutory targets, only the most stringent target of each case is used to derive the relevant → eco-factor. In most cases, lawmakers already factor in multiple impacts when setting the environmental targets. This avoids multiple counting and the resulting disproportionate weighting of substances with multiple impacts. The strictest requirements in the case of nitrogen oxides are the limit values for ground-level ozone and acidification. If these limit values are respected, over-fertilisation is also reduced sufficiently.

Similarly, when an inventory analysis is carried out, an emission is only counted once, namely the first time a substance passes from the human/technical sphere into the natural environment, or the other way around in the case of resources. Substance flows within the natural environment, even those of man-made substances, are not taken into account in the inventory analysis, since they would otherwise be counted twice.

For the assessment, the eco-points method also counts a substance only once – using the impact that produces the highest eco-factor, as explained above. Where a pollutant nevertheless is listed more than once among the eco-factors, this is because of varying limit values and emission situations for the different environmental compartments, i.e. air, water and soil. Depending on whether an emission is first released into water, air or soil, different eco-factors may result if the statutory emissions targets are different. This is especially the case with heavy metals: for instance, there is an eco-factor for 'lead to air' and another for 'lead to soil'. But multiple counting is avoided in this case, too.

2.2.12 How transparent is the eco-points method?

The eco-points method is transparent in its construction and, even with its fully aggregating approach, enables the results to be presented in any level of detail.

Keyword: Transparency

As far as transparency is concerned, it is important to distinguish between the method itself and the presentation of the results. The eco-points method is transparent: the principles are disclosed, the methodology is published and more detailed documentation on the many evaluated environmental issues are freely accessible.

Furthermore, the eco-points method allows aggregated and highly detailed results at the same time, which is a major advantage. If there is only one figure for the result (e.g. 'an averagely occupied car produces 200 UBP per kilometre driven'), this → fully aggregated value can easily be compared with the UBP values of other means of transport. In addition, in the presentation of results, the environmental impacts or even the emissions and resource uses that determine the result and the proportion of the specific processes involved can be differentiated. Where this is done, the eco-points method offers a high level of transparency, traceability and comprehensibility in its presentation (see Tab. 1, for example).

2.2.13 Why doesn't the eco-points method focus solely on the harmfulness of substances?

As there are complex transformation processes and interactions at work in nature, not every emission causes directly measurable damage. There may be many uncertainties associated with such damage.

Keyword: Harmfulness

The eco-points method assesses the harmfulness of an emission indirectly by evaluating the extent to which national and international environmental targets are achieved. In so doing, it draws on the expertise of the specialists involved in developing the environmental requirements. This process thus takes into account a wide range of scientific perspectives as well as the → precautionary principle.

The Swiss → eco-factors obtained using the eco-points method are based on the statutory provisions applicable in Switzerland. In developing these provisions, the authorities determine the emissions targets and limits in three main ways:

- If damage potential can be attributed to a substance through direct cause-and-effect relationships, then the environmental requirements are based on these. For instance, this is the case with sulphur dioxide (SO_2).
- If a substance or a non-substantial emission is involved in complex reaction chains leading to damages, the requirements are based as far as possible on modelling of these response patterns and their distribution over time. For example, the reaction of nitrogen oxides (NOx) with other components of air depends on the temperature and solar radiation, among other things, and the various greenhouse gases absorb thermal radiation to differing degrees and have different lifetimes.

- If a substance is suspected to entail significant damage potential but this cannot yet be directly assigned, the → precautionary principle is applied in accordance with the Swiss Environmental Protection Act. This principle has an indirect bearing on the rules for certain pollutants and a direct bearing on those for wastes to be deposited.

2.2.14 Why is the precautionary principle so important in the eco-points method?

Because the eco-points method is based on the environmental targets anchored in Swiss legislation and on the associated regulations for implementation.

Keyword: Precautionary principle

The Federal Constitution of Switzerland states that the Confederation shall legislate on the protection of the population and its natural environment against damage or nuisance and shall ensure that such damage or nuisance is avoided. Accordingly, the Swiss Environmental Protection Act lays down the precautionary principle in its purpose article: "Early preventive measures must be taken in order to limit effects which could become harmful or a nuisance." The bodies that enact and implement the provisions of environmental law take this principle into account in their work.

Consequently, this principle is factored in when defining target and limit values for substances and non-substance emissions, in addition to their direct → harmfulness. The precautionary principle is thus indirectly incorporated into the → eco-factors used in the eco-points method. It can be seen directly in the eco-factors for wastes with potentially problematic contents that have to be landfilled.

For example, carbon in itself is not harmful, but in various compounds of landfilled wastes can cause undesirable but generally unpredictable decomposition reactions and problematic emissions. Therefore, carbon levels in landfilled wastes are limited in Switzerland. Consequently, in the eco-points method for Switzerland, the eco-factor for landfilled wastes is based on this limitation and on the legally required safety levels for landfills.

2.2.15 How does the eco-points method compare with other LCA weighting approaches?

There are various ways of evaluating the consequences of an environmental pressure. Four basic principles predominate.

Keyword: Comparison

The eco-points method weights environmental pressures using the distance-to-target approach, but there are other ways of arriving at a → weighting (see for example Sala et al. 2016, Sala et al. 2018). Environmental pressures can be weighted in the following ways:

- Selection of a single environmental pressure
- Distance-to-target
- Panel-based weighting
- Monetary weighting

Selection of a single environmental pressure: Many LCA studies consider only one environmental pressure, usually greenhouse gas emissions. In this case, all other environmental aspects are weighted at zero. For a comprehensive ecological evaluation, such a weighting approach is only adequate if the commissioning party can justify that all other environmental aspects are negligible.

Distance-to-target: This approach is based on environmental policy targets. It is the foundation of the eco-points method presented here.

Panel-based weighting: In this approach, the weighting is determined by a panel comprising a limited number of selected individuals. In some cases, the chosen panellists are representative of society in the relevant region. For example, the panel-based weighting for ReCiPe 2016 was determined based on a survey of LCA practitioners. The weighting of the → European Union's Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) was also based on panel surveys, the panels being asked to weight the impact categories relative to one another. For LIME 3, a damage-oriented assessment method developed in Japan, extensive surveys were carried out in all regions of the world and in different population groups. In this approach, the composition of the panel and the type of questions asked are key for the resulting weighting. To assess the significance of a panel-based weighting, the following questions can be helpful: Who established the panel? What questions were put to the panel? What are the panellists' backgrounds (e.g. region of origin, professional expertise, social status and economic interests)?

Monetary assessment: Research has been under way for many years into how the consequences of environmental burdens can be expressed in monetary units. For example, surveys are used to determine what value the population ascribes to natural assets, or attempts are made to calculate the value of what is destroyed by environmental impacts. Damage-oriented monetary approaches quantify damage to humans and the environment in the same way as damage-oriented weighting methods: they assign a monetary value to a year of human life lost and to potentially disappeared species. In the United States, courts use such calculations to determine fines in cases of environmental pollution. In Europe, external environmental costs are taken into account in public procurement decisions.

In addition to these weighting approaches, the weighting may also be devised by the life cycle practitioners or commissioning parties. If the process is not documented and therefore not comprehensible to outsiders, it is known as custom weighting.

2.2.16 How does the eco-points method compare with other methods in terms of the environmental impacts considered?

Alongside a few others, the eco-points method is one of the most comprehensive methods for assessing environmental impacts.

Keyword: Environmental impacts

Some LCA methods depict numerous environmental impacts, and the eco-points method is one of these. It is currently the only impact assessment method that covers wastes (both landfillable and radioactive), noise and endocrine disruptors. Table 3 gives an overview of which method covers which environmental impacts.

The technical terms 'environmental pressure' and 'environmental impact' are similar but have different meanings:

Environmental pressure (synonym: elementary flow) is the umbrella term covering resource use, pollutant emissions and noise, as well as other selected flows (such as carbon in landfills). Environmental pressures are expressed in physical units such as kg, MJ or kBq.

Environmental impact refers to the observable effects in the environment caused by resource use, pollutant emissions and noise, as well as other selected flows. Environmental impacts are expressed in UBP (in the eco-points method).

Tab. 3: Environmental impacts and assessment methods

	Method Environmental impact	Greenhouse gas inventory	Ecological footprint	UBP method		ReCiPe 2016	Environmental Footprint EF 3.0	Impact-World+ (2019)
				Switzerland (UBP'21 CH)	Germany (UBP'15 DE)			
Resources	Primary energy, not renewable	⊗	⊗	√	√	√	√	√
	Primary energy, renewable	⊗	⊗	√	√	⊗	⊗	⊗
	Ores and minerals	⊗	⊗	√	⊗	√	√	√
	Freshwater use	⊗	⊗	√	√	√	√	√
	Biotic resources (wild animals)	⊗	⊗	√	⊗	⊗	⊗	⊗
	Land use (biodiversity)	⊗	⊗	√	⊗	√	⊗	√
	Land use (soil fertility)	⊗	√	⊗	⊗	⊗	√	⊗
	Marine habitats (biodiversity)	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Emissions	Greenhouse gas CO_2	√	√	√	√	√	√	√
	Other greenhouse gases	√	⊗	√	√	√	√	√
	Ozone-depleting substances	⊗	⊗	√	⊗	√	√	√
	Summer smog	⊗	⊗	√	√	√	√	√
	Human toxicity	⊗	⊗	√	√	√	√	√
	Ecotoxicity	⊗	⊗	√	√	√	√	√
	Acidification + Eutrophication	⊗	⊗	√	√	√	√	√
	Radioactive emissions	⊗	⊗	√	⊗	√	√	√
	Traffic noise	⊗	⊗	√	⊗	⊗	⊗	⊗
	Light pollution	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Others	Waste	⊗	⊗	√	√	⊗	⊗	⊗
	Radioactive waste	⊗	⊗	√	⊗	⊗	⊗	⊗
	Microplastics	⊗	⊗	√	⊗	⊗	⊗	⊗
	Erosion of fertile soil	⊗	⊗	⊗	⊗	⊗	⊗	⊗

Based on: Frischknecht R. (2020) Lehrbuch der Ökobilanzierung, SpringerSpektrum, Heidelberg, Tab. 4.13.

2.2.17 Is it possible to quantify impacts on biodiversity?

Yes, but to measure them is challenging. Biodiversity loss due to land use is taken into account in the eco-points method. A major driver of the pressure on biodiversity is thus factored in.

Keyword: Biodiversity

When humans change how an area of land is used, this often triggers changes in biodiversity. For example, a total picture of the environmental burden of soy from Brazil should take account of the fact that tropical primary rainforest has been cleared to create arable land. The evaluation of infrastructure construction in Switzerland, on the other hand, should consider how much soil is sealed. These LCAs should therefore include the loss of biodiversity due to land use, in addition to the CO_2 emissions from the soil and the cleared trees.

To calculate the biodiversity losses due to land use, a multi-stage process is used to determine the expected loss of species resulting from a certain type of land use (e.g. intensive agriculture, contiguous settlement area). To this end, over 800 different ecoregions are distinguished, and the diversity and vulnerability of the animal and plant species occurring in these regions are considered. The benchmark for biodiversity loss is the natural forest at that location in its pre-industrial condition. In the example above, the outcome of this process is that intensive agricultural use in Brazil per unit of area causes an environmental burden that is on average three times greater than that in Switzerland, because of the wealth and vulnerability of the biodiversity present in Brazil. Biodiversity is an area in which regionalisation of → eco-factors is applied (→ abroad). If the exact origin of a product cannot be determined, life cycle practitioners can fall back on country-specific average values.

2.2.18 Where are fully aggregated LCA results particularly beneficial?

Fully aggregated results are extremely useful for incorporating ecological aspects into the decision-making process.

Keyword: Aggregated results

Fully aggregated LCA results based on the eco-points method are particularly beneficial where:

- organisations and individuals are making choices with ecological implications, such as which purchase to make or which project alternative to pursue;
- the individuals involved are not qualified experts in the environmental areas concerned, as is the case, for example, in most companies, in local and regional administrations and in the private sector;
- organisations want to mainstream environmental aspects into their own decision-making processes, for example when making purchases or investment decisions over a certain amount;
- the environmental aspects need to be evaluated as neutrally as possible in terms of political and economic interests.

The advantages of a fully aggregated interpretation based on the eco-points method are less pronounced in the following cases:

- Choosing between different options is not the primary focus of an LCA interpretation. This is the case, for example, with an issue-based analysis, where individual → environmental impacts are considered and the relative importance of environmental aspects does not matter. Here, an interpretation based on impact categories or environmental issues is the main consideration.
- The aim is to provide the basis for a subsequent LCA, e.g. data sets for a database in order to compile an inventory analysis (→ procedure). However, even where the aim is only to compile inventory analyses, aggregated weighted interpretations can contribute to quality assurance by making it easier to identify outlier data.

2.2.19 How is the eco-points method used in other countries?

In recent years, the eco-points method has also been made available for use in European countries and Japan.

Keyword: Other countries

The eco-points method has been published and updated in Switzerland by the FOEN (formerly known as the SAEFL/BUWAL) since 1990. Next to widely being applied in Switzerland, the eco-points method using the Swiss → eco-factors is known to have been used outside Switzerland on a number of occasions. For example, a Swiss sanitary product manufacturer with plants in Switzerland and several other European countries uses the Swiss eco-factors for the operational LCAs of all its plants. Similarly, a German automotive manufacturer uses it for its operational LCA.

For Japan, Myjazaki et al. (2004) and later Büsser et al. (2012) developed local eco-factors. In recent years, eco-factors have also been developed for Germany (Ahbe et al. 2014) and for the European Union (EU) and its member states (Ahbe et al. 2018). Likewise, Muhl et al. (2019) have provided three different sets of eco-factors for the EU.

Ideally, the eco-factors for a country (or an entity such as the EU) are published by a body with responsibility for environmental policy, or at least their development is closely monitored by such a body. This ensures the trustworthiness of the eco-factors, which is a major advantage of the eco-points method (→ strengths). If private individuals, companies or scientific institutes devise eco-factors, it remains unclear to users whether the relevant environmental authority endorses these calculations (see Braunschweig 2019).

Eco-factors from one country cannot be combined with eco-factors from another country in the same LCA. This would be like directly adding up amounts in Canadian dollars and Czech korunas, say, on the same invoice, without converting them. However, the inventory analysis of an LCA may be interpreted using different complete national eco-factor sets, in line with the principle of using multiple weighting methods, as set out in the → ISO standards.

In the future, it is conceivable that one country's eco-factors could be supplemented by regionalised eco-factors from other countries. That said, this would only be meaningful and possible if the location of the individual environmental pressure were known as well, which is not usually the case in average inventory analysis data.

2.2.20 What approaches to fully aggregating weightings exist in the European Union?

The European Union has developed its own panel-based weighting approaches for life cycle assessments of products and organisations. There are also specially adapted forms of the eco-points method.

Keyword: European Union

The European Union (EU) wants to ensure that environmental claims and statements, put out by companies for example, and the requirements issued by authorities are based on a uniform method. To this end, the EU has over the past decade developed LCA methods for evaluating products (Product Environmental Footprint, PEF) and organisations (Organisation Environmental Footprint, OEF).[2] Weighting is part of the assessment in both approaches. This allows the result to be expressed as a single weighted number of points (→ fully aggregating approach). These EU methods contain weighting factors for 14 impact categories linked to environmental burdens such as climate change, acidification, land use, water use and resource use. The weighting methods are based on three approaches, with 100 weighting points to be allocated to each of these 14 impact categories: a survey of 2,400 laypeople in six EU countries, a survey of over 500 LCA experts from 48 countries and, finally, an evaluation of the 14 impact categories based on five aspects of the damage potentials (spatial distribution, duration, reversibility, extent of damage and intensity of damage). The three weighting results were combined on an equal footing.

For Germany and the EU as a whole, versed scientific authors have developed applications of the eco-points method (Ahbe et al. 2014, Ahbe et al. 2018 and Muhl et al. 2019). This means that the eco-points method can also be used in the EU in the future. However, unlike the Swiss → eco-factors, those for the EU have not yet been approved by the relevant environmental authorities.

2.2.21 Could the 'planetary boundaries' concept enable the eco-points method to be applied globally?

'Planetary boundaries' is a scientific approach for describing the earth's ecological limits and the current use or overexploitation of its resources. These boundaries could conceivably be used to derive global eco-factors.

Keyword: Planetary boundaries

The 'planetary boundaries' concept (Steffen et al. 2015) describes ecological limits that must not be exceeded to avoid endangering the stability of ecosystems and the foundations of human existence. The concept currently comprises nine dimensions with a total of 11 indicators. According to Steffen et al. (2015; see Fig. 6), four out of the nine boundaries have now been exceeded at a global level, namely climate change ('climate crisis'), biosphere integrity (especially extinctions), land-system change (especially deforestation) and biochemical flows (excessive phosphorus and nitrogen flows into the natural environment). Other pressures are above the tolerance value in some cases, i.e. in certain regions. One dimension is not yet quantifiable, and only two measured values are within a tolerable range, with ocean acidification already close to the proposed limit value and freshwater (described by other sources as regionally overexploited) as well.

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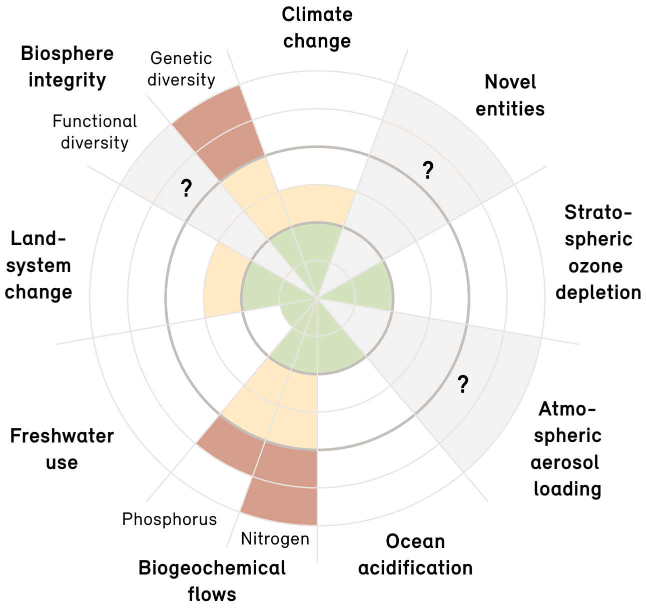
[2] *https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html* (Accessed: 29 April 2021)

Fig. 6: Planetary ecological boundaries and the current situation[3]



🟥 Beyond zone of uncertainty (high risk)

🟨 In zone of uncertainty (increasing risk)

🟩 Below boundary (safe)

⬜ Boundary not yet quantified

Source: based on Will Steffen et al. 2015

Planetary boundaries and the eco-points method are structurally similar: both approaches seek to ascertain the current relevant environmental impacts for a particular area and the respective tolerated target value. The statements arising from the planetary boundaries concept about the categories of environmental impacts to be considered, the associated current use or burden, and the applicable limits could therefore in principle be used for a global application of the eco-points method (see for example Doka 2016 and Sala et al. 2016). Frischknecht and Büsser Knöpfel (2015) have outlined one possible approach.

Nevertheless, there are important differences between the planetary boundaries and the current eco-factors for Switzerland:

- **Resolution:** All 11 concrete indicators also feature directly or indirectly in the latest Swiss eco-points. Besides these 11 indicators, the eco-points method, with the eco-factors for Switzerland, considers a plethora of other environmental pressures such as heavy metal emissions, radioactive emissions, many long-lived and toxic organic substances, endocrine disruptors, the use of energy and mineral resources, various types of waste and traffic noise.
- **Regionally differentiated evaluation:** Unlike the eco-points method with the eco-factors for Switzerland, the planetary boundaries consider burdens uniformly at a global level, even those whose impact differs from region to region. They are therefore to be understood as complementary to regional and local boundaries. A way of combining the planetary boundaries with regional boundaries has not yet been worked out, but scientific discussions to this end are under way (see for example Dearing et al. 2014, de Vries et al. 2013, Sabag Muñoz & Gladek 2017).
- **Formal status:** As described under → separation of powers, science and competent authorities have different tasks. In this sense, the planetary boundaries are an important scientific starting point. As an overall concept they have no formal legal validity, yet there are binding global agreements on some of the boundaries, i.e. climate change, stratospheric ozone ('ozone hole') and biodiversity. The eco-points method, meanwhile, is based on current environmental law. To develop it further, changes in environmental legislation (laws, ordinances, international treaties) are necessary.

Conclusion: The two concepts are complementary. While closely related, they differ in important ways.

For more information, see bafu.admin.ch/resource-consumption, under the 'planetary boundaries' concept

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[3] *https://science.sciencemag.org/content/sci/347/6223/1259855/F4.large.jpg?download=true* (Accessed: 3 April 2021)

2.2.22 How does the eco-points method relate to the UN Sustainable Development Goals?

The two approaches overlap slightly, but are qualitatively different and aimed at different actors.

Keyword: UN Sustainable Development Goals

The UN Sustainable Development Goals (SDGs) set out objectives for global sustainable development in 17 areas. Five of these goals relate directly to environmental quality and resource use (clean water, affordable and clean energy, climate action, life below water, life on land) and another four do so indirectly (zero hunger, good health and well-being, sustainable cities and communities, responsible consumption and production); the remaining goals are socially oriented. A total of 231 indicators have been defined to flesh out the 17 goals. There is some overlap between the SDGs and the eco-points method insofar as the latter evaluates environmental pressures that are related to the above goals either directly (e.g. greenhouse gases or wastewater pollution) or indirectly (e.g. particulate matter and NO_x with their negative effects on health, among other things).

On the other hand, there is a fundamental difference between the two approaches: the eco-points method assesses specific environmental pressures and allows them to be summated and compared, whereas the SDGs set out goals and indicators against which the development of society, infrastructure, the economy, etc. can be measured. Fewer than half a dozen of the 231 indicators deal with variables that are comparable to the → eco-factors used in the eco-points method. These include the greenhouse gas emissions of a region, the evaluation of water stress, and indicators on the protection of seas and land. The other indicators are concerned with status and progress, such as the number of countries that use ecosystem-based approaches for the management of marine areas, or the degree to which climate action and sustainability are taught in schools.

The SDGs are broadly defined and their criteria are formulated at a global level. Their measuring system is focused on results, e.g. at the end of a year. The results can be the outcome of different actions (laws, projects, etc.). By contrast, the eco-points method is more narrowly defined and is implemented nationally, based in this case on the situation in Switzerland. Its measuring system enables individual actions and items (laws, projects, products, etc.) to be evaluated in terms of their → environmental impact.

2.2.23 How does the eco-points method relate to the evaluation of companies' environmental performance?

The eco-points method can be combined with various environmental controlling and reporting instruments and enables comprehensive statements to be made about the environmental performance of organisations.

Keyword: Environmental controlling and reporting

Nowadays, many companies and other organisations record and assess the environmental performance of their operations and increasingly also the → environmental impact of their products and services. This may be an internal exercise for the company's management, or an external one aimed at investors, customers and other stakeholders. A range of methodological approaches have been developed for this environmental controlling and reporting, according to the different goals and target groups. These approaches address the assessment and weighting of environmental pressures in different ways.

All companies and organisations certified against the environmental management standard ISO 14001 carry out internal environmental controlling. Among other things, this entails identifying relevant environmental aspects, setting objectives for improving environmental performance, and recording and evaluating how this performance changes over time. To fulfil these tasks, some companies and organisations apply the life cycle assessment concept of → ISO 14040/14044 to their own activities as corporate ecobalance or LCA. Some have been doing this for many years. In some corporate LCAs, the eco-points method is used for assessing the environmental aspects, as it enables a large number of environmental pressures to be assessed and compared (→ benefits). The eco-points method thus helps to identify the organisation's relevant environmental aspects. As → environmental impacts can be added up and options can be compared, the eco-points method also supports efficient planning as well as the controlling of the environmental performance.

Other concepts for evaluating organisations' environmental performance focus on single environmental impacts. For instance, Greenhouse Gas Protocol (GGP) and CDP (formerly the Carbon Disclosure Project) are solely concerned with reporting on greenhouse gas emissions – other environmental issues are excluded. It is becoming apparent that the GGP system structure can be combined with ISO 14001 environmental controlling and the assessment of environmental aspects (using the eco-points method, for example). According to ISO 14001, an organisation's own processes are central to its environmental management, as its legal responsibility relates primarily to these processes. In addition, the ISO standard points to the often major importance of products and services, which environmental management must also take into account. This tallies with the definition used by GGP, which defines three areas, or 'scopes', from the organisation's perspective. According to this definition, organisations record their greenhouse gas emissions under three separate headings: own processes (scope 1), provision of final energy (in the form of electricity and district heating/cooling; scope 2), and all other processes, e.g. supply chains of purchased raw materials and semi-finished products, fuel supply chains, use of products by customers, transport by third parties, etc. (scope 3). Today, some organisations calculate greenhouse gas emissions based on a division into these three scopes, but also compile an overall (ecological) LCA using the eco-points method or other environmental assessment methods.

Other environmental controlling and reporting approaches dispense with a methodologically-based assessment of environmental aspects, such as reporting based on the GRI Standards.[4] The GRI Standards describe how an organisation should report on a wide range of environmental pressures and other environmental aspects. They do not specify which aspects are relevant for an organisation, leaving this to the discretion of the user organisation. Similarly, the VfU standard[5] for corporate environmental reporting by German-speaking financial service providers does not include an overall assessment or weighting of environmental aspects.

The technical specification for the life cycle assessment of organisations ISO/TS 14072 (2014) applies a → system boundary encompassing the organisation's internal processes as well as suppliers (and their supply chains), disposal companies, customers, and so on. As in the framework of → ISO standards 14040/14044, the eco-points method can also be used in such a corporate LCA to assess environmental pressures.

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[4] *https://www.globalreporting.org/how-to-use-the-gri-standards/* (Accessed: 4 April 2021)

[5] *https://www.vfu.de/tools/#kennzahlen* (in German) (Accessed: 4 April 2021)

Part 2

Methodological fundamentals

Part 2 presents the ecological scarcity method in detail. The explanations are aimed at a professional audience of commissioning parties as well as experts in research and industry. The content focuses on the fundamentals of the method, the formulas to calculate the eco-factors and the thematic structuring of the eco-factors 2021.

3 The ecological scarcity method

3.1 The basic principle

The ecological scarcity method is a 'distance-to-target' method as defined by SETAC (Udo de Haes 1996). The method offers standardised, generic weights.

Weighting is based on primarily national, but also some international environmental protection targets. These targets are

- ideally adopted in legally binding form or at least defined as targets by competent authorities,
- formulated by a democratically elected or legitimated body,
- and oriented towards the environmental dimension of sustainability as much as possible.

To determine the eco-factors for Switzerland, weighting is based on targets set by Swiss environmental policy. In specific cases, global, international or regional goals are used and converted to the Swiss level. The method can also be applied to other countries and regions independently of its implementation in Switzerland. To do so, information about the current environmental situation and the official environmental targets of the country concerned is required. Using the method described here, in recent years eco-factors have been published for Germany (Ahbe et al. 2014) and for the European Union and its member states (Ahbe S. et al. 2018; Muhl et al. 2019).

Discussions about planetary boundaries have prompted their use in the ecological scarcity method instead of statutory target values (Doka 2015).

The ecological scarcity method also lends itself to developing company-specific assessment methods for internal use. For this to be possible, the company's emissions and resource uses must be known, and the company has to set quantitative targets for individual pollutants and resources.

Through the manner in which the eco-factor is calculated, the ecological scarcity method permits **optimisation within the framework set by environmental policy targets.**

The method converts the various environmental pressures into points so that the values can be added and compared. The eco-factors are thus presented in the form of a utility analysis. The eco-factors (utility values) are determined from the current environmental situation (current flow), the target situation that environmental policy aims to achieve (critical flow) and the calculation algorithm (see Part 2, Section 3.3).

3.2 Original formula and derivation of the applied formula representation

The ecological scarcity method was introduced by Müller-Wenk (1978) and refined for the first time by Braunschweig (1982). It was then further developed a second time in the context of the interpretation of the life cycle assessments for packaging materials published by the SAEFL, the FOEN's precursor agency, in 1984 (Ahbe et al. 1990).

Ahbe et al. (1990) discussed various formulae that can be used to calculate eco-factors. The logistical function proposed by Braunschweig (1982) was replaced by a function in which the eco-factor is proportionate to the ratio of the current flow to the critical flow. From this, the authors derived the following formula:

$$\text{Eco-factor} = \frac{1\,\text{UBP}}{F_k} \times \frac{F}{F_k} \times c \tag{1}$$

F = Current flow: current annual load of a pollutant or resource, with Switzerland as the system boundary
F_k = Critical flow: critical annual load of a pollutant or resource, with Switzerland as the system boundary
c = $10^{12}/a$
UBP = Eco-point (the unit of the assessed result)

In the update performed by Brand et al. (1998), the formula was retained unchanged. The following reasons prompted the mathematical reformulation and careful modernisation of this formula in the second update in 2006:

- International life cycle assessment standard ISO 14044 prescribes the basic structure of an impact assessment. As set out in Section 3.3, the aim is to largely comply with its prescriptions.
- Environmental problems can vary greatly in time and place. This is the case for freshwater, for example, a resource that is very scarce in some regions in the world, but available in abundance in others. As there is no water scarcity in Switzerland, there was no eco-factor for freshwater as a resource in the first two versions of the assessment method. As a result, these aspects, which may be of environmental relevance, could not yet be taken into account in life cycle assessment studies of foods and resources from arid regions (e.g. tomatoes from southern Spain, or cotton from China). The formula revised as part of the second update in 2006 permits both regional and temporal differentiation.

As the new representation is based on a mathematical reformulation, a high degree of continuity is ensured, whereby

- if the critical and current flows of a pollutant are unchanged, the same eco-factor results from the revised formula as with the original formula,
- the linear dependence of the eco-factor (normalised with the critical flow) upon the ratio of the current flow to the critical flow remains,
- the past characterisation applied to pollutants that have the same type of impact (e.g. global warming potential of CO_2, methane and other greenhouse gases) remains, but it is at the same time facilitated through systematisation,
- the eco-factors can be applied as they were in the past: a table listing the eco-factors is provided and used to assess the inventory analysis results.

The representation of the original equation (1) (Ahbe et al. 1990; Brand et al. 1998) was modified slightly. In mathematical terms, this changes nothing in the formula at first. The derivation from the original equation (1) of the new equation introduced with the update in 2006 for annual flows of an individual pollutant for all of Switzerland shown in (2) and (3) illustrates that the outcome of the two forms of representation is identical.

In the original formula (1), normalisation was initially performed on the basis of the critical flow, while weighting was performed using the ratio of F to Fk. Equation (2) shows the form extended by the current flow F/F. Finally, the reconfiguration of the coefficients resulted in the equation (3), the starting point for the eco-factor formula (4) used since 2006, which is explained in the following section.

$$\text{Eco-factor} = \frac{1\ \text{UBP}}{F_k} \times \frac{F}{F_k} \times c \qquad (1)$$

$$\text{Eco-factor} = \frac{1}{F_k} \times \frac{F}{F} \times \frac{F}{F_k} \times c \qquad (2)$$

$$\text{Eco-factor} = \frac{1}{F} \times \left(\frac{F}{F_k}\right)^2 \times c \qquad (3)$$

3.3 Ecological scarcity and eco-factor calculation

The ecological scarcity method weights environmental pressures, i.e. pollutant emissions and resource uses, with 'eco-factors'. The eco-factor is derived from environmental legislation or corresponding political targets. In its basic form, it can be composed of the following three elements in accordance with ISO standard 14044:

- characterisation,
- normalisation and
- weighting

(International Organization for Standardization (ISO) 2006). The starting point for the revised eco-factor formula is equation (3) as set out above.

For every environmental pressure, the eco-factor is defined as follows:

$$\text{Eco-factor} = \underbrace{K}_{\substack{\text{Characterisation}\\ \text{(optional)}}} \times \underbrace{\frac{1\,\text{UBP}}{F_n}}_{\text{Normalisation}} \times \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \times \underbrace{c}_{\text{constant}} \quad (4)$$

where:
K = Characterisation factor of a pollutant or a resource
Flow = Load of a pollutant, quantity of a resource consumed, level of a characterised environmental pressure or level of an exchange within the technosphere, e.g.carbon content in waste
Fn = Normalisation flow: Current annual flow with Switzerland as the system boundary
F = Current flow: Current annual flow in the reference area
Fk = Critical flow: Critical annual flow in the reference area
c = Constant (10^{12}/a)
UBP = Eco-point: the unit of the assessed result

The eco-factor for the greenhouse gas nitrous oxide (N_2O), rounded to two significant digits, is calculated on the basis of this formula as follows:

$$270\ \text{UBP/kg} = \underbrace{265}_{\substack{\text{Characterisation}\\ \text{in kg CO}_2\text{-eq/kg}}} \times \underbrace{\frac{1\,\text{UBP}}{61\,826\,000\,000}}_{\substack{\text{Normalisation}\\ \text{in kg CO}_2\text{-eq/kg}}} \times \underbrace{\left(\frac{61\,826\,000\,000}{7\,829\,000\,000}\right)^2}_{\text{Weighting}} \times \underbrace{c}_{\text{constant}}$$

Characterisation factors are determined for pollutants and resources that can be allocated to a specific environmental impact (e.g. global warming potential). Here, the effect of a certain pollutant (e.g. the global warming potential of methane) is placed in relation to the impact of a reference substance (carbon dioxide in this case). Section 4.4 in Part 2 discusses the rules for applying the characterisation.

Normalisation relates the scarcity situation (weighting) to the current emissions/resource uses in a region. It is performed on the basis of the annual pollutant emissions or resource uses for Switzerland as a whole. ISO 14044 and the relevant SETAC publications (e.g. Udo de Haes 1996) also propose conducting normalisation on the basis of the current flows in a region.

The final weighting of pollutants, resources or characterised environmental impacts is performed on the basis of their 'distance to target', or **'ecological scarcity'**. For that purpose, the method usually uses the total present flows of an environmental pressure in Switzerland per year (current flows) and the maximum permissible flows of the same environmental pressure in Switzerland per year (critical flows) within the context of environmental policy goals. Depending on the way the specific environmental target or environmental legislation is formulated, either individual substances or (characterised) environmental impacts are considered.

The ratio of current to critical flow is squared. The effect of this is that a major exceedance of the target value (critical flow) is weighted over-proportionately, and if the current flow is substantially lower than the critical flow, it is weighted under-proportionately. This means that the higher the current pollution already is, the more strongly every additional emission is weighted.

Weighting is a dimensionless quantity determined exclusively by the **ratio of current to critical flow**. The absolute level of the flows has no influence whatsoever on the weighting. Thus, regardless of whether there is a current flow of 2,000 t/a and a critical flow of 1,000 t/a, or whether these flows are much lower at 6 and 3 kg/a respectively, an identical weighting factor will result. In both cases, the ratio of the flows is 2:1, and the weighting factor is 4.

The constant c is identical for all eco-factors and serves to make the factor easier to present; it delivers more practicable orders of magnitude and takes account of the temporal dimension that remains from the quantitative units.

The unit in which the eco-factor is expressed is 'eco-points (UBP) per unit of environmental pressure', e.g. '8.3 UBP per gram SO_2', or 'eco-points (UBP) per unit of environmental impact', e.g. '1.0 UBP per gram CO_2-equivalent'.

The new representation of the formula makes it possible to determine temporally and spatially differentiated eco-factors and eco-factors for the subgroups of specific pollutants. These eco-factors are all fully compatible with the basic scheme and the annual eco-factors for Switzerland and can be combined seamlessly. The following sections describe the differentiation options.

3.4 Regionalisation of eco-factors

The breakdown of the eco-factor into characterisation, normalisation and weighting terms permits conversion from and to different regions. The weighting factor is calculated on the basis of the current and critical flows of a certain area. Normalisation is calculated on the basis of the current flow of the region to which the eco-factor should apply, which is Switzerland in the case above (see equation (5)). Equation (5) corresponds to equation (4) if Region 1 is identical to Switzerland;

$$\text{Eco-factor}^{\text{Region 1}} = K \times \frac{1\ \text{UBP}}{F_n^{\text{CH}}} \times \left(\frac{F^{\text{Region 1}}}{F_k^{\text{Region 1}}}\right)^2 \times c \tag{5}$$

where:
K = Characterisation factor of a pollutant or a resource
Flow = Load of a pollutant, quantity of a resource consumed, level of a characterised environmental pressure or level of an exchange within the technosphere, e.g. carbon content in waste
F_n^{CH} = Normalisation flow: Current annual flow with Switzerland as the system boundary
$F^{\text{Region 1}}$ = Current flow: current annual flow with Region 1 as the system boundary
$F_k^{\text{Region 1}}$ = Critical flow: critical annual flow with Region 1 as the system boundary
c = Constant (10^{12}/a)
UBP = Eco-point: the unit of the assessed result

There are three ways in which this regionalised eco-factor calculation can be applied:

1. A weighting factor determined for a certain region can be normalised to Switzerland and thus integrated in the assessment. For example, a national weighting factor can be calculated for SO_2 emissions in Spain on the basis of the current and critical flows there. This way the significantly higher demand in reducing the emissions in Spain compared to Switzerland can be taken into account. Normalisation to the current Swiss flow results in an eco-factor that is compatible with Swiss eco-factors and represents the scarcity situation in Andalusia. Using this eco-factor, SO_2 emissions in Spain can now be assessed from a Swiss perspective.
2. Where environmental policy sets targets that vary greatly in terms of their spatial reference, eco-factors can be determined for smaller areas (e.g. regional or even site-specific factors) if substantially more critical situations arise that are not or insufficiently captured with an average factor for all of Switzerland. For instance, the state of Swiss lakes varies greatly. Lakes in the Central Plateau, such as Lake Greifensee or Lake Hallwil, have greater phosphorus pollution levels than, for instance, Lake Brienz or Lake Constance. Measures taken to reduce phosphorus loads in lakes with previously higher pollution levels lead to a greater reduction of environmental impacts.
3. In cases where Swiss environmental policy is bound legally to international objectives, weighting factors can be calculated for regions larger than Switzerland on the basis of these objectives. For example, European weighting factors are normalised to the Swiss situation. Thus, Switzerland has agreed with the North Sea states to cut nitrogen discharges to the North Sea by half (from their 1985 level).

If regionally specific eco-factors have been determined within Switzerland, then they should be used to calculate the average Swiss eco-factor. The weighted sum of the regional eco-factors is thus formed: Equation (6) shows an example with two regions:

$$\text{Eco-factor}^{\text{CH}} = \text{Eco-factor}^{\text{Region 1}} \times r_1 + \text{Eco-factor}^{\text{Region 2}} \times r_2 \tag{6}$$

where:
r_1 = Share of the current flow of Region 1 in the current flow of Switzerland as a whole
r_2 = Share of the current flow of Region 2 in the current flow of Switzerland as a whole

Through the quadratic function of the weighting factor, spatial differentiation is not mathematically neutral, but gives greater weight to regions where environmental pressure is higher.

3.5 Temporal differentiation of eco-factors

In similar fashion, the new formula representation permits temporal differentiation of weighting and thus of the eco-factor. For instance, a distinction could be made for the current and critical flows of airborne pollutants in specific periods, such as the summer and winter halves of the year (cf. equation (7)):

$$\text{Eco-factor}^{\text{Period 1}} = K \times \frac{1\ \text{UBP}}{F_n^{\text{year}}} \times \left(\frac{F^{\text{Period 1}}}{F_k^{\text{Period 1}}}\right)^2 \times c \qquad (7)$$

where:
K = Characterisation factor of a pollutant or a resource
Flow = Load of a pollutant, quantity of a resource consumed, level of a characterised environmental pressure or level of an exchange within the technosphere, e.g. carbon content in waste
F_n^{Year} = Normalisation flow: Current annual flow with Switzerland as the system boundary
$F^{\text{Period 1}}$ = Current flow: current annual flow during Period 1 (e.g. in the daytime or in the summer half of the year) with Switzerland as the system boundary
$F_k^{\text{Period 1}}$ = Critical flow: critical annual flow during Period 1 (e.g. in the daytime or in the summer half of the year) with Switzerland as the system boundary
c = Constant (10^{12}/a)
UBP = Eco-point: the unit of the assessed result

The resulting eco-factors can then in turn be weighted and aggregated to establish a daily or annual average. This is illustrated in an example with two periods:

$$\text{Eco-factor}^{\text{year}} = \text{Eco-factor}^{\text{Period 1}} \times p_1 + \text{Eco-factor}^{\text{Period 2}} \times p_2 \qquad (8)$$

where:
p_1 = Share of the current flow of Period 1 in the annual current flow
p_2 = Share of the current flow of Period 2 in the annual current flow

The formula can be used for every kind of temporal differentiation; a breakdown into any number of periods is also conceivable, such as four periods in accordance with the four seasons of the year.

Here again, situations in which the current flow is substantially higher than the critical flow are weighted over-proportionately stronger due to the squared weighting factor. Therefore, an annual eco-factor calculated on the basis of temporally differentiated eco-factors is not the same as an eco-factor determined on the basis of annual loads.

3.6 Eco-factors for pollutant subgroups

In certain cases, the legislators adopted an environmental target for a group of pollutants (such as PM10), but not for individual subgroups that may be included in inventories or that users of the method may wish to examine separately for other reasons (such as PM2.5). In this situation, all subgroups should receive the same eco-factor as the entire group since the applicable environmental law provides no grounds for differentiation.[6] However, the formation of pollutant subgroups (PM2.5 and PM2.5–10) must not have any influence on the level of the eco-factor when the same environmental target applies to all subgroups.

The original eco-factor formula did not permit free differentiation of pollutant groups, as every breakdown of substance flows led to appreciably higher eco-factors. The revised formula representation provides an elegant solution for such situations:

Eco-factors for parts of a pollutant group can be formed by using the flow of the entire pollutant group for normalisation in the eco-factor formula; in our example, this would be the annual PM10 load for Switzerland as a whole.

As the PM2.5 and PM2.5–10 subgroups are subject to the same relative reduction target, the weighting factor for PM10, PM2.5–10 and PM2.5 is identical. Therefore, the same eco-factors result for PM10, PM2.5 and PM2.5–10.

$$\text{Eco-factor}^{\text{PM10}} = K \times \frac{1\ \text{UBP}}{F_n^{\text{PM10}}} \times \left(\frac{F^{\text{PM10}}}{F_k^{\text{PM10}}}\right)^2 \times c \qquad (9a)$$

$$\text{Eco-factor}^{\text{PM2.5}} = K \times \frac{1\ \text{UBP}}{F_n^{\text{PM10}}} \times \left(\frac{F^{\text{PM2.5}}}{F_k^{\text{PM2.5}}}\right)^2 \times c \qquad (9b)$$

$$\text{Eco-factor}^{\text{PM2.5–10}} = K \times \frac{1\ \text{UBP}}{F_n^{\text{PM10}}} \times \left(\frac{F^{\text{PM2.5–10}}}{F_k^{\text{PM2.5–10}}}\right)^2 \times c \qquad (9c)$$

In this way, inconsistent artefacts that previously arose when subdividing pollutant groups can now be prevented in a plausible manner.

A different procedure is applied if a different reduction target applies to individual substances within a pollutant group. These substances must be broken out of the group and analysed separately.

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[6] This applies despite the fact that PM2.5 tends to be more harmful than the entire PM10 group.

4 Principles governing the derivation of eco-factors

4.1 Taking account of natural background levels

Wherever possible, only anthropogenic flows are considered for the calculation of eco-factors (e.g. nitrogen in bodies of water). Natural sources of emissions such as non-methane volatile organic compound (NMVOC) emissions from forests cannot be regulated or influenced by legal regulations and are therefore outside the system boundary.

4.2 Aggregate parameters

Parameters that aggregate several substances (e.g. NMVOCs, total nitrogen) are used if the environmental policy targets are only formulated for the aggregate parameter or if the environmental impact of the individual substances is similar. If an aggregate parameter is in widespread use in present-day life cycle inventories, an eco-factor can be calculated for that parameter as a proxy.

Using aggregate parameters presents a risk of double counting if substances that are already contained in an aggregate parameter are also designated separately in inventory analysis databases and are assessed twice as a result. For that reason, the assessment should be performed at the level of the individual active substances, wherever possible.

4.3 Precautionary principle

The precautionary principle is defined and handled in slightly different ways depending on the source, the country and the issue at hand. What is common to all definitions, however, is that the principle applies when there is not enough conclusive scientific evidence of cause-effect relationships, but there are indications that a threat to human or animal health or the environment is probable (BAG et al. 2003).

The article discussing the aim of the Swiss Environmental Protection Act (EPA) explicitly mentions the precautionary principle: *"Early preventive measures must be taken in order to limit effects which* ***could*** *become harmful or a nuisance."* The right or obligation to take precautionary action can be derived from the precautionary principle (BAG et al. 2003, p. 4f.).

Even in cases where a threshold can be defined at which there is no harm, adverse effects continue to be possible for certain persons or environmental compartments. For example, individual sensitivity to exposure to ozone or other airborne pollutants varies widely. Nevertheless, pressures below the threshold of no harm or not subject to a defined threshold must be reduced only to the extent that is operationally (technically) feasible and economically viable. If the threshold of no harm is exceeded, this restriction does not apply and the mitigation action must be taken. Federal Swiss agencies other than the FOEN may use slightly different definitions (BAG et al. 2003, p. 8ff.). Their specifications, however, have little relevance to the derivation of eco-factors.

4.4 Using characterisation factors

The fundamental condition determining the application of characterisation factors is that the **characterisation matches the legislators' intention**.

Two examples should make this clear. Volatile organic compounds (VOCs) contribute in varying degrees to creating ground-level ozone. However, since legislators set the VOC levy per kg of VOC and not on the basis of ozone creation potential, no characterisation is applied for VOCs.

The current Swiss CO_2 Act governs the emissions of all greenhouse gases. Consequently, characterisation is applied for greenhouse gases.

In addition, the following applies:

a) The characterisation factors used should be scientifically recognised.
b) The characterisation factors can be derived from political targets.

4.5 Determination of normalisation

The current flows on which the weighting is based are generally identical to the flows that are used for normalisation. If, however, a characterisation is performed or a regional or temporal differentiation is carried out, the current flow will differ from the normalisation flow if the environmental target is not also formulated on the basis of the characterised emissions. The characterised flow comprises only those substance flows whose eco-factors are determined through the characterisation. In accordance with the principle of the highest eco-factor (Part 2, Section 4.11), eco-factors must always be assessed in relation to the strictest target.

Certain rules must be observed when deriving the normalisation flows:

- As a priority, the current annual loads in Switzerland should be used. This applies particularly and without exception to eco-factors that are differentiated within Switzerland (site-specific or cantonal eco-factors).
- If these are not known or if the environmental pressure does not arise, European or global annual loads should be used and converted to 'Swiss' loads through the ratio of the European/global population or area, or some other suitable metric, to that of Switzerland.
- If these are not known, the annual loads of a specific industrialised nation should be used and corrected by the ratio of population or area or some other suitable metric.

In the case of pollutants and resources that are characterised, the characterised annual impacts must be used for normalisation.

4.6 Determination of weighting

The representation of the formula results in an independent weighting term with a ratio of F to Fk squared. The quadratic weighting makes it possible for slight exceedances of the critical flow to receive a much smaller weighting than large exceedances: If, for instance, the current flow is 10% above the critical flow (F = 1.1 Fk), this gives a weighting factor of 1.21. If the current flow is 40% above the critical flow (F = 1.4 Fk), this gives a weighting factor of around 2, and if the critical flow is exceeded by 100% (F = 2 Fk), the weighting factor is 4.

National annual flows are generally used for weighting. Depending on the issue at hand, site-specific, cantonal, national, regional, continental or global, as well as seasonal or annual current and critical flows, can be used for certain environmental concerns. The flows are quantified either as individual substances or as characterised environmental impacts in accordance with the environmental targets and ideally in a suitable manner for the normalisation.

The current and critical flows must therefore be expressed in the same unit. This is why the weighting term does not have any unit.

The weighting function is also quadratic when eco-factors are differentiated spatially and temporally. This differs from the proposal made by Dinkel et al. (2004), where the weighting factor is linear for regionalised eco-factors.

Current flows should always be determined with regard to the reduction target. The system boundary used to determine the current and critical flows must be the same. In most cases, the current flow is identical to the normalisation flow.

Critical flows are generally based on binding political targets (which in turn can be based on scientific findings). These are primarily protection targets established by law (annual loads, ambient limit values). Where no statutory provisions exist, critical flows are based on the most binding possible political statements of intent (e.g. the Federal Council decision to set a target of net zero greenhouse gas emissions by 2050).

4.7 Determination of the eco-factor

Through characterisation, normalisation and weighting, the eco-factors capture political and statutory evaluations of the environmental relevance of pollutant emissions. For example, the emissions of a heavy metal to air, soil and water are each assessed with a specific eco-factor, which is calculated from the specific current and critical flows. This normally leads to different eco-factors for the emission of one and the same pollutant to water, air or soil. These differences reflect the different statutory requirements and current pressures.

4.8 Temporal aspects of eco-factor determination

Stipulations anchored in statutes, such as ambient limit values for airborne pollutants, generally do not set any explicit time horizon apart from transitional provisions. The provisions apply after they come into force. When political goals are set, in contrast, specific targets can be defined for certain points in time. As shown in its report on sustainable development in Switzerland (Swiss Federal Council 2016), the Swiss Federal Council seeks a long-term perspective, as already stipulated in the Federal Constitution (Art. 73). Moreover, the preamble to the Federal Constitution mentions the responsibility towards future generations.

In cases where there are several political targets with (very) different time horizons, which may be used for the determination of an eco-factor, an appraisal of the current political situation should be done by the competent authority to either select one of the points in time or perform an interpolation to an intermediate point in time.

4.9 Time lag between current flows and future impacts

The ecological scarcity method proceeds from the present situation when determining eco-factors. But how should the pressures listed in life cycle inventories be handled if they already arose long ago or will only arise in the distant future?

Pressures listed in life cycle inventories that arose long ago can be taken into account or not, depending on the issue being analysed. In general, no special adjustment is necessary.

The situation is somewhat different for pressures triggered by current processes that will (or may) only arise in a very distant future. One example is the long-term emissions from landfills (modelled in the UVEK LCI Data DQRv2:2022 and ecoinvent v3 to 60,000 years in the future), generated by wastes deposited today.

Such emissions in the distant future should not simply be assessed with an eco-factor of zero and thus neglected. On the other hand, these pressures may never arise: with sufficient engineering effort, landfills can be cleaned up at practically any time. For that reason, it is acceptable to either take only partial account of such emissions in the very distant future, or to determine a specific eco-factor for them. The ecological scarcity method is guided in principle by present political goals and the targets set out in environmental laws. A different assessment of long-term emissions is therefore conceivable in principle, as not only the goals and targets but also the exposure situation at the point in time when the long-term emissions occur can differ substantially from the present situation.

In any case, the way long-term emissions are handled in inventory analysis data needs to be checked carefully. Depending on the method, a more differentiated analysis and assessment of long-term emissions may be required.

4.10 Spatial aspects

Political and statutory goals are sometimes spatially differentiated. For instance, this is the case for the limit values governing pollutants in surface waters and groundwater. In most cases, however, provisions apply uniformly across Switzerland. If a relevant distinction is made, this should be captured with corresponding eco-factors.

Differentiation is appropriate when there is a uniform limit value across Switzerland for pollutants but the pollution situation varies greatly from region to region. For airborne pollutants, the differences are usually too minute or cannot be quantified. For water pollutants, however, relevant and quantifiable differences in levels of pollution can arise (e.g. phosphorus in lakes, see Part 3, Section 10.3). In such cases, regionalised eco-factors should be applied in order to determine the eco-factor for Switzerland as a whole (see also Part 2, Section 3.4).

4.11 Eco-factor selection when several derivations are possible (highest eco-factor principle)

For some pressures, there are several ways to derive eco-factors. For example, specific ammonia emissions to air can be assessed on the basis of the political target for nitrogen, but also on the basis of their acidification potential. The principle governing the ecological scarcity method is that the **highest resulting eco-factor in each instance** is used. Weighting is then performed on the basis of the dominant assessable environmental impacts.

5 Principles governing the application of eco-factors

5.1 Selection of substances

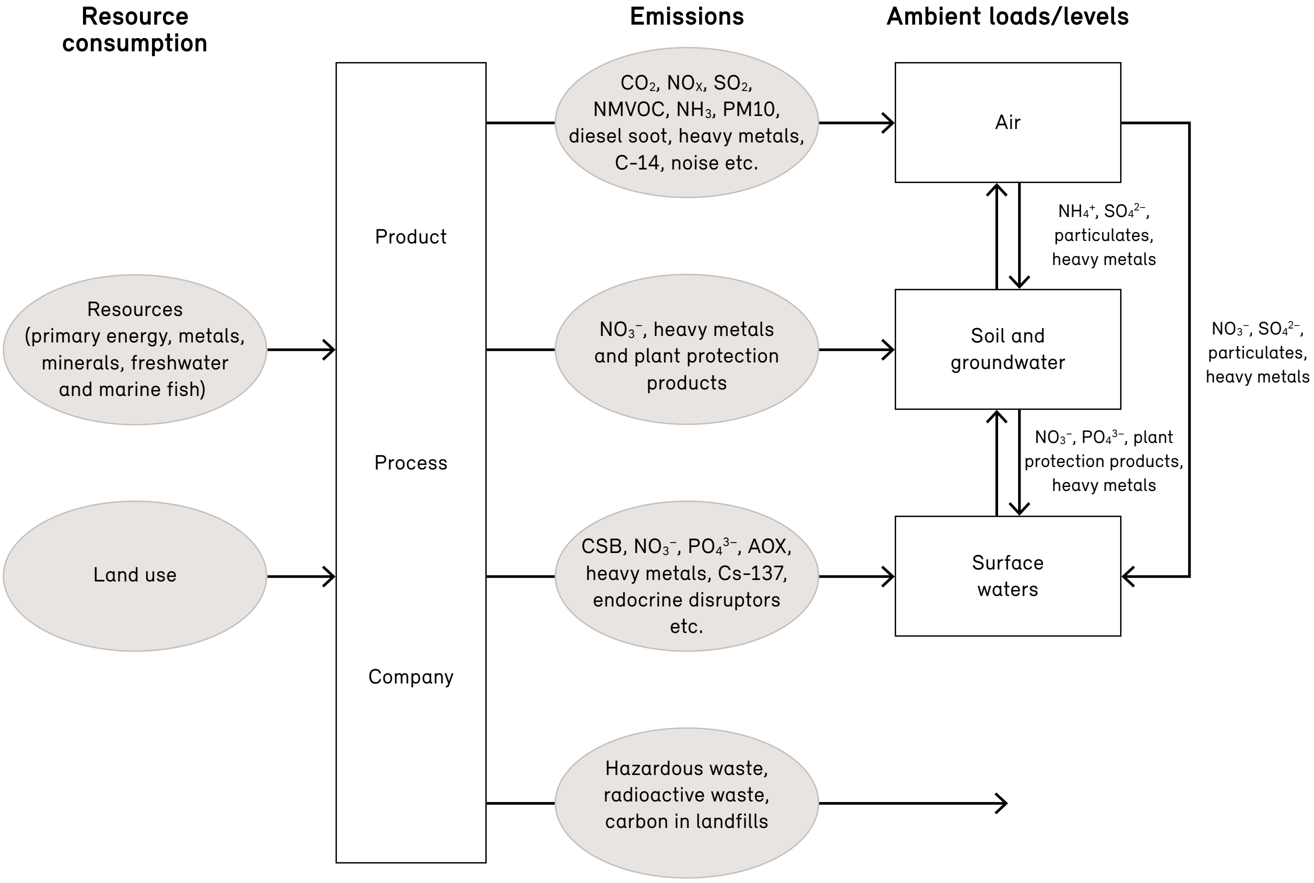
The ecological and political relevance of a substance is decisive in whether an eco-factor is determined for it. This limits the list of environmental pressures that can be weighted. After all, environmental policy by no means sets targets for all substances, especially not for those that have little environmental relevance in Switzerland and Europe (such as sulphate emissions to bodies of water) or for which knowledge is lacking (e.g. nanoparticles). The substance list has nevertheless been expanded each time it has been updated.

With the exception of diesel soot particles, all the eco-factors from the previous report (Frischknecht & Büsser Knöpfel 2013b) continue to be determined. Almost all of the eco-factors are derived in the same way, but with updated values.

Substances are usually inventoried when they pass from the technosphere to the ecosphere. This boundary is not always clearly defined – especially between soil and groundwater. A more detailed discussion of this boundary is provided in the section on soil (Part 3, Section 12.1.2). Fig. 7 provides a schematic overview of the points at which environmental pressures are assessed with eco-factors

Fig. 7: Overview of system boundaries

The environmental pressures assessed by eco-factors are shaded grey.



(fields shaded grey). Each emission should be assessed only once – when it first passes from the technosphere to the ecosphere. Other substance flows within the ecosphere, including those that are anthropogenic in origin, are not taken into account in order to prevent double counting.

If legislators regulate (limit) a flow that does not leave the technosphere, the eco-factor is applied to this. In the current edition, this is the case for the following flows:

- carbon content of wastes consigned to landfill;
- mass of wastes stored in an underground disposal site abroad;
- radiotoxicity index of radioactive wastes disposed of in deep repositories.

5.2 Spatial and temporal validity of the eco-factors

Life cycle inventories of product systems generally comprise globally distributed emissions and resource uses. Therefore, care must be taken when applying the eco-factors so that each emission is weighted as if it were taking place in Switzerland (except for freshwater consumption, land use, radioactive emissions and oil emissions to the North Sea). Through this approach, even when a process is moved to another country, it does not affect the outcome of a life cycle assessment if the absolute level of specific emissions is the same. When environmental pressures have a globally uniform impact, such as greenhouse gas emissions, the eco-factors for all emissions are globally applicable. In other cases, the environmental impacts of a pollutant emission or resource use can differ from region to region (e.g. water pollutant emissions or use of water resources). The regionalisation of eco-factors presented in the section above makes it possible to take account of such differences.

In practice, however, a great deal of effort is generally needed to take systematic account of specific regional circumstances for a product life cycle assessment, due to the lack of information on the specific environmental situation and the environmental policy goals that apply there. This would require an independent and systematic definition of eco-factors for that region. It is definitely conceivable for an eco-factor of particular relevance to a life cycle assessment to be adjusted to the specific regional scarcities in a manner similar to a sensitivity analysis (e.g. specific pollutant emissions to water in a region where pollution levels are very high or very low). However, such case-specific or scientifically based eco-factors must be interpreted with great caution.

This approach can also be taken when interpreting a site audit as part of the environmental management activities of a company, or when assessing the on-site pressures of a locally defined project (such as the construction of a deep repository for radioactive waste).

As the eco-factors reflect present environmental targets, their informative value declines over time. However, a comparison of the 1990 eco-factors with those of 1997, 2006, 2013 and 2021 shows that the pollution situation, i.e. the current flows, and the political targets, i.e. the critical flows, have changed significantly in some cases.

It takes time for an environmental issue to be reflected in political targets. For that reason, target values rarely encapsulate the most recent scientific findings. In the same vein, the current flows often represent an extrapolation of past values. This is why the eco-factors must continue to be updated in the future at regular intervals.

6 Data quality

The stated data quality grades relate to the underlying data. For the current flows, they represent the accuracy of the available data. For the critical flows, the assignment of different quality grades reflects the binding nature of the underlying statutory provisions or political statements.

The quality or binding nature of the data is graded in the explanatory part of the report in accordance with the following table:

Tab. 4: Indicators of the quality and binding nature of data

Quality indicator	Uncertainty with respect to the current flow
A	< 20 %
B	20 bis 40 %
C	> 40 %

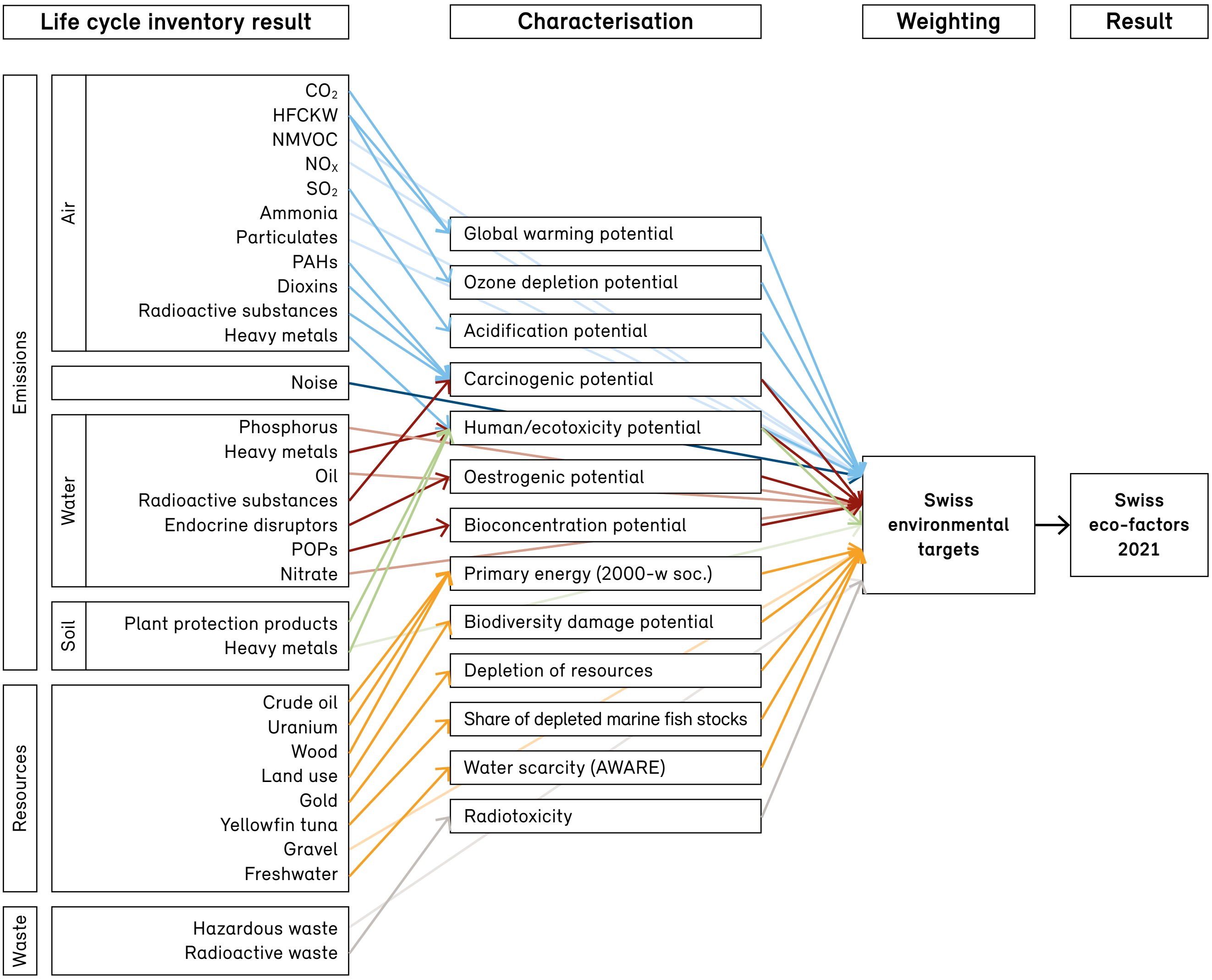
Indicator of the binding nature	Derivation of the critical flow
a	Calculation or derivation from statutory emission/ambient targets and/or from political statements of intent
b	Expert recommendation/expert estimate
c	Modelling assumption of advisory group

7 Characterisation

Characterisation factors describe the relative environmental impact of substances compared to a reference substance. The characterised quantity is normally expressed in reference substance equivalents. In the case of greenhouse gases, carbon dioxide is the reference substance, and kg CO_2-equivalent (kg CO_2-eq.) is the unit of the quantity characterised.

The characterisation factors are based on scientific knowledge of the relative effectiveness of pollutants in terms of a specific environmental impact. In the case of greenhouse gases, for instance, the characterisation value of 265 kg CO_2-eq./kg N_2O for nitrous oxide (N_2O) means that 1 kg of N_2O has the same global warming impact as 265 kg of CO_2.

Fig. 8: Basic diagram of the ecological scarcity method (Swiss eco-factors 2021) including the inventory analysis result, characterisation and weighting steps



Tab. 5: Characterisation methods used in the 2021 and 2013 reports

	Abbr.	Reference unit	Implementation in the ecological scarcity method		
			2013	2021	Source 2021
Global warming potential	GWP	kg CO_2-eq.	Yes	Sect. 9.2	IPCC 2013a
Ozone depletion potential	ODP	kg R11-eq.	Yes	Sect. 9.3	UNEP 2007
Acidification potential	AP	kg SO_2-eq.	Yes	Sect. 9.7.6	Guinée et al. 2001a
Human toxicity potential of heavy metal emissions to air		kg Cd-eq.		Sect. 9.11	Fantke et al. 2018
Ecotoxicity potential of heavy metal emissions to air		kg Cd-eq.		Sect. 9.11	Fantke et al. 2018
Carcinogenic potential of PAH, dioxin, furan and benzene emissions to air	CTU	CTUh	Yes	Sect. 9.10	Fantke et al. 2018
Carcinogenic potential of radioactive emissions to air		kBq C-14-eq.	Yes	Sect. 9.12	Frischknecht et al. 2000
Human toxicity potential of heavy metal emissions to surface waters		kg As-eq.		Sect. 10.5	Fantke et al. 2018
Ecotoxicity potential of heavy metal emissions to surface waters		kg As-eq.		Sect. 10.5	Fantke et al. 2018
Carcinogenic potential of radioactive emissions to surface waters		kBq U-235-eq.	Yes	Sect. 10.6	Frischknecht et al. 2000
Carcinogenic potential of radioactive emissions to the Sea		kBq C-14-eq.	Yes	Sect. 10.7	Frischknecht et al. 2000
Oestrogenic potential of endocrine disruptors		kg E2-eq.	Yes	Sect. 10.11	Rutishauser et al. 2004
Bioconcentration factor of persistent organic pollutants	POP	2,4,6-tribromphenol-eq.	Yes	Sect. 10.12	Ruiz et al. 2012
Human toxicity potential of heavy metal emissions to soil		kg Zn-eq.		Sect. 12.2	Fantke et al. 2018
Ecotoxicity potential of heavy metal emissions to soil		kg Zn-eq.		Sect. 12.2	Fantke et al. 2018
Human toxicity potential of plant protection products		kg glyphosate-eq.		Sect. 12.3	Fantke et al. 2018
Ecotoxicity potential of plant protection products		kg glyphosate-eq.		Sect. 12.3	Fantke et al. 2018
2000-watt society primary energy resources		MJ oil-eq.	Yes	Sect. 13.2	–
Biodiversity damage potential through land use	BDP	m^2 settlement area-eq.	Yes	Sect. 13.3	Chaudhary et al. 2015; Chaudhary & Brooks 2018
Water shortage through water consumption	AWARE	m^3 water-eq.		Sect. 13.6	Boulay et al. 2017
Abiotic depletion potential, ultimate reserves (resources in the earth's crust)	ADP	kg Sb-eq.	Yes	Sect. 13.4	van Oers et al. 2019
Depleted stock fraction	DSF	kg PS-eq.		Sect. 13.7	Hélias et al. 2018
Radiotoxicity of radioactive waste	RTI	cm^3 HLW-eq.	Yes	Sect. 14.4	Nagra (2014)

The sources cited relate to the 2021 report

In the ecological scarcity method, a characterisation may be applied if the corresponding environmental impact played a key role when the target was set. Accordingly, the current CO_2 Act stipulates that all greenhouse gases must be taken into account. Therefore, it is both possible and appropriate to use global warming potential values.

Characterisation is not, however, appropriate in every theoretically conceivable case. It should not be used in cases where the environmental impact of the characterisation does not match the legislators' intention with regard to the way the reduction target (or the limit or target value) was set. For instance, the legislators adopted a uniform VOC levy. Characterising individual NMVOCs according to their photochemical oxidation potential (PCOP) is therefore inappropriate.

The eco-factor formula includes an explicit characterisation term (K). Tab. 5 and Fig. 8 list the characterisations used in this report and compare them to those of the report in 2013. Characterisations of heavy metal emissions to air, water and soil have been added to this list. A new characterisation approach has been applied for plant protection products in soil. Biodiversity losses due to land use are characterised using the most up-to-date and comprehensive approach.

8 Eco-factors grouped by environmental issues

In the interests of approximating the concept of midpoint indicators, the 2013 eco-factors were, for the first time, largely regrouped according to environmental impacts and issues so that they could be used in life cycle assessment tools.

The environmental issues and classification of resources and pollutants are shown in Tab. 6. For practical reasons, the list is a combination of impact-based groups (climate change, ozone layer depletion) and primarily issue-based groups (main air pollutants and particulate matter, heavy metals). Laws often govern individual pollutant emis-

Tab. 6: Classification of pollutants and resources by environmental impact and issue

English	German	Pollutants, resources
Water resources	Wasser-Ressourcen	Dissipative use of surface water, groundwater and fossil water from aquifers
Energy resources	Energie-Ressourcen	*Non-renewable: natural gas, crude oil, raw lignite, raw hard coal. Uranium* *Renewable: harvested quantities of wood, solar radiation, kinetic energy (wind energy) potential energy (water power), geothermal energy*
Mineral primary resources	mineralische Primärressourcen (MIneralien and Metalle)	Dissipative use of aluminium (in bauxite), cadmium, chromium, iron ore, indium, copper, dolomite, lime, gravel, phosphorus, etc.
Biotic resources	Biotische Ressourcen	Marine fish, caught in the wild
Land use	Landnutzung	Various types of land use
Climate change	Klimawandel	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, etc.
Ozone layer depletion	Ozonschichtabbau	CFCs, H-CFCs, halons, ether and ether compounds
Main pollutants and PM	Hauptschadstoffe und Partikel	SO_2, NO_X, NMVOC, NH_3, PM10, PM2.5
Carcinogenic substances into air	Krebserregende Stoffe in Luft	Benzene, dioxins, PAHs
Heavy metals into air	Schwermetalle in Luft	Lead, cadmium, mercury, zinc, copper, nickel, chrome
Water pollutants	Wasserschadstoffe	Nitrogen, nitrate, phosphorus, CODs, AOXs, chloroform, PAHs, endocrine disruptors
Heavy metals into water	Schwermetalle ins Wasser	Arsenic, lead, cadmium, chrome, copper, nickel, mercury, zinc, iron, manganese
POP into water	POP ins Wasser	Persistent organic pollutants
Pesticides into soil	Pestizide in den Boden	Plant protection products
Heavy metals into soil	Schwermetalle in den Boden	Lead, cadmium, copper, mercury, zinc, nickel, chrome
Radioactive substances into air	Radioaktive Substanzen in die Luft	Carbon-14, caesium 137, iodine-129, etc.
Radioactive substances into water	Radioaktive Substanzen ins Wasser	Carbon-14, caesium 137, iodine-129, etc.
Noise	Lärm	Noise emissions from trucks, cars, trains and airplanes
Waste, non radioactive	Abfälle, nicht radioaktiv	Hazardous wastes stored underground in landfills, landfills with wastes containing carbon Landscape change through landfills, macroplastics and microplastics
Radioactive waste to deposal sites	Radioaktive Abfälle in Endlager	Radioactive waste deposited in waste disposal sites

sions, but not their direct impact on the environment or humans. For instance, in the Swiss federal government's plan for clean air measures (Swiss Federal Council 2009), the clean air targets are described in the form of tolerable annual loads of the following airborne pollutants: NO_x, SO_2, NMVOCs, NH_3 and particulate matter.

A consistent and universally applied characterisation is not used, primarily for technical reasons. The environmental policy targets refer to individual substances in most cases. However, they are often aimed at reducing all or several of the potentially negative environmental impacts of the individual substance concerned. Classification and characterisation are therefore unnecessary. They would actually result in multiple assessments.

Part 3

Derivation of eco-factors for Switzerland

Part 3 presents the details of the calculations for all eco-factors. In this part, experts will find the scientific bases and environmental policies that are used in the UBP method to evaluate the impacts that are linked to emissions, resource uses and other material flows.

9 Emissions to air

9.1 Introduction

9.1.1 Selection of substances

Air pollutants are selected on the basis of their environmental relevance for the whole of Switzerland and the availability of statistical data. In addition, eco-factors are calculated for greenhouse gases and ozone-depleting, acidifying, carcinogenic and radioactive substances by means of characterisation.

A range of different measures has succeeded in reducing emissions to air in recent years, in some cases substantially. Some of the remaining emissions and their impacts in Switzerland are therefore of subordinate importance. However, the fact that eco-factors are applied not only to emissions from Swiss processes, but also to processes taking place abroad, must also be taken into account. An eco-factor is therefore retained for substances that may be unproblematic in Switzerland, but have the potential to continue to be environmentally relevant abroad.

Tab. 7 lists the air pollutants assessed with an eco-factor. It also has broad categories that specify the impacts of pollutants and which impacts are significant in the determination of the eco-factor.

9.2 CO_2 and other greenhouse gases

9.2.1 Environmental impact

Human-induced amplification of the greenhouse effect has very likely contributed to the 0.75 °C to 0.99 °C global warming in the last 100 years or so (IPCC 2019). Warming in Switzerland has been twice as high as the global mean (Swiss Federal Council 2016) and is set to continue. Modelling shows that the global mean temperature can be expected to rise by 0.3 °C to 4.8 °C between 1990 and 2100, depending on the development of greenhouse gas emissions, and the sea level can be expected to rise by 26 cm to 82 cm (IPCC 2013b). Furthermore, more precipitation and extreme events are expected, with regionally disparate patterns. It is well established that the global temperature has not changed at a comparable rate at any time in the past 10,000 years.

The Swiss Sustainable Development Strategy (Swiss Federal Council 2016) cites the reduction of CO_2 emissions as a priority goal of environmental policy. Several measures are in place or in preparation (buildings programme, emissions regulations for passenger vehicles, CO_2 levy, emissions trading system, compensation requirement for fuels, etc.) that contribute to reducing CO_2 emissions. Aviation fuels are also to be covered in the future within the framework of an international agreement.

The gases with the greatest global warming impact are CO_2, CH_4 (methane) and N2O (nitrous oxide). In addition, various chlorinated and fluorinated hydrocarbons (CFCs, HCFCs, HFCs, PFCs) and SF6 have a direct radiative forcing effect. While the global warming impact of the latter substances per kilogram can be several thousand times greater than that of CO_2, their contribution to the overall emissions inventory of Switzerland is between 2% and 3% (see Tab. 9).

9.2.2 Characterisation

Greenhouse gases comprise the substances that contribute to global climate change. To exert their effect as greenhouse gases, they must enter the atmosphere.

The updated publication by the IPCC (2013a) provides reference information for the global warming potentials (GWPs) of the various gases. The reference substance is carbon dioxide (CO_2). When the need arises, the potentials are adjusted to new scientific findings, and new substances are characterised. The values vary depending on the period of time over which the effects are summated. It is common practice to apply the GWP100 values (integrated over 100 years; see Tab. 8, and the full list in A2), which is why this is also applied to the characterisation used in the method described in this report.

The current Fifth IPCC Assessment Report (IPCC 2013b) rates the relative radiative forcing of individual gases somewhat differently than was the case in the Fourth Assessment Report from 2007 (IPCC 2007). The GWP values of the latter form the basis for the national greenhouse gas inventories. The changes in the GWPs are due above all to advances in the radiative forcing model.

Tab. 7: Impact mechanisms of the assessed air pollutants

	Environmental								Human						
	Global warming potential (GWP)	**Ozone depletion potential (ODP)**	**Ozone creation potential (POCP)**	**Eutrophication**	**Acidification**	**Damage to flora**	**Impairment of soil fertility**	**Damage to built structures**	**Respiratory diseases**	**Carcinogenicity**	**Mutagenesis**	**Embryonal damage**	**Other / further types of damage**	**Characterisation**	**Notes**
CO_2 and other greenhouse gases	#	x	x											GWP	
Ozone-depleting substances	x	#	x											ODP	
NMVOCs			#			x			x	x		x	x	-	
Nitrogen oxides (NOx)			*	*	*	x			x					-	Targets are designed to protect humans, animals and plants
Ammonia (NH_3)				*	*			x						-	Targets are designed to protect ecosystems. Alternative assessment via AP
SO_2 and other acidifying substances					#	x		x	x					AP	
Particulates									#	x			x	-	Derivation from the Swiss Air Pollution Control Ordinance
Carcinogenic pollutants (benzene, PAHs, dioxins/furans)			x							#	(x)	x	x	CTUh	Application of precautionary principle
Lead (Pb)						x	#						x	CTUh/ CTUe	Emissions to air are assessed using the weighting factor for soil, as the greatest scarcity prevails there
Cadmium (Cd)							#		x	x		(x)	x	CTUh/ CTUe	ditto
Zinc (Zn)						x	#						x	CTUh/ CTUe	ditto
Mercury (Hg)						x	x			#			x	CTUh/ CTUe	Evaluation via characterisation
Radioactive isotopes										#	x			C14	

x Impact or link proven
(x) Impact or link presumed
Impact significant in determining the eco-factor
* Several significant impacts

Tab. 8: Global warming potentials of the substances regulated under the Kyoto and Montreal Protocols

		GWP100	
		Used in this report (IPCC 2013a) (kg CO_2-eq./kg)	Used in the Kyoto Protocol (IPCC 2007) (kg CO_2-eq./kg)
Carbon dioxide	CO_2	1	1
Carbon dioxide and other climate-impacting compounds from aviation	CO_2 +	2,5 **	1
Methane	CH_4	30	25
Nitrous oxide	N_2O	265	298
Chlorofluorocarbons *	CFCs/HCFCs	5 820–13 900	5–14 400
Partially halogenated fluorocarbons	HFCs	<1–12 400	124–14 800
Perfluorinated hydrocarbons	PFCs	<1–11 100	7 390–12 200
Sulphur hexafluoride	SF_6	23 500	22 800
Nitrogen trifluoride	NF_3	16 100	17 200

* These substances are regulated under the Montreal Protocol (UNEP 2007).

** not according to GWP100, the other climate-impacting effects are expressed as multiples of the CO_2 impact according to Switzerland's long-term climate strategy

The radiative forcing of emissions from aviation is considered in accordance with Switzerland's long-term climate strategy (Swiss Federal Council 2021). According to that publication, a radiative forcing index (RFI) factor of 2,5 must be applied to the CO_2 emissions in order to properly take into account the radiative forcing of pollutant emissions from air traffic. The CO_2 emissions of kerosene, which is used as aircraft fuel, are therefore characterised with a GWP of 2.5 kg of CO_2-eq. per kg of CO_2.

Some greenhouse gases also damage the ozone layer, which is why their ozone depletion potential is also assessed, and the higher of the resulting eco-factors is used in each case. Other environmental impacts of greenhouse gases (such as the herbicidal effect of the decomposition products of fluorocarbons) are not taken into account here.

9.2.3 Normalisation

The normalisation flow is calculated using the current GWP values, as greenhouse gases are characterised with the current GWPs (IPCC 2013b). Greenhouse gas emissions averaged over the years 2016–18 were around 62 million t CO_2-eq./a (see Tab. 9).

9.2.4 Weighting

At 61.826 million t CO_2-eq. (Tab. 9), the current flow is identical to the normalisation flow.

There are both medium- and long-term targets for reducing greenhouse gases in Switzerland. In its Sustainable Development Strategy 2016–19 (Swiss Federal Council 2012, 2016), the Federal Council states that for industrial nations to reach the 2 °C target by 2030, it will be necessary to reduce greenhouse gases by 50% compared with their 1990 emission levels. Furthermore, on 28 August 2019 the Federal Council decided that Switzerland should reduce its greenhouse gas emissions to net zero by 2050. With this target, Switzerland aims to help achieve the internationally agreed goal of limiting global warming to 1.5 °C above pre-industrial levels.

For the eco-factor for greenhouse gases, a reduction target for 2040 has been determined in consultation with the FOEN. It corresponds to a 75% reduction from 2030 emission levels or an 87.5% reduction compared with emission levels in the reference year 1990. To meet the target of net zero by 2050, the remaining 25% of the emission reduction based on 2030 levels will need to be achieved between 2040 and 2050.

Reducing greenhouse gases by 87.5% under their 1990 levels will result in a critical flow of approximately 7.8 million t CO_2-eq. for the year 2040. This includes all sources, except those in the land-system change and forestry sector (e.g. the sink effect of forests).

Tab. 9: Greenhouse gas emissions in Switzerland

according to the FOEN (2012d, 2020c), weighted with the radiative forcing (GWP100) indicated by the IPCC (2013a)

	GWP100 (IPCC 2013b) (CO_2-eq.)	3-year average emissions 2016-2018 (1 000 t CO_2-eq.)	Percentage in overall greenhouse gas emissions
CO_2	1	38 176	61,7%
CO_2 and other climate-impacting compounds from aviation	2,5 *	13 385	21,7%
CO_2 ship transportation	1	22	0,04%
CH_4	30	5 856	9,5%
N_2O	265	2 663	4,3%
HFCs	<1–12 400	1 503	2,4%
PFCs	<1–11 100	29	0,05%
SF_6	23 500	191	0,3%
Total		**61 826**	**100%**

* not according to GWP100, the other climate-impacting effects are expressed as multiples of the CO_2 impact according to Switzerland's long-term climate strategy

In addition to the massive reduction of greenhouse gas emissions that is necessary, CO_2 must be removed from the atmosphere in the future and permanently stored ('negative emissions') so that the long-term climate goals can be achieved. A number of negative emission technologies (NETs) exist today, but they have either not yet been tested in practice or are not ready for use on a scale that would impact the climate. Research and development of NETs require additional resources and therefore result in additional emissions and burdens on the environment, which are not addressed here. The approach introduced and applied here therefore underestimates the eco-factor for greenhouse gases.

9.2.5 Eco-factors for greenhouse gases

The eco-factor for greenhouse gases is determined on the basis of the widely accepted '1.5 degree target', which corresponds to the reduction of greenhouse gas emissions in Switzerland by 87.5% under their 1990 levels by 2040.

The eco-factor has risen by more than 100% in comparison with 2013.

Tab. 10: Eco-factor for CO_2 and other greenhouse gases in UBP/g CO_2-equivalents

	Edition 2021	Q	Notes	Edition 2013
Normalisation (1000 t CO_2-eq./a)	61 826	A	Emissions under Kyoto Protocol according to greenhouse gas inventory, with GWP_{100} value as per IPCC (2013a)	53 040
Current flow (1000 t CO_2-eq./a)	61 826	A	Emissions under Kyoto Protocol according to greenhouse gas inventory, with GWP_{100} value as per IPCC (2013a)	53 040
Critical flow (1000 t CO_2-eq./a)	7 829		Interpolated targets from CO_2 Act 2030 and net zero 2050, reference year: 2040	10 766
Weighting (–)	62,4			24,3
Eco-factor (UBP/g CO_2-eq.)	**1,00**			0,46

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 11: Eco-factors for selected greenhouse gases, calculated from the eco-factor for CO_2

	Formula	GWP	Eco-factor 2021 (UBP/g)	Basis 2021	Eco-factor 2013 (UBP/g)	Basis 2013
Carbon dioxide	CO_2	1	**1.0**	GWP	0.46	GWP
*Carbon dioxide + ***	CO_2 +	2,5 ***	**2,5**	GWP ***	0.46	GWP
Methane	CH_4	28	**28**	GWP	12	GWP
Nitrous oxide	N_2O	265	**270**	GWP	140	GWP
HCFC-22	$CHClF_2$	1 760	**1 800**	GWP*	830	GWP*
HCFC-142b	CH_3CF_2Cl	1 980	**2 000**	GWP*	1 100	GWP*
HFC-125	CHF_2CF_3	3 170	**3 200**	GWP	1 600	GWP
HFC-134a	CH_2FCF_3	1 300	**1 300**	GWP	660	GWP
Sulphur hexafluoride	SF_6	22 800	**24 000**	GWP	10 000	GWP

The detailed list is in A2.
* The eco-factor can be derived on the basis of GWP and ODP; the higher of the two is used and listed here.
** Carbon dioxide and other climate-impacting compounds from aviation
*** not according to GWP100, the other climate-impacting effects are expressed as multiples of the CO_2 impact according to Switzerland's long-term climate strategy

9.2.6 Eco-factors of other greenhouse gases

The other greenhouse gases together contribute around 17% of Swiss greenhouse gas emissions (Tab. 9). Their eco-factors are determined through characterisation using global warming potential (GWP100 values according to IPCC 2013a; cf. Tab. 11 and the detailed list in A2).

In cases where substances contribute to both global warming and ozone depletion, both eco-factors are calculated and the higher of the two is used.

9.2.7 Eco-factors from global warming for carbon monoxide (CO)

The three-year average (2016–18) for carbon monoxide emissions is 159 091 t (BAFU 2020a). The IPCC (2001) mentions a range of 1 kg to 3 kg CO_2-eq./kg CO for the GWP100 of CO. In stoichiometric terms, 1,57 kg of CO_2 are formed from 1 kg of CO. This value is taken for the GWP100 of CO. An eco-factor of 1,60 UBP/g CO results.

9.3 Ozone-depleting substances

9.3.1 Environmental impact

Depletion of the stratospheric ozone layer is caused by volatile substances that contain chlorine and/or bromine atoms.

The ozone layer protects the biosphere from a part of the ultraviolet radiation of the sun. Depletion of the ozone therefore increases, among other things, the rate of humans and animals with skin cancer and eye diseases and the rate of mutation in all organisms. In addition, it accelerates ageing in plastic polymers.

The most important ozone-depleting substances are CFCs (chlorofluorocarbons), halons and carbon tetrachloride (CCl_4). HCFCs (partially halogenated CFCs), which initially served as substitutes for CFCs, have the same effect on the ozone layer but to a lesser extent. Use of the above substances is therefore widely prohibited today. Tab. 12 shows that the ozone depletion potential of HCFCs is substantially lower than that of CFCs as they are less stable, while the quantities of emissions are in the same order of magnitude.

At the same time, CFCs and HCFCs are both contributors to human-induced climate change (see Part 3, Section 9.2).

9.3.2 Characterisation

The intensity of the ozone-depleting effect is stated in terms of the Ozone Depletion Potential (ODP), a dimensionless quantity, whereby the ODP of CFC-11 (R-11) is set at 1.0. ODP values are internationally binding, as they are set out in the Montreal Protocol. Tab. 12 presents a selection of them, while A2 gives the entire list. This list is expanded to include new substances as required. The status of the year 2007 is used for characterisation (UNEP 2007).

Halogenated hydrocarbons that contain no chlorine or bromine atoms, but contain fluorine (HFCs), for instance, have no ozone-depleting effect. Most ozone-depleting substances also have a global warming potential. Following the principles of the ecological scarcity method, the higher of the resulting eco-factors is used (see Part 2, Section 4.11).

9.3.3 Normalisation

The ozone-depleting substances are characterised. As the environmental target is based on the characterised values, the normalisation flow is identical to the characterised current flow.

9.3.4 Weighting

The Montreal Protocol on Substances that Deplete the Ozone Layer bans the production and use of these substances. Bans on individual substances have been in effect in industrialised countries since 1994 and in developing countries since 2002 and have been continuously extended. Exemptions still apply to certain limited uses of CFCs, tetrachloromethane, halons and other substances.

Due to the formation of stocks in the past, current emissions of ozone-depleting substances are substantially greater than the quantities currently imported. Emissions can be classed in four source groups:

1. Diffuse emissions from foam insulation materials containing CFCs and HCFCs that are already in place in buildings and refrigeration systems.
2. Losses of CFCs and HCFCs as refrigerants in refrigeration and air conditioning systems and heat pumps.
3. Releases from the disposal of insulation material, equipment and systems that contain CFCs or HCFCs (e.g. refrigeration equipment, refrigerators).
4. Halon emissions resulting from the use of fire control equipment and systems.

Tab. 12: Ozone depletion potentials (ODPs) of a number of important substances

		ODP (kg R11-eq./kg)”
CFCs	CFC-11 (R11)	1
	CFC-12	1
	CFC-115	0,6
HCFCs	HCFC-22	0,055
	HCFC-124	0,022
	HCFC-141b	0,11
Halons	Bromomethane	0,6
	Halon 1211	3
	Halon 1301	10
Solvents	Tetrachloromethane	1,1
	1,1,1-trichlorethane	0,1

See also A2

* Due to space constraints, the abbreviated term R11-eq is still used for the unit, although the designation R11 is obsolete

The emissions of ozone-depleting substances were determined by FOEN[7] experts on the basis of the stocks and annual depletion rates, exemptions, expert estimations, available registers and import statistics (see Tab. 13). This results in a current flow of 95.0 t R11-eq.

The Swiss Chemical Risk Reduction Ordinance (ORRChem 2013) prohibits the production, importation and use of ozone-depleting substances. Exemptions regarding importation and use are currently only in place for halons in specific areas of military, nuclear energy and aviation use and for special technical applications.

The provisions of the Chemical Risk Reduction Ordinance have led to a sharp reduction in emissions of ozone-depleting substances. However, the stocks formed mainly in building insulations materials (primarily CFC-11) will

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[7] Written communications, Norbert Egli, FOEN, March/April 2020

release considerable amounts in the coming decades. Emissions will therefore only drop slowly.

The Chemical Risk Reduction Ordinance thus regulates the use of ozone-depleting substances, but not their emission. No critical flow can therefore be derived directly from the wide-ranging ban on the consumption of ozone-depleting substances.

Tab. 13: Swiss emissions of ozone-depleting substances that are relevant to Switzerland in t/a and as R11-eq./a in 2017 and 2040

		ODP		Emissions 2017		Emissions 2040		
		(kg R11-eq./kg)	Use	(t/a)	(t R11-eq./a)	(t/a)	(t R11-eq./a)	Notes/Source
CFCs								
CFC-11 (R11)	CCl_3F	1	Foam	56	56	55	55	Assumption: Volume of emissions from foams remains approximately the same as today
CHF-12	CCl_2F_2	1	Refrigerant	13	13	0	0	Assumption: Emissions from refrigerants decline to 0
HCFCs								
HCFC-22	$CHClF_2$	0,055	Refrigerant, foam	70	3,85	54	2,97	Assumption: Volume of emissions from foams remains approximately the same as today
HCFC-141b	$C_2H_3Cl_2F$	0,11	Solvent, foam	16	1,76	14	1,54	Assumption: Volume of emissions from foams remains approximately the same as today
HCFC-142b	$C_2H_3Cl_2F$	0,065	Foam	31	2,02	26	1,69	Assumption: Volume of emissions from foams remains approximately the same as today
Halons								
Bromomethane	CH_3Br	0,6	Research, analysis, chemical synthesis	3,4	2,0	0	0	Assumption: Continuous decline in laboratory and analytical applications and as a precursor for chemical synthesis
Halon 1211	$CBrClF_2$	3	Extinguishing agent	3,9	11,8	0	0	Assumption: Emissions from fire-extinguishing agents decline to 0
Halon 1301	$CBrF_3$	10	Extinguishing agent	0,38	3,8	0	0	Assumption: Emissions from fire-extinguishing agents decline to 0
Solvents								
Tetrachloromethane	CCl_4	1,1	Research, analysis	0,09	0,099	0,09	0,099	Assumption: 40–90 kg p.a., used exclusively in laboratory and analysis work, not all 'emitting' consumption, 90 kg p.a. also a conservative assumption.
Trichlorethane	$C_2H_3Cl_3$	0,1	Solvent, chemical synthesis	6,8	0,68	0	0	Assumption: Continuous decline in applications as a solvent (emitting) and as a precursor for chemical synthesis
Total Air emissions					**95.0**		**61.3**	

Source: written communication, Norbert Egli, FOEN, 30 April 2020

The tolerated emissions are taken as a basis for determining the critical flow. As these decline gradually, the choice of reference year is decisive. The following estimation is performed for the emissions of ozone-depleting substances that are to be anticipated in 2040 (see Tab. 13). Accordingly, the emissions to be anticipated in 2040, i.e. the critical flow, amount to 61.3 t R11-eq. .

9.3.5 Eco-factor for ozone-depleting substances

The new eco-factor is higher than the one for 2013. Since the critical flow is significantly lower, the weighting factor has increased, although the current flow has also decreased considerably. The normalisation flow is only half as high as in 2013.

9.3.6 Eco-factor for other ozone-depleting substances

The eco-factor for other ozone-depleting substances can be derived from the characterisation values for the ozone depletion potential (ODP) and the eco-factor for R11-equivalents derived in Section 9.3.4.

Many ozone-depleting substances also contribute to global warming. For these, both the eco-factor resulting from global warming and the eco-factor resulting from their ozone-depleting effect were calculated. A2 lists all substances and their respective dominant impacts.

No separate eco-factors are calculated for refrigerant blends. The values for blends can be calculated from the eco-factors of the individual components, weighted according to their respective share in mass.

9.3.7 Implementation in the UVEK LCI Data DQRv2:2022

The substance 'halogenated solvents, chlorinated' is assessed with the eco-factor of HCFC-22.

Tab. 14: Eco-factor for R11-uivalents in UBP/g R11-eq

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t R11-eq./a)	95,0	B		191
Current flow (t R11-eq./a)	95,0	B	Estimate by FOEN experts	191
Critical flow (t R 11-eq./a)	61,3	b	Estimate by FOEN experts	150
Weighting (–)	2,4			1,63
Eco-factor (UBP/g R11-eq.)	**25 000**			8 500

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 15: Eco-factors for ozone-depleting substances, stated in UBP/g of substance

	Formula	ODP (kg R11-eq./kg)	Eco-factor 2021 (UBP/g)	Basis 2021	Eco-factor 2013 (UBP/g)	Basis 2013
CFC-11	CCl_3F	1	**25 000**	ODP*	8500	ODP*
CFC-12	CCl_2F_2	1	**25 000**	ODP*	8500	ODP*
CFC-111	C_2Cl_5F	1	**25 000**	ODP	8500	ODP
HCFC-123	$CHCl_2CF_3$	0,02	**500**	ODP*	170	ODP*
HCFC-142b	CH_3CF_2Cl	0,065	**2 000**	GWP*	1100	GWP*
HCFC-225ca	$CF_3CF_2CHCl_2$	0,025	**630**	ODP*	210	ODP*
Halon 1211	$CBrClF_2$	3	**75 000**	ODP*	26 000	ODP*
Halon 1301	$CBrF_3$	10	**250 000**	ODP*	85 000	ODP*
Methane, bromo-	CH_3Br	0,6	**15 000**	ODP*	5100	ODP*

* Data available for GWP and ODP, the higher value is used

9.4 Non-methane volatile organic compounds (NMVOCs)

9.4.1 Environmental impact

Volatile organic compounds (VOCs) are a group comprising a range of non-toxic to highly toxic and carcinogenic compounds. The Swiss VOC Ordinance (OVOC 2013) defines VOCs as "organic compounds with a vapour pressure of at least 0.1 mbar at 20 °C or a boiling point of maximum 240 °C at 1013.25 mbar". NMVOCs (non-methane volatile organic compounds) are VOCs excluding the gas methane.

Along with nitrogen oxides, NMVOCs are important precursors for photochemical oxidants (giving rise to tropospheric ozone or 'summer smog'), which can harm human health and flora. In addition, many VOCs lead to further undesirable impacts on humans and flora and fauna. These further effects are not, however, taken into account in the eco-factor calculation, which is why individual VOCs (benzene and dioxins) are assessed with separate eco-factors.

9.4.2 Characterisation

Photochemical ozone creation potential (POCP) is a measure of the contribution of a molecule to ozone formation and could provide a starting point for characterisation. As the Swiss VOC Ordinance (OVOC 2013) intentionally makes no distinction between different NMVOC substances, characterisation is inappropriate.

9.4.3 Normalisation

The current flow relates to the whole of Switzerland. For that reason, normalisation is identical to the current flow.

9.4.4 Weighting

Annual NMVOC emissions in Switzerland rose from 70,000 to 324,000 tonnes during the period from 1950 to 1985. Emissions have been declining since 1985. In 1995, they amounted to 200,000 tonnes (BAFU 2012c, Table 2–1). The introduction of the VOC tax in 2000, in combination with increasingly stringent regulations for vehicles, has contributed to further reducing current emissions to 80,000 t/a (BAFU 2020a; BUWAL 2003).

The Swiss Federal Air Pollution Control Ordinance sets ambient limit values for ozone (O_3). These are often still exceeded in the summer months, although NMVOC emissions are now slightly below the target set in the air pollution control strategy. In general, the peak ozone values in the Southern Alps are higher than in the Northern Alps (BAFU 2012b).

In order to comply with the ambient limit values, and specifically to reduce the maximum 1-hour mean value for O_3 to the range of limit values, the Swiss Federal Council (2009, Table 2) states that NMVOC emissions need to be reduced by 20% to 30% from their 2005 levels. This matches the previous critical flow of 81 000 t/a for NMVOCs.

9.4.5 Eco-factor for NMVOCs

The eco-factor has dropped since 2013, as NMVOC emissions in Switzerland and hence the current flow and normalisation flow have been further reduced thanks to the measures taken. It can be assumed that emissions will continue to drop in the future.

Tab. 16: Eco-factor for volatile organic compounds (excluding methane, CFCs) in UBP/g NMVOC

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t NMVOC/a)	79 727	A		89 025
Current flow (t NMVOC/a)	79 727	A	(BAFU 2020a)	89 025
Critical flow (t NMVOC/a)	81 000	a	(Swiss Federal Council 2009)	81 000
Weighting (–)	0,97			1,21
Eco-factor (UBP/g NMVOC)	**12**			**14**

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 17: Ratio of current to critical flow for NMVOCs in selected European countries and EU28 (Ahbe et al. 2018; Muhl et al. 2019)

	Current flow	Critical flow	Ratio	Weighting
Germany	1 006	826	1,22	1,48
France	1 232	702	1,75	3,08
Italy	1 286	836	1,54	2,37
Spain	809	631	1,28	1,64
United Kingdom	1 088	740	1,47	2,16
EU28, according to Ahbe et al. 2018	7 500	6 366	1,18	1,39
EU28, according to Muhl et al. 2019	6 723	5 534	1,21	1,48

9.4.6 Situation in selected European countries

The ratio of current to critical flow in selected European countries and in the EU as a whole is between 1.2 and 1.75 (Ahbe et al. 2018; Muhl et al. 2019). The weighting factors of these countries therefore tend to be higher than the Swiss one.

9.5 Nitrogen oxides (NOx)

9.5.1 Environmental impact

Nitrogen oxide loads cause many forms of pressure and damage. Sensitive ecosystems are seriously threatened by the acidifying effect. Moreover, nitrophilous plants are promoted, which can lead to a reduction of plant diversity and the loss of ecologically valuable terrestrial and aquatic ecosystems (e.g. oligotrophic grassland and open submerged swards).

Nitrogen dioxide (NO_2) and the secondary particles formed from nitrogen oxides are particularly harmful to human health. Respiratory tract diseases and cardiac dysrhythmia are direct effects. This reduces life expectancy over the longer term. NO attaches to haemoglobin and thus reduces oxygen transport capacity in blood. Moreover, nitrogen oxides are major precursors in the formation of ground-level ozone, which in turn impairs health.

NO_x appears to at least promote damage to built structures caused by biological processes (dissolution of carbonate materials by nitrifying microflora) (BUWAL 1996, 2005).

9.5.2 Normalisation

The air pollution control strategy aims to reduce the quantity of NO_x emitted (stated as NO_2), and no characterisation is performed. For that reason, the normalisation flow is identical to the current flow.

9.5.3 Weighting

Annual NO_x emissions in Switzerland (measured as NO_2) rose from 31 300 t to 179 000 t in the period from 1950 to 1985. Emissions have been declining since 1985. Thanks to the measures taken, NO_x emissions have dropped substantially. The current flow (calculated as a three-year average for the years 2016–18) is 70 733 t/a (BAFU 2020a).

The Swiss Air Pollution Control Ordinance (OAPC 2010) stipulates ambient limit values for nitrogen dioxide (NO2) and ozone (O_3). These were set so that when they are complied with, no danger arises to humans, animals, plants, their biotic communities or their habitats. At present, the limit values for nitrogen dioxide are exceeded everywhere in urban centres, and in some cases substantially, while in rural areas they are generally complied with. In contrast, the ambient limit values for ozone are frequently exceeded above all in rural areas and conurbations (Swiss Federal Council 2009, Table 1).

Substantial emissions reductions are therefore essential in order to comply with the ambient limit values. The Swiss Federal Council (2009) seeks to reduce NO_x emissions by around 50% from their 2005 levels (93,036 t, BAFU 2020a) in order to comply with the ambient limit value for O_3 and the limits for acid deposition. This reduction also has the effect of reducing the contribution to over-fertilisation to an acceptable level over the longer term (BUWAL 1996). The reduction results in a critical flow of 46,518 t/a of NO_x.

9.5.4 Eco-factor for NO_x

The decline in the current flow and the increase in the critical flow (due to an update of the underlying data on emissions in the reference year 2005) mean that the eco-factor is 15% lower than in the 2013 edition. A further reduction in emissions is expected due to changes in the vehicle fleet and generally stricter exhaust regulations.

NO_x emissions into the upper troposphere/lower stratosphere have an eco-factor of zero, as these emissions are not included in the UNECE inventory, and the negative impacts of nitrogen oxides on ecosystems and human health occur at ground level. In addition, the climate effects of nitrogen oxides emitted in the upper troposphere/lower stratosphere are taken into account in the increased global warming potential of CO_2 from kerosene (see Section 9.2.2).

9.5.5 Situation in selected European countries

The ratio of current to critical flow in selected European countries and in the EU as a whole is between 1.7 and 2.2 (Ahbe et al. 2018; Muhl et al. 2019). With the exception of Italy and France (and the EU28 according to Ahbe et al. 2018), the weighting factors are higher, and in some cases substantially so.

9.6 Ammonia (NH_3)

9.6.1 Sources and environmental impact

Agriculture is the main source of ammonia emissions, accounting for 92%. Ammonia forms as a result of livestock management (animal housing, farmyard manure storage and field application) and is emitted when mineral nitrogen fertilisers are applied. Overall, livestock rearing specifically accounts for 62% (BAFU 2012c).

Ammonia also contributes to acidification and over-fertilisation of aquatic and terrestrial ecosystems, which causes longer-term direct and indirect changes to ecosystems. Because of the complexity of the processes, the effects

Tab. 18: Eco-factor for nitrogen oxide in UBP/g NO_X as NO_2

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t NO_x as NO_2/a)	70 733	A		78 704
Current flow (t NO_x as NO_2/a)	70 733	A	(BAFU 2020a)	78 704
Critical flow (t NO_x as NO_2/a)	46 518	a	(Swiss Federal Council 2009)	45 000
Weighting (–)	2,31			3,06
Eco-factor (UBP/g NO_x as NO_2)	**33**			39

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 19: Ratio of current to critical flow for nitrogen oxide in selected European countries and the EU28 (Ahbe et al. 2018; Muhl et al. 2019)

	Current flow 1 000 t	Critical flow 1 000 t	Ratio –	Weighting –
Germany	1 288	652	1,98	3,90
France	1 430	715	2,00	4,00
Italy	1 212	727	1,67	2,78
Spain	1 292	762	1,69	2,87
United Kingdom	1 580	711	2,22	4,94
EU28, according to Ahbe et al. 2018	9 000	6 585	1,37	1,87
EU28, according to Muhl et al. 2019	7 820	4 389	1,78	3,17

of elevated nitrogen loads are difficult to predict. They include increased sprout growth and greater susceptibility to parasites, and the promotion of nitrophilous plants, which displace endemic plant species. Ecosystems recover very slowly from over-fertilisation, and when they do, this can be expected only over a very lengthy period (BUWAL 1996, 2005).

Ammonia also contributes to the formation of secondary particles, which cause human health impacts. Moreover, ammonia in air promotes the formation of sulphuric acid (H2SO4) from sulphur dioxide (SO_2) (BUWAL 1996, 2005).

9.6.2 Normalisation

The reduction target relates to both the over-fertilising impact and the acidifying impact of ammonia. No characterisation is performed. For that reason, the normalisation flow is identical to the current flow.

9.6.3 Weighting

Ammonia emissions rose gradually from the early 20th century onwards and peaked in 1980. Since then, emissions have dropped. The three-year average (2016–18) is 45,378 t NH_3-N/a (corresponding to 55,173 t NH_3/a, BAFU 2020a).

The Swiss Federal Council (2009, Table 2) seeks to reduce ammonia emissions by 40% under 2005 levels in order to comply with the load limit for nitrogen. The reduction corresponds to a critical flow of 28,997 t NH_3-N (i.e. 35,256 t NH_3).

9.6.4 Eco-factor for NH_3

The eco-factor is 34% lower than in 2013. This is due to a lower current flow and a higher critical flow. The higher critical flow compared with 2013 is due to an (upward) adjustment of the emission volume in the reference year 2005.

Another way to derive an eco-factor for ammonia is characterisation using the acidification potential, which results in an eco-factor of 16 UBP/g NH_3 (see Part 3, Section 9.7.6). The eco-factor derived from the direct reduction target is higher and therefore applied.

Major reduction potential is possible in agriculture, among other areas, through low-emission animal housing and slurry storage, as well as optimised slurry application to fields. If these and other technical options are exploited, it is possible to reduce emissions by 30–40% (BUWAL 2004a).

9.6.5 Situation in selected European countries

The ratio of current to critical flow in selected European countries and in the EU as a whole is between just under 1.0 and 1.75 (Ahbe et al. 2018; Muhl et al. 2019). The weighting factors of the European countries are all lower than the Swiss one, and in some cases substantially lower.

Tab. 20: Eco-factor for ammonia in UBP/g NH_3-N and in UBP/g NH_3

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t NH_3-N/a)	45 378	A		51 463
Current flow (t NH_3-N/a)	45 378	A	(BAFU 2020a)	51 463
Critical flow (t NH_3-N/a)	28 997	a	(BAFU & BLW 2008)	25 000
Weighting (-)	2,45			4,24
Eco-factor (UBP/g NH_3-N)	**54**			82
Eco-factor (UBP/g NH_3)	44			67

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 21: Ratio of current to critical flow for ammonia in selected European countries and the EU28 (Ahbe et al. 2018; Muhl et al. 2019)

	Current flow 1 000 t	Critical flow 1 000 t	Ratio –	Weighting –
Germany	563	426	1,32	1,75
France	661	635	1,04	1,08
Italy	416	395	1,05	1,11
Spain	365	354	1,03	1,06
United Kingdom	307	282	1,09	1,18
EU28, according to Ahbe et al. 2018	3 500	3 584	0,98	0,95
EU28, according to Muhl et al. 2019	3 918	3 287	1,19	1,42

9.7 Sulphur dioxide (SO_2) and other acidifying substances

9.7.1 Environmental impact

Sulphur dioxide (SO_2) leads to respiratory tract diseases. Through its acidifying effect, it also damages plants, sensitive ecosystems and built structures. Moreover, SO_2 is an important precursor of acid precipitation and aerosols (BUWAL 1995, Tab. 2.1).

9.7.2 Characterisation

Sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) are the most important acidifying air pollutants. The acidification potential (AP) is stated in SO_2-equivalents using sulphur dioxide as a reference substance. The 'generic APs' given by Guinée et al. (2001b, as per April 2004) were adopted as characterisation factors.

Tab. 22: Characterisation factors for acidification potential according to Guinée et al. (2001b, as per 2004, 'generic AP') in relation to SO_2

		Acidification potential (SO_2-eq.)
Ammonia	NH_3	1,88
Hydrogen fluoride	HF	1,6
Phosphoric acid	H_3O_4P	0,98
Nitric acid	HNO_3	0,51
Hydrochloric acid	HCl	0,88
Sulphur dioxide	SO_2	1,0
Sulphuric acid	H_2SO_4	0,65
Hydrogen sulphide	H_2S	1,88
Nitrogen oxides	NO_x (as NO_2)	0,7

9.7.3 Normalisation

The target for sulphur dioxide is based on its acidifying effect. The other acidifying substances (cf. Tab. 24 in Part 3, Section 9.7.6) would also need to be taken into account for the normalisation flow. Separate targets have been established for NO_x and NH_3, which is why these two substances are not included in the normalisation. Due to a lack of data, however, the other acidifying substances could not be taken into account for the calculation of the normalisation flow. It can be assumed that sulphur dioxide makes by far the largest contribution and that the stated normalisation flow of around 5,200 t SO_2-eq./a only slightly underestimates the real situation (see Tab. 23).

9.7.4 Weighting

Annual SO_2 emissions in Switzerland rose from 46 200 to 116 000 tonnes in the period from 1950 to 1980. They have been falling sharply since 1980. The three-year average (2016–18) is now 5 208 t/a (BAFU 2020a).

The Swiss Federal Council (2009) seeks to use pre-emptive measures to prevent a resurgence of SO_2 emissions from their 2005 levels and to comply with the ambient limit values for SO_2 set out in the Swiss Air Pollution Control Ordinance (OAPC 2010) as well as the limits for acid deposition. This corresponds to the previous critical flow of 25,000 t/a.

The protection of ecosystems against acidification is also regulated by the United Nations Economic Commission for Europe (UNECE). The Swiss parliament ratified the second sulphur protocol in 1997. In Article 2, it establishes the long-term target that sulphur loads are to remain below the critical loads for ecosystems (UNECE 1994, UNECE 1999).

Tab. 23: Eco-factor for sulphur dioxide in UBP/g SO_2-eq

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t SO_2-eq./a)	5208	A	See text	12 861
Current flow (t SO_2/a)	5208	A	(BAFU 2020a)	12 861
Critical flow (t SO_2/a)	25 000	a	(Swiss Federal Council 2009)	25 000
Weighting (-)	0,043			0,265
Eco-factor (UBP/g SO_2-eq.)	**8,3**			21

Q = data quality; for explanation, see Part 2, Chapter 6

9.7.5 Eco-factor for SO_2

The eco-factor for SO_2 is 60% lower than in 2013. This is due to significantly lower normalisation and current flows.

9.7.6 Eco-factors for other acids

Other substances in addition to sulphur dioxide are responsible for the acidification of ecosystems. An eco-factor can be derived for other substances by using the acidification potential, which characterises the relative acidification attributable to a substance in relation to SO_2 (see Part 3, Section 9.7.2).

The eco-factors only assess the acidifying effect, as they are linked to SO_2 through characterisation. Other effects of individual acids are not taken into account. Nitrogen oxides and ammonia are weighted more heavily due to their specific reduction targets (cf. Part 3, Sections 9.5 & 9.6), which is why their eco-factor applies in this case.

9.7.7 Situation in selected European countries

The ratio of current to critical flow in selected European countries and in the EU as a whole is between just under 1.4 and 3.0 (Ahbe et al. 2018; Muhl et al. 2019). Ranging from 2.0 to over 9, the weighting factors of the European countries are significantly higher than the Swiss one.

Tab. 24: Eco-factors for substances with acidifying potential in UBP/g acid, characterised in reference to sulphur dioxide

		Acidification potential (kg SO_2-eq./kg)	Eco-factor 2021 (UBP/g)	Notes	Eco-factor 2013 (UBP/g)
Ammonia	NH_3	1.88		Eco-factor from direct derivation is higher (cf. Section 9.6)	
Hydrogen fluoride	HF	1,6	**13**		34
Phosphoric acid	H_3O_4P	0,98	**8,1**		21
Nitric acid	HNO_3	0,51	**4,2**		11
Hydrochloric acid	HCl	0,88	**7,3**		18
Sulphuric acid	H_2SO_4	0,65	**5,4**		14
Hydrogen sulphide	H_2S	1,88	**16**		39
Nitrogen oxides	NO_x	0,7		Eco-factor from direct derivation is higher (cf. Section 9.5)	

For weighting and normalisation see Tab. 23

Tab. 25: Ratio of current to critical flow for SO_2 in selected European countries and the EU28 (Ahbe et al. 2018; Muhl et al. 2019)

	Current flow 1 000 t	Critical flow 1 000 t	Ratio –	Weighting –
Germany	445	324	1,37	1,89
France	467	210	2,22	4,94
Italy	403	262	1,54	2,37
Spain	1 282	423	3,03	9,18
United Kingdom	706	290	2,44	5,95
EU28, according to Ahbe et al. 2018	5 000	3 209	1,56	2,43
EU28, according to Muhl et al. 2019	3 083	1 622	1,90	3,61

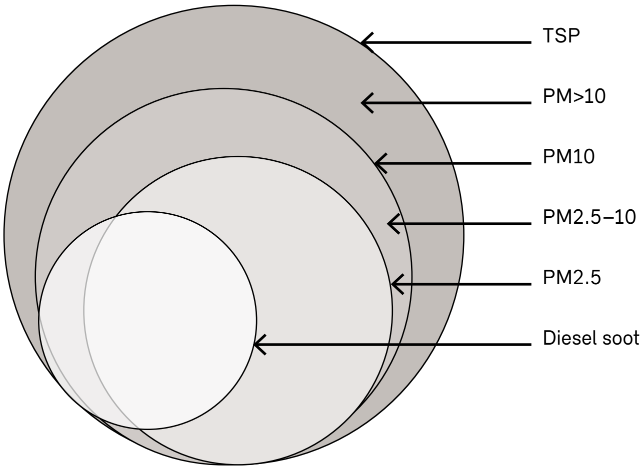
9.8 Particulate matter: PM10, PM2.5, PM2.5–10 and diesel soot

9.8.1 Environmental impact

Particulate matter (PM) is a mixture that is complex in both physical and chemical terms. It comprises, among other things, soot, geological material, heavy metals, abrasion particles, biological material (e.g. spores) and particles formed in secondary processes in the air (sulphate, nitrate, ammonium, organic carbon) (BAFU 2011c).

The harmfulness of particles depends on their size and composition. Their size is taken into account by determining eco-factors for PM2.5 and PM2.5–10 in addition to the eco-factor for PM10. However, legislators have not yet introduced this differentiation. Unlike in 2013, a separate assessment of diesel soot has not been carried out due to new insights into its carcinogenicity and toxicity.

Fig. 9: Schematic representation of particle sizes and their relationships



TSP: Total suspended Particles

Epidemiological studies have shown that particles with a diameter of less than 10 micrometres (**PM10**) correlate closely with the observed human health impacts of air pollution. PM10 comprises those particles that can move beyond the larynx and enter the lungs. PM10 is a mixture of primary emissions (particles from combustion processes, resuspended road dust and particles from the abrasion of pavings and tyres) and aerosols formed in secondary processes (BAFU 2011c). For instance, National Research Programme 26 (Man, Health and Environment) showed that if long-term exposure increases by 10 micrograms of PM10 per m^3, the risk of various diseases of the respiratory tract rises by 30% to 60%.

The 'coarse' fraction of suspended particulate matter (**PM2.5–10**) is associated more closely with coughing, asthma attacks and other diseases of the respiratory tract. These larger aerosols can be coughed out of the lung. The fine fractions (**PM2.5**) correlate more with cardiac dysrhythmia and an increased incidence of cardiovascular diseases. These fine particles remain much longer in the lungs and accumulate there, as they are difficult to cough up. Ultrafine particles (PM0.1) can enter the bloodstream and lymphatic system through the lungs. Over time, they are decomposed by the immune system and excreted (BAFU 2011c).

Building upon these more recent findings, more detailed eco-factors are derived below for particles of different sizes and properties. The fact that the 'total particulate' emissions previously listed in some inventory analyses cannot be converted directly into the new categories is tolerated.

Tab. 26: Eco-factor for PM10 in UBP/g PM10

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t PM10/a)	14 994	A		20 470
Current flow (t PM10/a)	14 994	A	PM10 emissions including diesel soot (BAFU 2020a)	20 500
Critical flow (t PM10/a)	9 639	a	(Swiss Federal Council 2009)	12 000
Weighting (-)	2,42			2,91
Eco-factor (UBP/g PM10)	**160**			140

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 27: Eco-factor for PM2.5 in UBP/g PM2.5

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t PM2.5/a)	14 994	A	Applying target for PM10	20 470
Current flow (t PM2.5/a)	7 089	A	PM2.5 emissions including diesel soot (BAFU 2020a)	9 741
Critical flow (t PM2.5/a)	4 558	a		5 710
Weighting (-)	2,42			2,91
Eco-factor (UBP/g PM2.5)	**160**			140

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 28: Eco-factor for PM2.5–10 in UBP/g PM2.5–10

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t PM2.5–10/a)	14 994	A	Applying target for PM10	20 470
Current flow (t PM2.5–10/a)	7 904	A	Difference between PM2.5 and PM10, emissions including iesel soot	10 729
Critical flow (t PM2.5–10/a)	5 082	a		6 290
Weighting (-)	2,42			2,91
Eco-factor (UBP/g PM2.5–10)	**160**			140

Q = data quality; for explanation, see Part 2, Chapter 6

Currently, there is only a reduction target for PM10. Although it is to be assumed that the health impacts of PM2.5 are more severe than those of PM10, no corresponding differentiation has yet been performed at the political or statutory level.

9.8.2 Normalisation

Due to a lack of robust data, no characterisation is performed. PM2.5–10 and PM2.5 are subgroups with the same environmental policy target. Therefore, the normalisation flow for the entire PM10 group and for the PM2.5–10 and PM2.5 subgroups is identical to the current flow of PM10.

9.8.3 Weighting

The current flow of 14,994 t/a for **PM10** is based on the three-year average (2016–18, BAFU 2020a). **PM10** emissions from abrasion and resuspension are difficult to quantify. As the update is partially based on estimated values, a degree of uncertainty remains in this regard. For **PM2.5**, the current flow, i.e. the three-year average (2016–18, BAFU 2020a), is 7,089 t/a. The current flow for **PM2.5–10** results from the difference of the annual loads for PM2.5 and PM10 and is 7,904 t.[8]

The Swiss Air Pollution Control Ordinance (OAPC 2010) has stipulated ambient limit values for **PM10** (annual mean 20 µg/m^3; 24-h mean 50 µg/m^3) since 1 March 1998. These were adopted at the recommendation of the Swiss Federal Commission for Air Hygiene based on the health impacts

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[8] The total for PM2.5 and PM2.5–10 emissions is slightly less than the PM10 emissions. This is a rounding difference.

of fine particulate exposure (BUWAL 1996b). According to the Swiss Federal Council (2009), the emission target is to reduce **PM10** emissions by 45% under the 2005 levels, which corresponds to the previous critical flow of 9,639 t/a.

There is no individual emission target for **PM2.5** in Switzerland. As it is a subgroup of PM10, the same relative reduction target (45%) is therefore applied, making the critical flow 4,558 t/a.

The relative reduction target for PM10 (45%) is also taken for the **PM2.5–10** fraction, i.e. the critical flow is 5,082 t/a.

9.8.4 Eco-factors for PM10, PM2.5 and PM2.5–10

For all subgroups (PM10, PM2.5 and PM2.5–10), the resulting eco-factor is 160 UBP/g. Although PM10 emissions have declined compared with the situation in 2013, the eco-factors are now somewhat higher. This is because the PM10 emissions from (reference year) 2005 have been amended, resulting in a lower emissions target and thus a lower critical flow than 2013. The eco-factors for PM2.5 and PM2.5–10 are identical to that for PM10, as the same (relative) reduction target is applied in each case. The eco-factor for particulate emissions described here also applies to the 'diesel soot' subgroup, which is no longer assessed separately.

Particulate emissions into the upper troposphere/lower stratosphere have an eco-factor of zero, as these emissions are not included in the UNECE inventory, and the negative impacts of particulate matter on human health occur at ground level. In addition, the climate effects of particulate matter emitted in the upper troposphere/lower stratosphere are taken into account in the increased global warming potential of CO_2 from kerosene (see Section 9.2.2).

9.8.5 Situation in selected European countries

The ratio of current to critical flow in selected European countries and in the EU as a whole is between just under 1.1 and 1.6 (Ahbe et al. 2018; Muhl et al. 2019). The weighting factors of the European countries are mostly lower than the Swiss one.

9.9 Carbon monoxide (CO)

Carbon monoxide is an air pollutant that is formed in incomplete combustion processes. CO emissions can also arise naturally from the chemical transformation processes of microorganisms (e.g. oxidation of methane). Motor vehicle traffic generates more than 60% of anthropogenic CO emissions (BAFU 2012c).

CO is a colourless, odourless and tasteless gas. It is toxic when inhaled; low concentrations in the inhaled air already significantly reduce the oxygen transport capacity in the human body (BUWAL 1995).

In Switzerland, there are statutory provisions governing maximum permissible concentrations, but not for loads. Therefore, the carbon monoxide eco-factor is derived on the basis of its global warming potential (Part 3, Section 9.2.7)

Tab. 29: Ratio of current to critical flow for PM2.5 in selected European countries and the EU28 (Ahbe et al. 2018; Muhl et al. 2019

	Current flow 1000 t	Critical flow 1000 t	Ratio	Weighting
Germany	111	79	1,41	1,97
France	304	222	1,37	1,88
Italy	166	149	1,11	1,23
Spain	93	79	1,18	1,38
United Kingdom	81	57	1,43	2,04
EU28, according to Ahbe et al. 2018	1 350	1 173	1,15	1,32
EU28, according to Muhl et al. 2019	1 214	767	1,58	2,51

9.10 Carcinogenic pollutants: benzene, dioxins & furans (PCDD/PCDF) and polycyclic aromatic hydrocarbons (PAH)

9.10.1 Sources and environmental impact

Benzene, dioxins and furans, and polycyclic aromatic hydrocarbons (PAH) are carcinogenic substances and characterised in similar ways. That is why these substances are discussed in the same section.

Benzene is present in small quantities in crude oil and is formed when mineral oil is refined or organic matter is burnt incompletely. Benzene emissions to the atmosphere result primarily from combustion processes. In Switzerland, motorised transport is responsible for just over half of all benzene emissions. The remainder are mostly due to emissions from industry and wood- and oil-fired heating systems (Heldstab et al. 2013). Inhalation is the main exposure route for benzene. Benzene is soluble in fat and therefore stored in the fatty tissue of the body. As women have a higher body fat ratio than men, the impacts of benzene are greater for women. Individuals living or working near busy roads or near petrol stations are also more exposed. Uptake through the skin is only relevant when benzene is handled directly (BUWAL 2003b). Benzene is toxic to blood formation, and chronic exposure can lead to leukaemia. There is unequivocal evidence that benzene is carcinogenic and strong indications that it is mutagenic. There is no threshold below which exposure to benzene is not a hazard to human health (BUWAL 2003b).

Dioxins and furans (PCDD and PCDF) are chlorinated aromatic hydrocarbons, and some of them are highly toxic to humans and animals. There are a total of 76 dioxins and 135 furans. They are formed in technological and natural combustion processes in the presence of chlorine. These processes always generate a mixture of various individual substances, expressed as a 'dioxins and furans' aggregate parameter (PCDD/F) in international toxicity equivalents (I-TEQs[9]). They accumulate in the food chain and are also embryotoxic. Dioxins impair embryonal development in several ways. In particular, they appear to give rise to miscarriage, deformity of the (genital) organs, and intellectual deficits (BUWAL 1995; Lippmann 2000). Dioxins and furans are scarcely volatile; their dispersal occurs mainly through attachment to particles. The main exposure route is the ingestion of foods containing fat. In 2001, WHO (2002), together with FAO, recommended a PTMI (provisional tolerable monthly intake) of 70 pg I-TEQ/kg per body weight and month. Based on the precautionary principle, the target is a value of less than 1 pg I-TEQ per kilogram of body weight and day. This also corresponds to the German position (UBA 2012).

Tab. 30: Characterisation of specific polycyclic aromatic hydrocarbons (PAH) according to EPA (1993)

	Characterisation (g BaP-eq./g)
Benzo(a)pyren	1,000
Benzo(a)anthracen	0,100
Benzo(b)fluoranthen	0,100
Benzo(k)fluoranthen	0,010
Chrysen	0,001
Dibenz(a,h)anthracen	1,000
Indeno(1,2,3-cd)pyren	0,100

Polycyclic aromatic hydrocarbons (PAHs) is the term used for a group of different compounds. PAHs have some carcinogenic effect in mammals. The various PAH substances are aggregated, similar to dioxins, with toxicity equivalents (TEQs) in accordance with EPA (1993) (see Tab. 30). Toxicity equivalents also enable mixtures of different PAHs to be evaluated for toxicity, with benzo(a)pyrene used as the lead substance. This substance is characterised for its toxicity using USEtox. The characterisation factors of the other PAHs are derived using the TEQs according to EPA.

9.10.2 Characterisation

For the characterisation of individual substances, see Tab. 31. For the three classes of PAHs, dioxins and furans, and benzene, the characterisation factors for carcinogenic substances toxic to humans (human toxicity, carcinogenic effects, recommended+interim) according to USEtox are used and expressed in 'Comparative Toxic Units[10] (CTUh)'.

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[9] I-TEQ: International toxicity equivalent is a weighting factor that relates the various dioxins and furans according to their respective toxicities. For dioxins and furans, the factor 1 is assigned to the Seveso dioxin 2,3,7,8-TCDD. For PAHs, the factor 1 is assigned to benzo(a)pyrene.

[10] For human toxicity, this corresponds to the probability of a form of cancer per kilogram of emitted chemical.

USEtox is a model developed by the UNEP/SETAC Life Cycle Initiative, based on scientific consensus, to characterise the human and ecotoxicological effects of chemicals (Fantke et al. 2018). The various PAHs were differentiated using the toxicity equivalents (TEQs) according to EPA.

9.10.3 Normalisation

The normalisation flow corresponds to the characterised quantity of emissions of the PAH substances, dioxins and furans, and benzene concerned and is identical to the current flow (see Tab. 31).

9.10.4 Weighting

The current flow corresponds to the characterised quantity of emissions of the relevant PAH substances, dioxins, furans and benzene and is 4.71 CTUh/a (see Tab. 31).

In 2018, benzene emissions totalled 785 t, of which 446 t came from road transport and 14.5 t from non-road engines, with 325 t of benzene coming from combustion processes, fuel handling and some other sources (EMIS, as per 30 March 2020 (Jenk 2020b)). The current flow for benzene is thus 785 t/a.

Prior to 1955, dioxin and furan emissions were under 40 g I-TEQ/a. They rose to 485 g I-TEQ/a in the period from 1955 to 1980. Due to better exhaust purification technology, they have since dropped again, as today all municipal waste incineration plants are fitted with a flue gas purification system (BUWAL 2002b). Annual emissions were reduced to 20 g I-TEQ/a by 2018 (BAFU 2020). The annual mean value from 2017 to 2019 according to the FOEN (BAFU 2018, 2019, 2020) is 20 g I-TEQ/a, which is used as the current flow.

The annual mean value from 2017 to 2019 (BAFU 2020) is 797 kg for benzo(a)pyrene emissions, 843 kg for benzo(b)fluoranthene emissions, 560 kg for benzo(k)fluoranthene emissions and 503 kg for indeno(1,2,3-cd)pyrene emissions.

The critical flow is individually derived and summated for each substance group. The sum of the characterised critical flows is 2.69 CTUh/a.

There is no threshold value for the carcinogenic effect of benzene. In accordance with the minimisation rule for emissions of carcinogenic substances (OAPC 2010, Annex 1 No 82 para. 1), the precautionary principle should be applied (Part 2, Section 4.3). This means that all technologically and operationally feasible and economically viable measures must be taken.

Engines in line with Euro-6 standards are the state of the art in road transport. In Switzerland, the EU standards for small, petrol-driven equipment have been in effect since 1 January 2011. The figures projected by the EMIS database for 2035 are used here for fuel handling and storage and for combustion processes.

The new forecasts for benzene emissions from road transport (excluding petrol stations) are significantly lower than in the last update of the eco-factors, standing at 153.8 t of benzene for 2035. The reason is that the factors by which the hydrocarbon emissions are multiplied to calculate the benzene emissions were reviewed when the factors were last updated and are now significantly lower for today's vehicles than in the past.

According to the non-road database, benzene emissions from non-road engines will be 10.3 t in 2035, compared with around 14.5 t in 2018.

In 2018, benzene emissions totalled 785 t, of which 446 t came from road transport and 14.5 t from non-road engines, i.e. 325 t of benzene come from combustion processes, fuel handling and various other sources.

Assuming that the non-engine emissions will also decrease somewhat and given that there are uncertainties in the forecasts, it is assumed that benzene emissions for the year 2035 will decrease to a total of 450 t of benzene, thus defining the critical flow (Jenk 2020b).

As dioxins and furans accumulate in the food chain, their formation needs to be prevented wherever possible. Emissions have been reduced from 67.6 g I-TEQ/a in 2006 to 20 g I-TEQ/a. For the period to 2035, emissions are expected to drop further to 19 g I-TEQ/a. Therefore, in line with the precautionary principle, the critical flow corresponds to 19 g I-TEQ/a (Jenk 2020a).

For the PAHs group, the forecast emissions for 2035 according to the FOEN (BAFU 2020) are applied, as with the dioxins. The corresponding emissions are set out in Tab. 32 below.

As no emissions data were available for benz(a)anthracene, chrysene and dibenz(a,h)anthracene, these substances were not taken into account in the calculation of the characterised totals. However, eco-factors can still be derived using the existing USEtox. These are shown accordingly in the table.

Tab. 31: Characterisation factors according to USEtox (human toxicity, carcinogenic effects, recommended), emitted quantities according to the FOEN (BAFU 2020) and calculated characterised quantities

Substance	Characterisation factor (CTUh/kg)	Emitted quantities 2018 (kg/a)	Characterised quantities (CTUh/a)
Benzo(a)pyrene	$4{,}05\times10^{-3}$	796,67	3,23
[a]Benzo(b) fluoranthene	$4{,}05\times10^{-4}$	843,33	0,34
[a] Benzo(k) fluoranthene	$4{,}05\times10^{-5}$	560,00	0,02
[a] Indeno (1,2,3-cd) pyrene	$4{,}05\times10^{-4}$	503,33	0,20
[a] Benz(a)anthracene	$4{,}05\times10^{4}$	n,a,[b]	n,a,
[a] Chrysene	$4{,}05\times10^{-6}$	n,a,[b]	n,a,
[a] Dibenz(a,h)anthracene	$4{,}05\times10^{-3}$	n,a,[b]	n,a,
Dioxins	35,17	0,02	0,70
Benzene	$2{,}67\times10{-}^{7}$	785 000	0,20
Total			**4.71**[c]

[a] The characterisation factors were calculated using the characterisation factor in USEtox for benzo(a)pyrene and the TEQ factors according to EPA (1993)

[b] No current emissions data available

[c] The total may diverge slightly from the sum of all quantities on account of rounding differences

Tab. 32: Characterisation factors according to USEtox (human toxicity, carcinogenic effects, recommended), targets based on text and resulting characterised critical flow

Substance	Characterisation factor (CTUh/kg)	Target	charakterisierte kritische Menge (CTUh/a)
Benzo(a)pyrene	4.05×10^{-3}	720	2.92
[a]Benzo(b) fluoranthene	$4{,}05\times10^{-4}$	780	0,32
[a]Benzo(k) fluoranthene	$4{,}05\times10^{-5}$	540	0,02
[a]Indeno (1,2,3-cd) pyrene	$4{,}05\times10^{-4}$	470	0,19
[a]Benz(a)anthracene	$4{,}05\times10^{-4}$	n/a	n/a
[a]Chrysene	$4{,}05\times10^{-6}$	n/a	n/a
[a]Dibenz(a,h)anthracene	$4{,}05\times10^{-3}$	n/a	n/a
Dioxins	35,17	0,019	0,67
Benzene	$2{,}61\times10^{-7}$	450 000	0,12
Critical flow			4,23

[a] The characterisation factors were calculated using the characterisation factor in USEtox for benzo(a)pyrene and the TEQ factors according to EPA (1993)

9.10.5 Eco-factor for benzene, dioxins and furans, and PAHs

Compared with 2013, the eco-factors for PAHs have increased significantly, while those for dioxins and benzene have decreased. This is mainly because the importance of the individual substances within the sum product for determining the characterised flows has shifted. While in the 2013 version this sum was dominated by dioxin and benzene in equal parts, benzo(a)pyrene is responsible for much of the contribution in the 2021 version, as the characterisation factor is around 100 times greater. In contrast, the factors for dioxins and furans were only slightly higher. The USEtox factor for benzene has even decreased in the new version.

The 2021 eco-factor for dioxins and furans is still very high. This not only reflects the lower emission levels (a few grams per year), but also the high degree of damage caused by these substances. The eco-factor for benzene has decreased significantly compared with 2013 due to the new distribution of contributions in the sum product.

Tab. 34: Eco-factors for benzene, dioxins and furans, and PAHs in UBP/g substance

Substance	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
Benzo(a)pyrene	**Eco-factor 2013**	95 000
*Benzo(b) fluoranthene	**110 000**	9500
*Benzo(k) fluoranthene	**11 000**	950
*Indeno (1,2,3-cd) pyrene	**110 000**	9500
*Benz(a)anthracene	**1100 000**	9500
*Chrysene	**1100**	95
*Dibenz(a,h)anthracene	**1 100 000**	95 000
Dioxins and furans	**$9{,}2 \times 10^9$**	$7{,}9 \times 10^{10}$
Benzene	**69**	810

9.10.6 Regionally specific eco-factors for PAHs

In addition to the factors identified in Section 9.10.5, specific eco-factors were calculated for the average PAH emissions on individual continents, while one eco-factor was assigned to the global PAH average (Yanxu & Shu 2009). The eco-factors for the regional PAH compositions are substantially lower than those of the individually listed PAH substances, as the regional PAH compositions are a mixture of 16 substances, of which nine have no characterisation factor for carcinogenic effect (characterisation factor = 0). Global PAH emissions are dominated by the burning of biomass (including bioenergy use and uncontrolled fires). In contrast, PAH emissions in North and Central America are generated primarily by the use of consumer goods and the burning of fuels (Yanxu & Shu 2009). Both processes generate primarily naphthalene emissions. As naphthalene accounts for 74% of the emissions and has a characterisation factor for carcinogenic effect of zero in North and Central America according to Yanxu and Shu (2009), the average PAH emissions in this region have the lowest characterisation factor and thus the lowest eco-factor.

9.10.7 Eco-factors for other carcinogenic substances under the Swiss Air Pollution Control Ordinance (OAPC)

Table 83 in Annex 1 Art. 3 para. 1 of the Swiss Air Pollution Control Ordinance (OAPC) lists other carcinogenic substances (OAPC 2010). An eco-factor is calculated for these substances, provided characterisation factors are indicated in USEtox (Fantke et al. 2018). The factors for carcinogenic substances, as derived in Sections 9.10.3 and 9.10.4, were used for the normalisation and weighting.

Tab. 33: Eco-factors for benzene, dioxins and furans, and PAHs in UBP/g substance

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (CTUh/a)	4,71	C	see text	0,90
Current flow (CTUh /a)	4,71	C	see text	0,90
Critical flow (CTUh /a)	4,23	b	see text	0,58
Weighting factor (–)	1,24			2,46
Eco-factor (UBP/ CTUh))	**2.6×10^{11}**			2.7×10^{12}

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 35: Characterisation and eco-factors of PAHs for regional average values

		Characterisation (g BaP-eq/g)	Eco-factors 2021 (UBP/g)	Eco-factors 2013 (UBP/g)
Regional average values	PAHs global average	0,014	**16 000**	1 400
	PAHs Africa	0,012	**13 000**	1 100
	PAHs Asia	0,017	**19 000**	1 600
	PAHs Europe	0,012	**13 000**	1 100
	PAHs North- & Central America	0,0067	**7 300**	630
	PAHs Oceania	0,012	**14 000**	1 200
	PAHs South America	0,013	**15 000**	1 300

Tab. 36: Substances that are classified in the OAPC (2020) Table 83 as carcinogenic and assessed with USEtox, as well their characterisation factors and eco-factors in UBP/g

Assessed substances in the OAPC Table 83		CAS	Characterisation factor (CTUh/kg)	Eco-factor 2021 (UBP/g)	Ökofaktor 2013 (UBP/g)
Acrylnitrile	C_3H_3N	107-13-1	$2{,}02 \times 10^{-6}$	**910**	5 500
1,3 Butadiene	C_4H_6	106-99-0	$5{,}71 \times 10^{-7}$	**300**	1 600*
1-Chloro-2,3-epoxypropane	C_3H_5ClO	106-89-8	$5{,}26 \times 10^{-7}$	**120**	1 400*
1,2-Dibromethane	$C_2H_4Br_2$	106-93-4	$1{,}96 \times 10^{-5}$	**6 500**	53 000
3,3-Dichlorbenzidine	$C_{12}H_{10}N_2Cl_2$	91-94-1	$6{,}31 \times 10^{-6}$	**3 400**	17 000
1,4 Dichlorbenzene	$C_6H_4Cl_2$	106-46-7	$2{,}15 \times 10^{-7}$	**71**	590
1,2-Dichlorethane	$C_2H_4Cl_2$	107-06-2	$4{,}15 \times 10^{-7}$	**140**	1 100*
1,2 Epoxypropane	C_3H_6O	75-56-9	$2{,}65 \times 10^{-7}$	**96**	720*
Ethylene oxide	C_2H_4O	75-21-8	$8{,}30 \times 10^{-7}$	**270**	2 300*
2-Naphthylamine	$C_{10}H_9N$	91-59-8	$4{,}84 \times 10^{-7}$	**270**	1 300
2-Nitrotoluene	$C_7H_7NO_2$	88-72-2	$6{,}03 \times 10^{-6}$	**2 200**	16 000
Vinyl chloride	C_2H_3Cl	75-01-4	$2{,}75 \times 10^{-6}$	**1 300**	7 500*
N-Vinyl-2-pyrrolidon	C_6H_9NO	88-12-0	$1{,}25 \times 10^{-6}$	**620**	3 400

* An eco-factor is also derived for these substances through NMVOCs (cf. Part 3, Section 9.4), which is nevertheless lower than the eco-factor derived here. According to the methodological principles, the highest of the resulting eco-factors is applied in each case.

9.10.8 Implementation in the UVEK LCI Data DQRv2:2022

The ecoinvent database and UVEK LCI Data include the following PAH elementary flows to air:

- Acenaphthene
- Benzo(a)pyrene
- PAHs (polycyclic aromatic hydrocarbons)

No carcinogenic effect is detected in acenaphthene, which is why this substance has no eco-factor (eco-factor = 0). PAHs are polycyclic aromatic hydrocarbons that are not specified further, which is why they are assessed with the eco-factor for PAHs according to the global average.

9.11 Heavy metal emissions to air

9.11.1 Environmental impact and development of emissions

Lead exposure harms animals and plants, and impairs soil fertility. Lead accumulates in food chains, can impair blood formation and can cause developmental disorders in children (BUWAL 1991, p. 29). As lead was blended into petrol, lead emissions rose sharply from the 1950s onwards. They peaked at 2,160 t/a in 1970. Thanks to the introduction of unleaded petrol, emissions have since dropped. Other uses of lead include batteries, paints and lead for bullets. Total emissions were 15 t/a in 2018 (BAFU 2020a). These 15 tonnes are generated mainly by fuel use, waste incineration plants and industrial combustion processes.

Even small quantities of cadmium are toxic to humans and animals if exposure is chronic. When attached to aerosols, cadmium is resorbed particularly readily in the lungs. It is bioaccumulative and, moreover, disturbs storage of vital metals in the body. Cadmium is also carcinogenic. The consequences of chronic cadmium exposure can include diseases of the respiratory tract, kidney damage, and anaemia due to iron deficiency. Moreover, it is toxic to plants and microorganisms and impairs soil fertility (BUWAL 1991, p. 30). Cadmium emissions peaked at 7 t/a around 1970. As a result of measures taken in waste incineration and the metal industry, they

Tab. 37: Characterisation factors according to USEtox (human toxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substanz	DALY/kg	In Cd-equivalents (kg Cd-eq/kg)	Emitted quantities (kg/a)	Characterised quantities (Cd-eq/a)
Lead	0,045176264	0,22	15 100	3 303,45
Cadmium	0,206499487	1,00	1 200	1 200,00
Copper	0,000020352	0,00	–	–
Zinc	0,016517084	0,08	398 000	31 834,46
Mercury	3,728447913	18,06	670	12 097,17
Nickel	0,001292665	0,01	–	–
Chromium (III)	0,000000001	0,000000004	–	–
Chromium (VI)	0,038923899	0,19	–	–
Total				**48 515,07**

Tab. 38: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2019) and calculated characterised quantities

Substance	PDF x m³ x day / kg	In Cd-equivalents (kg Cd-eq. / kg)	Emitted quantities (kg / a)	Characterised quantities (Cd-eq. / a)
Lead	2 724	0,004	15 100	54,65
Cadmium	752 616	1,00	1 200	1 200,00
Copper	20 980	0,03	–	–
Zinc	59 321	0,08	398 000	31 449,33
Mercury	10 699	0,01	670	9,52
Nickel	66 113	0,09	–	–
Chromium (III)	2 885	0,004	–	–
Chromium (VI)	37 120	0,05	–	–
Total				**32 713,51**

have dropped substantially since 1980. The main applications of cadmium are alloys and the production of dry batteries and colouring pigments. In 1995, emissions amounted to approximately 2.5 t/a (BUWAL 1995, p. 90). According to the FOEN (BAFU 2020), cadmium emissions were around 1.2 t/a in 2018.

Mercury is highly toxic to humans and animals. It is taken in through the respiratory tract and accumulates in various organs. It is also toxic to plants and microorganisms and impairs soil fertility (BUWAL1995). The principal generators of mercury emissions are waste incineration plants and non-metal-producing operations such as the cement industry. According to the FOEN (BAFU 2020a), mercury emissions were 670 kg/a in 2018.

Zinc loads impair plant growth (BUWAL 1991, p. 29). Until the 1970s, zinc emissions came mainly from steelworks and the unfiltered burning of waste. Total emissions peaked in 1970 at 1,750 t/a. In 1995, approximately 630 t were still emitted, whereby falling emissions in industry and commerce were partly offset by rising zinc emissions from road traffic (tyre and road abrasion). According to the FOEN (BAFU 2020a), zinc emissions were 399 t/a in 2018, with transport being the main source, accounting for over 80%. The trend towards increasing zinc emissions from transport appears to be persisting, meaning that overall zinc emissions can be expected to rise again, as no further significant reductions are anticipated in industry (Bass 2020).

9.11.2 Characterisation

In the 2013 edition, heavy metals were not characterised but a weighting was derived for each of the four heavy metals lead, cadmium, mercury and zinc. Heavy metals are now treated as a group, meaning that the current and critical flows are determined for the group of metals as a whole, and a weighting factor for the heavy metals group is then derived from this. The individual heavy metals are characterised with regard to their toxic damage according to USEtox version 2 (Fantke et al. 2018) – see Tab. 48 to Tab. 51. Cadmium is used as the lead substance, with the toxic impact expressed in Cd-equivalents/kg. For human toxicity, USEtox provides factors for carcinogenic and non-carcinogenic substances (human toxicity, cancer and non-cancer effects, recommended+interim). These are summated in disability-adjusted life years (DALYs) according to their damage to health. Toxicity factors for ecotoxic impacts are also provided, although these cannot be offset against the factors for human toxicity. Consequently, a set of eco-factors was determined using the characterisation factors for human toxicity and ecotoxicity respectively, and from these two sets the higher factor for each heavy metal was used (see Tab. 37 to Tab. 40). Eco-factors can also be derived for copper, chromium and nickel using their respective USEtox factors, even if no emission quantities or targets are known for these metals. This results in slightly overestimated eco-factors for heavy metals, given that the normalisation flow does not include the three metals copper, chromium and nickel due to a lack of corresponding data relating to these flows. However, this is still considered more useful than not taking them into account at all.

9.11.3 Normalisation

The normalisation flow corresponds to the characterised quantity of emissions of lead, cadmium, copper and zinc, as emissions flows are only available for these heavy metals (see Tab. 37 for human toxicity and Tab. 38 for ecotoxicity).

9.11.4 Weighting

The Swiss Air Pollution Control Ordinance (OAPC 2010) stipulates ambient limit values (annual mean values) for lead, cadmium and zinc in dust deposition. However, no critical flow

Tab. 39: Eco-factors for heavy metals to air, in Cd-eq./a

	Human toxicity	Ecotoxicity	Q	Notes
Normalisation flow (kg Cd-eq./a)	$4{,}85\times10^{4}$	$3{,}27\times10^{4}$	C	
Weighting factor (-)	1,94	1,97		Taken from the weighting factor for soil, see Section 12.2.4
Eco-factor (UBP/ kg Cd-eq.))	$4{,}00\times10^{7}$	$5{,}93\times10^{7}$	–	

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 40: Eco-factors for heavy metals to air, in UBP/g

Substance	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
Lead	8700	22 000
Cadmium	59 000	460 000
Copper	1700	–
Zinc	4700	5600
Mercury	720 000	550 000
Nickel	5200	–
Chromium (III)	230	–
Chromium (VI)	7500	–

can be derived from this. Yet a theoretical critical flow can be derived from the weighting factor for soil, as described below.

The purpose of the Swiss Air Pollution Control Ordinance is to "[…] protect human beings, animals and plants, their biological communities and habitats, and the soil against harmful effects or nuisances caused by air pollution" (OAPC, Art. 1). Soil protection is thus a stated goal of the Swiss Air Pollution Control Ordinance. It is therefore possible to apply the targets established for soils to air emissions as well, i.e. to make use of the weighting factors for emissions to soils. If soil is taken to be a target of protection in its own right, the ratio of current to critical flow for heavy metal emissions to air that ultimately enter the soil through deposition must be the same as that for direct emissions to soil. The weighting factors for heavy metal emissions to soil, as described in Part 3, Section 12.2, are therefore used. These are 1.94 for human toxicity and 1.97 for ecotoxicity (see Tab. 39 and Tab. 79).

9.11.5 Eco-factors for heavy metals

The Tabl. 39 shows the calculation of the eco-factors per kg Cd-eq and Tab. 40 summarises the calculated eco-factors for all heavy metals in eco-points per gram. In each case, the higher factor from the categories of human toxicity and ecotoxicity is selected. The new approach to characterising heavy metals based on the USEtox factors leads to significantly lower eco-factors for heavy metals to air compared with the 2013 edition, with one exception. The main reason for this is that the heavy metals were no longer considered individually but grouped together, resulting in a significantly greater normalisation flow.

There are also differences between the relative assessments of the various heavy metals. This is due to use of the USEtox method, which evaluates the toxic damage caused by the various heavy metals. This means, for example, that mercury is rated more highly relative to the other heavy metals and is the only heavy metal to receive a higher eco-factor than in the 2013 edition due to the very high characterisation factor with USEtox.

9.12 Radioactive emissions to air

9.12.1 Introduction

Although the radioactive emissions to air from nuclear installations in Switzerland are well within statutory limits, it is important to assess them as part of the ecological scarcity method. These emissions have been included in the assessment since 2013.

Tab. 41: Characterisation factors for the carcinogenic potential of radioactive emissions to air, according to Frischknecht et al. (2000), reference element C-14

		Carcinogenic potential of radioactive elements (kBq C-14-eq./kBq)
Carbon-14	C-14	1,0
Cobalt-58	Co-58	0,002
Cobalt-60	Co-60	0,076
Cesium-134	Cs-134	0,057
Cesium-137	Cs-137	0,062
Tritium	H-3	$6{,}7 \times 10^{-5}$
Iodine-129	I-129	4,5
Iodine-131	I-131	0,00076
Iodine-133	I-133	$4{,}5 \times 10^{-5}$
Krypton	Kr-85	$6{,}7 \times 10^{-7}$
Lead-210	Pb-210	0,0071
Polonium-210	Po-210	0,0071
Plutonium-alpha	Pu alpha	0,40
Plutonium-238	Pu-238	0,32
Radium-226	Ra-226	0,0043
Radon-222	Rn-222	0,00011
Thorium-230	Th-230	0,21
Uranium-234	U-234	0,46
Uranium-235	U-235	0,10
Uranium-238	U-238	0,039
Xenon-133	Xe-133	$6{,}7 \times 10^{-7}$

9.12.2 Environmental impact

Exposure to radiation transfers energy into human tissue, and in doing so, can interfere with the molecular structure. This can disturb or destroy cell functions in living organisms (somatic effects, i.e. fatal or non-fatal cancer), or it can alter the genetic code of the cells (mutagenic effects).

The characterisation factors take both of these effects into account. The impact of radiation on ecosystems is not considered here, nor are the potential impacts of accident-related releases of large quantities of radioactive substances.

9.12.3 Characterisation

The environmental impact of the emission of radioactive elements is characterised according to its carcinogenic impact on humans. Impacts on ecosystems are not considered.

The characterisation of emissions to air is based on the work of ExternE (1999). Carbon-14 serves as the reference substance. Tab. 41 lists the characterisation factors according to Frischknecht et al. (2000).

9.12.4 Normalisation

Data on emissions of radioactive substances from nuclear installations are compiled by the Federal Office of Public Health (BAG 2020) and the Swiss Federal Nuclear Safety Inspectorate (ENSI 2020). The characterisation of the corresponding nuclides as set out in Part 3, Section 9.12.3 results in a total volume of emissions of 0.91 TBq C-14-eq. for 2019. In the above-mentioned case of radioactive emissions to air, the current flow corresponds to the normalisation flow.

9.12.5 Weighting

Characterised emissions of radioactive substances from Swiss nuclear installations were 0.91 TBq C-14-eq. in 2019 (BAG 2020; ENSI 2020).

The emission limits of radioactive substances from Swiss nuclear installations are set for individual installations, but they differ when it comes to noble gases, aerosols and iodine-131 for nuclear power plants and β-/γ-aerosols, α-aerosols, tritium and carbon-14 for interim storage facilities. The emission limits correspond to those authorised for each nuclear installation. For nuclear power plants, the limit is set so that the dose for individuals in the vicinity is under 0.3 mSv/year. For the central interim storage facility in Würenlingen, the limit for the dose is 0.05 mSv/year, while for the Paul Scherrer Institute (PSI) it is 0.15 mSv/year (ENSI 2020). Hospitals emit no isotopes to the air.

The nuclide C-14 is used for determining the eco-factor as its emissions are significantly higher than those of the other nuclides. A separate limit has not been set for nuclide C-14 from nuclear power plants (ENSI 2020). The real emissions are used to set approximate limits for individual nuclear installations in line with the ratio of permitted annual dose to actual annual dose. The actual annual doses range between 0.3% and 2.0% of the permitted annual doses, depending on the nuclear installation (excluding PSI).

Through the characterisation and addition of the emissions of all installations, the limits are aggregated to one single value. This results in a characterised critical flow of 89.2 TBq C-14-eq. per year.

Tab. 42: Eco-factor for radioactive emissions to air in UBP/GBq C-14-eq.

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (TBq C-14-eq./a)	0,91	A	Emissions from nuclear power plants (ENSI 2020)	1,08
Current flow (TBq C-14-eq./a)	0,91	A	Emissions from nuclear power plants (ENSI 2020)	1,08
Critical flow (TBq C-14-eq./a)	89,2	b	Based on the annual dose for individuals in the vicinity (ENSI 2020)	1164
Weighting factor (-)	$1{,}1\times10^{-4}$			$8{,}6\times10^{-7}$
Eco-factor (UBP/GBq C-14-eq.)	**110 000**			800

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 43: Eco-factors for the discharge of radioactive isotopes into air, deduced from their impact potential according to Frischknecht et al. (2000)

		Carcinogenic potential of radioactive elements (kBq C-14-eq./kBq	Eco-factor 2021 (UBP/kBq)
Carbon-14	C-14	1,0	**0,11**
Cobalt-58	Co-58	0,0020	**0,00022**
Cobalt-60	Co-60	0,076	**0,0084**
Cesium-134	Cs-134	0,057	**0,0063**
Cesium-137	Cs-137	0,062	**0,0068**
Tritium	H-3	0,000067	**0,0000074**
Iodine-129	I-129	4,5	**0,50**
Iodine-131	I-131	0,00076	**0,000084**
Iodine-133	I-133	0,000045	**0,0000050**
Krypton	Kr-85	0,00000067	**7,40*10^{-8}**
Lead-210	Pb-210	0,0071	**0,00078**
Polonium-210	Po-210	0,0071	**0,00078**
Plutonium-alpha	Pu alpha	0,40	**0,044**
Plutonium-238	Pu-238	0,32	**0,035**
Radium-226	Ra-226	0,0043	**0,00047**
Radon-222	Rn-222	0,00011	**0,000013**
Thorium-230	Th-230	0,21	**0,023**
Uranium-234	U-234	0,46	**0,051**
Uranium-235	U-235	0,10	**0,011**
Uranium-238	U-238	0,039	**0,0043**
Xenon-133	Xe-133	0,00000067	**7,40*10^{-8}**
Radioactive species, other beta emitters	*	0,027	**0,0030**
Noble gases, radioactive, unspecified	*	0,00000016	**1,70*10^{-8}**
Aerosols, radioactive, unspecified	*	0,029	**0,0032**

* For explanation, see Part 3, Section 9.12.8

9.12.6 Eco-factor for radioactive emissions to air

The eco-factor for radioactive emissions to air has increased significantly compared with the 2013 version. This is mainly due to a calculation error affecting the C-14 emission limits in the 2013 version, which meant that the 2013 eco-factor was underestimated by a factor of 100.

9.12.7 Eco-factors for individual isotopes

Using the characterisation described in Part 3, Section 9.12.3, it is possible to calculate eco-factors for selected isotopes. These are listed in Tab. 43 and apply to the emissions of these substances to air. These eco-factors should not be used for loads in other compartments. Eco-factors for discharges into seas and inland waters are derived in Sections 10.6 and 10.7.

9.12.8 Guidelines for using UVEK LCI Data DQRv2:2022

In the current UVEK LCI Data DQRv2:2022, emissions of individual nuclides are indicated in summary form. The compositions of the mixtures are determined from the data on radioactive emissions from European nuclear power plants and reprocessing plants (Van der Stricht & Janssens 2005, 2010). The eco-factor for the mixture is determined using the eco-factors of the individual nuclides (see Tab. 43). The resulting eco-factors are conservative values, as not all components of the mixtures are characterised.

10 Emissions to surface waters

10.1 Introduction

10.1.1 Preliminary remarks

The eco-factors for the weighting of emissions to waters are based on the loads for the whole of Switzerland and therefore apply to the 'average' situation in the country. Regional conditions are only taken into account in the case of phosphorus. For example, substances that pose a problem in individual small bodies of water still present levels in the Rhine below the required concentration limit for bodies of water, due to dilution. Ideally, graded eco-factors should be made available to reflect the situation in different bodies of water. This has not been done on economic grounds, but if need be, it could be undertaken at any time, as set out in the chapter on methodology (Part 2, Chapter 4).

The derivation of eco-factors for emissions to bodies of water is based on simplifications that do not take ecological conditions fully into account. The aim of determining eco-factors is not to be able to make an ecological assessment of individual pollutant emissions in a specific body of water, but to produce a comparative weighting across all environmental media within life cycle assessments.

As explained in the section on groundwater (see Part 3, Section 11), the eco-factors for surface waters should not be applied to pollutants emitted to groundwater.

10.1.2 Selection of substances

Due to the effluent purification measures that have been taken, the emissions to surface waters of a number of

Tab. 44: Impact mechanisms of the assessed water pollutants

	Environmental				Human						
	Environmental	Human	Characterisation	Bioakkumulation	Metabolic disturbances	Carcinogenicity	Mutagenesis	Embryonal damage	Other/further types of damage	Characterisation	Notes
Nitrogen	#		(x)							–	
Phosphorus	#									–	
Organic matter (BOD, COD, DOC, TOC)		#								–	
Heavy metals and arsenic				x	x	x		(x)		As-eq	As per ICPR Rhine quality target Characterisation with USETox
Radioactive emissions to inland waters						x	x		x	U235-eq	Emission limits according to the FOPH
Radioactive emissions to the Sea						x	x		x	C14-eq	Reduction to natural background levels
Oil emissions to the Sea			x							–	As per OSPAR target
AOXs				x	x	(x)			x	$HCCl_3$-eq	As per IAWR Rhine quality target Characterisation mit USETox
PAHs						x				–	As per ICPR Rhine quality target
Endocrine disruptors					#			x	x	E2-eq	EU directive, 2018
Persistent organic pollutants (POP)			x	#		x	x		x	2,4,6-T-eq	Characterisation with USEtox

x impact or link proven
(x) impact or link presumed
impact significant to determining the eco-factor

substances have been reduced significantly. Therefore, some of the remaining emissions are of subordinate importance for the ecology of Swiss waters. This poses the question as to what extent eco-factors should be assigned to such substances. The fact that eco-factors are applied not only to emissions within Switzerland, but also outside the country should be taken into consideration. An eco-factor is therefore provided, wherever possible, for substances that may be unproblematic in Switzerland, but have the potential to be environmentally relevant abroad. For example, eco-factors are also provided for plant protection products whose use is prohibited in Switzerland.

According to the Federal Council's Environmental Report (Federal Office for the Environment (FOEN), 2018), the status of many bodies of surface water is still inadequate. In particular, small bodies of water are polluted with nutrients and pesticides from agriculture, while medium-sized and larger bodies of water are additionally contaminated by micro-pollutants from households and the industry. In this chapter, eco-factors are calculated for nutrients, selected eco-toxic substances and micro pollutants. It should be noted that the list of eco-factors developed is not exhaustive. Indeed, no factors are evaluated for various drugs like diclofenac or ibuprofen, even if these substances are considered relevant when assessing water pollution, see also Chapter 17. Eco-factors are derived for plant protection products (PPPs) in the chapter on soil impacts. The reason for this is that the inputs of PPPs occur via the soil and the LCA inventories show the emissions into the soil accordingly. The evaluation of eco-factors is now based on the USEtox method, which considers the discharge into water bodies and the resulting impairments. This choice allow for the consideration of current water quality problems even if the chapter does not directly tackle these topics.

Annex 2 of the Swiss Waters Protection Ordinance (WPO 2020) sets out water quality requirements for watercourses. The list of numerical requirements in Annex 2 Nos 11 and 12 of the WPO represents a starting point for the selection of eco-factors for substances that pollute waters. Additions to the list include phosphorus, on account of its significant impact on water quality in lakes, polycyclic aromatic hydrocarbons (PAH), adsorbable organic halogens (AOX), endocrine disruptors, radioactive emissions (in Switzerland and from reprocessing spent fuel), oil emissions to the sea and persistent organic pollutants (POP).

The water pollutants weighted with an eco-factor are listed in Tab. 44. The impacts of the pollutants are also outlined, and those that are critical in determining the eco-factor are indicated. In many instances, the quality target set by the ICPR (International Commission for the Protection of the Rhine), which does not relate only to the environmental impact, has been used.

10.1.3 Guidelines for application

Substances from Switzerland reach the sea through the Rivers Rhine, Rhone, Ticino and Inn. Two thirds of the water flowing out of Switzerland reaches the North Sea through the Rhine. Due to the import of products from countries located on seas, further direct emissions are discharged into them. The eco-factors for nitrogen, radioactive emissions and oil are already based to some extent on marine protection targets. For that reason, the eco-factors derived in this chapter should be applied to emissions to the sea. One exception is the eco-factor for oil emissions to the sea. This eco-factor refers exclusively to emissions to the sea and may not be applied to other water compartments (e.g. rivers).

10.2 Nitrogen (N)

10.2.1 Environmental impact

Over 90% of anthropogenic total nitrogen in surface waters consists of nitrate and ammonium or ammonia. Sources of nitrogen in bodies of water are agricultural fertilisers and industrial, commercial and household effluents. The eco-factors in this section evaluate only the nitrogen loads in surface waters. Nitrogen compounds (particularly nitrate), which are first released into groundwater and enter surface waters from there, are assessed separately in the section on groundwater (see Part 3, Section 11.2).

Although local problems may still persist with regard to nitrogen, and there are indications that the N:P ratio can have problematic effects, the total nitrogen load in the North Sea and other shallow seas is of particular concern with regard to eutrophication. Therefore, the aim is to achieve a marked reduction in the nitrogen discharged

Tab. 45: Eco-factor for total nitrogen in surface waters in UBP/g N

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t N/a)	64 000	B	Extrapolated for Switzerland based on measurements in the Rhine	36 197
Current flow (t N/a)	44 364	A	Rhine catchment only from measurements in the Rhine in Basel	28 656
Critical flow (t N/a)	29 113	a	50% reduction target in Rhine catchment from 1985 levels (Heldstab et al. 2013)	19 875
Weighting factor (-)	2,32			2,08
Eco-factor (UBP/g N)	**36**			57

Q = data quality; for explanation, see Part 2, Chapter 6

into the North Sea, by reducing nitrogen loads in the Rhine, among other measures (BAFU 2010).

10.2.2 Normalisation

No characterisation is performed. The nitrogen load in the Rhine was determined from measurements taken at the Rhine monitoring station at Weil am Rhein near Basel. The anthropogenic nitrogen load for the Rhine catchment in 2019 was 44,364 t N/a. Water discharge (flow rate) in the Rhine amounts to a long-term mean of around 33 billion m^3/a, while the total for Switzerland comes to 47 billion m^3/a. Extrapolated to the total flow rate, this produces a load of 64,000 t N/a for the whole of Switzerland.

10.2.3 Weighting

Since the reduction target refers only to emissions in the Rhine catchment within Switzerland (see below for the critical flow), the current flow must cover the same area. According to measurements at the Rhine monitoring station, the current flow is 44,364 t N/a.

In 1987, as a result of the over-use of fertilisers, which became evident during the 1980s, the countries bordering the North Sea issued a declaration of intent.[11] Its aim was to reduce loads of phosphorus and nitrogen to 50% of 1985 levels by 1995. Although it is responsible for only a small amount of the total discharge into the Rhine, Switzerland has contributed to these efforts (BUWAL 1996, p. 36). In the case of nitrogen, the target has still not been reached, but a reduction of 34% had been achieved by 2019.

This target is used as a basis for establishing the critical flow for total nitrogen emissions (N_{tot}). As no continuous measurement values for Ntot in the Rhine at Basel are available for 1985, the nitrogen flow had to be determined from modelling. This modelling was updated in 2013. In the process, it was found that the nitrogen load in 1985 was considerably higher than the value previously used. The revised value is 58,227 t N/a (Heldstab et al. 2013, p. 90). As a result, the critical flow is 29,113 t N/a. Deriving the critical flow from the Swiss Waters Protection Ordinance would result in a significantly higher critical flow,[12] which is why it is not used.

10.2.4 Eco-factor for nitrogen in surface waters

The eco-factor for nitrogen has dropped by almost 40% compared to the 2013 edition. The main reason is that continuous measurements at the Rhine monitoring station in Basel have shown that the nitrogen discharge in the Rhine catchment is significantly higher than the value used in the previous edition. Consequently, the normalisation flow has increased significantly more than the weighting factor, which has only risen slightly. The critical flow was adjusted due to the fact that nitrogen emissions from diffuse sources in 1985 were recalculated and now stand at 58,227 t N/a (Heldstab et al. 2013, p. 90). This is around 50% higher than the value derived from earlier models, which was used in the 2013 edition.

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[11] Second International Conference on the Protection of the North Sea, London, 24–25 November 1987

[12] Assuming a mean discharge in the Rhine of 1 000 m^3/s and taking the required value of 5.6 mg NO_3-N/l, a critical flow of 176,600 t NO3-N/a would result for the Rhine catchment alone.

10.3 Phosphorus (P)

10.3.1 Environmental impact

The phosphorus load is more critical for lakes (and certain parts of seas) than rivers, as in standing bodies of water, it is mostly the amount of phosphorus available that represents the limiting factor for algal growth. Algal growth elevated by phosphorus can cause sedimentation and the increased aerobic decomposition of this biomass, leading to oxygen deficiency and fish mortality in the deep waters of lakes (BLW & BUWAL 1998).

The phosphorus load in lakes varies greatly depending on the location. Alpine lakes (e.g. Lake Lucerne, Lake Thun) exhibit very low concentrations of phosphorus, whereas lakes in areas of intensive farming can still be severely polluted by the phosphorus that is applied to the fields in the form of manure and synthetic fertilisers. Soil erosion and phosphorus discharged by urban drainage can contribute to higher phosphorus loads. The connection of households and businesses to sewage treatment works and the ban on phosphates in textile detergents led to a marked drop in the phosphorus load in the 1980s and 1990s (BLW & BUWAL 1998; BUWAL 2004b).

Phosphorus is released into bodies of water as particle-bound phosphate, mainly through erosion and leaching from cropland. Agriculture's continuing substantial contribution to the loads is also a consequence of the liberal use of fertilisers in the past. Thus, pastures and agricultural land in Switzerland register a phosphorus content that greatly exceeds the annual requirements of plants. The Waters Protection Act (WPA 2020) requires a balanced quantity of fertilisers so that bodies of water are not adversely affected by runoff and quantities of fertiliser washed into them. Consequently, it is now only permitted to use as much phosphorus as the crops can take up. Moreover, the Chemical Risk Reduction Ordinance (2013) contains regulations on permitted applications of fertilisers. Thus, fertiliser guidelines, plant stocks, nutrient levels in soil and weather conditions, among other factors, must all be taken into consideration.

10.3.2 Normalisation

No characterisation is performed. The amount of phosphorus discharged into surface waters across Switzerland can only be estimated, as it is impossible to directly measure the runoff from agricultural land, which accounts for a significant proportion. Therefore, phosphorus is equated with discharge through watercourses. Phosphorus entering the bodies of water is absorbed by algae and aquatic plants and eventually deposited through sedimentation of the biomass in lakes or released back into the water when the biomass decomposes.

To determine the total phosphorus load, measurements of P concentrations in the Rivers Rhine, Rhone, Ticino and Inn at the points where they flow out of Switzerland were used and multiplied by the respective flow rates. The most recent annual data, from 2017 to 2019, were used for this. This results in a phosphorus discharge through watercourses of 1,485 t P/a for the whole of Switzerland.

10.3.3 Weighting: protecting the North Sea

The current flow differs from the normalisation flow, as the reduction target only applies to the Rhine catchment. The mean phosphorus load in the Rhine at Basel in recent years was 979 t P/a. The values are decreasing, with the load in 2019 around 40% lower than in 2015.

The countries bordering the North Sea have issued a ministerial declaration aimed at reducing phosphorus and nitrogen loads to 50% of their 1985 levels. Switzerland has also signed this declaration. The phosphorus target has already been comfortably achieved. At 1,502 t P/a (OSPAR Commission 2008b), the critical flow for the Rhine catchment is significantly higher than the current flow. This results in a weighting factor of 0.42.

10.3.4 Weighting: phosphorus content in Swiss lakes

The numerical limit set out in the Waters Protection Ordinance does not apply to phosphorus, but rather to the oxygen required by organisms. The general environmental target for lakes is an oxygen content of 4 mg per litre at each depth of a lake (WPO 2011, Annex 2 No 13). Furthermore, the nutrient content must permit at most an average production of biomass (WPO 2020, Annex 2 No 13). Each lake is a special case due to its morphology and geographical location or weather exposure. The nutrient content requirements for average production at most cannot therefore be determined with one single value that applies in the same way to all lakes. According to the FOAG and the FOEN (BAFU & BLW 2008), this requirement is met in many lakes, if the average content or concentration value of spring circulation is less than 20 mg of total phosphorus per cubic metre (20 µg P per litre) for several years. This corresponds to the environmental target for agriculture, in which the total phosphorus content in lakes, whose phosphorus loads mainly come from agriculture, should be less than 20 µg of phosphorus per litre (BAFU & BLW 2008).

The weighting factor (and the resulting eco-factor) for phosphorus can also be calculated separately for each lake in Switzerland (Tab. 46). For lakes with an average phosphorus concentration above 20 mg/m^3, the target value is the same as the target for agriculture,[13] while for lakes with a concentration under 20 mg P/m^3, the target is the average phosphorus concentration for the period from 2016 to 2018. For Lake Greifensee and Lake Pfäffikon, the canton's target value of 25 mg P/litre is used. Some lakes have a measured value that is well below 20 mg/m^3 (Lake Walen), while others exceed it quite considerably (Lake Zug and the north basin of Lake Lugano). The ecological scarcity of the large Swiss lakes is thus extremely varied when it comes to phosphorus.

To determine the average ecological scarcity of phosphorus in Switzerland, both the individual phosphorus concentrations and the volume of water in the lakes are relevant. The lakes' capacity to absorb phosphorus is dependent upon these two parameters. As the weighting factor has the effect of squaring the ratio of the current to the target concentration, the average weighting factor is determined on the basis of the sum of the weighting factors of each lake, weighted with their respective volumes (see Tab. 46).

10.3.5 Eco-factor for phosphorus

In Sections 10.3.3 and 10.3.4, the weighting has been derived by two different methods: in one instance, from the 50% reduction target for emissions to the North Sea and, in the second, from the derived target values (environmental target for agriculture and average phosphorus concentration of the last three years) for Swiss lakes. The calculation of the eco-factor from the derived target values for Swiss lakes leads to higher values. The eco-factor derived from the 50% reduction target will therefore not be included in Tab. 47.

The lower weighting factor reflects the slight easing of the phosphorus problem and the effect of the measures taken. However, as shown in Tab. 46, some lakes are still subject to severe pollution. As the total phosphorus load and thus the normalisation flow have decreased more than the weighting factor, the eco-factor is almost 10% higher.

Tab. 46: Calculation of the weighting factor for Swiss lakes based on the current and critical concentrations

Only lakes with reliable values for the years 2016 to 2018 based on testing frequency have been included

	Volume of lake	Total concentration of phosphorus	Derived target value*	Weighting factor
	Million m^3	mg/m^3	mg/m^3	(–)
Lake Geneva	89 900	19,0	20	0,90
Lake Constance	48 000	8,0	8,0	1,00
Lake Neuchâtel	14 170	8,3	8,3	1,00
Lake Maggiore	37 100	12,7	12,7	1,00
Lake Lucerne	11 800	4,5	4,5	1,00
Lake Zurich	3900	24,3	20	1,48
Lake Lugano, north basin	4690	69,7	20	12,13
Lake Lugano, south basin	1140	45,0	20	5,06
Lake Thun	6500	2,0	2,0	1,00
Lake Bienne	1240	11,0	11,0	1,00
Lake Zug	3210	82,3	20	16,95
Lake Brienz	5170	3,3	3,3	1,00
Lake Walen	2490	3,7	3,7	1,00
Lake Morat	600	14,0	14,0	1,00
Lake Sempach	660	25,3	20	1,60
Lake Hallwil	215	12,0	12,0	1,00
Lake Greifensee	149	46,7	25	3,48
Lake Baldegg	178	23,3	20	1,36
Lake Pfäffikon	57	16,0	25	0,41
Weighting factor for Switzerland				**1,44**

* The Waters Protection Act requires that nutrient content allow for average biomass production at most. Therefore, the environmental target for agriculture has been selected for lakes with an average phosphorus concentration above 20 mgP/m^3, while the target for the other lakes is the average concentration of the last 3 years (2016-2018) unless there is a specific target value for the lake in question.

Source: Phosphorgehalt in Seen_BAFU_14.02.2020.xls[14]

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[13] Exceptions are Lake Greifensee and Lake Pfäffikon, for which the cantonal authorities have set a target of 25 mg P/m^3 (Gewässerschutz Kt. Zürich 2019a, b).

[14] 'Phosphor in Seen' data received from the Federal Office for the Environment, 14.2.2020. The data was collected by international water protection commissions (CIPEL, CIPAIS, IGKB), cantonal water protection agencies, Eawag and Wasserversorgung Zürich (WVZ, for Lake Zurich and Lake Walen). This data has been supplemented by information from the Water Protection Department of the Canton of Zurich for Lake Greifensee, Lake Baldegg and Lake Pfäffikon.

Tab. 47: Eco-factor for phosphorus in UBP/g P

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t P/a)	1490	B	Extrapolated using NADUF runoff data (BAFU 2011a) from the loads for the Rhine catchment according to the OSPAR Commission (2008b)	1854
Current flow (t P/a)	–			–
Critical flow (t P/a)	–			–
Weighting factor (–)	1,44		Calculated from the lake protection target	1,65
Eco-factor (UBP/g P)	**970**			890

Q = data quality; for explanation, see Part 2, Chapter 6

10.4 Organic matter (BOD, COD, DOC, TOC)

10.4.1 Environmental impact

BOD (biochemical oxygen demand), COD (chemical oxygen demand), DOC (dissolved organic carbon) and TOC (total organic carbon) are parameters for the concentration of organic matter in waters. These organic substances originate in part from natural sources and in part from wastewater. In essence, all organic substances pollute waters in that they consume oxygen, thus restricting the habitat of the fauna that depends on it. In addition, many substances (such as chlorinated organic compounds or endocrine disruptors) can have specific toxic impacts that should be recorded separately (Kummert & Stumm 1989; Sigg & Stumm 1989). Separate eco-factors are therefore determined for these substances.

Due to measures to improve effluent treatment, the pollution of Swiss bodies of water by organic substances has fallen in recent decades. Moreover, the legislation (WPO) requires the implementation of measures to reduce organic matter in effluent to a level at which there is no ecological detriment to bodies of water. In most cases, the residual load from effluent treatment works is non-critical in terms of the total oxygen available. For that reason, persistent, bioaccumulative and toxic organic substances are of foremost environmental importance (see POPs, Part 3, Section 10.12). However, the specific impacts of the substances encompassed by the aggregate parameter 'organic matter' cannot be considered here.

The concentration of organic matter in bodies of water can be recorded using the parameters COD, DOC and, where necessary, TOC.

- **BOD (biochemical oxygen demand)**
  BOD_x expresses the amount of oxygen consumed by biological activity in water in x days. Incubation takes place in the dark, at 20 °C and normally over a period of five days (BOD_5). The proportion of hydrocarbons that break down readily, particularly through microbial degradation, is determined from this. The BOD value is always lower than the COD value. Usually, BOD_5 is determined.

- **COD (chemical oxygen demand)**
  COD expresses the amount of oxygen required to oxidise organic compounds. In Switzerland, COD is used mainly to determine the quality of the discharge from water treatment works (effluent parameter). In most other countries, water pollution by organic matter is assessed in terms of COD. Many life cycle inventories contain figures for COD emissions.

- **DOC (dissolved organic carbon)**
  DOC measures the bound organic carbon content from dissolved organic compounds. This measurement produces more exact results than the COD test when dealing with small concentrations such as those in Swiss watercourses (clean water parameter).

- **TOC (total organic carbon)**
  TOC is a measure of the total carbon bound in organic molecules. It is made up of dissolved organic carbon and particle-bound organic carbon.

Since many life cycle inventories state COD values, an eco-factor has been determined for it. If necessary, DOC can be converted into COD using the COD estimation

Tab. 48: Eco-factor for COD (chemical oxygen demand) in UBP/g COD

The eco-factors for BOD, DOC and TOC can be calculated using the general rules of thumb BOD ≈ COD, COD ≈ 3 DOC and DOC ≈ TOC, if no inventory analysis data are available for COD – see also the text regarding double counting.

	Edition 2021[15]	Q	Bemerkungen	Edition 2013
Normalisation flow (t COD/a)	37 002	B	Total runoff loads for Switzerland (VSA 2011)	37 002
Current flow (t COD/a)	37 002	B	Total runoff loads for Switzerland (VSA 2011)	37 002
Critical flow (t COD/a)	73 527	b	Derived from GSchV 2011	73 527
Weighting factor (-)	0,25			0,25
Eco-factor (UBP/g COD)	**6,8**			6,8
Eco-factor (UBP/g BOD)	6,8		Rough approximation: BOD ≈ COD	6,8
Eco-factor (UBP/g DOC)	21		Derived from the eco-factor for COD with COD ≈ 3 DOC	21
Eco-factor (UBP/g TOC)	21		Rough approximation: COD ≈ 3 DOC ≈ 3 TOC	21

Q = data quality; for explanation, see Part 2, Chapter 6

factor (in g) » 3 DOC (in g). A lower estimate for COD can also be derived from BOD, where COD (in g) = BOD (in g). If only the TOC value has been measured, this can be regarded as equivalent to DOC for the purposes of a rough approximation, or COD can be estimated as COD (in g) » 3 TOC (in g) (Brand et al. 1998).

10.4.2 Data sources

The FOEN usually surveys these parameters every five to six years. Because of the switch to GIS data, the surveying has been delayed, and new data will not be available until 2021 at the earliest.[16] The values from the 2013 edition have therefore been used.

10.4.3 Normalisation

No characterisation is performed. The total load cannot be extrapolated from the COD concentrations at the places where the large rivers flow out of Switzerland, as some of the organic substances are of natural origin and degrade to some extent relatively quickly in watercourses, which means that they do not reach the measuring stations at these runoff points.

The data collected by the VSA (2011) cover over 80% of Switzerland's inhabitants who are connected to a sewage disposal system, and thus provide a good basis for the extrapolation of organic matter emissions from wastewater treatment plants. The annual runoff loads of COD amount to 37 000 tonnes. Here too, in the absence of more recent data, the data from the 2013 edition were used.

10.4.4 Weighting

The current flow is identical to the normalisation flow, since the reduction target is also based on the total load for Switzerland.

The Waters Protection Ordinance (WPO 2011) sets out a purification capacity of 85% for dissolved organic carbon when it comes to the disposal of communal effluents discharged into bodies of water. When applied to an annual incoming load of 490 000 tonnes of COD, this results in a critical flow of about 74 000 tonnes of COD per year.

10.4.5 Eco-factors for BOD, COD, DOC and TOC

As all of these factors measure the same thing (i.e. organic carbon), care must be taken not to count them twice. It is preferable only to assess COD, for which the eco-factor has been derived directly from the current and critical flows. In inventory analyses, missing COD values can then be derived from the other values using the rule of thumb in Part 3, Section 10.4.1.

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[15] Values taken from the 2013 edition as no new measurements exist, see Section 10.4.2.

[16] Information provided orally by P. Fischer of the FOEN's Water Body Protection Section on 4 February 2020.

As no new measurements were available, the existing values were adopted and hence the eco-factor remains unchanged.

The weighting of specific impacts of persistent bioaccumulative substances is not possible with the eco-factor for COD. These substances are assessed separately (see Part 3, Section 10.12).

10.5 Heavy metals and arsenic

10.5.1 Environmental impact

Heavy metals and arsenic damage the aquatic ecosystem by accumulating in organisms, where they can cause growth impairments and metabolic disturbances. They are able to propagate extensively through the food chain.

Zinc and copper come from roof runoff and the use of pipes made of these metals to carry the drinking water supply. In addition, zinc is released through tyre wear and enters waters via road runoff. Copper is also used as a fungicide in vineyards and as a food supplement in pig rearing.

Cadmium is an ingredient of phosphorus fertilisers and pesticides. For that reason, agriculture is another source of heavy metals. Chromium arises mainly from the corrosion of chromium steel products. As the use of leaded petrol has declined and industrial effluent discharges have been cleaned up, these have now become the predominant diffuse sources of heavy metals (BUWAL 2002a).

The role of chromium(III) (Cr^{3+}-ions) in the human body is currently the subject of controversy. There is evidence that chromium(III) could play a role in the carbohydrate and fat metabolism of mammals. This evidence is currently being investigated. Earlier indications that the popular dietary supplement chromium(III) picolinate has a beneficial effect on body composition could not be confirmed in later studies. A study with hamster cells found that chromium(III) picolinate is mutagenic and can cause cancer.

The data currently available suggest that chromium deficiency is extremely unlikely to occur. Even higher doses of chromium(III) are unlikely to trigger a toxic effect, as the solubility product of chromium(III) hydroxide is extremely low (6.7 x 10–31). It is therefore probably only slightly absorbed in the human gut. In the United States, the recommended intake of chromium(III) has been reduced from 50–200 µg per day to 35 µg per day for adult men and 25 µg per day for adult women.

Chromium(VI) compounds are extremely toxic. They are mutagenic and damage DNA. They enter the body through the respiratory tract and damage the lung tissue. People chronically exposed to such compounds are at increased risk of lung cancer.[17]

Arsenic is carcinogenic to humans (IARC Group 1). It causes skin and bladder cancer in particular, but other types of cancers as well, due to chronic exposure through drinking water (IARC 1987). Arsenic arises as a by-product of metal extraction, but is also used in industrial processes (e.g. glass production and as gallium arsenide in electronic equipment). In some countries (e.g. Bangladesh and Vietnam), even natural sources can lead to concentrations in drinking water that are harmful to health (Lippmann 2000).

10.5.2 Characterisation

In the 2013 edition, heavy metals were not characterised but a weighting was derived for each individual heavy metal based on the targets of the International Commission for the Protection of the Rhine (ICPR). Heavy metals are now treated as a group, meaning that the current and critical flows are determined for the group of metals as a whole, and a weighting factor for the heavy metals group is then derived from this. The individual heavy metals are characterised with regard to their toxic damage according to USEtox version 2 (Fantke et al. 2018) – see Tab. 49 to Tab. 52. Arsenic is used as the lead substance, with the toxic impact expressed in As-equivalents/kg. For human toxicity, USEtox provides factors for carcinogenic and non-carcinogenic substances (human toxicity, cancer and non-cancer effects, recommended+interim). These are summated in DALYs[18] according to their damage to health. Toxicity factors for ecotoxic impacts are also provided, although these cannot be offset against the factors for human toxicity. Consequently, a set of eco-factors was

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[17] Salnikow, K.; Zhitkovich, A. (2008). "Genetic and Epigenetic Mechanisms in Metal Carcinogenesis and Cocarcinogenesis: Nickel, Arsenic, and Chromium". Chem. Res. Toxicol. 21 (1): 28–44. doi:10.1021/tx700198a.

[18] DALY: Disability-adjusted life year. One DALY corresponds to the loss of one year of life, or a loss of quality of life over a corresponding period, e.g. 20% disability over five years.

determined using the characterisation factors for human toxicity and the ecotoxicity factors respectively, and from these two sets the higher factor for each heavy metal was used (see Tab. 54). Eco-factors can also be derived for manganese, chromium and iron using their respective USEtox factors, even if no emission quantities or targets are known for these metals. This results in slightly overestimated eco-factors for heavy metals, given that the normalisation flow does not include the three metals manganese, chromium and iron due to a lack of corresponding data on the flows. However, this is still considered more useful than not taking them into account at all.

10.5.3 Normalisation

As a characterisation is performed, the normalisation flow now corresponds to the sum of the characterised quantities of heavy metal emissions. The normalisation flow for human toxicity corresponds to the characterised quantity of emissions of the relevant heavy metals lead, cadmium, chromium, nickel, mercury, copper, zinc and arsenic and is identical to the current flow (see Tab. 53). For the USEtox characterisation according to ecotoxicity, iron and manganese are also taken into account when deriving the normalisation flow, which again is identical to the current flow.

10.5.4 Weighting

In Weil am Rhein, heavy metal concentrations in the water are determined in accordance with NADUF guidelines (BAFU 2011b), and the heavy metal content of suspended matter is measured according to the International Commission for the Protection of the Rhine (AUE 2017). The NADUF values have been used to determine the normalisation, as these include dissolved heavy metals. In order to compensate for the occasional extreme variations in concentration from one year to another and obtain more representative values, the mean value for the years 2013 to 2017 has been used in each case (BAFU 2020d).

The following factors may account for a difference between the actual situation and the extrapolated flow:

- The total concentration of heavy metals rises with the concentration of suspended matter, since the metals accumulate there. In the Rhone, which registers comparatively high particle concentrations, concentrations of heavy metals may therefore exceed those in the Rhine.
- Between entering the water and being measured in Basel, the heavy metals undergo some degree of exchange with the sediment. Depending on the concentration ratios in the river and the sediment, net heavy metals are either dissolved or deposited.

Seven heavy metals with implications for the environment are listed in the Swiss Waters Protection Ordinance (WPO 2020). They are mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn) and nickel (Ni). The Waters Protection Ordinance sets out quality requirements for watercourses in the form of required and guideline values and for the discharge of effluent into sewers and bodies of water.

In addition, the Convention on the Protection of the Rhine (ICPR 1999), which was renewed in 1999 and signed by Switzerland, came into force in 2003. The ICPR (International Commission for the Protection of the Rhine), like the Swiss Waters Protection Ordinance, sets water quality targets in the form of concentrations limits, which include limits for heavy metals.

The ratio of the heavy metal content in the suspended solids to the target values according to AUE (2009) is substantially higher than the ratio of the total concentration of heavy metals in water to the concentration limits under the Swiss Waters Protection Ordinance. Therefore, the more stringent targets, and thus higher eco-factors based on ICPR data, are used for the weighting. To produce the weighting factor, the concentrations in the suspended solids (rather than the flows) are compared directly with each other. The data on current concentrations are taken from the 2013 to 2017 annual reports of the Rhine monitoring station at Weil am Rhein (AUE Basel-Stadt 2013a; AUE Basel-Stadt 2013b; AUE Basel-Stadt 2014a; AUE Basel-Stadt 2014b; AUE Basel-Stadt 2015a; AUE Basel-Stadt 2015b; AUE Basel-Stadt 2016a; AUE Basel-Stadt 2016b; AUE Basel-Stadt 2017b; AUE Basel-Stadt 2017a), which give the most recent figures.

The current flow for the category human toxicity therefore corresponds to the characterised quantity of emissions of the relevant metals lead, copper, cadmium and zinc and amounts to 14 700 As-eq./a (see Tab. 49).

Tab. 49: Characterisation factors according to USEtox (human toxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	DALY/kg	In As-equivalents (kg As-eq. / kg)	Current flow RUES (measured value) kg / a	Characterised quantities (As-eq. / a)
Arsenic (As)	0,0721229	1,00	12 051	12 050,95
Lead (Pb)	0,0001376	0,002	31 012	59,16
Cadmium (Cd)	0,0128527	0,18	382	67,99
Chromium (Cr)	0,0000000	0,000000008	61 109	0,00
Chromium VI (Cr VI)	0,1139507	1,58	0	n/a
Iron II (Fe II)	–	–	–	n/a
Iron III (Fe III)	–	–	–	n/a
Iron (Fe)	–	–	26 285 600	n/a
Copper (Cu)	0,0000004	0,00001	47 420	0,24
Manganese (Mn)	–	–	885 760	n/a
Nickel (Ni)	0,0013857	0,02	40 513	778,38
Mercury (Hg)	0,0501849	0,70	204	142,21
Zinc (Zn)	0,0007126	0,01	162 847	1 608,88
Total				**14 707,82**

Tab. 50: Characterisation factors according to USEtox (human toxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised critical quantities

Substance	DALY / kg	In As- equivalents (kg As-eq. / kg)	Critical flow RUES kg / a	Characterised quantities (As-eq. / a)
Arsenic (As)	0,0721229	1,00	44 794	44 793,71
Lead (Pb)	0,0001376	0,002	111 984	213,63
Cadmium (Cd)	0,0128527	0,18	1120	199,56
Chromium (Cr)	0,00000000006	0,000000008	111 984	0,00
Chromium VI (Cr VI)	0,1139507	1,58	0	n/a
Iron II (Fe II)	-	-	-	n/a
Iron III (Fe III)	-	-	-	n/a
Iron (Fe)	-		0	n/a
Copper (Cu)	0,0000004	0,00001	55 992	0,29
Manganese (Mn)	-		0	n/a
Nickel (Ni)	0,0013857	0,02	55 992	1075,79
Mercury (Hg)	0,0501849	0,70	560	389,61
Zinc (Zn)	0,0007126	0,01	223 969	2212,75
Total				**48 885,33**

The critical flow corresponds to the characterised quantity of emissions set by the targets and amounts to 48 900 As-eq./a (see Tab. 50).

The current flow for the category ecotoxicity therefore corresponds to the characterised quantity of emissions set by the relevant targets and amounts to 921,971 As-eq./a (see Tab. 51).

Tab. 51: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	PDF x m^3 x day / kg	In As-equivalents (kg As-eq. / kg)	Current flow RUES (measured value) kg / a	Characterised quantities (As-eq. / a)	Normalisation flow (As-eq. / a)
	40 291	1,00	12 051	10 784	12 051
Lead (Pb)	6 607	0,16	31 012	5085	5 085
Cadmium (Cd)	2 093 661	51,96	382	19 824	19 824
Chromium (Cr)	8 095	0,20	61 109	12 277	12 277
Chromium VI (Cr VI)	104 329	2,59	–	n/a	0
Iron II (Fe II)	13 433	0,33	–	n/a	0
Iron III (Fe III)	345 012	8,56	–	n/a	0
Iron (Fe)	241 042	5,98	26 285 600	n/a	157 253 697
Copper (Cu)	56 312	1,40	47 420	66 275	66 275
Manganese (Mn)	16 411	0,41	885 760	n/a	360 780
Nickel (Ni)	181 732	4,51	40 513	182 732	182 732
Mercury (Hg)	22 079	0,55	204	112	112
Zinc (Zn)	154 294	3,83	162 847	623 615	623 615
Total				**921 971**	**158 536 448**

Tab. 52: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised critical quantities

Substance	PDF x m^3 x day / kg	In As-equivalents (kg As-eq. / kg)	Critical flow RUES kg / a	Characterised quantities (As-eq. / a)
Arsenic (As)	40 291	1,00	44 794	44 794
Lead (Pb)	6 607	0,16	111 984	18 362
Cadmium (Cd)	2 093 661	51,96	1 120	58 191
Chromium (Cr)	8 095	0,20	111 984	22 498
Chromium VI (Cr VI)	104 329	2,59	–	n/a
Iron II (Fe II)	13 433	0,33	–	n/a
Iron III (Fe III)	345 012	8,56	–	n/a
Iron (Fe)	241 042	5,98	–	
Copper (Cu)	56 312	1,40	55 992	78 256
Manganese (Mn)	16 411	0,41	–	n/a
Nickel (Ni)	181 732	4,51	55 992	252 550
Mercury (Hg)	22 079	0,55	560	307
Zinc (Zn)	154 294	3,83	223 969	857 679
Total				**1 332 636**

Tab. 53: Eco-factors for heavy metals to water, in As-eq./a

	Human toxicity	Ecotoxicity	Q	Edition 2013
Normalisation flow (kg As-eq./a)	$1{,}47\times10^{4}$	$1{,}59\times10^{8}$	C	Data not directly comparable as a different basis was used
Current flow (kg As-eq. /a)	$1{,}47\times10^{4}$	$9{,}21\times10^{5}$	C	
Critical flow (kg As-eq. /a)	$4{,}89\times10^{4}$	$1{,}33\times10^{6}$	a	
Weighting factor (-)	0,09	0,48		
Eco-factor (UBP/ kg As-eq.)	$\mathbf{6{,}15\times10^{6}}$	$\mathbf{3{,}02 \times 10^{3}}$	–	

Q = data quality; for explanation, see Part 2, Chapter 6

Due to the large quantity of iron and manganese, the normalisation flow amounts to 158,536,488 As-eq./a.

The critical flow corresponds to the characterised quantity of emissions of the relevant metals lead, copper, cadmium and zinc and amounts to 1,332,636 As-eq./a (see Tab. 52).

10.5.5 Eco-factors for heavy metals and arsenic in surface waters

Tab. 54 below summarises the calculated eco-factors for all heavy metals in UBP per gram, with the higher factor out of the categories human toxicity and ecotoxicity being selected in each case.

Tab. 54: Eco-factors for heavy metals in surface waters in UBP/g of each heavy metal

	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
Arsenic (As)	**6200**	10 000
Lead (Pb)	**12**	4 200
Cadmium (Cd)	**1100**	250 000
Chromium (Cr)	**1**	12 000
Chromium VI (Cr VI)	**9700**	–
Iron II (Fe II)	**1**	–
Iron III (Fe III)	**26**	–
Iron (Fe)	**18**	–
Copper (Cu)	**4**	13 000
Manganese (Mn)	**1**	–
Nickel (Ni)	**120**	11 000
Mercury (Hg)	**4300**	860 000
Zinc (Zn)	**61**	6200

The new approach to characterising heavy metals based on the USEtox factors leads to significantly lower eco-factors for heavy metals in water compared with the 2013 edition. The main reason for this is that the heavy metals were no longer considered individually but grouped together, resulting in a significantly greater normalisation flow. There are also differences between the relative assessments of the various heavy metals. This is due to use of the USEtox method, which evaluates the toxic damage caused by the various heavy metals.

The new factor for iron is rather high, higher than for copper and lead. The literature seems to confirm this for at least some aquatic species (Cadmus et al. 2018). New eco-factors were introduced for oxidation states II and III. According to Didukh et al. (2017) and Udall (1962), a relatively rapid oxidation of Fe(II) to Fe(III) takes place in surface waters, which is why a distribution of 69% Fe(III) and 31% Fe(II) was assumed for the unspecified iron emissions. The factors for unspecified iron emissions to water were determined using the information in Yan et al. (2000). However, in anoxic conditions such as groundwater bodies, the reverse may very well apply (Yan et al. 2000, p. 1884).

10.6 Radioactive emissions to inland waters

10.6.1 Introduction

Emissions of radioactive substances to rivers from nuclear power plants and hospitals in Switzerland are well below statutory limits. Nevertheless, it is important to chart radioactive emissions to rivers, and they have therefore been included in the assessment since 2013.

Tab. 55: Characterisation factors for the carcinogenic potential of radioactive emissions to rivers, according to Frischknecht et al. (2000), reference element U-235

		Carcinogenic potential of radioactive elements (kBq U-235-eq./kBq)
Silver-110m	Ag-110m	0,22
Cobalt-58	Co-58	0,018
Cobalt-60	Co-60	19
Cesium-134	Cs-134	61
Cesium-137	Cs-137	74
Tritium	H-3	$1{,}91 \times 10^{-4}$
Iodine-131	I-131	0,22
Manganese-54	Mn-54	0,13
Radon-226	Ra-226	0,056
Antimony-124	Sb-124	0,35
Uranium-234	U-234	1,04
Uranium-235	U-235	1,0
Uranium-238	U-238	1,0

10.6.2 Environmental impact

Exposure to radiation transfers energy into human tissue, and in doing so, can interfere with the molecular structure. This can disturb or destroy cell functions in living organisms (somatic effects, i.e. fatal or non-fatal cancer), or it can alter the genetic code of the cells (mutagenic effects).

The characterisation factors take both of these effects into account. The impact of radiation on ecosystems is not considered here, nor are the potential impacts of accident-related releases of large quantities of radioactive substances.

10.6.3 Characterisation

The environmental impact of the emission of radioactive elements is characterised according to its carcinogenic impact on humans. Impacts on ecosystems are not considered. Uranium-235 is the reference substance. Tab. 55 lists the characterisation factors according to Frischknecht et al. (2000).

10.6.4 Normalisation

Data on emissions of radioactive substances from nuclear installations and hospitals are recorded by the Federal Office of Public Health and the Swiss Federal Nuclear Safety Inspectorate (BAG 2020; ENSI 2020). The characterisation of the corresponding nuclides as set out in Part 3, Section 10.6.2 results in a total volume of emissions for 2019 of 36.2 GBq U-235-eq. In the case of radioactive emissions to rivers, the current flow corresponds to the normalisation flow.

10.6.5 Weighting

According to the FOPH (BAG 2020), emissions from Swiss nuclear installations and hospitals in 2019 were 36.2 GBq U-235-eq.

Emission limits for radioactive substances from Swiss nuclear installations and hospitals are set for individual facilities and differ when it comes to tritium and the nuclide mixture, as they do not include tritium for nuclear installations and iodine-131 for hospitals. The emission limits correspond to those authorised for each nuclear installation. For nuclear power plants, the limit is set so that the dose for individuals in the vicinity is under 0.3 mSv/year. For the central interim storage facility in Würenlingen, the limit for the dose is 0.05 mSv/year, while for the Paul Scherrer Institute (PSI) it is 0.15 mSv/year (ENSI 2020). Effluent discharged from hospitals may not exceed the activity concentration of 1/50 of the permitted limit for iodine-131 on a weekly average basis (BAG 2020). Through the characterisation and addition of the values for all facilities, the limits are aggregated to one single value. This results in a characterised critical flow of 35.38 TBq U-235-eq. per year, which is around 1,000 times greater than the current flow.

10.6.6 Eco-factor for radioactive emissions to surface waters

The eco-factor for radioactive emissions to inland waters has decreased sharply compared with 2013. This is because emission loads are significantly lower, while the critical flow has remained almost constant.

Tab. 56: Eco-factor for radioactive emissions to rivers in UBP/GBq U-235-eq.

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (TBq U235-eq./a)	0,036	A	Emission from Swiss nuclear power plants	0,289
Current flow (TBq U235-eq./a)	0,036	A	(BAG 2020)	0,289
Critical flow (TBq U235-eq./a)	35,38	a	(BAG 2020)	36,14
Weighting factor (-)	$1{,}05\times10^{-6}$			$6{,}37\times10^{-5}$
Eco-factor (UBP/GBq U235-eq.)	**29 000**			220 000

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 57: co-factors for the discharge of radioactive isotopes into rivers, deduced from their impact potential according to Frischknecht et al. (2000)

		Carcinogenic potential of radioactive elements (kBq U-235-eq./kBq)	Eco-factor 2021 (UBP/kBq
Silver-110m	Ag-110m	0,22	**0,0063**
Cobalt-58	Co-58	0,018	**0,00053**
Cobalt-60	Co-60	19	**0,55**
Cesium-134	Cs-134	61	**1,8**
Cesium-137	Cs-137	74	**2,1**
Tritium	H-3	$1{,}91\times10^{-4}$	**0,0000055**
Iodine-131	I-131	0,22	**0,0063**
Manganese-54	Mn-54	0,13	**0,0039**
Radon-226	Ra-226	0,056	**0,0016**
Antimony-124	Sb-124	0,35	**0,010**
Uranium-234	U-234	1,04	**0,030**
Uranium-235	U-235	1,0	**0,029**
Uranium-238	U-238	1,0	**0,029**
Radioactive species, nuclides, unspecified	*	13	**0,37**
Radioactive species, alpha-emitters	*	0,014	**0,00039**

* explanation, see Part 3, Section 10.6.8

10.6.7 Eco-factors for individual isotopes

Using the characterisation described in Part 3, Section 10.6.2, it is possible to calculate eco-factors for selected isotopes. These are listed in Tab. 57. They apply to the load of these substances discharged into rivers. Because of the way these eco-factors have been derived, they may not be used for discharges into other compartments.

10.6.8 Guidelines for using UVEK LC Data DQRv2:2022

In life cycle inventories on nuclear energy, emissions of individual nuclides are indicated in summary form. The composition of the ‘radioactive species, nuclides, unspecified’ mixture is specified in the ecoinvent report (Dones 2007, p. 209). The ‘radioactive species, alpha-emitters’ mixture includes the emissions of alpha emitters from nuclear power plants. The composition of these mixtures is determined on the basis of available data on radioactive emissions from European nuclear power plants (Van der Stricht & Janssens 2010).

The characterisation and the eco-factors for the summary parameter were averaged based on the eco-factors of emitted single nuclides. The resulting eco-factors of the mixtures are conservative, as not all single nuclides are characterised. This primarily concerns the alpha-emitter mixture.

10.7 Radioactive emissions to the Sea

10.7.1 Introduction

The reason why radioactive emissions to the Sea are assessed lies in the OSPAR Conventions for the protection of the North Sea. The OSPAR member states have agreed to substantially reduce the loads of radioactive substances from reprocessing plants that end up in the Irish and North Seas.

The eco-factor is derived on the basis of emissions occurring outside Switzerland. The reduction targets are based on international agreements that Switzerland supports.

The moratorium on reprocessing spent fuel elements, which came into effect on 1 July 2006, has no influence on the scarcity formula produced here. This is an exceptional situation, which will last for a limited period. The cessation of reprocessing and its associated emissions of radioactive elements to seas will nevertheless have an impact on future inventory analyses of electricity generation at Swiss nuclear power plants. Indeed, the inventory analyses of French nuclear energy, for instance, remain unaffected, in line with France's strategy for the disposal of spent fuel elements. Emissions generated by French nuclear energy are still relevant to Switzerland because of the electricity Switzerland imports from France.

10.7.2 Environmental impact

Exposure to radiation transfers energy into human tissue, and in doing so, can interfere with the molecular structure. This can disturb or destroy cell functions in living organisms (somatic effects, i.e. fatal or non-fatal cancer), or it can alter the genetic code of the cells (mutagenic effects).

The characterisation factors take both of these effects into account. The impact of radiation on ecosystems is not considered here, nor are the potential impacts of accident-related releases of large quantities of radioactive substances.

10.7.3 Characterisation

The environmental impact of the emission of radioactive elements is characterised according to its carcinogenic impact on humans. Impacts on ecosystems are not considered. The reduction targets for discharges into the Irish and North Seas are stipulated under the OSPAR Convention. Therefore, the characterisation values of pollutant discharges into seas are of interest here. Carbon-14 has been chosen as the reference substance. The characterisation factors are determined on the basis of Frischknecht et al. (2000) and listed in Tab. 58.

Tab. 58: Characterisation factors for the carcinogenic potential of radioactive emissions to the Sea, according to Frischknecht et al. (2000), reference element C-14

		Carcinogenic potential of radioactive elements (kBq C-14-eq. /kBq)
Americum-241	Am-241	26
Carbon-14	C-14	1,0
Curium-alpha	Cm alpha	47
Cobalt-60	Co-60	0,33
Cesium-134	Cs-134	0,067
Cesium-137	Cs-137	0,067
Tritium	H-3	$5{,}79\times10^{-5}$
Iodine-129	I-129	84
Plutonium-alpha	Pu alpha	6,1
Ruthenium-106	Ru-106	0,12
Antimony-125	Sb-125	0,012
Strontium-90	Sr-90	0,0033
Uranium-234	U-234	0,019
Uranium-235	U-235	0,021
Uranium-238	U-238	0,019

10.7.4 Normalisation

The annual emissions classified by isotopes are documented by the OSPAR Commission (2014, 2015, 2016, 2017b). The radionuclides listed there are assigned characterisation factors in accordance with Tab. 58. The characterised quantity of emissions amounts to an average of 167 TBq C-14-eq./a for the years 2014 to 2017.

Switzerland's share of Europe's electricity production from nuclear power plants is around 2.4% (BFE 2018; ENTSO-E 2018). This percentage is used for normalisation, resulting in a normalisation value of 4.02 TBq C-14-eq./a.

At the two reprocessing plants of La Hague and Sellafield, around 2,500 tonnes of spent fuel rods are reprocessed annually (Select Committee on Science and Technology 1999). As the OSPAR Convention stipulates the target in absolute terms, the quantity of reprocessed spent fuel rods is not relevant to the calculation.

10.7.5 Weighting

OSPAR targets are defined separately for alpha and beta emitters (see next paragraph). The two separate targets have been amalgamated here into a single goal by means of characterisation. As the French reprocessing plant at La Hague does not set any quantitative targets, it is assumed that the Sellafield target is also applicable to the French facility. Based on this assumption, it is sufficient to look at the emissions from the Sellafield reprocessing plant and compare them with its target to determine the weighting factor.

The emissions from the Sellafield plant fluctuate from year to year (see OSPAR Commission 2008a, 2009, 2010, 2011, 2014, 2015, 2016, 2017b). In order to exclude random val-

Tab. 59: Eco-factor for radioactive emission to the Sea in UBP/kBq C-14-eq.

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (TBq C-14-eq./a)	4,02	C		3,85
Current flow (TBq C-14-eq./a)	36,5	B	Four-year average (2014-2017) of alpha and beta emitter emissions from the Sellafield plant	26,0
Critical flow (TBq C-14-eq./a)	46,6	b	Characterised emissions target for 2020 for the Sellafield plant (OSPAR Convention 2003)	46,6
Weighting factor (-)	0,61			0,31
Eco-factor (UBP/kBq C-14-eq.)	**150**			81

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 60: Eco-factors for the discharge of radioactive isotopes into the Sea, deduced from their impact potential according to Frischknecht et al. (2000)

		Carcinogenic potential of radioactive elements (kBq C-14-eq./kBq)	Eco-factor 2021 (UBP/kBq
Americum-241	Am-241	25,8	**3900**
Carbon-14	C-14	1	**150**
Curium-alpha	Cm alpha	47,5	**7200**
Cobalt-60	Co-60	0,325	**50**
Cesium-134	Cs-134	0,066	**10**
Cesium-137	Cs-137	0,066	**10**
Tritium	H-3	$5{,}75\times10^{-5}$	**0,0088**
Iodine-129	I-129	83,3	**13 000**
Plutonium-alpha	Pu alpha	6,17	**940**
Ruthenium-106	Ru-106	0,117	**18**
Antimony-125	Sb-125	0,0125	**2**
Strontium-90	Sr-90	0,0033	**0,5**
Uranium-234	U-234	0,0192	**3**
Uranium-235	U-235	0,0208	**3**
Uranium-238	U-238	0,0192	**3**
Actinides, radioactive, unspecified	*	10,25	**1500**
Radioactive species, Nuclides, unspecified	*	4,06	**1200**

* For explanation, see Part 3, Section 10.7.8

ues, a sliding average over four years (2014–17) is used. This four-year average value of the current emissions from Sellafield amounts to 36.5 TBq C-14-eq. (1.42 TBq C-14-eq. alpha and 35.0 TBq C-14-eq. beta emitters).

The OSPAR decision in 2000 aims to prevent pollution of the North Sea from ionising radiation by substantially reducing the disposal, emission and loss of radioactive substances. The goal is to reduce the concentrations of natural isotopes in the seas to background pollution levels and synthetic isotopes to almost zero (OSPAR Convention 2000).

This general demand was put in more concrete terms in a progress report (OSPAR Convention 2003, p. 15). Whereas no specific targets have been set for France, the emission targets for the British plant have been concisely defined. By 2020, the emissions from alpha emitters were to be reduced to 0.2 TBq per year, and the beta emitters to 50 TBq per year (OSPAR Convention 2003). This results in a characterised quantity of emissions totalling 46.6 TBq C-14-eq. (2.32 TBq C-14-eq. alpha and 44.3 TBq C-14-eq. beta emitters; see Frischknecht & Büsser Knöpfel 2013a).

10.7.6 Eco-factor for radioactive emissions to the Sea

The eco-factor for radioactive emissions to the Sea is almost double that in 2013. This is owing to the characterised volume of radioactive isotopes emitted into the sea. Although the total quantity is still below the emissions target (critical flow), it has increased compared with the mean value of the total quantity in 2006–09, which was used in the 2013 edition. The main driver of this increase is a substantial rise in the quantities of radioactive iodine (I-129) emitted in comparison with previous years.

10.7.7 Eco-factors for individual isotopes

Using the characterisation described in Part 3, Section 10.7.3, it is possible to calculate eco-factors for selected isotopes. These are listed in Tab. 60. They apply to the load of these substances that is discharged into seas.

10.7.8 Guidelines for using UVEK LCI Data DQRv2:2022

With the exception of tritium, caesium-134 and 137 and strontium-90, emissions of radioactive isotopes are given only in summary form in life cycle inventories on nuclear energy. The alpha emitters (Am-241, Cm-alpha, Pu-alpha and uranium) are listed under 'actinides, radioactive, unspecified'. Cobalt, caesium, antimony, strontium and other isotopes are listed under 'radioactive species, nuclides, unspecified'.

Isotopes with very different impacts are aggregated within these two groups. The eco-factors for both of these aggregate parameters were averaged on the basis of the eco-factors for the isotopes emitted, whereby each individual eco-factor was weighted with its three-year average value for the emissions from Sellafield plus La Hague.

In the case of actinides, plutonium determines the eco-factor, whereas for the other substances, the emission ratio of iodine-129 to the other isotopes is decisive in deducing the level of the average eco-factor.

10.8 Oil emissions to the Sea

10.8.1 Environmental impact

The accident that occurred at the oil platform in the Gulf of Mexico in 2010 and the resulting oil spill brought the issue of crude oil pollution in the sea back into the spotlight. However, oil is also discharged into the sea during the normal operations of offshore platforms in the oil and gas industry, as well as by tankers.

In seas, oil sticks to seabird plumage and animal fur, causing animals to drown or freeze to death. It sticks to coral, plants (leaves and roots) and fish gills. It impedes or inhib-

Tab. 61: Estimated oil emissions to the sea by all OSPAR members

Figures in tonnes per year

	Oil emissions (t/a)	Notes
Offshore platforms	9377	(OSPAR Commission 2019)
Ships	184 373	GESAMP (2007), EUROSTAT (2017) and UNCTAD
Other sources (refineries near the sea, recreational watercraft, etc.)	44 054	(GESAMP 2007)
Total	**237 804**	

its photosynthesis and suffocates fish. Oil is acutely toxic when swallowed, inhaled or filtered (mussels, shrimp). Individual components of oil can also trigger allergic reactions in humans (rashes, burns) if they come into contact with skin. Fluid components (benzene, toluene, etc.) can irritate the eyes and respiratory tracts and cause nausea and headaches upon inhalation. Lipophilic components accumulate in the food chain and can, for instance, be absorbed by fish and humans when consumed (Kienle & Bryner 2010).

10.8.2 Normalisation

No characterisation is performed. The normalisation flow is composed of the oil emissions of offshore platforms, tankers and other sources (refineries near the sea, recreational watercraft, etc.) for which Switzerland is responsible, i.e. in proportion to its share of consumption. Emissions resulting from operations and some unforeseeable events are taken into account in the normalisation flow.

The OSPAR Commission (OSPAR Commission 2019) reports on the oil emissions of offshore platforms in the North-East Atlantic at regular intervals. In 2017, a total of around 9,400 tonnes of oil were emitted into the sea, with accidents accounting for less than 5%. In 2007, GESAMP (2007) carried out a survey of global oil emissions from shipping. In the absence of more recent data, this survey and the development in goods volumes handled at ports in the OSPAR region (approximately 3.15 billion tonnes in 2018 (*https://ec.europa.eu/eurostat/web/transport/overview*) were used to estimate the oil load at 184,000 tonnes. 'Other sources' in the OSPAR region emitted 44,000 tonnes of oil (OSPAR Commission 2019). This results in a total of almost 240,000 tonnes of oil emitted by various sources in the OSPAR region. Tab. 58 shows the oil emissions caused by OSPAR members.

Switzerland's share in the OSPAR members' total demand for crude oil is 2.3%. Thus, the normalisation flow is 5,467 tonnes.

10.8.3 Weighting

The OSPAR Commission's target for the reduction of oil emissions through produced water from oil platforms is used for the weighting. This flow includes only part of the various oil emissions used for the normalisation flow. However, there are no targets for total oil emissions that can be used for the weighting.

The current flow amounts to 9,377 tonnes for 2017 (OSPAR Commission 2019). This value, as well as the target (see below), is based on the oil emissions from produced water, which is discharged into the sea when crude oil is produced on offshore platforms.

Switzerland is a Contracting Party to the OSPAR Convention and therefore supports its decisions, recommendations and agreements. The OSPAR Commission set the target of reducing oil emissions from produced water by 15% under 2000 emission levels (OSPAR Convention 2001). According to the calculations of the OSPAR Commission (2003), the oil emissions from produced water amounted to 8,700 tonnes in 2000. Thus, a 15% reduction means a critical annual load of 7,403 tonnes of oil.

Tab. 62: Eco-factor for oil emissions to the sea in UBP/g oil

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t oil/a)	5467	B	Emissionen aus Offshore Plattformen, Schiffen und weiteren Quellen bezogen auf die Schweiz	6210
Current flow (t oil/a)	9377	A	Emissionen mittels produziertem Wasser aller OSPAR-Staaten	9596
Critical flow (t oil/a)	7403	a	Reduktion der Ölemissionen im produzierten Wasser um 15 % im Vergleich zum Jahr 2000 (8709 Tonnen)	7403
Weighting factor (-)	1,60			1,68
Eco-factor (UBP/g oil)	**290**			270

Q = data quality; for explanation, see Part 2, Chapter 6

10.8.4 Eco-factor for oil emissions to the sea

Tab. 62 shows the resulting eco-factor for oil emissions to the sea due to shipping and oil production.

The eco-factor has increased slightly from the previous version of the method.

This eco-factor is applied to all oil emissions to the sea. However, it should not be used for oil emissions to other bodies of water (lakes, rivers, etc.) due to its derivation method.

10.9 Adsorbable organic halogenated compounds (AOX)

10.9.1 Environmental impact

Adsorbable organic halogenated compounds (AOX) are materials of both anthropogenic and natural origin, such as chlorinated non-aromatic hydrocarbons (e.g. chloroform), chlorinated aromatic hydrocarbons, polychlorinated biphenyls (PCBs) and certain pesticides.

The toxicity and environmental impact of the compounds in the AOX group varies widely. One criterion for toxicity is the ability of the substance to accumulate in an organism. This is possible for fat-soluble substances. In the previous version (2013 edition), the eco-factor was set in relation to chlorine, as a higher chlorine content increases fat solubility and thus bioavailability. In order to better map the toxic properties of AOX, a characterisation of the substances with USEtox (Fantke et al. 2018) was performed as part of this update. Chloroform is also assessed within this group of substances, rather than a separate factor for chloroform being derived as in the 2013 edition. One of the reasons why this approach makes sense now is that AOX and chloroform pollution of surface waters in Switzerland has fallen significantly in recent years and lost much of its importance in water protection efforts. Furthermore, AOX is no longer a parameter in the Rhine substance list maintained by the International Commission for the Protection of the Rhine. A separate eco-factor is derived for persistent organic pollutants (Part 3, Section 10.12). These too have seen a marked drop in pollution in the intervening period due to bans on their use.

10.9.2 Characterisation

The various substances are characterised by their toxic properties using the USEtox method. The characterisation factors for ecotoxic impact are used. For ease of understanding, the relative toxic properties have been given as

Tab. 63: Characterisation factors for AOX

	Characterisation factors	
	Chloroform ($HCCl_3$) equiv.	**USEtox PDF x m^3 x day/ kg emitted**
AOX	9,37	
Chlorinated solvents, unspecified	9,37	
Trichlorofluoromethane	9,37	
1,1-dichlorethene	0,76	15,6
Dichloromethane	0,35	7,3
trans-1,2-dichloroethene	0,49	10,0
1,1- dichloroethane	0,22	4,6
cis-1,2- dichloroethene	0,49	10,0
Dichlorofluoromethane	9,37	
Chloroform	1,00	20,6
1,1,1-trichloroethane	0,53	10,8
Tetrachloromethane	1,59	32,7
1,2-dichloroethane	0,37	7,6
Trichloroethene	2,02	41,5
1,2-dichloropropane	1,11	22,9
Bromodichloromethane	0,52	10,7
trans-1,3-dichloropropene	17,30	355,9
cis-1,3-dichloropropene	17,30	355,9
1,1,2-trichloroethane	1,06	21,7
Tetrachloroethene	14,75	303,4
Dibromochloromethane	2,64	54,2
Chlorobenzene	12,19	250,8
Bromoform	4,60	94,7
1,1,2,2-tetrachloroethane	7,87	161,8
1,3-dichlorobenzene	12,11	249,2
1,4-dichlorobenzene	23,89	491,5
1,2-dichlorobenzene	14,26	293,3
Hexachloroethane	45,63	938,8
Chloroethene	9,37	
1,3,5-trichlorobenzene	42,28	869,9
1,2,4-trichlorobenzene	53,48	1100,3
Hexachlorobutadiene	186,12	3829,0
1,2,3-trichlorobenzene	180,95	3722,7

chloroform equivalents. The characterisation factor for the aggregate parameter AOX was determined from the proportions of the various substances in the Rhine according to measurements taken at the Rhine monitoring station (RUES) in 2019. This value was also used for those substances for which no USEtox factor was found (Tab. 63). In addition, it was possible to determine the total amount of chlorine in these organic compounds in the Rhine from the measured values. This comes to 15.3 t Cl^- per year. In the 2013 edition, the AOX were indicated as Cl^-. The following applies to the composition in the Rhine at Basel: 1 g AOX as Cl^- corresponds to 16,9 g chloroform equivalents.

10.9.3 Normalisation

The mean of the measurements at the Rhine monitoring station in Weil am Rhein, weighted with the characterisation factors (AUE Basel-Stadt 2020), was used for normalisation. Almost all of the substances listed in Tab. 63 are measured daily at this monitoring station. Those not measured are the aggregate parameter AOX, the unspecified chlorinated solvents, chloromethane and dichlorofluoromethane. The values of many measurements were below the detection limit. For the calculation of the normalisation flow, the quantities for these measurements were assumed to be 20% below the detection limit.

10.9.4 Weighting

The current flow corresponds to the amount of chloroform extrapolated for Switzerland, as the quality target for chloroform is used as the target value.

The Swiss Waters Protection Ordinance (WPO 2020) contains various regulations concerning AOX. One of these stipulates that a limit of 10 g/l applies in groundwater used for drinking water. However, there is no quality target in Switzerland for AOX concentrations in surface waters.

Nevertheless, the International Association of Waterworks in the Rhine Basin (IAWR) has set the following target values for surface waters: 25 g/l for AOX and 0.6 g/l for chloroform (IAWR 2003). This target meets the requirements of the drinking water supply. This recommendation is in no way legally binding. The eco-factors were determined for both target values. The chloroform target was found to result in higher eco-factors, so this was used to determine the eco-factors. If this quality target is taken as the basis for determining a critical flow for chloroform ($HCCl_3$) for Switzerland, it results in a critical chloroform flow of approximately 1 t/a. This corresponds to approximately 370 t $HCCl_3$-eq./a. Due to degradability, this is a lower limit.

10.9.5 Eco-factor for AOX

The AOX group is made up of various individual substances with widely differing environmental impacts. The characterisation according to USEtox was therefore used to determine eco-factors for the individual substances. The eco-factor for AOX represents an average composition in the Rhine. It can be used if only this aggregate parameter is available. Persistent organic substances that also belong to the AOX group are assessed in the section on POPs (persistent organic pollutants, Part 3, Section 10.12).

When comparing the eco-factors in the 2021 and 2013 editions, it should be noted that they have different units. The following applies to AOX composition in the Rhine: 1 g AOX as Cl^- corresponds to 16.9 g $CHCl_3$-eq. Accordingly, the new

Tab. 64: Eco-factor for AOX in UBP/g $CHCl_3$-equivalents

	Edition 2021	Q	Bemerkungen	Edition 2013	Bemerkungen
Normalisation flow (t $CHCl_3$ Äq./a)	370	C	RUES 2019 measurements extrapolated for CH	250	Normalisation flow (t Cl^-/a)
Current flow (t $CHCl_3$/a)	0,97	C	RUES 2019 measurements	250	Current flow (t Cl^-/a)
Critical flow (t $CHCl_3$/a)	28,0	a	Quality target for surface waters (IAWR, 2003)	1200	Critical flow (t Cl^-/a)
Weighting factor (–)	0,0012			0,043	Weighting factor (–)
Eco-factor (UBP/g $CHCl_3$ Äq.)	**3,20**		54 (UBP/g AOX as Cl^-)	170	Eco-factor (UBP/g AOX as Cl^-)

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 65: Eco-factor for various chlorinated substances in UBP/g

	CAS	Characterisation (g CHCl$_3$/g)	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
AOX as Cl$^-$		16,90	**54,0**	170
Benzene, chloro-	000108-90-7	12,20	**39,0**	54
Chlorinated solvents, unspecified as Cl$^-$		16,90	**54,0**	170
Chloroform	000067-66-3	1,00	**(3,2)***	(150)*
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	0,53	**1,7**	140
Ethane, 1,2-dichloro-	000107-06-2	0,37	**(1,2)***	(120)*
Ethane, hexachloro-	000067-72-1	45,60	**150,0**	150
Ethene, chloro-	000075-01-4	16,90	**54,0**	97
Ethene, tetrachloro-	000127-18-4	14,70	**(47,0)***	(150)*
Ethene, trichloro-	000079-01-6	2,02	**(6,5)***	140
Methane, dichloro-, HCC-30	000075-09-2	0,36	**(1,1)***	140
Methan, dichlorfluor-, HCFC-21	000075-43-4	16,90	**54,0**	120
Methane, tetrachloro-, CFC-10	000075-43-4	1,59	**5,1**	120
1,1-dichloroethene	0000075-35-4	0,76	**2,4**	–
1,1,1-trichloroethane	0000071-55-6	0,53	**1,7**	–
Trichloroethene	0000079-01-6	2,02	**6,5**	–
1,2-dichloropropane	0000078-87-5	1,11	**3,6**	–
1,1,2,2-tetrachloroethane	0000079-34-5	7,87	**(25,0)***	
1,2-dichlorobenzene	0000095-50-1	14,30	**46,0**	
Hexachloroethane	0000067-72-1	45,60	**150,0**	
1,2,4-trichlorobenzene	0000120-82-1	53,50	**170,00**	
1,2,3-trichlorobenzene	0000087-61-6	181,00	**580,00**	

Derivation using POPs (see Part 3, Section 10.12) results in higher factors

eco-factor is around three times smaller than that in the 2013 edition. This also reflects the fact that AOX are no longer a major problem in bodies of water.

10.9.6 Eco-factor for individual chlorinated substances

An eco-factor is derived for individual AOX substances contained in the ecoinvent version 3 database, using the USEtox characterisation (Tab. 65).

10.10 Polycyclic aromatic hydrocarbons (PAHs)

10.10.1 Environmental impact

Polycyclic aromatic hydrocarbons (PAHs) is the term used for a group of different compounds. PAHs have some carcinogenic effect in mammals. They occur mainly in suspended matter. For that reason, the PAH concentration is dependent upon the concentration of suspended matter in bodies of water. Their sources are combustion processes and runoff from roads. The most common PAHs (including CAS numbers and synonyms) are listed in A3.

10.10.2 Normalisation

A characterisation is not performed. The calculation of Switzerland's total discharge into bodies of water is extrapolated from the concentration in the Rhine at the Weil am Rhein monitoring station. Since 2007, the Weil am Rhein monitoring station has been taking readings for 16 PAHs[19] (AUE Basel-Stadt 2020). In most cas-

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[19] Acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, benzo(a) pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd) pyrene, naphthalene, phenanthrene, pyrene.

es, the PAH concentrations fall under the detection limit and can only be determined in individual samples. Every year, 13 samples are taken. For the purposes of establishing a mean value, PAH concentrations that fall under the detection limit equal zero. A mean of the measured values from 2019 is used, resulting in a load of 515 kg/a for the Rhine. Extrapolated to the Swiss discharge of 47.5 billion m^3/a, this results in a load for Switzerland of 744 kg/a.

10.10.3 Weighting

The weighting factor is determined from the concentration readings and the target values. The measured concentration of PAHs amounts to 0.0119 µg/l. The ICPR target (ICPR 2011) is set at 0.1 µg/l and is therefore substantially higher.

10.10.4 Eco-factor for PAHs

The newly derived eco-factor is somewhat higher than in the 2013 edition. This is primarily due to the higher concentration readings in 2019.

There are insufficient data available for a characterisation of individual PAHs. That is why individual substances are assessed with the same eco-factor. For those PAHs that are also classed as persistent organic pollutants (POPs), the eco-factor of each PAH was compared with that calculated for the same substance as a POP. The higher value was then used. A3 has a non-exhaustive list of other PAH substances.

10.10.5 Benzo(a)pyrene (BaP)

Benzo(a)pyrene (BaP) belongs to the PAH group (see Part 3, Section 10.10). BaP is not produced commercially, but is nevertheless widespread, as it is formed in the incomplete combustion of organic material, e.g. in furnaces and engines, and also in cigarettes. The carcinogenicity of BaP has long been proven in experiments on animals, and is probably the case in humans too (IARC Group 2A, EPA 2006; IARC 1983; UGZ 2003).

Sources relevant to bodies of water are wood preservatives containing creosote, which is used on railway sleepers, for example. Creosote contains benzo(a)pyrene, which is washed out over time and enters bodies of water. The Chemical Risk Reduction Ordinance (ORRChem) now prohibits the use of creosote in wood preservatives for domestic purposes. However, it is permitted for commercial use, provided that the benzo(a)pyrene content is less than 50 mg/kg.

Benzo(a)pyrene was already assessed as part of the POPs in the 2013 edition (see Part 3, Section 10.12.6), as this resulted in a higher eco-factor for benzo(a)pyrene than assessing it as an individual substance. The current version therefore also derives the eco-factor for benzo(a)pyrene in the POPs group.

Tab. 66: Eco-factor for PAHs in UBP/g PAHs

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (kg PAH/a)	744	B		328
Current concentration (µg PAH /l)	0,0119	B	Calculation from concentration readings (AUE 2007, 2008, 2009, 2010)	0,0068
Critical concentration (µg PAH /l)	0,1	a	Target for surface waters (ICPR 2009)	0,1
Weighting factor (–)	0,0142			0,0047
Eco-factor (UBP/g PAH)	**19 000**			14 000

Q = data quality; for explanation, see Part 2, Chapter 6

10.11 Endocrine disruptors

10.11.1 Environmental impact

Endocrine disruptors are hormonally active exogenous substances that attack and disrupt one of the various hormone systems of humans and animals. Hormones are chemical messengers between tissues and cells that regulate processes in the body. Sex hormones play a very important role in reproduction and the development of an organism. Hormones are already effective in very small concentrations (BUWAL 1999; SNSF 2002). In humans especially, substances that interfere with the reproductive endocrine systems are linked to developmental abnormalities of embryos in the womb, reduced fertility, and breast, testicular and prostate cancer. Fertility disorders have been proven in numerous animal species – both aquatic and terrestrial (BUWAL 1999; SNSF 2002). There are also indications that elevated amounts of endocrine disruptors (particularly PCBs) in otters' prey have led to reproductive problems that have made the long-term survival of this species in Switzerland impossible (BUWAL 1999).

Endocrine substances can operate in two ways:

1. They bind to hormone receptors and so imitate (or impede) the effect of the body's own hormones.
2. They disrupt the production or breakdown of the body's own hormones or inhibit their transportation.

Female and male sex hormones (oestrogen and androgen) can attack the reproductive endocrine system and potentially cause oestrogenous and androgenous effects, as well as anti-oestrogenous and anti-androgenous effects (BUWAL 1999).

In humans, endocrine disruptors are principally absorbed through the digestive tract, the skin or the lungs. Aquatic organisms absorb them mainly from the water. As certain types of hormone receptors occur throughout the animal kingdom, a very large number of species can be affected by a single endocrine disruptor (SNSF 2002).

Concentrations of endocrine disruptors have been found particularly close to the water discharge points of sewage treatment plants that are high enough to trigger oestrogenous (feminising) effects in male fish (BUWAL 1999).

Hormonal effects have been proven in the case of the following substances and substance groups (Nies et al. 2017):

- natural (e.g. 17β-estradiol, estrone) and synthetic oestrogens (e.g. 17α-ethinylestradiol)
- phyto and myco-oestrogens (e.g. isoflavones)
- alkylphenol polyethoxylates (APEOs) and degradation products (e.g. nonylphenol, octylphenol)
- various pesticides: organochlorine compounds, dithiocarbamates, triazole compounds (e.g. DDT, methoxychlor, lindane, kepone, thiram, amitrole, zineb)
- certain industrial chemicals used in plastics (e.g. PCBs, bisphenol A, octamethylcyclotetrasiloxane)
- certain phthalates that are or were used as plasticisers in plastics, among other uses (e.g. benzyl butyl phthalate (BBP), dibutyl phthalate (DBP), bis(2-ethylhexyl) phthalate (DEHP))
- certain fragrances (e.g. nitrified musk compounds)
- various polychlorinated dibenzo-p-dioxins and furans (PCDDs/PCDFs)
- organotin compounds used in antifouling ship paints, among other uses (e.g. tributyltin (TBT) and triphenyltin (TPT))
- benzophenones as UV filter substances in sun creams (e.g. benzophenone 1 and 2)
- parabens used as preservatives in cosmetics and pharmaceuticals (e.g. butylparaben, methylparaben)

It should be noted here that many of the chemicals currently on the market have not been tested for effects of this type.

10.11.2 Characterisation

For the characterisation, the USEtox ecotoxicity factor was considered and set in relation to 17β-estradiol (abbreviation E2). For other endocrine disruptors for which a USEtox value was not available, the oestrogenic potential according to Rutishauser et al. (2004) was used. This work lists the oestrogenic potential of several endocrine disruptors. This figure describes the strength of the impact of an endocrine disruptor in relation to 17β-estradiol (abbreviation E2). The equivalence factors were determined by using YES (yeast estrogen screening), as other methods can easily produce slightly inaccurate factors. The YES procedure is well accepted in scientific circles.

For substances where both the Rutishauser oestrogenic potential and USEtox values were available, the higher characterisation factor was used in each case.

The characterisation factors are listed in Tab. 68.

10.11.3 Normalisation

The average quantity of endocrine disruptors from anthropogenic sources, which are discharged directly into surface waters through the runoff from sewage treatment plants, amounts to 1 µg E2-equivalent (BAFU 2009a) per inhabitant and day. This value is based on representative measurements in Swiss surface waters and a substance model for the whole of Switzerland (Ort et al. 2007). With a population of 8.57 million (BFS 2019), this results in an annual load of 3.1 kg of E2-equivalents for Switzerland. Since not all endocrine disruptors were measured in the substance modelling, the annual load is likely to be an underestimate.

10.11.4 Weighting

As the critical flow target refers to the whole of Switzerland, the current flow is identical to the normalisation, i.e. 3.1 kg E2-eq./a.

Statutory limits or required values for an endocrine disruptor aggregate parameter do not yet exist. In accordance with the proposal for an EU directive, an annual average concentration of 0.4 ng E2/l should not be exceeded in inland waters (European Commission 2018). This value, taken in conjunction with Switzerland's total discharge of 47.5 billion m^3/a, results in a critical flow of 19.0 kg E2-eq./a.

10.11.5 Eco-factor for endocrine disruptors

The current flow is almost unchanged from the 2013 edition. The slight increase can be explained solely by the increase in population. Overall, the newly derived eco-factor is therefore about 10% higher than the previous one.

10.11.6 Eco-factor for individual endocrine disruptors

The characterisation method using USEtox described in Part 3, Section 10.11.2 is used below to calculate other eco-factors for individual endocrine disruptors. The eco-factor in Tab. 67 serves as a starting point.

Tab. 67: Eco-factor for endocrine disruptors in UBP/g E2-eq

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (kg E2-eq./a)	3,1	C		2,9
Current flow (kg E2-eq./a)	3,1	C	Based on measurements in surface waters and substance flow models (BAFU 2009a)	2,9
Critical flow (kg E2-eq./a)	19,0	a	Recommended environmental quality standard for water bodies (European Commission, 2018)	19,2
Weighting factor (–)	0,026			0,022
Eco-factor (UBP/g E2-eq)	**$8{,}7\times10^6$**		E2 = 17β-oestradiol	$7{,}8\times10^6$

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 68: Eco-factors of individual endocrine disruptors in UBP/g of the substance, calculated using oestrogenic potential as the characterisation factor

Substance	Characterisation factor (kg E2-eq.-/kg) by USEtox	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g
3,4-dichloroaniline	$4,66\times10^{-5}$	$4,0\times10^{2}$	
Benzyl-n-butylphthalate	$2,52\times10^{-5}$	$2,2\times10^{2}$	
Bisphenol A	$3,72\times10^{-5}$	$3,2\times10^{2}$	$9,6\times10^{2}$
Di(2-ethylhexyl)phthalate (DEHP)	$1,43\times10^{-6}$	$1,2\times10^{1}$	
Diethyl phthalate (DEP)	$1,88\times10^{-6}$	$1,6\times10^{1}$	
Dimethyl phthalate (DMP)	$7,43\times10^{-7}$	$6,4\times10^{0}$	
E1 estrone	$1,05\times10^{-4}$	$9,1\times10^{2}$	$3,3\times10^{6}$
E2 estradiol	$1,00\times10^{0}$	$8,7\times10^{6}$	$8,7\times10^{6}$
E2-Val estradiol valerate	$2,10\times10^{-1}$	$1,8\times10^{6}$	$1,8\times10^{6}$
E3 estriol	$2,40\times10^{-3}$	$2,1\times10^{4}$	
EE2 ethinylestradiol	$1,40\times10^{-2}$	$1,2\times10^{5}$	$1,0\times10^{7}$
Ethylene thiourea	$9,39\times10^{-8}$	$8,2\times10^{-1}$	
Fentin acetate	$1,56\times10^{-1}$	$1,4\times10^{6}$	
Hexachlorobenzene	$4,56\times10^{-4}$	$4,0\times10^{3}$	
Hydroxybenzoic acid	$9,56\times10^{-7}$	$8,3\times10^{0}$	
Mestranol MES	$1,30\times10^{-2}$	$1,1\times10^{5}$	$1,1\times10^{5}$
Methyl tert-butyl ether	$2,96\times10^{-8}$	$2,6\times10^{-1}$	
Nonylphenol	$7,14\times10^{-5}$	$6,2\times10^{2}$	$2,2\times10^{2}$
Octamethylcyclotetrasiloxane	$2,39\times10^{-3}$	$2,1\times10^{4}$	
Octylphenol	$7,80\times10^{-6}$	$6,8\times10^{1}$	$6,8\times10^{1}$
Pentachlorophenol	$4,03\times10^{-4}$	$3,5\times10^{3}$	
Resorcinol	$1,68\times10^{-6}$	$1,5\times10^{1}$	
Styrene	$8,25\times10^{-7}$	$7,2\times10^{0}$	
Tetrabutyltin	$8,76\times10^{-7}$	$7,6\times10^{0}$	
Tetramethylbutylphenol	$1,55\times10^{-4}$	$1,3\times10^{3}$	
Tributylstannane	$6,07\times10^{-4}$	$5,3\times10^{3}$	
Triclosan	$5,88\times10^{-4}$	$5,1\times10^{3}$	
Trifluralin	$4,79\times10^{-4}$	$4,2\times10^{3}$	
Tripropyltin chloride	$6,83\times10^{-2}$	$5,9\times10^{5}$	

10.12 Persistent organic pollutants (POPs)

10.12.1 Preliminary remark

For the 2013 edition, the procedure for assessing persistent organic pollutants (POPs) in the ecological scarcity method was developed in close collaboration with the Safety and Environmental Technology Group[20] at ETH Zurich. The scientific bases and the characterisation factors were quantified by Ruiz et al. (2012). The current version uses the same method. Where more recent data on concentrations in the Rhine were available, the relevant updates were made.

10.12.2 Environmental impact

Persistent organic pollutants (POPs) are often toxic chemical substances with extremely poor degradability. Once they are discharged through the air and water, or even through the food chain, they can spread around the world and harm humans and the environment at locations far from their point of discharge. In this way, they can, for instance, cause cancer, disrupt hormones and adversely affect reproduction.

In 2003, Switzerland ratified the Stockholm Convention. The goal of the Stockholm Convention on Persistent Organic Pollutants (POPs) is to minimise the loads of these substances that are discharged into the environment (UNEP 2009).

POPs are mentioned in various laws and regulations, such as in the Chemicals Ordinance (ChemO 2013), the Chemical Risk Reduction Ordinance (ORRChem 2013), the Ordinance on Biocidal Products (OBP 2013), the Plant Protection Products Ordinance (PlantPPO 2010), the Technical Ordinance on Waste (TOW 2011), and others. An overview is provided by the Swiss National Implementation Plan for the POP Convention (BAFU 2006) and the amendment of 2012.

The eco-factors derived here are based on the work of the Safety and Environmental Technology Group of the Institute of Chemical and Bioengineering at ETH Zurich (Ng et al. 2012; Ruiz et al. 2012). A total of 227 substances from the groups of PCBs (polychorinated biphenyls), HFCs (hydrofluorocarbons), PBDEs (polybrominated diphenyl ethers), industrial chemicals and plastics additives, which are discharged into bodies of water, are taken into account. The substances are defined as POPs in the Stockholm Convention, classified as persistent, bioaccumulative and toxic substances by REACH or are mentioned on the Candidate List of Substances of Very High Concern (SVHC).

According to Ruiz et al. (2012), substances with a particularly high bioaccumulative potential are emitted to Swiss surface waters in smaller quantities than substances with a comparatively low bioaccumulative potential.

10.12.3 Characterisation

The characterisation is based on the bioconcentration factor (BCF). This expresses the ratio between the concentration of a substance in fish and the concentration of the same substance in water. The BCF is an indicator of the basic toxicity of a substance, as substances accumulate in fat tissue, i.e. in the cell membranes, and inhibit metabolism there. For that reason, the BCF is a simple indicator of the ecotoxic impact of substances.

The United States Environmental Protection Agency (EPA) keeps a database of BCF values (EPA 2013). The higher the BCF, the higher the ecotoxic impact of a substance. The BCF is expressed in litres of water per kg of body weight and ranges from 10^{-1} to 10^5 l/kg for the substances considered here. PCBs exhibit high BCFs of between $4*10^3$ and $2*10^5$ l/kg, as do flame retardants and polymer additives. 2,4,6-tribromophenol, which has a BCF of 245 l/kg, was selected as the reference substance. The characterisation factors were determined by Ruiz et al. (2012).

10.12.4 Normalisation

The POPs are characterised. The normalisation flow is identical to the characterised current flow. POP emissions in Swiss surface waters are determined for every substance with various models (direct emissions, extrapolated using POP concentrations in Zurich waters, extrapolated using POP emissions in Zurich air, extrapolated using POP emissions in Swedish air). The models are explained in Ruiz et al. (2012) and refer to the period from 2006 to 2010. Certain POPs such as chloroform, trichlorethylene and trichlorobenzene are measured at the Rhine monitor-

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[20] Sandi Ruiz, Carla Ng, Martin Scheringer, Konrad Hungerbühler, Safety and Environmental Technology Group, Institute for Chemical and Bioengineering, ETH Zurich

ing station (AUE Basel-Stadt 2020). The measured values were used for these substances.

The resulting normalisation flow is now 306 t 2,4,6-tribromphenol-eq. per year.

10.12.5 Weighting

The current flow is identical to the normalisation flow and amounts to 306 t 2,4,6-tribromophenol-eq. per year.

Switzerland has signed the Stockholm Convention. Therefore, the production, distribution, import and use of the substances listed in the Stockholm Convention, except for perfluorooctane sulfonic acid (PFOS), are banned in Switzerland. The Waters Protection Ordinance (WPO 2020), Article 1) governs water quality and ensures that bodies of water are not contaminated.

Under REACH, substances with persistent, bioaccumulative and toxic characteristics (PBT substances, vPvB substances) are subject to authorisation. The limit criterion is a bioconcentration factor (BCF) of over 2,000 l/kg for B substances or over 5,000 l/kg for vB substances (ECHA 2012). The goal of implementing the EU regulation on substances subject to authorisation is to ensure the same level of protection for humans and the environment in Switzerland as in the EU (BAFU 2013)

In addition, there are no quantitative political targets for POP emissions to surface waters in Switzerland that can be directly applied here. Therefore, the following approach was taken:

- The critical flow of substances that fall under the Stockholm Convention is set at 0.
- The critical flow of substances that have a BCF of over 2,000 l/kg is set at 0.
- The critical flow of all the other POP substances is equated to the present current flow.

Thus, a critical flow for all 227 substances is defined and characterised. The characterised critical flow amounts to 72 t 2,4,6-tribromophenol-eq./a.

10.12.6 Eco-factor for POPs

Tab. 69 below shows the resulting eco-factor for POP emissions to bodies of water.

The current flow is almost unchanged from the 2013 edition. The slight increase is due to the fact that the current measured values for certain substances indicate somewhat higher emissions today. This results in slightly higher normalisation and current flows.

Tab. 69: Eco-factor for POP emissions to surface waters in UBP/g 2,4,6-tribromophenol-eq

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t 2,4,6-tribromophenol-eq./a)	306	A	(Ruiz et al. 2012)	294
Current flow (t 2,4,6-tribromophenol -eq./a)	306	A	(Ruiz et al. 2012)	294
Critical flow (t 2,4,6-tribromophenol -eq./a)	72,2	a	(Ruiz et al. 2012)	72,2
Weighting factor (–)	18			16,6
Eco-factor (UBP/g 2,4,6-tribromophenol -eq.)	**59 000**			57 000

Q = data quality; for explanation, see Part 2, Chapter 6

Source: BCF based eco-factors_Sandi_Ruiz.xlsx[21]

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[21] File sent by Sandi Ruiz, ETH Zurich, on 26 March 2013

Tab. 70: Eco-factor of selected POP substances in UBP/g substance

Name	CAS No	Characterisation factor (kg 2,4,6-tribromophenol-eq./kg)	Eco-factor 2021 (UBP/g	Eco-factor 2013 (UBP/g)
Dioxin, 2,3,7,8 tetrachlorodibenzo-p-	1746-01-6	56	**3 300 000**	3 200 000
Anthracene	120-12-7	11	**660 000**	640 000
Pentabromodiphenyl ether	32534-81-9	62	**3 600 000**	3 500 000
Benzene, pentabromomethyl-	87-83-2	78	**4 600 000**	4 400 000
Antioxidant MD-1024	32687-78-8	13	**780 000**	750 000
Benzo(a)pyrene	50-32-8	34	**2 000 000**	1 900 000
Toluol	108-88-3	0,1	**6100**	5800
Xylol	1330-20-7	0,24	**14 000**	13 000

Full list in A4

10.12.7 Eco-factor for individual POP substances

The characterisation method using BCF described in Part 3, Section 10.12.3 is used to calculate other eco-factors for individual POP substances. The eco-factor in Tab. 69 serves as a starting point. A complete list of all substances is included in A4. Tab. 70 shows eco-factors of selected POP substances.

The directly derived eco-factor for benzo(a)pyrene (cf. Part 3, Section 10.10.5) is lower than the one that was determined using the POPs. In accordance with the methodological principles, the highest of the resulting eco-factors is applied in each case (see Part 2, Section 4.11).

11 Emissions to groundwater

11.1 Introduction

More than 80% (1 billion m^3/a) of Switzerland's drinking water supply comes from groundwater (Kozel 2013). In addition, another 0.5 billion m^3/a is used as process water. For that reason, groundwater is particularly important and justifies stricter quality requirements for its use than surface waters.

The boundaries between groundwater and surface water are very porous. Water that initially enters the groundwater via precipitation and drainage will sooner or later reach surface waters, either through natural processes or via groundwater use. Conversely, the most important sources of groundwater in Switzerland are definitely supplied by river water infiltration. As a result, the quality of river water in many cases also contributes to the quality of groundwater.

Not only nitrogen loads from agriculture, but also the total nitrogen loads, including nitrogen loads from effluents, contribute to the nitrogen loads in surface waters and their dissemination to seas.

Only nitrate is assessed, as it is the only substance for which relevant emissions data are currently available.

The Waters Protection Ordinance (WPO 2020) sets out, among other things, limit values for concentrations of plant protection products (PPPs) and VOCs in groundwater. The limit value for PPPs was exceeded by roughly one sixth of the monitoring wells in catchment areas dominated by agriculture or settlements and transport (BAFU 2009b). PPPs enter groundwater through the soil and are recorded and assessed in life cycle assessments as emissions (see Part 3, Section 12.3). The numerical quality requirement for VOC concentration has been exceeded at least once per year at 6% to 8% of the tested monitoring wells (BAFU 2009b). VOC concentrations in groundwater are discussed in Part 3, Section 17.1.

11.2 Nitrate (NO_3)

11.2.1 Environmental impact

Nitrate-polluted groundwater that is used as drinking water can lead to health problems (precursor of carcinogenic nitrosamines, BUWAL 1996). Nitrate concentrations in groundwater, especially in areas with intensive agriculture, often exceed the required limits for groundwater that is used or reserved for use and even the tolerance value for drinking water. Nitrogen fertiliser applied to fields can be washed from the soil into groundwater. New farming systems (crop cultivation, plant selection/crop rotations, ploughing, areas without vegetation in the winter, etc.), soil characteristics and groundwater recharge rates are decisive factors in this.

11.2.2 Normalisation

No characterisation is performed. According to the FOEN (Heldstab et al. 2013), the nitrate load discharged into groundwater from agriculture amounts to 34,000 t N/a (extrapolation for 2020, p. 43). As other nitrogen compounds are only present in small quantities, this normalisation flow can be used not only for nitrate, but also for nitrogen loads in general.

The flows demonstrated by the FOEN (Heldstab et al. 2013) are based on modelling and older estimates. These show that nitrate discharge into the hydrosphere has decreased only marginally since 2005.

As well as agricultural soils, nitrate is also leached from forest (7,000 t N/a) and other soils (10,000 t N/a) into the hydrosphere (Heldstab et al. 2013). These loads are not taken into account here, as they are to a large extent attributable to landfills and not to the application of nitrogen fertilisers.

11.2.3 Weighting

The current flow is identical to the normalisation flow (34,000 t N/a), as the reduction target for nitrate also applies to the whole of Switzerland.

Based on the targets and limits for groundwater and, by extension, drinking water, the SAEFL (BUWAL 1996) called for a target to halve the 1994 level of nitrate leaching due to agriculture. This results in a critical flow of 17,000 t NO_3-N/a for nitrate discharged into groundwater.

11.2.4 Eco-factor for nitrate in groundwater

As nothing has changed in either the current or critical flow, the eco-factor for nitrate in groundwater remains unchanged from the previous eco-factor in 2013. It is still higher than the eco-factor for the load discharged into surface waters. This is due to the fact that nitrate in groundwater, as opposed to surface waters, can still present a problem, especially as concerns the use of groundwater as drinking water.

Tab. 71: Eco-factor for nitrate-N in groundwater in UBP/g NO_3^--N and for nitrate in groundwater in UBP/g NO_3^-

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t N/a)	34 000	B		34 000
Current flow (t N/a)	34 000	B	(BAFU 2010)	34 000
Critical flow (t N/a)	17 000	a	(BUWAL 1996, S. 37) (BUWAL 1996c, S. 37)	17 000
Weighting factor (-)	4,0			4,0
Eco-factor (UBP/g NO_3-N)	**120**		Eco-factor for **nitrate-N** in groundwater	120
Eco-factor (UBP/g NO_3-)	27,1		Eco-factor for nitrate in groundwater	27,1

Q = data quality; for explanation, see Part 2, Chapter 6

12 Emissions to soil

12.1 Introduction

12.1.1 Background

The quality of soils in Switzerland is impaired by various substance-related impacts (acidification, over-fertilisation, contamination by heavy metals and organic pollutants). The contamination stems not only from the direct input of substances into the soil (plant protection products, fertiliser, waste landfilling), but also indirectly from the deposition of pollutants emitted to air.

The Swiss Ordinance on the Pollution of Soil (SoilPO 2016) is not applicable to all surfaces. Thus, soils that are permanently paved over, sediment in bodies of water, and soils making up land whose designated use precludes soil protection (e.g. football pitches, motocross tracks, percolation facilities, roadside drainage strips) are not covered by the Ordinance. However, it does apply to rocky soils, provided that at least sparse vegetation grows or can grow on them (BUWAL 2001a, p. 9). For that reason, soil protection is addressed not only in the SoilPO but also in other ordinances with indirect relevance to soils, such as the Ordinance on Air Pollution Control or the Chemical Risk Reduction Ordinance (EPA 2018, Art. 33 para. 1). In each of these, the long-term conservation of soil fertility must be taken into account (BUWAL 2001).

The partial or total destruction of soils by paving over them, erosion and mechanical damage (soil compaction) is equally important to long-term soil fertility conservation. These pressures can be assessed partly through land use and are discussed separately in Part 3, Section 13.3.

The assessment of the most important substance-related contaminations is discussed in this chapter.

12.1.2 Separating the soil and groundwater compartments

The ecological scarcity method assesses the substance flows at their point of entry into the environment, i.e. when they leave the anthroposphere. While the boundary between anthroposphere and environment is relatively easy to define in the case of emissions to air and surface waters ('end of pipe' concept: top of the chimney, outfall from the sewage treatment plant), separating the systems is more difficult when it comes to soil and groundwater. Thus, nutrients from fertilisers are available to agricultural crops and are absorbed by them to some extent as long as they remain in the root zone of the soil. In other words, nutrients absorbed by plants do not leave the agricultural production system.

However, heavy metals that enter the topmost layers of soil and accumulate there do not form part of the desired agricultural cycles. The guidelines for pollutant content of soil in the Ordinance on the Pollution of Soil (SoilPO) refer to the top 20 cm of the soil. Therefore, in the meaning of the Ordinance, this soil layer belongs to the 'environment', as far as heavy metals are concerned.

For that reason, the boundary between the anthroposphere and the soil/groundwater compartment is drawn at the point where substances are no longer part of agricultural use. Current and critical flows for nutrients are thus assessed when they leave the productive agricultural system, and by extension when they are washed into groundwater (nitrate), when entering surface waters through erosion or runoff (phosphate) or when emitted to the air (ammonia and nitrous oxide). Heavy metals, in contrast, are already pollutants when they enter the soil and are inventoried at that point.

12.1.3 Selection of substances

The various paths of entry should be distinguished in the case of substance-related soil contamination:

- non-point inputs of nutrients, acidifiers and heavy metals from the atmosphere
- entry via fertilisers (can contain traces of harmful substances, such as heavy metals and fluoride)
- entry via plant protection products

The non-point input of pollutants occurs either in liquid form (wet disposition) or bound to dust particles (dry deposition).

The most important non-point source pollutants include:

- heavy metals: lead, cadmium, copper, mercury and zinc
- acidifiers: SO_4^{2-}, NO_3^-, NH_4^+. With the exception of SO_4^{2-}, they also contribute to the over-fertilisation of ecosystems.

Non-point airborne inputs to soils (atmospheric deposition) are inventoried and assessed at the point of their emission to air (cf. Part 3, Section 9.11). Separate eco-factors for non-point inputs to soil are therefore unnecessary. For that reason, only the direct inputs to soils listed in Tab. 72 are assessed. However, non-point inputs to soil are necessary for determining the normalisation flow.

12.2 Heavy metals in the soil

12.2.1 Environmental impact

Heavy metals impair plant growth, disturb soil fertility and can accumulate in food chains. A high intake of a range of heavy metals with food (plants build available heavy metal into their biomass) over a long period can lead to chronic poisoning (BUWAL 1995). Moreover, major resource inputs are required to clean up soils contaminated with heavy metals.

12.2.2 Characterisation

The characterisation of heavy metal emissions to soil is performed using factors according to USEtox version 2 (Fantke et al. 2018), whereby the individual heavy metals are characterised with regard to their toxic damage (see Tab. 75 to Tab. 76). Zinc is used as the lead substance, with the toxic impact expressed in Zn-equivalents/kg. For human toxicity, USEtox provides factors for carcinogenic

Tab. 72: Impact mechanisms of the assessed soil pollutants

	Environmental			Human						
	Damage to flora	Impairment of soil fertility	Bioaccumulation	Metabolic disturbances	Carcinogenicity	Mutagenesis	Embryonal damage	Other/further types of damage	Characterisation	Notes
Heavy metals	x	#	x	x	x		(x)		Zn-eq	Target as in SoilPO Characterisation USETox
Plant protection products (PPP)	x	x	x	x	x	x	x	x	Glyphosate-eq.	A single PPP normally only exhibits some of the impacts listed. Moreover, plant damage is an intentional effect of herbicides.
Plastic	?	?	(x)	?	?	?	?	(x)	–	

x Impact or link proven
(x) Impact or link presumed
Impact significant to determining the eco-factor

and non-carcinogenic substances (human toxicity, cancer and non-cancer effects, recommended+interim). These are summated in DALYs[22] according to their damage to health. Toxicity factors for ecotoxic impacts are also provided, although these cannot be offset against the factors for human toxicity. Consequently, a set of eco-factors was determined using the characterisation factors for human toxicity and the ecotoxicity factors respectively, and from these two sets the higher factor for each heavy metal was used (see Tab. 73). Eco-factors can also be derived for mercury, chromium and nickel using their respective USEtox factors, even if no emission quantities are known for these metals.

Tab. 73: Normalisation flow in kg Zn-eq.: calculated from deposition and direct input of heavy metals into the soil (see also Tab. 74)

	Characterised by USETox human toxicity kg Zn-eq.	Characterised by USETox ecotoxicity kg Zn-eq.
Lead (Pb)	5 724	1 269
Cadmium (Cd)	33 883	25 490
Copper (Cu)	62	43 412
Zinc (Zn)	834 004	834 004
Total	**873 673**	**904 175**

12.2.3 Normalisation

As a characterisation is performed, the normalisation flow corresponds to the sum of the characterised emissions of the heavy metals lead, cadmium, copper and zinc to the surface area determined in accordance with the SoilPO (2016). These four heavy metals were used because relevant substance flows were only available for them. This means that the normalisation flow is too small. Slightly overestimated eco-factors for heavy metals can therefore be expected. However, this is still considered more useful than not taking the other heavy metals (mercury, nickel and chromium) into account. The whole of Switzerland was used as the reference area for the normalisation flow. The normalisation flow comprises deposition as well as the heavy metals applied directly to agricultural land by plant protection products and organic and mineral fertilisers.

12.2.4 Weighting

It is not possible to derive critical flows from the guideline values in the SoilPO. However, the long-term conservation of soil fertility is stated in Article 1 as the purpose of this Ordinance (this applies only to soil types included in the SoilPO – see Section 12.1.1). To achieve this, heavy metals may not accumulate in the soil, i.e. the maximum input must be only as great as the output. As this target relates to agricultural land, the utilised agricultural area was ascertained as a reference area for determining the current and critical flows (BFS 2011). This works out at approximately 1.5 million ha. The reference area for the current flow therefore differs from that of the normalisation flow.

The Swiss Soil Monitoring Network (NABO) records eight heavy metals and fluoride at 105 different sites. Of the heavy metals regulated by the Ordinance on the Pollution of Soil (SoilPO 2016), only molybdenum is not measured by NABO. The measurements enable an inventory and evaluation of the current heavy metal load in soils to be performed (BUWAL 2000). Keller et al. (2005) have compiled detailed substance inventories for lead, cadmium, copper and zinc on 48 selected representative areas of land in connection with the NABO measurement programme. The median[23] of these values was used for the annual heavy metal inputs and outputs. The more up-to-date values of the FOEN (BAFU 2020a) are used for the atmospheric deposition. The corresponding current and critical flows per ha are listed in Tab. 74. These data and the USEtox characterisation factors are used to determine the current flow of heavy metals into the soil via non-point atmospheric input and direct input onto agricultural land in the unit Zn-eq./a. Lead, copper, cadmium and zinc are taken into account, as the corresponding flows are only available for these metals. The current flow is 686 976 Zn-eq./a according to USEtox (human toxicity) (see Tab. 75) or 717 542 Zn-eq./a if the ecotoxicity characterisation factors are used (see Tab. 76).

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[22] DALY: Disability-adjusted life year. One DALY corresponds to the loss of one year of life, or a loss of quality of life over a corresponding period, e.g. 20% disability over five years.

[23] Using the median reduces the influence of individual extreme values (e.g. owing to the application of copper as a PPP in vineyards) on the calculation of the current flow, compared to the mean value.

Tab. 74: Data on the critical and current flows for heavy metal input into soil per ha

	Discharge, or critical flow as per Keller et al. (2005) g / (ha*a)	Deposition (g/(ha*a))	Direct input (g/(ha*a))
Lead (Pb)	19,4	3,66	8,25
Cadmium (Cd)	1,3	0,29	0,55
Copper (Cu)	58,0	5,05	68,4
Zinc (Zn)	303,0	65,4	376

Tab. 75: Characterisation factors according to USEtox (human toxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	DALY/kg	In Zn-equivalents (kg Zn-eq./kg)	Registered quantities (kg/a) Deposition	Registered quantities (kg/a) Direct input	Characterised quantities (Zn-eq./a)
Lead	$8{,}13\times10^{-5}$	0,21	5 486	12 375	3 721
Cadmium	$6{,}53\times10^{-3}$	16,73	436	83	21 100
Copper	$1{,}95\times10^{-7}$	0,0005	7 575	102 600	55
Zinc	$3{,}90\times10^{-4}$	1,00	98 100	564 000	662 100
Mercury	$3{,}54\times10^{-2}$	90,79	–		–
Nickel	$7{,}14\times10^{-4}$	1,83	–		–
Chromium(III)	$2{,}81\times10^{-11}$	$7{,}19\times10^{-8}$	–		–
Chromium(VI)	$5{,}72\times10^{-2}$	146,6	–		–
Total					**686 976**

Tab. 76: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	PDF x m³ x day/kg	In Zn-equivalents (kg Zn-eq./kg)	Registered quantities (kg/a) Deposition	Registered quantities (kg/a) Direct input	Characterised quantities (Zn-eq./a)
Lead	3 905	0,05	5 486	12 375	825
Cadmium	1 064 054	12,59	436	825	15 873
Copper	29 726	0,35	7 575	102 600	38 744
Zinc	84 532	1,00	98 100	564 000	662 100
Mercury	15 592	0,184	–		–
Nickel	93 616	1,107	–		–
Chromium(III)	4 065	0,048	–		–
Chromium(VI)	52 397	0,62	–		–
Total					**717 542**

Keller et al. (2005) assess only the output via plants, and this is used as a first approximation for the critical flow (see also Tab. 74). The transfer of heavy metals into groundwater or their transportation through erosion were not investigated. However, except for antimony and chromium(VI), this effect is of little relevance. For the defini-

Tab. 77: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	DALY/kg	In Zn-equivalents (kg Zn-eq./kg)	Target (kg/a)	Characterised quantities (Zn-eq./a)(Zn-eq./a)
Lead	$8{,}13 \times 10^{-5}$	0,21	29 100	6 062,60
Cadmium	$6{,}53 \times 10^{-3}$	16,73	1 950	32 628,52
Copper	$1{,}95 \times 10^{-7}$	0,0005	87 000	43,41
Zinc	$3{,}90 \times 10^{-4}$	1,00	454 500	454 500,00
Mercury	$3{,}54 \times 10^{-2}$			
Nickel	$7{,}14 \times 10^{-4}$			
Chromium(III)	$2{,}81 \times 10^{-11}$			
Chromium(VI)	$5{,}72 \times 10^{-2}$			
Total				**493 234,54**

Tab. 78: Characterisation factors according to USEtox (ecotoxicity), emitted quantities according to the FOEN (BAFU 2020a) and calculated characterised quantities

Substance	PDF × m³ × day/kg	In Zn-equivalents (kg Zn-eq./kg)	Target (kg/a)	Characterised quantities (Zn-eq./a)
Lead	3 905	0,05	29 100	1 344,39
Cadmium	1 064 054	12,59	1 950	24 545,93
Copper	29 726	0,35	87 000	30 594,23
Zinc	84 532	1,00	454 500	454 500,00
Mercury	15 592			
Nickel	93 616			
Chromium(III)	4 065			
Chromium(VI)	52 397			
Total				**510 984,54**

Tab. 79: Eco-factors for heavy metals to soil, in kg Zn-eq/a

	Human toxicity	Ökotoxizität	Q	Edition 2013
Normalisation flow (kg Zn-eq./a)	873 673	904 175	C	Data not directly comparable due to different approach
Current flow (kg Zn-eq. /a)	686 976	717 542	C	
Critical flow (kg Zn-eq. /a)	493 235	510 985	a	
Weighting factor (–)	1,94	1,97		
Eco-factor (UBP/ kg Zn-eq.))	**$2{,}82 \times 10^6$**	**$2{,}75 \times 10^6$**	–	

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 80: Eco-factors for heavy metals to soil, in UBP/g

Substance	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
Lead	**460**	17 000
Cadmium	**37 000**	270 000
Copper	**770**	14 000
Zinc	**2 200**	2800
Mercury	**200 000**	
Nickel	**4 100**	
Chromium (III)	**100**	
Chromium (VI)	**330 000**	

tion of the critical flow, only agricultural land was taken into account, as the discharge of heavy metals takes place primarily via this land. The characterisation based on human toxicity results in a critical flow of 493,235 Zn-eq./a (see Tab. 77). Where the characterisation is based on ecotoxicity, the critical flow is 510,985 Zn-eq./a (see Tab. 78).

12.2.5 Eco-factors for heavy metals to soil

The eco-factors were determined for both human toxicity and ecotoxicity, and the higher factor for each heavy metal was selected. Tab. 80 above summarises the calculated eco-factors in UBP per gram of heavy metal, with the higher factor out of the categories human toxicity and ecotoxicity being selected in each case.The new approach to characterising heavy metals based on the USEtox factors leads to significantly lower eco-factors for heavy metals in soil compared with the 2013 edition, except in the case of zinc. The main reason for this is that the heavy metals were not considered individually but grouped together, resulting in a significantly greater normalisation flow. In addition, there have been relative changes among the heavy metals. For example, lead and copper are rated much lower compared with cadmium than in the 2013 edition. The reason for this is the new assessment based on USEtox, which evaluates the toxic damage caused by heavy metals.

12.3 Plant protection products (PPPs)

12.3.1 Environmental impact

According to the Plant Protection Products Ordinance (PlantPPO 2020), plant protection products (PPPs) are crop protectants, plant development regulators and post-harvest protection products. These can be substances, organisms and preparations that are specifically developed to destroy undesirable plants or parts of plants. Safeners[24] and synergists[25] are also considered plant protection products. The environmental problems associated with their use are a function of the primary effects, the quantities applied, the rates of degradation and dispersal behaviour (mobility) of the active agents, and the types and behaviour of degradation products and residues.

Plant protection products are applied above all in open arable farming, large farming operations, specialist fruit growing and viticulture. Their use is minimal on grassland (BLW 2020c).

The movement of soil particles with the wind and atmospheric transportation of plant protection products has in the meantime also led to the detection of active agents in mountain lakes and rain. Human health impacts of these products arise particularly from the use of groundwater as drinking water. In Switzerland, a large quantity of pesticides is regularly analysed in groundwater in conjunction with the current NAQUA monitoring campaigns. However, measurements of several particularly mobile pesticide degradation products are still lacking (BLW 2020a).

12.3.2 Characterisation

Characterisation is now based on toxicity according to USEtox (Fantke et al. 2018). The characterisation was performed with regard to both ecotoxicity and human toxicity. For PPPs not yet integrated into USEtox, the mean value of the other PPPs in the relevant plant protection group (e.g. neonicotinoids, pyrethroids) was used as an approximation. For PPPs that cannot be assigned to a group, or

[24] Substances or preparations that are added to a plant protection product in order to suppress or reduce the phytoxic effect of the plant protection product on specific plants

[25] Substances or preparations that exhibit little or no effect in accordance with Section 1 of the Plant Protection Products Ordinance, but intensify the effect of the active agent or active agents in a plant protection product

for groups in which no USEtox value was available for any PPP, the mean value of the respective category (herbicide, insecticide, fungicide, rodenticide, etc.) was used.

The main reason for characterising with USEtox is that this method is recommended by UNEP for assessing the toxic impacts of substances. Another advantage of this approach is that PPPs that are not used in Switzerland can also be taken into account.

Glyphosate is used as the reference unit to perform the characterisation. Glyphosate is widely used in Switzerland as a PPP (herbicide). All active agents sold in Switzerland, as well as the PPPs that are included in common databases, are characterised. It should be noted that only PPPs applied on land used for agriculture are taken into account. Plant protection products that are exclusively authorised for private gardens, golf courses or silviculture are not taken into account. Tab. 82 shows the characterisation factors for selected PPPs. The full list can be found in A5.

12.3.3 Normalisation

As a characterisation is performed, the normalisation flow corresponds to the sum of the characterised quantities of PPPs sold in Switzerland in 2018 (BLW 2020b). Substances that are not sold in Switzerland are therefore excluded from the characterised normalisation flow. This results in an annual flow of 9 761 t glyphosate-eq. for human toxicity and 22 643 t glyphosate-eq. for ecotoxicity.

12.3.4 Weighting

The current flow corresponds to the normalisation flow.

The Plant Protection Products Action Plan (PPP Action Plan 2017) set a target of reducing the risk associated with PPP application by 50% compared with the period 2012–15. The risk is equated with the environmental impact. The critical flow thus corresponds to around 5,854 t glyphosate-eq. for human toxicity and 14,574 t glyphosate-eq. for ecotoxicity.

12.3.5 Eco-factor for the lead substance glyphosate

Eco-factors were derived from both the human toxicity and ecotoxicity characterisation, with the higher eco-factor obtained being used in the method.

The new factor is around two times higher than in 2013. The main reasons for this are the new derivation through USEtox and the more stringent target in the PPP Action Plan compared with the previous target.

12.3.6 Eco-factors of other plant protection products

Eco-factors for individual PPPs can be calculated using the USEtox characterisation described in Section 12.3.2. Tab. 82 shows eco-factors for selected substances compared with those in the 2013 edition. The complete list can be found in A5.

The characterisation using USEtox means that 23 PPPs have an eco-factor more than 100 times higher than glyphosate. This includes many of the substances that are now banned in Switzerland, the EU or worldwide. Initial test calculations found that the environmental burden

Tab. 81: Eco-factor for the emission of plant protection products to soil in UBP/g glyphosate-eq

	Edition 2021 Human toxicity: used	Edition 2021 Ecotoxicity: not used	Q	Notes	Edition 2013
Normalisation (t glyphosate-eq./a)	9 761	22 643	C		8241
Current flow (t glyphosate-eq./a)	9 761	22 643	C	Reference year 2018 (BLW 2020b)	2208 (t PSM/a)
Critical flow (t glyphosate-eq./a)	5 854	14 574	a	50% reduction in environmental impact since 2012-2015, PPP Action Plan, 2017)	1995 (t PSM/a)
Weighting (–)	2,8	2,4			1,22
Eco-factor (UBP/g glyphosate-eq.)	**280**	**107**			150

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 82: Eco-factors of selected PPPs

Active agent	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)
Herbicides		
Atrazine	**11 000**	360
Glyphosate	**280**	150
Metsulfuron-methyl	**1 100**	63 000
Terbutylazine	**11 000**	500
Insecticides		
Bifenthrin	**2 000**	20 000
Chlorpyrifos-ethyl	**19 000**	920
Mineral oil	**11**	69
Fungicides		
Folpet	**5 000**	140
Chlorothalonil	**11 000**	300
Metconazole	**2 800**	4 200

The full table can be found in A5

of agricultural products outside the EU was in some cases very heavily dominated by the PPP assessment. Even if determining toxicity based on USEtox is unquestionably the best approach currently available, it nevertheless entails very significant uncertainties. In addition, there is a relatively high level of uncertainty in the inventory analysis data with regard to the PPPs used and those that have entered the environment. A cap of a factor of 100 was introduced to prevent the LCA results from being dominated by the PPP assessment, which is very uncertain. This approach was also adopted for the assessment of water scarcity using the AWARE method, in which the characterisation factor for water scarcity was also limited to 100 (see Section 13.6.3). This cap means that all 23 PPPs with an eco-factor more than 100 times higher than glyphosate had their eco-factor limited to 44,000 UBP/g, i.e. 100 times the eco-factor for glyphosate. Even with the cap, these PPPs still have a significant influence on the results.

The new eco-factors are very different from the old ones. Some are much higher, others much lower. The main reason is that the characterisation is now based on toxicity according to USEtox, whereas in 2013 the characterisation was made inversely proportional to the recommended spray quantity. This was based on the assumption that ‘the less that needs to be applied, the greater the impact and therefore also the damage’. It turns out, however, that effectiveness does not correlate with toxicity. A telling example is copper, which needs to be applied in relatively large quantities in order to be effective as a fungicide, but which is nevertheless highly toxic to aquatic flora and fauna.

12.4 Plastic in soil

12.4.1 Environmental impact

Currently, the extent to which microplastics and macroplastics affect the health of humans, flora and fauna is still unclear. There is evidence of direct impacts by macroplastics in the form of injuries to the digestive tracts of animals or entanglement and suffocation in fishing nets and plastic bags in the oceans (Erny et al. 2020). Aside from the physical hazard posed by plastic, there is also concern that organisms are endangered by ingesting hazardous chemicals contained in plastic or adsorbed on its surface (UNEP and GRID-Arendal 2016).

12.4.2 Characterisation

Owing to a lack of information on which to base such a distinction, no differentiation is made between microplastics and macroplastics. It is currently assumed that their impact on the environment is the same. Most plas-

Tab. 83: Plastic entering the environment in Switzerland according to Erny et al. (2020), supplemented by Schleiss (2017a)

	Plastic entering the environment in t / year	Proportion in %
Tyre abrasion	7 696	47 %
Littering	2 700	17 %
Roads	1 502	9 %
Buildings and construction sites	1 320	8 %
Sports facilities	1 120	7 %
Households	850	5 %
Waste disposal	474	3 %
Industry and commerce	620	4 %
Agriculture	3	0 %
Total	16 285	100 %

tic enters the soil, with only a small proportion entering the water (Kawecki & Nowack 2019). No distinction was made between plastics entering the soil and those entering water, the two being viewed as equivalent.

12.4.3 Normalisation

The normalisation flow corresponds to the current flow and represents the total amount of plastic entering the environment in Switzerland each year. That amount stands at 16,285 t. The basis for this was a study on plastic pollution in Switzerland (Erny et al. 2020), supplemented with data from Schleiss (2017a) on plastic pollution from waste disposal, compost and digestate. According to these sources, 47% is due to tyre abrasion and 17% to littering, while 24% comes from roads, buildings and sports facilities, 5% from households and 4% from industry and commerce. Pollution from agriculture and waste disposal accounts for 3% (see Tab. 83).

12.4.4 Weighting

For the weighting, only plastic pollution from compost and digestate was considered on the basis of the Chemical Risk Reduction Ordinance (ORRChem) Annex 2.6.2.2.1 2b. There are currently no legal bases for other sources of plastic pollution.

According to Schleiss (Schleiss 2017a), the average plastic content of compost and digestate is 0.07% per unit of dry matter. Assuming an annual quantity of around 1.37 million t of organic waste (extrapolated from Schleiss (2017b)), this corresponds to a current flow of around 474 t per year.

ORRChem Annex 2.6.2.2.1 2b. states that organic waste spread on the land may not contain more than 0.1% plastic per unit of dry matter. Assuming an annual quantity of around 1.37 million t of organic waste (extrapolated from Schleiss (2017b)), this corresponds to a critical flow of 687 t per year.

12.4.5 Eco-factor

In the previous version compiled in 2013, there was no eco-factor for plastic entering the soil.

12.4.6 Guidelines for using databases such as ecoinvent or UVEK

We recommend adding the parameters 'to soil' and 'to water' to the two substance flows 'microplastics' and 'macroplastics' in the relevant inventories. It also makes sense to distinguish between microplastics and macroplastics at the substance flow level. This will establish the basis for a future differentiation between microplastics and macroplastics as soon as the science allows.

Tab. 84: Eco-factor for plastic entering the environment (soil or water)

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t plastic/a)	16 285	A	Erny et al. 2020	–
Current flow (t plastic /a)	474	A	Schleiss 2017a	–
Critical flow (t plastic /a)	687	a	Calculated from Schleiss 2017b and ORRChem Annex 2.6.2.2.1 2b	–
Weighting (–)	0,476			–
Eco-factor (UBP/g plastic)	**29**			–

Q = data quality; for explanation, see Part 2, Chapter 6

13 Resources

13.1 Overview

The use of natural resources is also weighted with an eco-factor. Until now, the consumption or use of energy resources, water, gravel, primary mineral resources and land have been weighted in the ecological scarcity method. In the case of energy resources (Part 3, Section 13.2), a distinction is made between an eco-factor for renewable (limited rate of replenishment) and non-renewable energies (limited supply). This makes it possible to take account of the different sustainability aspects of these types of energy. Furthermore, eco-factors are defined for land use (Part 3, Section 13.3), for the dissipative use of primary mineral resources (Part 3, Section 13.4), and for the extraction of natural gravel (Part 3, Section 13.5) and freshwater (Part 3, Section 13.6), as these resources are increasingly considered to be ecologically scarce. Eco-factors for the use of marine fish are included for the first time (Part 3, Section 13.7).

13.2 Energy resources

13.2.1 Environmental relevance

The Federal Constitution (2012, Art. 89) states the goal of efficient and environmentally sound energy supply in the same sentence in which it calls for a reliable and economical supply: *«Within the scope of their powers, the Confederation and Cantons shall endeavour to ensure a sufficient, diverse, safe, economic and environmentally sustainable energy supply as well as the economic and efficient use of energy.»*

It is not only non-renewable energy carriers, such as oil, gas and uranium, which are available in limited quantities; the same applies to renewables. The sun, the driving force behind most renewable energies, only supplies a limited quantity of energy to the earth per unit time. Moreover, some of this energy is required to keep the earth's ecosystem running, e.g. for the biogenic production of oxygen, pollination and seed dispersal by wind, the hydrological cycle or the provision of daylight. Furthermore, the efficiency of converting solar energy into renewable energy carriers is relatively low. Therefore, the proportion of renewable energy that can be utilised sustainably is not known. It can at least be concluded that an upper utilisation limit also applies to renewable energies. Therefore, it is reasonable to assign an eco-factor both to renewable and non-renewable energy carriers.

While technical efficiencies are often low when renewables are converted into final energy, especially when solar radiation is converted into biomass, due to the remaining ecological benefits, the energy not utilised technically does not in fact dissipate uselessly. This is why renewable energies are assessed on the basis of the primary energy yielded.

In contrast, where non-renewable energy carriers deliver no further ecological benefit, all of the energy contained in the resource should be utilised wherever possible, which is why the eco-factor is applied to the primary energy content.

For renewable and non-renewable energy resources alike, the assessed energy corresponds to the quantity of energy yielded: the energy content of the harvested biomass, the rotation energy in the case of wind and hydropower generators, the electrical energy delivered to the inverter in photovoltaic installations, the thermal energy delivered to the heat storage system in the case of solar collectors, and the energy quantity extracted from the geosphere in the form of crude oil, raw hard coal, lignite, natural gas and fissile uranium. This provides a consistent concept for evaluating the primary energy demand.

The eco-factor for energy consumption assesses the scarcity of the energy resource; the environmental impacts of energy uses caused by emissions are taken into account through the corresponding eco-factors for air, water and soil pollution.

13.2.2 Characterisation

Besides reducing energy consumption, another goal of the 2000-watt society (see also Part 3, Section 13.2.4) is to increase the proportion of renewable energy carriers: the 2040 interim target for the 2000-watt society (see Section 13.2.4) puts the share of renewable energies at 75% (EnergieSchweiz für Gemeinden 2020). The benchmark is the current conventional energy supply with non-renewable energy carriers (i.e. a characterisation factor of 1 MJ oil-eq./MJ non-renewable energy). The goal is for renewable resources to supply three times more energy than non-renewable sources, which results in a politically established characterisation factor of ⅓ MJ oil-eq./MJ (Tab. 82). In other words, 3 MJ of energy from renewable sources is rated as equivalent to 1 MJ from non-renewable sources.

Tab. 85: Characterisation factors for renewable and non-renewable energy carriers, based on EnergieSchweiz für Gemeinden (2020)

	Characterisation factor (MJ oil-eq./MJ)
Non-renewable energy	1
Renewable energy	⅓

13.2.3 Normalisation

Aggregate energy statistics (BFE 2020) present Switzerland's energy balance by energy carrier. This encompasses domestic production as well as imports and exports. This final consumption of energy carriers is converted into primary energy consumption in Switzerland by using the energy carrier compositions, fuel value conversion factors and primary energy factors from Stolz & Frischknecht (2017). The three-year average for 2017–19 of Switzerland's total, characterised primary energy demand is used for normalisation (see Tab. 86). This results in a normalisation flow of 1,295 PJ oil-eq./a, which is used for both renewable and non-renewable energy resources.

13.2.4 Weighting

The current flow corresponds to the characterised primary energy consumption in Switzerland (three-year average for 2016–18) and amounts to a total of 1,295 PJ oil-eq./a (see Tab. 86), of which 58 PJ oil-eq./a comes from renewable and 1,237 PJ oil-eq./a from non-renewable energy sources.

The goal of the 2000-watt society (Swiss Federal Council 2016) is used to determine the weighting factor and the critical flow. This long-term vision is operationalised based on the new guiding principles of the 2000-watt society (EnergieSchweiz für Gemeinden 2020).

According to the guiding principles, primary energy demand is to be reduced to 3,000 watts of continuous power per person by 2030 and to 2,000 watts by 2050, with 50% (2030), 75% (2040) and 100% (2050) of this continuous power to be met by renewable primary energy.

In relation to the reference year 2040, which is also used to determine the eco-factor for CO_2 and the other greenhouse gases, the target values are 2,500 watts of continuous power per person (average of the 2030 and 2050 targets), with renewables accounting for 75% of this, i.e. 1,875 watts of continuous power from renewable sources and 625 watts from non-renewable sources. This continuous power is converted into annual energy consumption and multiplied by the characterisation factors introduced in Section 13.2.2. For the projected total Swiss population of 10.044 million in 2040 (BFS 2015), this corresponds to a critical flow of 396 PJ oil-eq./a.

Tab. 86: Consumption of final energy by energy carrier in Switzerland in the years 2017 to 2019 according to the energy statistics for 2018 (BFE 2019) and 2019 (BFE 2020), its conversion into renewable and non-renewable primary energy consumption (both in TJ) and characterised primary energy consumption, total (in TJ oil-eq.)

	Energy consump-tion (lower heating value) (TJ)	Composition	Ratio lower/upper heating value	Energy consumption (upper heating value) (TJ)	Primary energy factor, renewable	Primary energy factor, non-renewable	Primary energy consumption, renewable (TJ)	Primary energy consumption, non-renewable (TJ)	Primary energy consumption, total (TJ oil-eq.)
Total							**174 295**	**1 236 571**	**1 294 670**
Fossil energy carriers									
Heating oil (extra light)	114 543		0,94	121 855	0,01	1,23	1 100	149 811	150 178
Heating oil (medium and heavy)	53		0,94	57	0,01	1,23	1	70	70
Petrol coke	773		0,94	823	0,01	1,45	11	1 196	1 199
Other petroleum fuels	3 253		0,94	3 461	0,01	1,23	31	4 255	4 265
Gas	115 453		0,90	128 281	0,00	1,06	573	136 387	136 578
Petrol	98 277		0,93	105 674	0,00	1,27	448	134 286	134 436
Diesel	115 540		0,94	122 915	0,00	1,21	386	148 368	148 497
Aviation fuel	79 103		0,94	84 152	0,00	1,20	257	101 238	101 324
Propane/butane	0		0,92	–	0,01	1,15	0	0	–
Coal	4 237								
Hard coal		72,7 %	0,96	3 208	0,01	1,20	27	3 838	3 847
Lignite briquettes		19,4 %	0,96	857	0,01	1,20	7	1 025	1 028
Hard coal coke		7,9 %	0,96	348	0,01	1,45	5	506	507
Biomass									
Wood	39 407								
Timber		45,0 %	0,92	19 275	0,99	0,12	19 159	2 244	8 630
Wood chips		50,0 %	0,90	21 893	1,05	0,06	23 010	1 374	9 044
Pellets		5,0 %	0,91	165	1,04	0,16	2 247	341	1 090
Biogas	8 770		0,90	9 744	0,03	0,30	313	2 917	3 022
Solar/wind/geothermal energy									
Solar energy use	2 570			2 570	1,61	0,22	4 132	568	1 945
Ambient heat use	17 003								
Heat source: air		40 %		6 801	0,82	0,91	5 561	6 174	8 028
Heat source: brine or water		60 %		10 202	0,87	0,67	8 872	6 785	9 742
Other energy carriers									
Industrial waste	11 070			11 070	0,01	0,05	103	558	593
District heat, Swiss average	20 257			20 257	0,33	0,55	6 598	11 127	13 326
Electricity, Swiss consumption mix	207 993			207 993	0,49	2,52	101 455	523 503	557 322

Tab. 87: Eco-factor for non-renewable energy resources, 2040 interim target according to the guiding principles of the 2000-watt society (EnergieSchweiz für Gemeinden 2020) in UBP/MJ oil-eq.

	Edition 2021	Q	Notes	Edition 2013
Characterisation (MJ oil-eq./MJ)	1			1
Normalisation (PJ oil-eq./a)	1295	A	Characterised energy quantity	1428
Current flow (PJ oil-eq./a)	1295	A	Switzerland's primary energy consumption, non-renewable (3-year average for 2016–2018)	
Critical flow (PJ oil-eq./a)	396	b	Calculated from the interpolated targets for 2050 and 2030 to 2040 and proportion of renewable in 2040 according to the guiding principles of the 2000-watt society 2020	
Weighting (–)	10,7			4,92
Eco-factor (UBP/MJ oil-eq.)	**8,3**			3,4

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 88: Eco-factor for renewable energy resources, 2040 interim target according to the guiding principles of the 2000-watt society (EnergieSchweiz für Gemeinden 2020) in UBP/MJ oil-eq.

	Edition 2021	Q	Notes	Edition 2013
Characterisation (MJ oil-eq./MJ)	0,33			0,33
Normalisation (PJ oil-eq./a)	1295	A	Characterised energy quantity	1428
Current flow (PJ oil-eq./a)	1295	A	Switzerland's primary energy consumption, non-renewable (3-year average for 2016–2018)	
Critical flow (PJ oil-eq./a)	396	b	Calculated from the interpolated targets for 2050 and 2030 to 2040 and proportion of renewable in 2040 according to the guiding principles of the 2000-watt society 2020	
Weighting (–)	10,7			4,92
Eco-factor (UBP/MJ oil-eq.)	**2,8**			1,1

Q = data quality; for explanation, see Part 2, Chapter 6

13.2.5 Eco-factors for primary energy

The eco-factors for renewable and non-renewable primary energy differ by a factor of three, according to the characterisation factors introduced (see Section 13.2.2). The time horizon for the interim target used is the same as that for greenhouse gases (see Section 9.2).

Because of the more stringent target for the 2000-watt society, the 2021 eco-factor for 1 MJ oil-eq. of non-renewable primary energy is almost 150% higher than the 2013 eco-factor.

Like the eco-factor for 1 MJ oil-eq. of non-renewable primary energy, the eco-factor for 1 MJ oil-eq. of renewable primary energy is around 150% higher than the 2013 eco-factor, for the same reason.

13.2.6 Guidelines for using UVEK LCI Data DQRv2:2022

The results of applying the two energy eco-factors to the energy resources featured in UVEK LCI Data DQRv2:2022 are listed in Tab. 89.

If an inventory analysis is based on other assumptions concerning energy content and/or transformation ratio of primary energy resources, the eco-factors must be adjusted to that specific situation following the same method.

Tab. 89: Eco-factors for the consumption of primary energy resources. Calculated using the eco-factors from Tab. 87 and Tab. 88 and the energy values in Hischier et al. (2010)

	Energy content		Eco-factor, primary energy 2021	
Fossil energy				
Crude oil (before refining)	45,8	MJ/kg	**380**	UBP/kg
Natural gas (before refining)	38,3	MJ/Nm^3	**320**	UBP/Nm^3
Mine gas	39,8	MJ/Nm^3	**330**	UBP/Nm^3
Hard coal (in mine)	19,1	MJ/kg	**160**	UBP/kg
Lignite (in mine)	9,9	MJ/kg	**80**	UBP/kg
Nuclear energy				
Uranium (in ore)	560 000	MJ/kg	**4 600 000**	UBP/kg
Biomass				
Energy in biomass	1	MJ/MJ	**2,8**	UBP/MJ
Energy in biomass, primary forest clearcut	1	MJ/MJ	**8,3**	UBP/MJ
Hardwood, standing [a]	19,6	MJ/kg	**55**	UBP/kg
Softwood, standing [a]	20,4	MJ/kg	**57**	UBP/kg
Water				
Potential energy of water in impoundment [b]	0,95	MJ_e/MJ	**2,6**	UBP/MJ
Other renewable energies				
Kinetic energy in wind [b]	0,93	MJ_e/MJ	**2,6**	UBP/MJ
Solar energy in solar radiation [b]	0,91	$MJ_{e\ a.\ t}/MJ$	**2,5**	UBP/MJ
Geothermal energy [b]	1,00	MJ_t/MJ	**2,8**	UBP/MJ

[a] Wood may only be assessed if it has not already been taken into account as energy in biomass, as otherwise double counting would occur.

[b] According to the KBOB list of life cycle assessment data DQRv2:2022, the transformation ratio (quantity of primary energy yielded) is: hydro = 0.95; wind = 0.93; solar = 0.91 (average of photovoltaic (0.935) and solar thermal (0.885)); geothermal = 1.00.

13.3 Land use

13.3.1 Introduction

Based on information from the FSO land-use statistics and the associated analyses of land use and land cover in 2004/2009 (Federal Statistical Office 2009a), the surface area of Switzerland (41,285 km^2) can be divided into four broad types of use:

1. 7.5% settlement and urban areas (buildings, transport surfaces, recreational and green urban areas, landfills, construction sites)
2. 35.9% agricultural land (grassland, arable land, orchards)
3. 31.3% wooded areas (forest, shrub forest, woods)
4. 25.3% unproductive areas (rock, ice, lakes, rivers, glaciers)

The Swiss Spatial Planning Act (SPA 2012) stipulates that soil resources should be used economically and urban sprawl should be counteracted. Nevertheless, the settlement area has been and still is expanding, mainly at the expense of agricultural land. According to the Swiss land-use statistics for 2004/2009, the overall settlement area is growing at a rate of around one square metre per second, mostly at the expense of agricultural land in Switzerland's Central Plateau. In remote areas, agricultural land that is no longer managed turns back into wooded areas. While the unproductive areas are subject to constant change, their overall area remains roughly constant (BFS 2011).

According to the FSO land-use statistics (Federal Statistical Office 2009b), Switzerland's settlement area (3,079 km^2) has the following composition:

- 49% building areas
- 31% transport surfaces
- 8% industry and commerce
- 6% special urban areas
  (utility facilities, quarries/mines and dumps, construction sites)
- 6% recreational and green urban areas

The settlement area is growing as a result of the growing levels of land take per person and Switzerland's growing population. The goal of the Federal Council set out in the 2002 sustainable development strategy is to meet further demand wherever possible through inward development, i.e. improved utilisation of existing settlement areas (Swiss Federal Council 2012).

According to the FSO land-use statistics (Federal Statistical Office 2009c), Switzerland's agricultural land (14,816 km^2) has the following composition:

- 69% grassland and Alpine grazing areas
- 27% arable land
- 3% orchards, vineyards and horticulture

With agricultural land, too, the pressure on used land is growing with the increasing intensification of farming and the associated monotonisation and clearing of biotic and abiotic structures. The strategy for preserving biodiversity includes, among other things, measures to enhance and create areas that protect and promote biodiversity.

13.3.2 Environmental impact

Soil is a scarce, non-renewable resource. Quantitative loss of soil, sealing, compacting, over-fertilisation, pollution and loss of organic matter are the main problems leading to the loss of biological diversity in and above the soil in Switzerland. Soils formed by nature constitute the basis for biodiversity (BAFU 2012a).

Biodiversity provides essential services to society and industry, known as ecosystem services. The diversity of these services is immense: among other things, biodiversity provides food, influences the climate, maintains water and air quality, is part of soil development and offers humans space for recreation. When biodiversity is degraded, this results in less of these services and thus threatens the sustainable development of industry and society (BAFU 2012a).

13.3.3 Characterisation of biodiversity

The influence of land use on biodiversity is characterised using the factors developed by Chaudhary and Brooks (Chaudhary & Brooks 2018a), which describe species losses according to the intensity of land use. The various types of land use are assessed on the basis of their intensity, the species losses caused by them are quantified in different ecoregions, and the loss is weighted based on the vulnerability of the ecosystem in the region concerned. The factors are determined in several steps:

- Reduction in the number of species compared with the natural state according to de Baan et al. (2012), Biodiversity Monitoring Switzerland and the GLOBIO3 database (Alkemade et al. 2009)
- Prediction of absolute species losses based on the relationship between land use and species in a region (species-area relationship (SAR))
- Weighting of the losses based on the vulnerability of the ecoregion concerned (endemic richness)

In this way, Chaudhary derives characterisation factors for the potential proportion of disappearing species ('potentially disappeared fraction', or PDF) for five different land-use types, each with three intensity levels, in 804 ecoregions spread across some 200 countries. These reflect the expected absolute species losses due to land use, taking into account the vulnerability of the ecosystems and the threat facing the species.

Chaudhary, following de Baan et al. (2012), chose natural systems like forests as the reference status for biodiversity. Consequently, the difference between the biodiversity of a specific type of land use and the biodiversity of 'natural forest' land use is decisive in the determination of the decline in species diversity. 'Swiss settlement area' land use is selected as the reference 'substance' for determining the characterisation factors. The use of 1 m^2 of settlement area during a year therefore corresponds to 1 m^{2}a of settlement area-equivalent.

In order to obtain a degree of detail that is suitable for life cycle assessments, the land-use categories featured previously in the 2013 version (Frischknecht & Büsser Knöpfel 2013), selected on the basis of Köllner & Scholz (2007a, b), were adopted. The characterisation factors from Chaudhary and Brooks (Chaudhary & Brooks 2018b), however, are not that detailed. Missing items of data were estimated by means of similar land-use types or interpolations, based on guidance from the recommendation on 'Equation of management intensity'. Details can be found in A6 and Section 13.3.10.

The use of *water surfaces* and *bare land* (e.g. rock) cannot be characterised using the same approach. However, with a few exceptions such as watercourses, these types are usually of minor importance for life cycle assessments, and hence neglecting them is unlikely to have any significant effect on the outcome. An assessment of the adverse impacts of hydropower is being examined.

For *unknown uses*, a category encountered occasionally in life cycle inventories, it is recommended to apply the factor for agriculture or settlements determined based on the land use of the country or continent, depending on the context.

The country-specific factor for agricultural land use is applied to intensive types of use, as the proportion of organically farmed agricultural lands is low from a global perspective.

The characterisation factors of several land categories are shown in Tab. 93 for various countries. The complete list of countries and continents can be found in A6. Whereas previously factors for 12 biomes were used, factors for countries and continents as well as over 800 ecoregions can now be derived from information on characterisation factors from Chaudhary and Brooks (Chaudhary & Brooks

Tab. 90: Switzerland-specific characterisation factors of selected land-use types (in m^2a CH-settlement area equivalents) evaluated with land-use classes from Chaudhary & Brooks 2018

CORINE+	Land use	Land use category as per characterisation by Chaudhary	CH settlement areas-equivalents m^2a (PDF 7.48E-14)
	Settlement area		
111	Urban fabric, continuous	Urban, intense use	1
112	Urban fabric, discontinuous	Urban, light use	0,9
121a	Industrial area, continuous >80% sealed	Urban, intense use	1
121b	Industrial area, discontinuous <80% sealed	Urban, light use	0,9
	Agricultural areas		
211b	Arable land, non-irrigated, conventional	Cropland, intense use	0,83
221	Permanent crops, vineyard	Cropland, light use	0,81
231a	Pastures and meadows, intensive	Pasture, intense use	0,84
231a	Pastures and meadows	Pasture, light use	0,76
	Forest		
244	Agroforestry lands	Crop, minimal use	0,7
311a	Forest, broad-leafed, plantations	Plantation, minimal use	0,98
311a	Forest, broad-leafed, intensive	Managed forests, clear-cut (patches)	0,86
311a	Forest, broad-leafed	Managed forests, selective logging	0
311a	Forest, broad-leafed, semi-natural	Managed forest, reduced impact logging	0
312	Forest, coniferous	Managed forests, selective logging	0

A6 provides the complete list and derivation of factors.

[1] For derivation, see Part 3, Section 13.3.4

2018). The factors for the more than 800 ecoregions are available in an Excel file.

13.3.4 Characterisation of forest management

Chaudhary & Brooks (2018) provide PDFs for three management intensities for the land-use class 'managed forest' and another three intensities for 'plantations', with natural forest used as a reference. Thus, the latter has a PDF of zero, i.e. no adverse impact. The average Swiss forest must be evaluated in terms of the intensity levels for 'managed forest'.

The results of the national forest inventory (Brändli 2010) show that Swiss forest is a relatively semi-natural ecosystem. Various indicators in the national forest inventory are combined on the basis of the biotope value models in order to provide a comprehensive, spatially differentiated relative evaluation of the status and development of the Swiss forest from an ecological perspective. The results of these surveys reveal that 53.9% of Switzerland's forest area has a high biotope value. Therefore, 53.9% of the forest area is assigned the PDF for 'semi-natural forest' (corresponding to 'reduced impact logging' where PDF = 0) and the remaining 46.1% is assigned the PDF for 'managed forest' (corresponding to 'selective logging' where PDF = 0). Current Swiss forest management practices do not include more intensive forms of forest management such as clear-cutting and short rotation periods in the manner of a plantation. The remaining proportion of highly artificial forest is in sharp decline and is not taken into account when evaluating the situation in Switzerland, as it attests to past forms of management.

Forest performs various functions. The Swiss forest provides wood and in many places fulfils a protective function. Forests are also used for recreation. This multifunctionality should be taken into consideration in the inventories. In ecoinvent inventories, this is addressed for Swiss forest by means of an economic allocation for the protective function and the revenue generated from timber production. For other inventories, assessors must check whether a corresponding allocation has been made and/or is necessary. This does not affect the assessment of Swiss forest management, as the average Swiss forest is largely managed in a semi-natural way and thus has a value of zero PDF or settlement area equivalents.

13.3.5 Normalisation

The normalisation flow corresponds to the current flow. It is calculated by multiplying the current land-use areas by the respective characterisation factors in settlement area equivalents (SA-eq.) and then adding them up. This results in a normalisation flow of around 1.5E+10 m^2a settlement area equivalents.

13.3.6 Weighting

The current flow is calculated in the same way as the normalisation flow and thus also has a value of around 1.5E+10 m^2a settlement area equivalents.

An evaluation is made based on the 'planetary boundaries' according to Steffen et al. (2015), with the natural background extinction rate used as the target value. The resulting goal is to stabilise species loss in the range of the natural background extinction rate of 1–10 E/MSY.[26] The mean value of 5.5 E/MSY is used as the target. From this, the global loss of species per year was calculated, which in turn was used to determine Switzerland's share based on population. Knowing the species loss per settlement area (Chaudhary & Brooks 2018), it was then possible to determine the critical flow of 4.9E+09 m^2a settlement area equivalents.

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[26] E/MSY: extinction rate per million species year

13.3.7 Eco-factor for land use in Switzerland

Tab. 91: Eco-factor for the land use of settlement area in UBP/m^{2}a

	Edition 2021	Q	Bemerkungen	Edition 2013
Normalisation flow (km^2*a SA-eq.)	15 045	A	Settlement, agricultural and forest areas of Switzerland with characterisation factors according to Chaudhary	2437
Current flow (km^2*a SA-eq.)	15 045	A	Settlement, agricultural and forest areas of Switzerland with characterisation factors according to Chaudhary	3027
Critical flow (km^2*a SA-eq.)	4900	a	Planetary boundaries approach to critical flow of natural background extinction in Switzerland Settlements characterisation factor from Chaudhary	3535
Weighting factor (–)	9,43			0,73
Eco-factor (UBP/m^2*a SA-eq.)	**630**		Eco-factor for settlement area	300

Q = data quality; for explanation, see Part 2, Chapter 6;
SA-eq. = settlement area-equivalent

13.3.8 Land use according to ecoregions and countries

Human activities can cause extensive changes in land use and thus a substantial reduction of biodiversity. One example is the clearing of primary forests for agricultural use. The land-use assessment, which previously focused on the Swiss situation, has been expanded so that the above-described land uses in different countries and ecoregions can also be assessed. The subdivision by country and ecoregion replaces the previously used biomes. The environmental impacts of various types of land use are represented using differences in observed biodiversity and vulnerability, based on the work of Chaudhary and Brooks (2018).

As reference systems, Chaudhary defines the natural state in over 804 ecoregions. The subdivision is based, among other things, on information contained in de Baan et al. (2012). Differences in the evaluation of species losses in ecoregions arise due to differences in the numbers of natural species and their vulnerability. The figure below illustrates this with the example of the projected extent of vertebrate extinction (see Fig. 10).

The characterisation factors for specific countries and continents are extrapolated based on the ecoregions they contain.

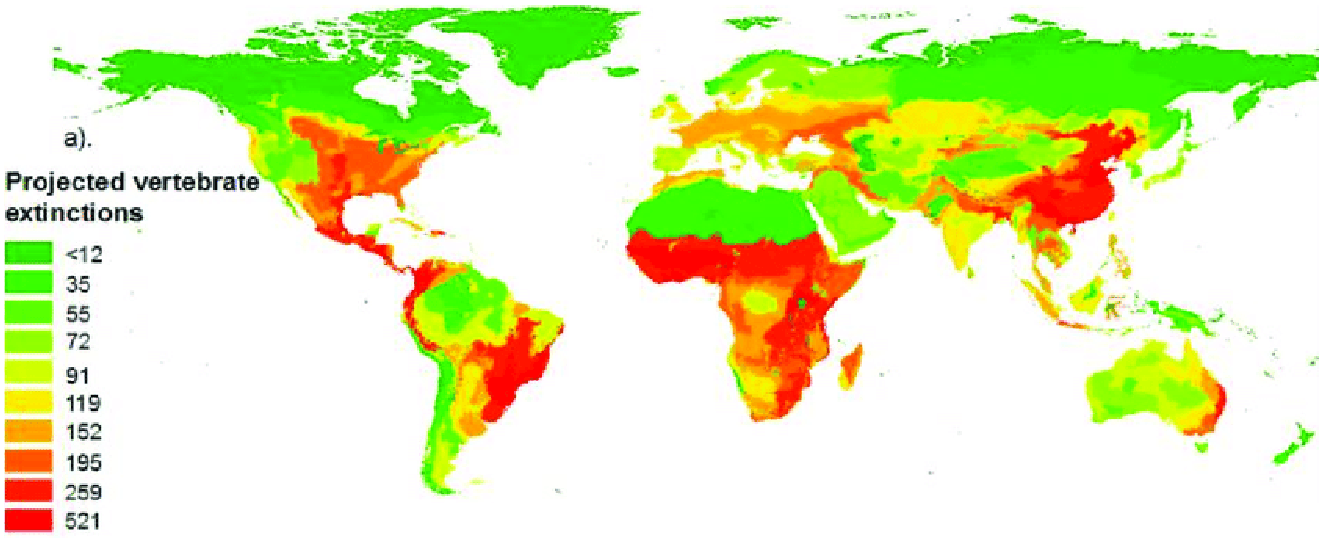
The eco-factors of several land categories for various countries are listed in Tab. 93. The complete list can be found in A6. It can be seen that land use in countries containing tropical regions with high species numbers and vulnerability has a higher eco-factor. For example, India has an eco-factor for settlement areas that is 3.7 higher than that in Switzerland. It should be noted that this factor depends not only on the countries but also on the land use.

Tab. 92: Characterisation factors for species losses from land areas, expressed as a ratio in relation to Switzerland according to species densities and vulnerability

Selection of countries	Ratio in relation to characterisation factors for Swiss settlement areas
Brazil	3,34
India	3,69
Switzerland	1
France	0,74
Sweden	0,16

The new 2021 eco-factors for land use in Switzerland can be compared with the previous eco-factors for biome 5. This shows that the new eco-factors for Switzerland, apart from forest management, are higher by a factor of 1.5 to 3.

Fig. 10: Projected extinction of vertebrates with current land use according to Chaudhary and Brooks (2018)



The new eco-factors for forest management are significantly lower than in the 2013 edition, with higher values being associated with an intensive form of forest management and plantations.

13.3.9 Guidelines for application: assessing special land-use types

There are two possible ways to handle land uses that are not covered by the extended CORINE nomenclature (cf. also Tab. 94 and Part 3, Section 16.1):

1. **Increase the degree of detail:** a land use can be broken down proportionally into defined levels of management intensity and the relevant ecoregion factored in. The assessment problem regarding intensity can thus be transferred to the inventory analysis level at which it is more readily resolved (e.g. for the assessment of wood from specific areas, by assigning a part to intensively managed forest land and a part to semi-naturally managed forest land in the life cycle assessment).
2. **Proceed by analogy:** a land use is similar to a type of use for which there is an eco-factor (e.g. the eco-factor for green urban areas can be applied to green roofs).

13.3.10 Implementation in the ecoinvent v3 database or UVEK

Characterisation factors from Chaudhary are available for the following land-use types, each of which is covered by three levels of management intensity:

- Managed forests: minimal, light and intense use
- Plantations: minimal, light and intense use
- Cropland: minimal, light and intense use
- Pasture and meadow: minimal, light and intense use
- Urban: minimal, light and intense use

The elementary flows in ecoinvent are assigned to these land uses and management intensity levels according to the listing in A6. The land use for managed forest ('occupation, forest') in the ecoinvent v3 database and UVEK is assigned to the land-use type 'managed forest, light use'. This corresponds to managed forests with selective logging according to Chaudhary's categorisation (cf. Tab. 93 and other lists in A6). This reflects Swiss forest management practices. In other countries, the intensity may be different. Consequently, the inventory analysis may have to be adjusted for wood from other countries with more intensive forms of management.

Tab. 93: Eco-factors of selected land-use types in UBP/m²a for various countries (focusing on examples of raw material imports such as soy, wood, grain and cotton)

CORINE+	Land use (classification of land use category according to Chaudhary)	Brazil (UBP/m²a)	France (UBP/m²a)	Switzerland (UBP/m²a)	India (UBP/m²a)	Sweden (UBP/m²a)	Edition 2013
	Settlement area						
111	Urban fabric, continuous (urban, intense use)	2090	460	**630**	2310	100	300
112	Urban fabric, discontinuous (urban, light use)	2040	410	**560**	2140	100	180
121a	Industrial area, continuous >80% sealed (urban, intense use)	2090	460	**630**	2310	100	300
121b	Industrial area, discontinuous <80% sealed (urban, intense use)	2040	410	**560**	2140	100	180
	Agricultural land						
211b	Arable land, non-irrigated, conventional (crop, intense use)	2040	390	**520**	1940	80	420
221	Permanent crops, vineyard (crop, light use)	2040	380	**510**	1910	80	290
231a	Pastures and meadows (pasture, light use)	2030	380	**480**	2100	90	230
	Forest						
244	Agroforestry lands (crop, minimal use)	1990	330	**(440)**	1690	70	140
311a	Forest, broad-leafed, plantations (Plantation, minimal use)	1960	440	**(610)**	2170	100	120
311a	Forest, broad-leafed (managed forests, selective logging)	1780	0	**0**	1890	0	30
312	Forest, coniferous (managed forests, selective logging)	1780	0	**0**	1890	0	30

A6 provides the complete list and derivation of factors.
Values in parentheses indicate land uses that do not occur in this country.

Tab. 94: Recommendation for the characterisation of 'FSC forest' and 'green roof'

Land-use type	Recommendation for classification	Notes
Forest, managed to FSC standards	a) Depending on the type of forest and management: 1) 311: Forest, broad-leafed 2) 312: Forest, coniferous 3) 313: Forest, mixed In the case of plantations, the subcategories 311a, 312a or 313c are to be used b) and, in accordance with the circumstances on the ground, proportions classified as semi-natural 1) 311b: Forest, broad-leafed, semi-natural 2) 312b: Forest, coniferous, semi-natural 3) 313: Forest, mixed	The Swiss FSC rules prescribe ecological management and the designation of at least 5% of the area as strict reserve (BUWAL 1999a). The rules are specified at the national level and may therefore differ in other countries. The inventorisation of FSC forest should be performed in the inventory analysis.
Green roof	1) 113: Urban fallow 2) 141: Green urban areas	Where plantings are ecologically valuable, e.g. oligotrophic grassland on a large flat roof Where roof planting is simple **Note**: areas are only counted once, either as a normal settlement area or as a green roof

Tab. 95: Recommended and applied assignment of land-use classes and elementary flows for forest and agricultural land in the ecoinvent v3 database and UVEK

Elementary flow in the ecoinvent v3 database	Classification of land use category by Chaudhary
Forest/plantations	
Occupation, forest, broad-leafed	managed forests, light use (selective logging)
Occupation, forest, intensive	managed forest, intense use (clear-cut patches)
Occupation, forest, broad-leafed, plantations	plantation, minimal use
Occupation, forest, broad-leafed, semi-natural	managed forests, reduced impact logging
Agricultural areas	
Occupation, arable, irrigated	crop land, intense use
Occupation, arable, non-irrigated	crop land, intense use
Occupation, arable, non-irrigated, monotone-intensive	crop land, intense use
Occupation, permanent crops	crop land, intense use
Occupation, arable, organic	crop land, light use
Occupation, permanent crops, extensive	crop land, minimal use
Occupation, arable, extensive	crop land, minimal use
Occupation, arable, non-irrigated, Brache	crop land, minimal use

For the elementary flows for arable land, it is recommended to use the category 'occupation, arable land' or 'occupation, arable land, non-irrigated' for the country concerned, except in the case of organically and extensively farmed lands and fallows. Tab. 95 shows how land-use categories are assigned to the elementary flows in the ecoinvent v3 database and UVEK.

13.4 Primary mineral resources (minerals and metals)

13.4.1 Introduction

The assessment of primary mineral resources is debatable. Economists argue that resource scarcity will automatically be reflected in the prices, and that resources themselves do not cause any external effects as a result. Following this logic, they should not be assessed separately in life cycle assessment methods. The opposing argument is that current resource prices are not only affected by the demand of the generations alive right now; future generations are excluded from price formation. In this sense, the intertemporal equitable distribution of mineral and metal resources is not currently being achieved, which is why these resources need to be included in the assessment.

The Federal Council's cleantech strategy (Swiss Federal Council 2011, p. 10) expresses the vision that Switzerland should reduce its resource consumption to sustainable levels (footprint 'one'). The Federal Council's sustainable development strategy (Swiss Federal Council 2012, p. 20) postulates in the new 4–2 measures (information and communications technologies and sustainable development) that recycling activities should be developed in the field of information and communications technologies in order to close material cycles. The Swiss federal government is promoting actions within the current 4b measure (integrated product policy) to close material cycles. This also involves conserving material resources by closing material cycles. The latest federal government documents on the circular economy, such as the postulate response on the promotion of the circular economy (Swiss Federal Council 2020), or on federal government measures for a resource-conserving, future-proof Switzerland (BAFU 2020b), do not include quantitative targets or the ability to derive such targets.

Consequently, material resources are once again, in the 2021 edition, included in the assessment on the basis of the two above-mentioned strategies from 2011 and 2012. A broad approach (annual depletion of reserves) has been selected from the various approaches presented and compared in scientific publications to be used for the characterisation. This approach quantifies the scarcity of

Tab. 96: Characterisation factors for selected metal and mineral resources according to their scarcity, with antimony (Sb) as the reference substance. Complete list in A7

Substance	Specification	Characterisation factor (kg Sb-eq/kg)
Antimony		1,00
Chromium	25.5% in chromite, 11.6% in crude ore	0,00079
Gypsum		
Indium	0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ore	0,11
Lead	5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	0,019
Tin	79% in cassiterite, 0.1% in crude ore	0,082
Gold	Au 2.1E-4%, Ag 2.1E-4%, in ore	1370
Zinc	9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ore	0,0028
Silver	3.2 ppm in sulfide, Ag 1.2 ppm, Cu and Te, in crude ore	8,6
Cadmium	0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ore	3,6

a specific resource and is therefore very similar to the basic principle of the ecological scarcity method.

13.4.2 Characterisation

The environmental impact of the dissipative use of metals and minerals is characterised by squaring the ratio of the cumulative volume extracted worldwide between 1970 and 2015 to the ultimately available reserves (amount present in the earth's crust) (Guinée et al. 2001a). The values used are taken from van Oers et al. (2019). The approach adopted here was recommended by the experts involved in a UN Environment Life Cycle Initiative project to harmonise environmental indicators (Frischknecht & Jolliet 2019). Applied to life cycle inventories, the indicator answers the question of what contribution a product and its supply chains make to the depletion of primary mineral resources (Berger 2020).

Antimony (Sb) is used as the reference substance. Tab. 96 lists a selection of the characterisation factors. A7 provides a complete list of all assessed metals and minerals.

13.4.3 Normalisation

The normalisation flow is determined based on the global production of minerals and metals and the ratio of the Swiss population to the world population. In 2018, a total of 6,010,000 tonnes of Sb-eq. were produced globally. According to the UN Population Division, the world population was 7,631.09 million in 2018.[27] In 2018, 8,544,500 people were living in Switzerland. This results in a total normalisation flow of 6,733 tonnes of Sb-eq. per year.

13.4.4 Weighting

The current flow corresponds to the normalisation flow.

The critical flow is equated with the current flow in a preliminary assessment based on the minimum goal. The qualitative goals chosen by the Federal Council are to reduce resource consumption, increase resource efficiency and close more material cycles (Swiss Federal Council 2012, p. 20). However, the quantitative goals, the timeframes for their achievement and the system of measurement to monitor goal achievement have not yet been set out in any binding manner. In this situation, 'no further deterioration', i.e. maintaining the status quo, is used as the binding minimum goal for the assessment of the critical flow.[28] As a result, the critical flow corresponds to the current flow.

13.4.5 Eco-factor for minerals and resources, lead substance antimony

The eco-factor for use of the resource antimony, the lead substance (see Tab. 97), is 86% lower than the 2013 eco-factor. The reason for this is a change in method (from

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[27] *http://esa.un.org/unpd/wpp/unpp/panel_population.htm* (Accessed: 9 January 2020)

[28] Written communication, Norbert Egli, FOEN, 12 September 2013

Tab. 97: Eco-factor for metal and mineral resources, with antimony as the lead substance; in UBP/g Sb-eq.

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (t Sb-eq./a)	6733	A	World production, Swiss proportion	904
Current flow (t Sb-eq./a)	6733	A	World production, Swiss proportion	904
Critical flow (t Sb-eq./a)	6733	c		904
Weighting factor (-)	1,00			1,00
Eco-factor (UBP/g Sb-eq.)	**150**		Characterisation factor = 1	1100

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 98: Eco-factors for selected metal and mineral resources

Substance	Specification	Characterisation (kg/kg Sb-eq)	Eco-factor (UBP/kg)
Metals			
Copper	1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	0,021	**3200**
Chromium	25.5% in chromite, 11.6% in crude ore	0,00079	**120**
Lead	5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In	0,019	**2 800**
Tantalum	81.9% in tantalite, 1.6E-4% in crude ore	0,0013	**190**
Silver	3.2 ppm in sulfide, Ag 1.2 ppm, Cu and Te, in crude ore	8,6	**1 300 000**
Gold	4.9E-5% in ore	1371	**200 000 000**
Minerals			
Gypsum			
Phosphorus	18% in apatite, 4% in crude ore	0,000071	**11,0**
Sulphur		0,00016	**23,0**

Complete list in A7

resources deemed economically exploitable to ultimate reserves) compared with the 2013 edition.

13.4.6 Eco-factors of other metals and minerals

The eco-factors of other metals and minerals are determined using the characterisation based on the scarcity approach (cf. Tab. 96 and the detailed list in A7).

13.4.7 Application guidelines for life cycle assessment databases and case studies

The goal of the Federal Council's strategy is to close material cycles (see Section 13.4.1). From this, it can be deduced that resource extraction is not decisive in the material use of resources, but rather the amount of extracted and processed resources that are dissipatively lost and therefore no longer available for future use. The remaining portion, which can be recovered or recycled, is only 'on loan' and may be used again in the future. Landfilling of primary mineral resources is classified here as dissipative use. For a more in-depth discussion of this issue, see the paper by Beylot et al. (2020).

In the way that the current eco-factors are presented and the extraction of primary mineral resources is modelled in life cycle inventories, it is resource extraction, and not dissipative use, that is assessed.

The eco-factor of mineral and metal resources should be applied to the difference between resource extraction and recycled resource. Alternatively, it can also be applied to the proportion of dissipatively used mineral or metal resource (which in theory leads to the same result). These methods should also be applied to the separately derived eco-factor for gravel.

A similar assessment should also be applied in the case of organic resources that are used for materials (wood, renewable raw materials). Resource extractions (wood and other renewable raw materials) are still assessed with the primary energy eco-factor. The particular proportion of raw material that is recycled should now be assessed with a negative primary energy factor. Accordingly, the 'borrowed' use of material resources is not assessed in this case either, but rather only the 'dissipative' use. The thermal treatment of products made of organic materials (e.g. wood) at the end of their life cycle is considered dissipative use.

In LCA case studies where the use of primary resources is important, it should be ensured that only dissipative use is assessed.

13.5 Gravel extraction

13.5.1 Introduction

Gravel (and sand) is a sui generis resource: it is both a construction material and an important material for protecting and forming groundwater. Not all physical gravel occurrences are extractable; permissible land uses set limits.

Gravel and sand are mainly used in the construction industry, particularly as concrete aggregate and in road and railway subgrades. Sand is also used in mobile phones, cosmetics and chips. The quality of gravel deposits can vary widely. High-grade alluvial gravels are found especially on valley floors, while morainic mounts often have a mixed composition, making gravel extraction more costly (Jäckli & Schindler 1986; Kündig et al. 1997). Sand is not only excavated for building purposes, but also to fill beaches (or create new ones). Sand is actually the most in-demand raw material after water in terms of mass. The consequences of unlimited sand mining include the loss of river beds and wildlife habitats (Chaton 2013).

Gravel resources replenish very slowly. Only around 1% of Switzerland's current annual gravel consumption is formed anew in rivers in the same period. Moreover, the geological gravel deposits are reduced by competing demands such as housebuilding, groundwater protection and, in some cases, forest protection and species diversity conservation. As a result, the extractable quantity is substantially smaller than the resource (Jäckli & Schindler 1986). In the canton of Zug, for instance, it is assumed that if extraction intensity remains at the same level, the utilisable gravel reserves will suffice for only 18 years (Raumplanungsamt Kt. Zug 2005). The above-mentioned items subject to protection are included in the 'extractable gravel quantities' set by the authorities. Therefore, the ecological scarcity of this form of land use can be determined using the gravel quantities.

According to Chaton (2013), the amount of sand being excavated is equal to the sand produced by all of the world's rivers in one year.

13.5.2 Normalisation

The normalisation flow is identical to the current flow, as the latter relates to all of Switzerland. No characterisation is performed.

13.5.3 Weighting

Gravel production at Swiss gravel works depends on construction sector activity and has ranged between 30 million and 40 million tonnes in the last 20 years. Production peaked in around 1990. In 2017, 36.1 million tonnes of sand and gravel were extracted (BFS 2017); this is used as the current flow.

The spatial planning authorities of the cantons are responsible for approving gravel extraction. Provisions governing extraction have therefore only been established, if at all, at the cantonal level. It has been clear for some time that gravel reserves will be exhausted in the foreseeable future (see e.g. Kündig et al. 1997; Raumplanungsamt Kt. Zug 2005). The volume of gravel reserves designated for extraction across Switzerland has always been sufficient for the next 15 to 20 years. Therefore, even though the resource is essentially finite, the current extraction situation is tolerated. Thus, the critical flow is taken to be equal to the current flow.

13.5.4 Eco-factor for gravel extraction

The eco-factor for gravel has decreased slightly. It reflects the currently tolerated extraction volume.

13.5.5 Guidelines for application

The eco-factor for gravel should be applied for gravel and sand from alluvial gravel pits. Gravel and sand excavated

Tab. 99: Eco-factor for gravel extraction in UBP/g gravel

	Edition 2021	Q	Notes	Edition 2013
Normalisation (million t gravel/a)	36,0	A		34,0
Current flow (million t gravel/a)	36,0	A	(BFS 2017)	34,0
Critical flow (million t gravel/a)	36,0	c		34,0
Weighting (–)	1,00			1,00
Eco-factor (UBP/g gravel)	**0,028**			0,030

Q = data quality; for explanation, see Part 2, Chapter 6

from rock (quarry, tunnel construction) or extracted from the bed load of rivers and lakes should not be assessed with this eco-factor.

For the assessment of gravel and sand that are recycled and reused for other purposes, see Section 13.4.7.

13.6 Freshwater consumption

13.6.1 Introduction

In some regions of the world, freshwater is scarce, while in others, there is a surplus. Switzerland is in the comfortable position of having access to more than enough clean water. However, this may change in the future due to climate changes. Nevertheless, the Federal Council (Swiss Federal Council 2002, p. 9) demands that "[…] natural resources be utilised with due regard to future generations" and specifies this by demanding that, among other things, "[…] the consumption of renewable resources (e.g. farmed biomass, water) is kept below the level at which they can regenerate or below the natural level of availability". The same document also notes the global freshwater problem, citing the OECD. One of the measures of the Federal Council's current sustainable development strategy (Swiss Federal Council 2016) is intended to strengthen the international environmental regime with a particular focus on the issue of 'water'. Against this backdrop, an assessment of water scarcity was included in the ecological scarcity method for the first time in 2006. This was based on the scarcity of freshwater resources expressed as the ratio of gross extraction to the available renewable water resource (precipitation plus inflows from neighbouring countries minus natural evaporation).

In the meantime, much research has been done on assessing water scarcity, and new approaches have been developed. Of particular note in this regard is the WULCA working group, established in August 2007 under the auspices of the UNEP[29]/SETAC[30] Life Cycle Initiative. It operates as an international working group focusing on the assessment of water use and the creation of water footprints from a life cycle perspective. For more information, see *http://www.wulca-waterlca.org*. This working group has refined and evaluated a number of approaches, and its work resulted in the recommendation to use the AWARE method (Available WAter REmaining per area) for assessing water scarcity – see Chapter 5 of Frischknecht & Jolliet (2016). This method was used for the first time for the characterisation of water scarcity, and the following types of eco-factors were derived for freshwater:

1. Country-specific (for Switzerland and all other countries in the world)
2. For the OECD and BRIC[31] countries (weighted average consumption) as food, if the water consumption is not differentiated in an inventory analysis
3. For the continents of Africa, Asia, Europe, Australia, North and Central America, South America and separately for OAPEC countries

Eco-factors are no longer derived for the six scarcity situations (low, moderate, medium, high, very high and extreme), as was the case in the 2013 edition. Instead, Section 13.6.6 describes how the eco-factors can be determined for a specific water catchment. These data also allow eco-factors to be derived for different months, meaning that seasonal fluctuations can be taken into account. In addition, the

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[29] UN Environment Programme

[30] Society of Environmental Toxicology and Chemistry

[31] Brazil, Russia, India and China

eco-factors for water scarcity by country and province, as monthly and annual averages, are made available in the form of an Excel file.

This differentiation by country or water catchment makes it possible – for instance, in life cycle assessments of foods or other products requiring large amounts of water for their production – to distinguish between origin from arid regions where water scarcity prevails and origin from regions with ample water resources, and so to take account of the aspect of water scarcity, which can be relevant in some cases. Users of the method can also derive regional or local eco-factors themselves to address specific issues.

Tab. 100 shows the terms used in this report in reference to water extraction, consumption and renewable water resources.

While the water stress index expresses the ratio of water withdrawal to water supply, the eco-factor developed here for product and corporate life cycle assessments is applied to consumptive water use.

13.6.2 Normalisation

The Swiss level of freshwater consumption, which is 2.61 km^3/a (approximately 350 m^3 per capita and year or 1,000 litres per capita and day), is used as the normalisation flow, as in the 2013 edition. This was based on FAO data, and according to the latest FAO yearbook, water use remained constant in Switzerland between 2007 and 2017 (FAO 2018).

This normalisation is used for all specific eco-factors of countries or water catchments. Specific water conditions are taken into account through the characterisation.

Tab. 100: Term definitions according to FAO (2012)

Term	Definition	Definition according to FAO (2012)	Term according to FAO (2012)
Water withdrawal	Water withdrawal means not only withdrawing water for use as drinking water, but also for irrigating agricultural areas and for industrial processes. In-stream uses that are characterized by a very low net consumption rate are not taken into account. This includes turbined water, navigation, recreational activities, fishing, etc.	Annual quantity of water withdrawn for agricultural, industrial and municipal purposes. It includes renewable freshwater resources as well as potential over-abstraction of renewable groundwater or withdrawal of fossil groundwater and potential use of desalinated water or treated wastewater. It does not include in stream uses, which are characterized by a very low net consumption rate, such as recreation, navigation, hydropower, inland capture fisheries, etc.	Total water withdrawal
Water consumption (consumptive water use)	Water consumption corresponds to the proportion of water that evaporates during its use (evaporation or evapotranspiration), is embodied in products or diverted from its original catchment to a different catchment.	The part of water withdrawn from its source for use in a specific sector (e.g. for agricultural, industrial or municipal purposes) that will not become available for reuse because of evaporation, transpiration, incorporation into products, drainage directly to the sea or evaporation areas, or removal in other ways from freshwater resources.	Water consumption, consumptive water use
Renewable water supply, renewable water resources	Renewable water resources include the long-term average runoff from rivers (surface water) and the accumulation of aquifers (ground water) through precipitation. Groundwater aquifers that are practically totally isolated from the natural water cycle and thus have only an insignificantly low accumulation rate (on a human time scale) are not classified as renewable	Total Natural Renewable Water Resources (TRWR_natural): The long-term average sum of internal renewable water resources (IRWR) and external natural renewable water resources (ERWR_natural). It corresponds to the maximum theoretical yearly amount of water actually available for a country at a given moment.	Water resources: total renewable (natural)

13.6.3 Characterisation

Characterisation factors from the AWARE method are used for characterisation. For more information, see *https://wulca-waterlca.org/aware/*. The characterisation factor is a measure of the relative available residual water per area in a water catchment after the needs of people and ecosystems have been met. It assesses the potential harm from water withdrawal, to either humans or ecosystems, and is based on the assumption that the less water that remains available per area, the greater the likelihood that another user will be deprived.

The AWARE method first calculates the water Availability Minus the Demand (AMD) of humans and ecosystems relative to the area (m^3/m^2 month). In a second step, the value is normalised with the world average result (AMD = 0.0136 m^3/m^2 month). The inverted value 1/AMD can be interpreted as a measure for water scarcity in this region. The indicator is limited to a range from 0.1 to 100, with a value of 1 corresponding to the world average, and a value of 10, for example, representing a region where there is ten times less available water remaining per area than the world average. Switzerland has a characterisation factor of 0.965, almost in line with the global average.

$$\begin{aligned}\text{Weighting} &= \left(\frac{\text{current flow}}{\text{critical flow}}\right)^2\\ &= \left(\frac{\text{water withdrawal}}{(\text{water supply}_{\text{renewable}} \times 20\,\%)}\right)^2\\ &= \left(\underbrace{\left(\frac{\text{water withdrawal}}{\text{water supply}_{\text{renewable}}}\right)}_{\text{scarcity ratio –}}\right)^2 \times \left(\frac{1}{20\,\%}\right)^2\end{aligned}$$

13.6.4 Weighting

Weighting is performed in the same way as in the 2013 edition. As according to FAO (2018) neither the renewable water resources nor water demand have changed, the weighting factor remains constant. The current flow, i.e. the quantity of freshwater consumed annually in Switzerland, is 2.61 km^3/a, according to FAO (FAO 2018). FAO also reports that the available annual renewable water resource in Switzerland is 53.5 km^3.

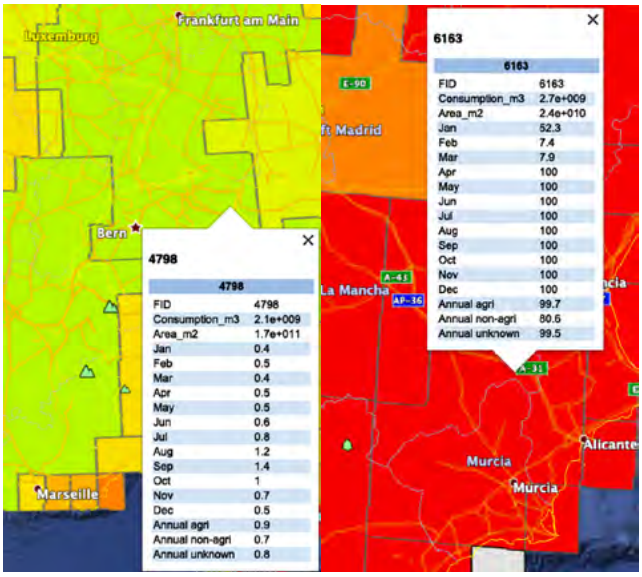
According to the OECD (2003), a tolerable water stress is the withdrawal of 20% of the renewable water supply. Therefore, the critical quantity of freshwater use for Switzerland is about 11 km^3/a.

The weighting factor is calculated by the ratio of water withdrawal to renewable water supply (without needing to know the absolute values) and based on the assumption that the critical flow is 20% of the water supply, as follows:

13.6.5 Eco-factor for Swiss freshwater

This eco-factor should be applied in product and corporate life cycle assessments for consumptive freshwater use in Switzerland. No water scarcity prevails in Switzerland. Nevertheless, water shortages can arise in the summer months in certain locations. The eco-factor stated here does not capture such temporally and spatially limited situations. A breakdown of the eco-factors by month and province (or canton in Switzerland) is provided in an Excel file. These can be used wherever such situations need to be assessed. In addition, users of the method can derive eco-factors themselves using the methodology set out in Sections 3.4 and 3.5 as well as 13.6.6.

Fig. 11: Examples of two water catchment areas: the Rhine catchment in Switzerland and Murcia in Spain, with the corresponding AWARE CFs



4798

4798	
FID	4798
Consumption_m3	2.1e+009
Area_m2	1.7e+011
Jan	0.4
Feb	0.5
Mar	0.4
Apr	0.5
May	0.5
Jun	0.6
Jul	0.8
Aug	1.2
Sep	1.4
Oct	1
Nov	0.7
Dec	0.5
Annual agri	0.9
Annual non-agri	0.7
Annual unknown	0.8

6163

6163	
FID	6163
Consumption_m3	2.7e+009
Area_m2	2.4e+010
Jan	52.3
Feb	7.4
Mar	7.9
Apr	100
May	100
Jun	100
Jul	100
Aug	100
Sep	100
Oct	100
Nov	100
Dec	100
Annual agri	99.7
Annual non-agri	80.6
Annual unknown	99.5

Tab. 101: Eco-factor for the consumption of Swiss freshwater in UBP/m³ freshwater

	Edition 2021	Q	Bemerkungen	Edition 2013
Characterisation factor	0,965			–
Normalisation (km³/a)	2,61	A		2,61
Current flow (km³/a)	2,61	A	(FAO 2011)	2,61
Critical flow (km³/a)	10,7	b	20% of the renewable water supply according to FAO (2011)	10,7
Weighting (–)	0,0597		Ratio of water withdrawal to supply: 0.049	0,0597
Eco-factor (UBP/m³)	**22**			23

Q = data quality; for explanation, see Part 2, Chapter 6

13.6.6 Derivation of region-specific and seasonal eco-factors

A Google Earth layer is available on the WULCA website (*https://wulca-waterlca.org/aware/*) showing the characterisation factors for all water catchments (see Fig. 11). Selecting a catchment (watershed) brings up a table with the AWARE characterisation factors (CFs) for that catchment. The number of the catchment appears at the top, followed by the CFs for all months and the annual averages. To obtain the eco-factor for the catchment in question, and where relevant the specific season/month, the value concerned must be multiplied by the uncharacterised eco-factor for Switzerland of 23 UBP/m³. For the average eco-factor of a catchment over the year, the 'Annual unknown' value must be used. In this way, region-specific eco-factors can be calculated for all water catchments around the world.

13.6.7 Guidelines for using eco-factors

In contrast to earlier versions, the 2013 edition began to assess consumptive water use, instead of water withdrawal, with the eco-factors for freshwater. There are three different types of consumptive water use. First, water can be embodied in products. Second, used water can evaporate/vaporise (due to plants or industrial processes). Third, water can be diverted from one water catchment and brought to another. In all three types of water use, the water in the catchment concerned is no longer available for other uses. Applications in which water is used and then returned to the same catchment from which it was withdrawn are excluded from the assessment using the freshwater eco-factor. Any contamination of the withdrawn, used and returned water is taken into account in the assessment of water pollutants (see Part 3, Chapter 10).

The eco-factor for consumptive freshwater use should be applied, but not limited to, the following cases:

- Evaporation in the case of drinking water use
- Irrigation in agriculture (proportion of water contained in the harvested plants plus evapotranspiration, excluding the proportion of rainwater)
- Vaporisation in industrial processes

The eco-factors for all countries and a number of regions are listed in A8. The AWARE characterisation factors are publicly available on the WULCA website (*https://wulca-waterlca.org/aware/*).

13.6.8 Guidelines for the application of inventory analysis data

This section explains how consumptive water use can be quantified from inventory data (unit processes) (see also Flury et al. 2012). The inventory analysis data should include the entire water balance (including rainwater). To do so, new elementary flows with country codes must be introduced so that a regional assessment is possible. In this connection, water input is no longer differentiated by source, but rather subsumed under an elementary flow. Embodied water is also considered a water input.

Tab. 102 provides an overview of elementary flows required for an industrial and agricultural process as an example. The water input (1 + 2) should match the water output (sum

Tab. 102: Elementary flows for a complete inventory of water used in processesen

No	Elementary flow	Industrial process	Agricultural process
Input			
1	Water, unspecified natural origin, country XY	Water for production process (e.g. cleaning devices, containers)	Water for irrigation
–	Water, rain	Not taken into account	Taken into account for complete inventory
2	Water, embodied, in product, country XY	Water embodied in raw materials	Water embodied in seeds
Output			
3	Water, country XY (emitted in the air)	Emission: water vaporised during the production process	Emission: evaporated water from farmed fields
4	Water, river/lake	Discharged directly from the industry into surface waters	Discharged from fields into surface waters
5	Water, sea	Discharged directly from industry into the sea	Discharged from the fields into the sea
6	Water, soil	Direct infiltration in the soil	Infiltration in the soil from fields
7	Water, embodied, in product, country XY	Water embodied in the product	Water embodied in the product
Total			
	Water withdrawal	1	
	Consumptive water use	3 + 7 – 2	

Tab. 103: Standard values for the proportion of consumptive water use, to be applied to existing elementary flows in UVEK LCI Data DQRv2:2022

Elementary flow in UVEK LCI Data DQRv2:2022	Standard value	Source
Elementary flow in UVEK LCI Data DQRv2:2022	5 %	(Muñoz et al. 2010, Rosiek et al. 2010, Jefferies et al. 2011, Gleick 1994, Shaffer 2008, Stiegel & al. 2008, Scown & al. 2011)
Water, cooling, in unspecified natural origin	10 %	(Shaffer 2008, Statistics Canada 2010)
Water, lake	10 %	
Water, river	10 %	
Water, well, in ground	10 %	
Water, unspecified natural origin	0	
Water, salt, ocean	0	
Water, salt, sole	0	
Water, turbine use, in unspecified natural origin		

of 3 to 7). If rainwater is also covered, it must be taken into account in the output as well.

The following is the minimum information required for a complete inventory and a flexible assessment of processes:

- Water withdrawal, country-specific (1)
- Evaporation: emission from water into the air, country-specific (3)
- Water, contained in the product, country-specific (2, 7)

13.6.9 Guidelines for using UVEK LCI Data DQRv2:2022

UVEK LCI Data DQRv2:2022 includes only data on water withdrawal and not on consumptive water use. The above-mentioned method is not feasible for UVEK LCI Data DQRv2:2022 with reasonable effort. The following simplified procedure is therefore recommended for an assessment of consumptive water use: correction factors are introduced into the assessment method. They quantify the average proportion of consumptive water use (e.g. through evaporation) in water withdrawal for each individual elementary flow.

13.7 Marine fish resources

13.7.1 Introduction

Like many other uses of natural resources, fishing has expanded steadily and rapidly since 1950. Around four times more fish and seafood are fished from the seas today than in 1950 (FAO 2020b). While the growth in global fishing between 1950 and 1990 was mainly driven by increasing wild catches, aquaculture in particular has become more prevalent since 1990 (FAO 2020b). Today, over 50% of consumed fish and seafood is farmed. An average of around 20 kg of fish per year is consumed by every individual living on this planet.[32] The associated intensive fishing has resulted in 70% of commercially exploited fish stocks now being on the edge of sustainability and 25% of stocks being overfished (FAO 2020b). Overfishing is therefore one of the biggest threats facing marine ecosystems (Costello et al. 2010).

Fishing plays a key role in the direct influence of humans on marine ecosystems, on the one hand through induced pressure on marine fish stocks and on the other hand through the impacts of fishing techniques, such as bottom trawling, on marine ecosystem quality. Furthermore, the species composition in marine ecosystems is being affected by the spread of invasive species as a result of human activity.

The proposed approach for assessing marine fish resources focuses on human-induced pressure on the various marine fish resources caused by fishing. Impacts on ecosystem quality and from the spread of invasive species are not reflected in this approach.

13.7.2 Characterisation

Characterisation is based on the characterisation model of Hélias et al. (2018). This differentiates according to both fish species and fishing area, taking into account the size of the stock and fishing pressure. According to the characterisation model by Hélias et al. (2018), the characterisation factor for the different marine fish resources is calculated from the ratio of the current catch and the square of the stock size multiplied by the intrinsic growth rate. The characterisation factor is described by the following formula:

$$CF_X = \frac{C_X}{r_X \times B_X^2}$$

CF_X: Characterisation factor for fishing area **X**
B_X: Current stock in tonnes in fishing area **X**
C_X: Catch in tonnes per year in fishing area **X**
r_X: Intrinsic growth rate per year in fishing area **X**

The stock size and 'intrinsic growth rate' are based on modelling of the population dynamics of marine fish stocks, drawing on Froese et al. (2017) and Hélias et al. (2018). The annual catches come from FAO capture statistics for the reference year 2015 (FAO 2020a).

The Peruvian anchovy (Engraulis ringens) is used as the lead fish resource ('reference substance'). The annual catch of Peruvian anchovy is the highest of any fish species in the world. Despite this, it is not currently endangered due to the size of the stock. The choice of lead fish resource serves to illustrate the characterisation and has no impact on the subsequent calculations, as the characterisation only expresses the relative 'intensity of intervention' between fish species. The original characterisation model by Hélias et al. (2018) does not use a lead fish resource. All adjustments to the characterisation model of Hélias et al. (2018) are described in detail by Itten & Stucki (2021).

Characterisation based on the Hélias et al. (2018) approach means that for some fish species with small stocks the characterisation factor is well over 1000 times higher than that of the lead fish resource (Peruvian anchovy). Such

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[32] *http://www.fao.org/in-action/globefish/fishery-information/world-fish-market/en/* (Accessed: 10 December 2020)

Tab. 104: Characterisation factors per kg live weight for different fishing areas and fish species (formed by the geometric mean of the fishing-area-specific characterisation factors, weighted by catch), based on Hélias et al. (2018); the lead fish species ('reference substance') is the Peruvian anchovy (PA); more detailed list available in A9

Name	Scientific name	FAO fishing area	CF fishing area (kg PA-eq. / kg)	CF fishing area (kg PA-eq./ kg)
Anchoveta(=Peruvian anchovy)	Engraulis ringens	Southeast Pacific	1	1
Alaska pollock(=Walleye poll.)	Theragra chalcogramma	Northwest Pacific	0,849	1,1
Alaska pollock(=Walleye poll.)	Theragra chalcogramma	Northeast Pacific	1,54	1,1
Atlantic cod	Gadus morhua	Northeast Atlantic	1,05	1,19
Atlantic herring	Clupea harengus	Northeast Atlantic	1,27	1,73
Pacific chub mackerel	Scomber japonicus	Northwest Pacific	1,39	2,53
Atlantic mackerel	Scomber scombrus	Northeast Atlantic	2,6	2,77
Japanese anchovy	Engraulis japonicus	Northwest Pacific	3,26	3,26
Skipjack tuna	Katsuwonus pelamis	Western Central Pacific	3,37	6,43
Yellowfin tuna	Thunnus albacares	Western Central Pacific	7,2	9,65
Yellowfin tuna	Thunnus albacares	Northwest Pacific	7,2	9,65
Yellowfin tuna	Thunnus albacares	Southwest Pacific	7,2	9,65
Yellowfin tuna	Thunnus albacares	Eastern Central Pacific	10,1	9,65
Yellowfin tuna	Thunnus albacares	Southeast Pacific	10,1	9,65
Yellowfin tuna	Thunnus albacares	Northeast Pacific	10,1	9,65
Yellowfin tuna	Thunnus albacares	Western Indian Ocean	11,7	9,65
Yellowfin tuna	Thunnus albacares	Eastern Indian Ocean	11,7	9,65
Sole	Solea solea	Northeast Atlantic	156	217
Sole	Solea solea	Mediterranean and Black Sea	299	217
Sole	Solea solea	Eastern Central Atlantic	915	217
Turbot	Psetta maxima	Northeast Atlantic	270	309
Turbot	Psetta maxima	Mediterranean and Black Sea	1000	309
Seabass	Dicentrarchus labrax	Northeast Atlantic	427	498
Seabass	Dicentrarchus labrax	Mediterranean and Black Sea	1000	498
Average characterisation factor for marine fish				9,21

species usually have low catches because they simply cannot be fished intensively. To prevent the catch factor results in life cycle assessments from being dominated by fish species with small stocks and low catches, the characterisation factors were limited to 1000 times that of the lead fish resource, Peruvian anchovy. (This is the same as the approach adopted for the characterisation of plant protection products and for that of water scarcity using the AWARE method; see Section 13.6).

The characterisation factors of selected fish resources are shown in Tab. 104. The species-specific characterisation factors for species fished in multiple fishing areas are formed by the geometric mean over different fishing areas, with this mean being weighted according to the catch. Hélias et al. (2018) use the same approach to form species-specific characterisation factors.

13.7.3 Normalisation

The normalisation flow corresponds to the characterised fish consumption of a region, in this case the quantity of fish products from the sea consumed by the Swiss population, with this quantity being multiplied by the characterisation factors. The data for Swiss consumption are based on fish imports to Switzerland according to the FAO trade

Tab. 105: Eco-factor for marine fish resources; the lead fish resource ('reference substance') is the Peruvian anchovy (PA); reference unit: kg live weight

	Edition 2021	Q	Notes	Edition 2013
Normalisation flow (1000 t PA-eq./a)	2629	B	Import Switzerland 2017	
Current flow (1000 t PA-eq./a)	2629	B	Import Switzerland 2017	
Critical flow (1000 t PA-eq./a)	1614	b	Import Switzerland 1982	
Weighting factor (-)	2,65			
Eco-factor (UBP/ kg PA-eq.)	**1000**			

Q = data quality; for explanation, see Part 2, Chapter 6

statistics for 2017 (FAO 2019), plus by-catch attributable to consumption.

Using FAO statistics for wild capture and aquaculture (FAO 2020a), the proportions of farmed fish for the various fishery products were estimated and the contribution to the normalisation flow was adjusted accordingly. In addition, species-specific by-catch rates were factored in, based on the FAO fisheries discard assessment (Pérez Roda et al. 2019). As the species composition of by-catch is unknown, the by-catch was characterised using the average characterisation factor for marine fish.

To take into account the difference between the imported product weight (e.g. fillet) and the live weight of the fish, the product weights of the different imported marine resources were adjusted based on the Handbook of Fisheries Statistics (FAO 1992; Annex I.1). The total volume of fishery products imported to Switzerland is 68,000 tonnes, which corresponds to a characterised normalisation flow of 2,629,000 tonnes PA-eq. The contributions of imported fishery products to the normalisation flow are shown in Tab. 135 in A9.

13.7.4 Weighting

The current flow corresponds to the normalisation flow.

The critical flow is the flow in 1982, calculated using FAO import statistics (FAO 2019). That was the year that the United Nations Convention on the Law of the Sea (UNCLOS 2009) was adopted. Switzerland has signed the convention, thereby committing itself to promote "the conservation of [the seas' and oceans'] living resources, and the study, protection and preservation of the marine environment". It is implicitly assumed that, as a signatory, Switzerland will endeavour to preserve fish resources as they were in the year in which the convention was adopted. According to FAO (2020b), the proportion of overfished species has almost doubled since 1982.

13.7.5 Eco-factors for marine fish resources, with Peruvian anchovy as the lead fish resource

The eco-factor for the use of marine fish resources is included for the first time in the current version. Tab. 105 shows the resulting eco-factor.

13.7.6 Eco-factors for other marine fish resources

Tab. 106 shows the characterisation factors and eco-factors for selected marine fish resources. A more detailed list of eco-factors per kg live weight is given in A9. A comprehensive list of all characterisation factors and eco-factors for the different fishing areas, fish species and aggregated fishery products according to international standards on the statistical classification of aquatic organisms, as well as a description of their derivation, can be found in the extended report.[33]

13.7.7 Guidelines for applying the eco-factors

The eco-factors for marine fish species apply to wild-caught fish and cannot be applied directly to farmed fish.

In order to apply the eco-factors for marine fish resources, new species-specific and, if possible, fishing-area-specific elementary flows for marine fish resources need to be introduced (e.g. 'Fish, Peruvian anchovy, Engraulis ringens, Southeast Pacific, in the sea'). The unit of these elemen-

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[33] *https://doi.org/10.21256/zhaw-2650*

Tab. 106: Eco-factors per kg live weight for selected marine fish species, averaged over all fishing areas (geometric mean of fishing-area-specific characterisation factors, weighted by catch)

Name	Scientific name	Characterisation factor (kg / kg PA-eq.)	Eco-factor (UBP / kg)
Anchoveta(=Peruvian anchovy)	Engraulis ringens	1	1000
Alaska pollock(=Walleye poll.)	Theragra chalcogramma	1,1	1100
Atlantic cod	Gadus morhua	1,2	1200
Atlantic herring	Clupea harengus	1,7	1700
Pacific chub mackerel	Scomber japonicus	2,5	2600
Atlantic mackerel	Scomber scombrus	2,8	2800
Japanese anchovy	Engraulis japonicus	3,3	3300
Skipjack tuna	Katsuwonus pelamis	6,4	6500
Yellowfin tuna	Thunnus albacares	9,7	9700
Sole	Solea solea	220	220 000
Turbot	Psetta maxima	310	310 000
Seabass	Dicentrarchus labrax	500	500 000

tary flows is kilogram of live weight. The eco-factors listed in Tab. 106 cannot therefore be applied directly to the amount of wild-caught fish sold or served to consumers.

As an approximation, the eco-factors relating to live weight may be multiplied by a factor of 2.18 for application to product weight. The conversion factor is based on the edible product weight making up 45% of the live weight according to USDA (1992) and 98% of the economic value according to Ayer et al. (2007). For a more precise conversion, see Annex I.1 of the Handbook of Fisheries Statistics (FAO 1992),[34] which contains a detailed list of conversion factors from live to product weight for different fish species and crustaceans as well as different processing stages and preservation methods.

By-catch is not included in the eco-factors for marine fish resources. If by-catch and discards are to be assessed, they must be systematically recorded at the inventory analysis level. If the volume and species composition of the by-catch are known, the specific eco-factors for the by-catch species can be used. FAO publishes aggregate by-catch rates according to catch method (Pérez Roda et al. 2019). However, a particular species can be fished by multiple methods. For a detailed assessment of by-catch and discards, the specific volume and species composition of the by-catch and discards as well as the fishing area must therefore be recorded in the inventory analysis. A practical example of by-catch assessment is described in Itten & Stucki (2021).

Aquaculture contributes to the exploitation of marine fish resources through the use of fishmeal and fish oil as animal feed. Fishmeal and fish oil can be made from fish processing waste or directly from wild-caught fish. For the marine fish resource eco-factors presented here to be accurately applied to the production of fishmeal and fish oil, the origin and species composition must be represented in the inventory analysis of fishmeal and fish oil production. The inclusion of origin and species composition in life cycle inventories of fishmeal and fish oil is described in Itten & Stucki (2021).

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[34] *http://www.fao.org/cwp-on-fishery-statistics/handbook/capture-fisheries-statistics/conversion-factors/en/* (Accessed: 16 February 2021)

14 Wastes

14.1 Introduction

As waste disposal can have a range of impacts on the environment, multiple protection goals/targets need to be taken into account. The ecological scarcity method considers the following impacts:

- Emissions of substances to soil, water and air. These are dealt with in the relevant chapters, according to their impacts.
- Land use by waste disposal sites. This is assessed in the section on land use.
- Possible reactivity of landfilled wastes. This is assessed below in Section 14.2 on carbon content.
- Landscape changes due to landfilled wastes. These are assessed for the first time in this version of the method – see Section 14.4.

The following wastes are addressed specifically:

- Radioactive wastes, as these are covered by specific legislation – see Section 14.5.
- Hazardous wastes in underground disposal sites abroad, as the disposal of waste abroad is specifically addressed in environmental protection legislation.

In this chapter, eco-factors are derived for landfilled wastes. Wastes in above-ground landfills are assessed on the basis of the carbon content in the stored wastes. Certain hazardous wastes (Part 3, Section 14.3) and radioactive wastes (Part 3, Section 14.4) are stored underground.

14.2 Carbon (C) in material consigned to landfills

14.2.1 Environmental relevance

The Swiss Environmental Protection Act stipulates that no wastes that may cause long-term problems can be stored in landfills in Switzerland. The indicator for the 'reaction potential' of waste is its carbon (C) content. The goal is to minimise the C flow to landfills. The experts at the FOEN therefore consider this to be the key and critical aspect when consigning waste to landfill types B to E.

14.2.2 Normalisation

No characterisation is performed. The normalisation flow is identical to the current flow, as the current flow represents the C flow to landfills for the whole of Switzerland.

14.2.3 Weighting

The current flow comprises the quantity of carbon that is stored through the waste in landfill types B, C, D and E. Tab. 107 lists the quantities of waste stored in landfills in 2018 according to the waste statistics of the Swiss Ordinance on the Charge for the Remediation of Contaminated Sites (BAFU 2018; CSRCO 2016). According to the Waste Ordinance (ADWO 2020), wastes in type E landfills must comply with a limit value of 5% carbon content, and all other wastes stored in landfills must meet the limit value of 2% carbon content. Based on current control measurements, it can now be assumed that the classes of stored material meet these requirements.[35]

The current flow is calculated based on the conservative assumption that the carbon content in wastes stored in landfills complies with the limit value, even though it should be assumed that the current flow is somewhat lower. This results in a current flow of 161,500 t C/a.

As the stored wastes meet the requirements of the ADWO (2020), the critical flow corresponds to the current flow of 161,500 t C/a.

14.2.4 Eco-factors for carbon in wastes consigned to landfills

The eco-factor is 13% higher than in the 2013 edition because the normalisation flow is somewhat lower.

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[35] Personal communication, FOEN Waste and Resources Division, 2020

Tab. 107: Quantities of waste consigned to landfills in Switzerland in 2018 and their maximum carbon content (Total Organic Carbon, TOC)

	2018 statistics (t)	TOC limit value ADWO (2020)	TOC (t)
Landfill B	6 015 600	2%	120 300
Landfill C	139 250	2%	2 790
Landfill D	731 063	2%	14 600
Landfill E	405 091	5%	20 250
Slag components*	174 063	2%	3 480
Total	7 465 066		161 500

* exported slag

Tab. 108: Eco-factor for carbon in landfill types B to E in UBP/g C. The table also lists eco-factors for average slags and other bioactive landfill wastes.

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t C/a)	161 500	B	VASA 2016; VVEA 2020	183 200
Current flow (t C/a)	161 500	B	VASA 2016; VVEA 2020	183 200
Critical flow (t C/a)	161 500	a	VASA 2016; VVEA 2020	183 200
Weighting (-)	1,00			1,00
Eco-factor (UBP/g C)	**6,2**			5,5

Q = data quality; for explanation, see Part 2, Chapter 6

14.2.5 Guidelines for using the ecoinvent v3.x and UVEK 2022 databases

To enable this eco-factor to be used, a new ‘organic carbon, placed in landfill’ flow was created and factored into the update of the data sets for disposal in landfills.

14.2.6 Guidelines for using modelling of wastes with organic carbon consigned to landfills

Wastes that contain organic carbon and are consigned to landfills should be assessed in the inventory analysis with the model for sanitary landfills, or landfills with stabilised residues, where possible. This ensures that the anticipated chemical reactions, landfill gas and leachate formation are appropriately taken into account in the life cycle assessment.

14.3 Hazardous wastes in underground disposal sites

14.3.1 Background

Of the approximately 1.85 million tonnes of hazardous wastes generated in Switzerland, four fifths are treated within the country. Around 35% can be recycled, 9% are chemically and physically treated, 43% can be incinerated and 13% are deposited after appropriate pretreatment (BAFU 2019b).

Hazardous wastes are only exported in exceptional cases; this accounts for around 20% of the total hazardous waste quantity. The proportion of hazardous wastes deposited in underground disposal sites abroad is around 1.5%. Filter dust from waste incineration plants accounts for just over 50% of this.

14.3.2 Normalisation

A characterisation is not performed, and both the current and critical flows comprise the entire quantity of hazardous wastes consigned to underground disposal

Tab. 109: Eco-factor for the consignment of hazardous wastes to underground disposal sites in UBP/g and UBP/cm³ waste

	Edition 2021	Q	Notes	Edition 2013
Normalisation (t waste/a)	31 682	A		37 223
Current flow (t waste/a)	31 682	A	(BAFU 2011a)	37 223
Critical flow (t waste/a)	14 939	c		37 223
Weighting (–)	4,5			1,00
Eco-factor (UBP/g waste)	**142**			27
Eco-factor (UBP/cm³ waste)	227		Density 1600 kg/m³ in accordance with Doka (2003b, Part III, S. 41)	43

Q = data quality; for explanation, see Part 2, Chapter 6

sites. For that reason, the normalisation flow is identical to the current flow.

14.3.3 Weighting

Swiss waste statistics give the quantity of wastes stored in underground disposal sites. This amounts to 31,682 t/a for 2018 and is exported in its entirety (BAFU 2019b), as there are no underground disposal sites in Switzerland.

As of 1 January 2021, filter ash may no longer be exported, but must be treated in Switzerland. This amounts to 16,743 t, resulting in a critical flow of 14,939 t per year. According to the FOEN's Waste and Resources Division, there is not yet any capacity for the treatment of filter ash. Accordingly, it must be assumed that, for the time being, the current flow will remain the same as the present flow.

14.3.4 Eco-factors for the consignment of hazardous wastes to disposal sites

This eco-factor relates exclusively to hazardous wastes stored in underground disposal sites. The final storage of wastes – including hazardous wastes – in normal above-ground landfills is assessed on the basis of volume utilisation, land use, emissions to air and water, and the C content of the waste. The eco-factor is around five times higher than in the 2013 edition. The reason for this is the requirement to treat filter ash in Switzerland, which more than halves the critical flow and thus increases the weighting accordingly.

14.4 Landfill volume

14.4.1 Background

To take account of the space requirements and associated landscape changes caused by landfilled wastes, e.g. by filling valleys or pits, a factor for this was developed as part of a preliminary analysis for the FOEN (Dinkel et al. 2018) and included in the method.

14.4.2 Characterisation

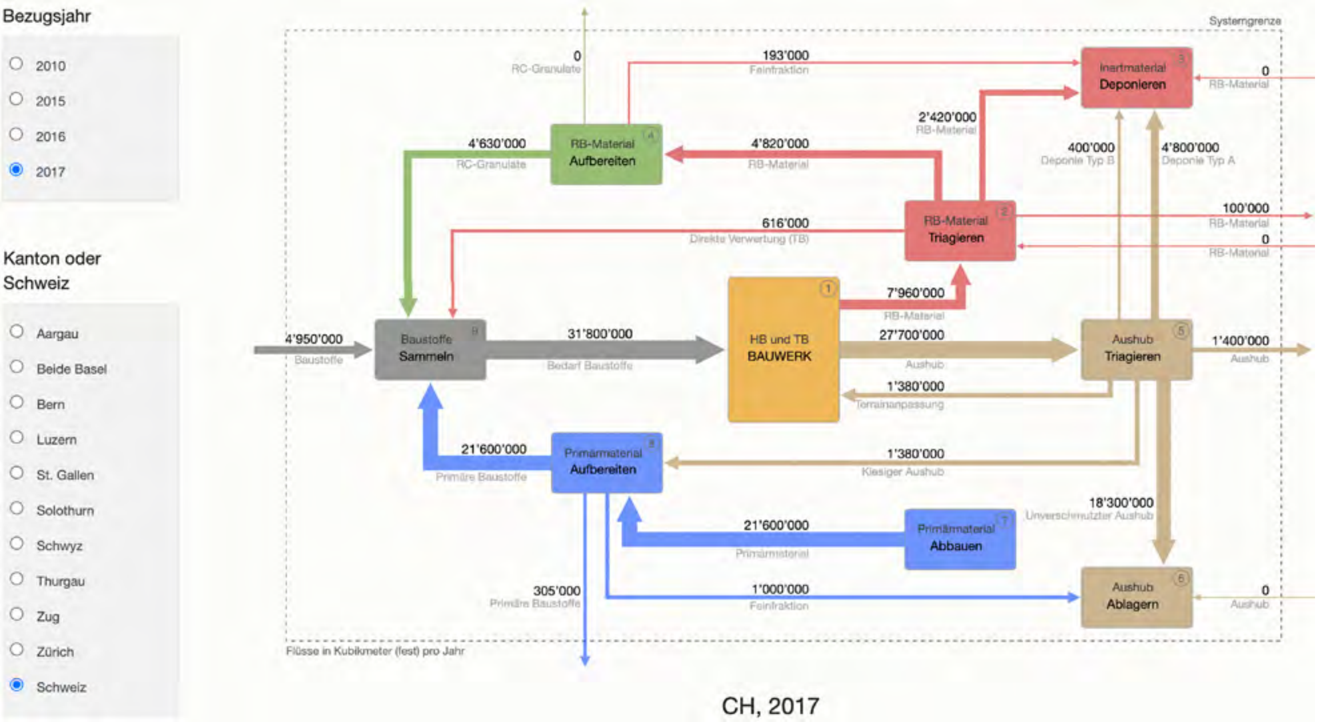
No characterisation is performed. In terms of the protection goal for landscape change caused by landfills, there is no difference between landfill types A to E, so an eco-factor is derived for all landfill types together.

14.4.3 Normalisation

Substance flows were determined using the KAR model (Rubli & Schneider 2018) supplemented by information on the quantities of waste stored in landfill types C, D and E according to the waste statistics of the Swiss Ordinance on the Charge for the Remediation of Contaminated Sites in BAFU 2018 and CSRCO 2016. The KAR model, whose results are available online at *http://www.kar-modell.ch/*, simulates gravel, excavated material and demolition material flows in Switzerland and in specific cantons. Figure 12 shows the substance flows for Switzerland in 2017. The data for 2018 were not yet available at the time this study was compiled.

The following metric was defined for the normalisation flow: quantity of material from Swiss construction works that is landfilled or stored at a disposal site. No distinction was made as to which type of landfill the material end-

Fig. 12: Construction waste volume flows in Switzerland according to the KAR model, figures in m^3



Bezugsjahr

○ 2010
○ 2015
○ 2016
● 2017

Kanton oder Schweiz

○ Aargau
○ Beide Basel
○ Bern
○ Luzern
○ St. Gallen
○ Solothurn
○ Schwyz
○ Thurgau
○ Zug
○ Zürich
● Schweiz

CH, 2017

ed up in, as in terms of the use of landfill space it makes no difference whether the space is occupied by excavated material, inert demolition material or other landfill material. Other environmental impacts for which the landfill types are differentiated are assessed separately – see Section 14.1. This decision was made in consultation with the client and representatives of the FOEN's life cycle assessment group, Peter Gerber and Norbert Egli. The normalisation flow thus comprises the substance flows set out in Tab. 110.

For landscape-changing substance flows due to landfilling, this results in a normalisation flow of 28,100,000 m^3 per year.

14.4.4 Weighting

The current flow corresponds to the normalisation flow for Switzerland.

When it came to determining the critical flow, it was agreed, following lengthy discussion with FOEN life cycle assessment experts, that the designation of landfill space could be treated in a similar way to that of gravel extraction. In the cantons, as much landfill space or gravel extraction volume as is required to meet demand is designated for spatial planning purposes. As Swiss legislators tolerate this situation, in this case the critical flow is equated with the current flow. Consequently, the critical flow is aligned with the current flow. Differences may arise depending on the canton and the planning status. It should be noted that this results in a rather conservative weighting. A higher weighting would also be conceivable.

14.4.5 Eco-factors for landfilling that changes the landscape

The eco-factor is 35,600 UBP/m^3. Assuming an average density of 1.5 t per m^3, this produces a factor of 24 UBP per kg of landfill material.

There was no such factor in the 2013 edition.

Tab. 110: Landscape-changing substance flows in landfills

Landfill type	Description	Volume
Material extraction sites	Unpolluted excavation material:	18 300 000 m³
A	Fine fraction from the processing of primary material:	1 000 000 m³
B	Excavation material from landfill type A	4 800 000 m³
B	Excavation material from landfill type B (formerly inert material landfill)	400 000 m³
B	Landfilling of demolition material (type B)	2 420 000 m³
B	Fine fraction from recycling (type B)	193 000 m³
C		93 000 m³
D		487 000 m³
E		270 000 m³
	Total	28 100 000 m³

Tab. 111: Eco-factor for landscape-changing landfills in UBP/kg and UBP/m³ waste

	Edition 2021	Q	Notes	Edition 2013
Normalisation (m³ waste/a)	28,1 Mio	A		–
Current flow (t waste/a)	28,1 Mio	A	(BAFU 2011a)	–
Critical flow (t waste/a)	28,1 Mio	c		–
Weighting (–)	1,00			–
Eco-factor (UBP/m³ waste)	**36 000**			–
Eco-factor (UBP/kg waste)	24		Density 1500 kg/m³	–

Q = data quality; for explanation, see Part 2, Chapter 6

14.5 Radioactive wastes

14.5.1 Preliminary remark

The generation of electricity in nuclear power plants produces radioactive wastes that must eventually be consigned to final storage. No final repository has yet been constructed in Switzerland. The Wellenberg site in the canton of Nidwalden was selected for low-level and medium-level wastes. In 2002, the construction of an exploratory shaft was rejected in a referendum. New sites for low-level and medium-level, high-level and long-lived radioactive wastes are now in the process of being evaluated. In Frischknecht & Büsser (2013b), eco-factors for radioactive wastes were newly determined on the basis of legal provisions and scientific calculations by Nagra.[36] Nagra quantifies the risk potential of radioactive wastes using the radiotoxicity index (Nagra 2008).

14.5.2 Background

The Swiss Nuclear Energy Act (Art. 30 para. 2) states the following as regards radioactive wastes: *"All radioactive waste produced in Switzerland shall, as a general rule, be managed in Switzerland."* In addition, a moratorium on the reprocessing of spent fuel elements has been in force since July 2006, and in 2016 was extended by a further ten years until 2026.[37]

In principle, two final repositories are planned – one for spent fuel elements, high-level wastes (HLW) and alpha-toxic wastes (ATW), and a second for low-level and medium-level wastes (LMLW). These final repositories may be built at separate sites or together at the same site.

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[36] Nagra (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle) is the national cooperative for radioactive waste storage in Switzerland.

[37] Nuclear Energy Act, Art. 106 para. 4: "Spent fuel elements may not be exported for reprocessing for a period of ten years from 1 July 2006 onwards. During this period, they are to be disposed of as radioactive wastes."

The planned capacities required for the repositories are based on the estimated quantities of radioactive wastes including their encasements. Nagra now also bases its calculations of required volumes on plant service lives of 55 years (reference scenario).

Based on this scenario, 8,515 m^3 of HLW in the form of spent (and conditioned) fuel elements (SF) and from reprocessing, and 1,441 m^3 of long-lived, medium-level (alpha-toxic) wastes (ATW) arise. Overall, the deep repository thus needs to be able to accommodate 9,956 m^3 of long-lived, high-level and medium-level wastes (all volume figures including encasements; Nagra 2014).

The total quantity of LMLW to be disposed of in a deep geological repository based on the 55-year service life of nuclear power plants is estimated at 92,636 m^2 (volume including encasements; Nagra 2014). Of this, 31,459 m^3 are wastes from nuclear power plant decommissioning, 33,109 m^3 from nuclear power plant operation (operating and reactor wastes), 25,775 m^3 from research, industry and medicine, and 2,293 m^3 from the interim repository and the encasement facility.

Overall, the total quantity of wastes to be stored in repository encasements is just under 103,000 m^3 (Nagra 2014).

The hazardousness of radioactive wastes depends on their persistence (half-life), and on the type and intensity of their radiation. The Swiss strategy for a final repository classes the various types of radioactive waste in two categories:

1. Short-lived low-level and medium-level wastes (LMLW)
2. Alpha-toxic wastes (ATW), high-level wastes (HLW) and spent fuel elements (SF)

The former are relatively short-lived, and already present a minor hazard after a shorter period. It is assumed that they require a shut-in time of around 500 years (KFW 2002; PSI 1996). The latter need to be stored safely for at least 100,000 years (EKRA 2000; PSI 1996).

The radiotoxicity of the individual isotopes contained in radioactive wastes and the various types of waste is quantified using the radiotoxicity index (RTI) of radioactive wastes. It is defined as

$$RTI = \Sigma_i A_i \times DF_i/DL$$

where:
Ai = activity of the nuclide i in Bq, DFi = dose factor for the ingestion of the nuclide i in Sv/Bq, dose limit value for the release from a deep geological repository DL = 0.1 mSv/a (Nagra 2008).

Nagra quantifies the annual radiotoxicity course of the radioactive wastes that arise and are stored. The course in Fig. 13 and Fig. 14 shows that the radiotoxicity index is projected to peak in 2044 and then steadily fall.

In 2044, the RTI of all radioactive wastes that will have to be consigned to a final repository in Switzerland is $7.5*10^{15}$ RTI (see also Tab. 112). This corresponds to the highest RTI of the total radioactive waste arising in Switzerland.[38]

14.5.3 Characterisation

The characterisation is based on the radiotoxicity potential. The different waste categories are characterised using their radiotoxicity index in the year 2044. High-level wastes (HLW) are the reference substance. Based on the RTI values per m^3 of waste (see Tab. 112), the characterisation factor of 1 cm^3 LMLW is $1.3*10^{-5}$ cm^3 HLW-eq., that of 1 cm^3 ATW is 0.0032 cm^3 HLW-eq. and that of 1 cm^3 ATW & HLW is 0.86 cm^3 HLW-eq.

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[38] As the maximum RTI does not occur for all radioactive wastes at the same point in time, the maximum total waste inventory shown in Fig. 6 does not correspond to the sum of the individual maximum RTI of wastes that arise at different points in time.

Fig. 13: Development of the radiotoxicity index (RTI) of radioactive wastes in Switzerland up to the year 2075. Data from Nagra (2014)

LMLW: low-level and medium-level wastes; ATW: alpha-toxic wastes; HLW: high-level wastes.

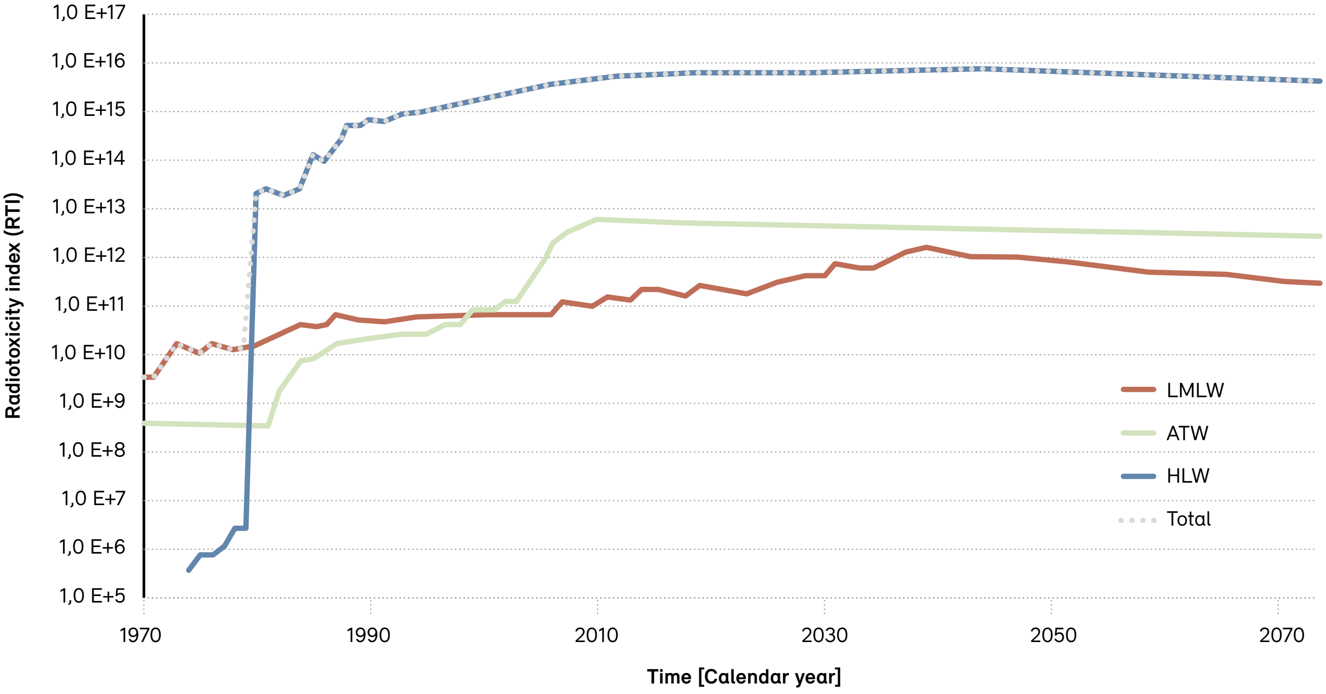
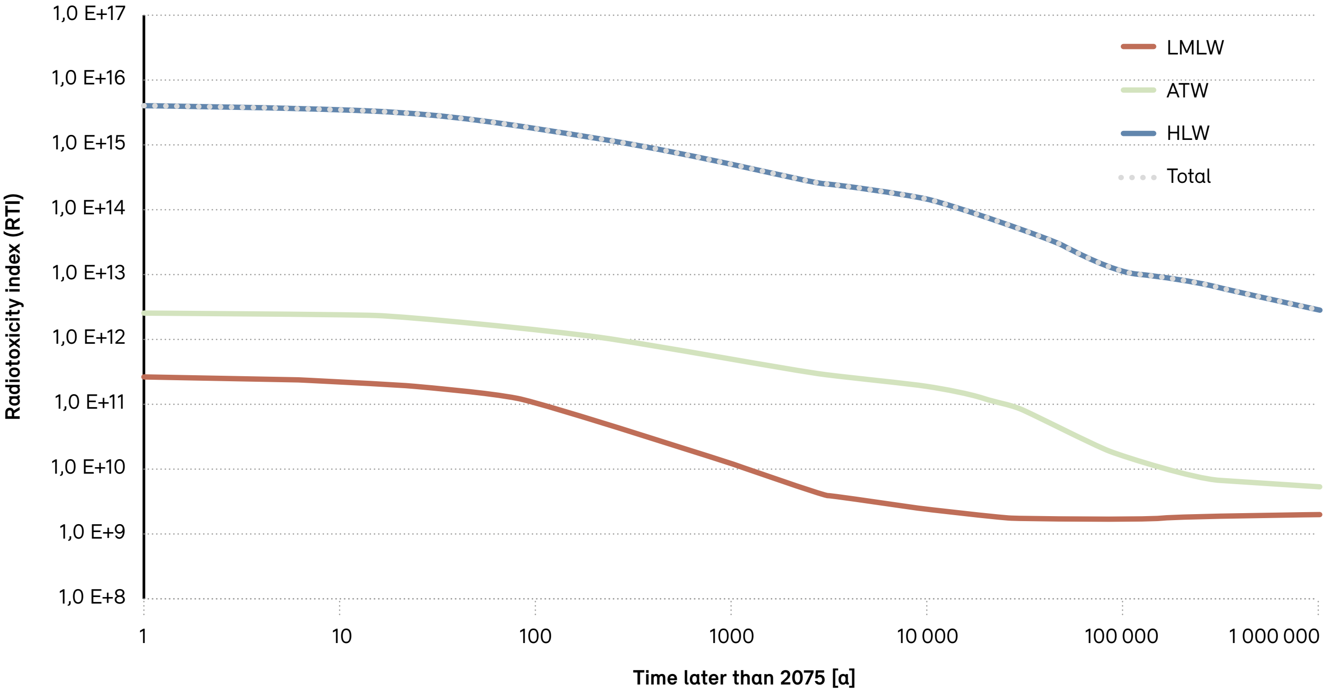


Fig. 14: Development of the radiotoxicity index (RTI) of radioactive wastes in Switzerland after the year 2075. Data from Nagra (2014)

LMLW: low-level and medium-level wastes; ATW: alpha-toxic wastes; HLW: high-level wastes.



Tab. 112: Volumes of radioactive waste, RTI in 2044 (absolute and per m^3 of waste) and at the time of closure of the radioactive waste repository to be determined by the Federal Council (expected in 2126), and characterization factors derived therefrom

	Waste volume (m^3)	RTI (–)	RTI per m^3 (m^{-3})	RTI at closing (-)	Characterisation factor (cm^3 HAA-eq/cm^3)
Low-level and medium-level wastes (LMLW)	92 636	$1{,}0\times10^{12}$	1,1×107	$1{,}5\times10^{11}$	0,000013
Alpha-toxic wastes (ATW)	1 441	$4{,}0\times10^{12}$	2,8×109	$1{,}8\times10^{12}$	0,0032
High-level wastes (HLW & SF)	8 515	$7{,}5\times10^{15}$	$8{,}8\times10^{11}$	$2{,}6\times10^{15}$	1,0
High-level and alpha-toxic wastes (HLW, SF & ATW)	9 956	$7{,}5\times10^{15}$	$8{,}8\times10^{11}$	$2{,}6\times10^{15}$	0,86
Total	**102 592**	**$7{,}5\times10^{15}$**		**$2{,}6\times10^{15}$**	

14.5.4 Normalisation

The normalisation flow corresponds to the characterised volume of radioactive wastes that arise in a year. The total characterised waste volume from 55 years of operation of Swiss nuclear power plants and from medicine and research comes to 8,521 m^3 HLW-eq. With a service life of 55 years of operation, a normalisation flow of around 155 m^3 HLW-eq./a results.

14.5.5 Weighting

The maximum RTI of Swiss radioactive wastes (see Part 3, Section 14.5.2) divided by the 55-year service life of nuclear power plants (1.37×10^{14} RTI) is used as the current flow.

When the repository and all storage chambers are closed, the observation phase begins, i.e. a longer period, during which a deep geological repository is monitored before being closed and the radioactive wastes can be retrieved (cf. Nuclear Energy Act (NEA 2009, Art. 3)). These stipulations by legislators reflect the internationally recognised principle of passive long-term safety, i.e. the safe enclosure of radioactive substances without the necessity of human intervention, and the social concern of longer monitoring and easier retrievability prior to closure. Even after the repository is closed, monitoring continues and the wastes can be retrieved, albeit at great expense. The length of the monitoring phase is not specified and may be 50, 100 or more years. The Federal Council orders the closure once it is convinced that the permanent protection of humans and the environment is ensured (NEA Art. 39 No 2). Ensuring the permanent protection of humans and the environment is therefore the basis for determining the critical flow.

According to Nagra planning (Nagra 2016), the final repository for low-level and medium-level radioactive wastes should be definitively closed in the period from 2115 to 2118 and the final repository for long-lived and/or high-level radioactive wastes should be closed in the period from 2125 to 2126. The closure time of the final repository for long-lived and/or high-level radioactive wastes is used to determine the eco-factor.

At the time of the closure in 2126, the RTI of the total radioactive wastes will be 2.6×10^{15} RTI (see Fig. 14 and Tab. 112). Divided by 55 nuclear power plant service years, this results in 4.7×10^{13} RTI/a. This value corresponds to the critical flow.

14.5.6 Eco-factor for other radioactive wastes

These eco-factors can be derived using the characterisation factors for other types of radioactive wastes. Tab. 114 shows the eco-factors for the 'low-level and medium-level wastes' and 'high-level and alpha-toxic wastes' categories used in UVEK LCI Data DQRv2:2022 and the ecoinvent v3 database.

The eco-factor is applied to packaged wastes, i.e. the specific volume of radioactive wastes, including their encasement.

The eco-factor for long-lived and/or high-level wastes is around 34% higher than in 2013, while the new eco-factor for short-lived low-level and medium-level wastes is more than 67% lower than the eco-factor in 2013.

14.5.7 Guidance on application for life cycle assessments of different types of deep repository

The eco-factors described here are applied to the various categories of radioactive wastes generated in nuclear power plants as well as in hospitals and research facilities. The eco-points arising from the radioactive wastes are assigned along the process chain to electricity generation at nuclear power plants or the irradiation of patients.

If a life cycle assessment is being used to estimate the environmental impacts of different types of deep repository, the environmental impacts of the radioactive waste to be stored must be excluded. The type and volume of radioactive wastes are not attributable to the repository; these wastes are merely its content. From a life cycle perspective, the environmental impacts of the wastes produced, even after their consignment to repositories, should – as explained above – not be attributed to the deep repositories but rather to electricity generation at nuclear power plants. No significant environmental burdens are to be expected from a closed final repository, whether from radioactive or any other emissions, due to the legal requirements governing the closure of such facilities and the multi-barrier principle.

Tab. 113: Eco-factor for high-level radioactive wastes

	Edition 2021	Q	Notes	Edition 2013
Normalisation (m^3 HLW-eq./a)	154,9	A	Calculated from information in NAGRA (2014)	146,6
Current flow (RTI/a)	$1{,}37 \times 10^{14}$	A	Calculated from information in NAGRA (2014)	$1{,}36 \times 10^{14}$
Critical flow (RTI/a)	$4{,}70 \times 10^{13}$	a	Calculated from information in NAGRA (2014)	$5{,}22 \times 10^{13}$
Weighting (-)	8,44			6,76
Eco-factor (UBP/ cm^3 HLW-eq.)	**54 000**			46 000

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 114: Eco-factors for short-lived low-level and medium-level wastes (LMLW) and for long-lived and/or high-level wastes (SF/ATW/HLW) in UBP/cm^3 waste

	Edition 2021 (UBP/cm^3)	Q	Characterisation factor (cm^3 HLW-eq/cm^3)	Edition 2013 (UBP/cm^3)
Low-level and medium-level wastes (LMLW)	**0,68**	A	0,000013	2,1
High-level and alpha-toxic wastes (HLW, SF & ATW)	**47 000**	A	0,86	35 000
High-level wastes (HLW & SF)	**54 000**	A	1,0	46 000
Alpha-toxic wastes (ATW)	**170**	A	0,0032	69

Q = data quality; for explanation, see Part 2, Chapter 6
Densities of the conditioned and encased wastes: LMLW: 5 t/m^3; HLW, SF & ATW: 6.85 t/m^3

15 Non-substance emissions

15.1 Noise

15.1.1 Introduction

Noise is an undesirable sound that can harm persons physically, psychologically and socially. Chronic and excess noise is a health hazard, undermines quality of life and the attractiveness of affected areas and generates huge costs to society (BAFU 2009c).

The goal of the Environmental Protection Act (EPA 2018) of 7 October 1983 is to protect the population from harmful and irritating noise. Early preventive measures must be taken in order to limit effects which could become harmful or a nuisance. The aim of reducing noise emissions is to ensure that fewer people suffer major annoyance from noise. That is why the eco-factor for 'persons affected by harmful or annoying traffic noise' is included. Improvements to the noise situation should be aimed at road, railway and air transport. A separate eco-factor is determined for each of the three means of transport, and for freight and passengers.

15.1.2 Normalisation

No characterisation is performed. The normalisation flow corresponds to the number of persons affected by harmful or annoying road, railway and aircraft noise. The normalisation flow amounts to around 821,000 persons (see Tab. 115).

15.1.3 Weighting

A specific eco-factor is calculated for each of the three sources of noise. The current flow corresponds to the number of persons affected by harmful or annoying traffic noise.

Information on the number of persons affected by harmful or annoying traffic noise comes from the sonBASE noise database and relates to the year 2015. Corresponding information on aircraft noise is based on the actual traffic volume at the international airports of Zurich and Geneva in 2015.

The noise level (L_{den}) is calculated to determine the proportion of persons affected by harmful or annoying traffic noise. L_{den} is a European measurement that is calculated based on L_{day} (6am to 6pm), $L_{evening}$ (6pm to 10pm) and L_{night} (10pm to 6am). As noise in the evening and at night is perceived as worse, $L_{evening}$ and L_{night} are given an additional 5 dB(A) and 10 dB(A). The proportion of persons affected by harmful or annoying traffic noise is determined using the exposure/impact relationship as defined by the EEA (2010). The current flow is calculated based on the number of persons per dB(A) class multiplied by the proportion of persons affected by harmful or annoying traffic noise in the same dB(A) class.

The FOEN has determined and provided the number of persons affected by harmful or annoying traffic noise for all means of transport (BAFU 2019a) (see Tab. 115).

The long-term goal of noise abatement is to prevent anyone from being disturbed by excessive noise. In the medium term, i.e. until around 2035, a reduction in noise

Tab. 115: Number of persons affected by harmful or annoying road, railway and aircraft noise (HAP), current flow, see text for sources

	Road noise	Railway noise	Aircraft noise	Total
Number of persons affected by harmful or annoying noise	716 200	45 400	59 400	821 000

Tab. 116: Number of persons affected by harmful or annoying road, railway and aircraft noise (HAP), critical flow, see text for sources

	Road noise	Railway noise	Aircraft noise
Number of persons affected by harmful or annoying noise	424 500	22 600	24 400

pollution of 5 dB(A) each for road, rail and air traffic is the goal (BAFU 2019a). The number of persons affected by harmful or annoying traffic noise at a noise level 5 dB(A) lower is determined in the same way as the current flow. By decreasing the noise level by 5 dB(A), the number of persons affected by harmful or annoying traffic noise is reduced by roughly half.

15.1.4 Eco-factor for persons

The eco-factor for noise refers to the number of persons affected by harmful or annoying noise (HAP or 'highly annoyed persons') and is stated separately for road, railway and aircraft noise. The metric 'persons affected by harmful or annoying traffic noise' is used because the goal of noise abatement is to protect people. However, easily quantifiable inventory analysis parameters are necessary for use in life cycle assessments and for the use of noise eco-factors in life cycle assessment databases such as ecoinvent. Noise kilometres are used for this purpose. The derivation of eco-factors per noise kilometre is described in Part 3, Section 15.1.5

The eco-factors for road, railway and aircraft noise have increased by 3%, 14% and 90% respectively compared with the eco-factors in 2013. The 90% increase in the aircraft noise eco-factor is due to a better data basis.

15.1.5 Eco-factor for traffic noise in current life cycle assessment databases

In the 2013 edition, six new elementary flows were proposed at the inventory level (see Tab. 120) and implemented in KBOB LCI Data DQRv2:2016 and in mobitool, so that the eco-factor for noise could be applied in current life cycle assessment databases. The units of these elementary flows are vehicle-kilometre of noise, passenger-kilometre of noise and tonne-kilometre of noise. For instance, operating an (average) passenger car over 1 km of distance causes 1 vkm of 'noise, road, passenger car', while one passenger-kilometre of train travel causes 1 pkm of 'noise, rail, passenger train' and so forth.

The eco-factor per vehicle-kilometre of noise, passenger-kilometre of noise and tonne-kilometre of noise is determined using the number of persons affected by harmful or annoying road, railway and aircraft noise. All three means of transport carry both people and goods. The impacts of noise emissions from road traffic, for instance, must therefore be broken down into the transport of people (passenger cars) and freight transport (trucks/lorries).

It is assumed from this that the noise emissions are largely independent of the payload. Therefore, in the case of road and railway traffic, the kilometres travelled in 2015 (BFS 2019; BFS & BAZL 2019) and the average noise emission level of passenger cars and trucks, and of passenger and freight trains, are used to differentiate the transport of people from freight transport.

Tab. 122 shows the noise levels of the various means of transport. The noise level of a truck is approximately 9 dB(A) higher than the noise level of a passenger car. In railway transport, freight trains are approximately 4 dB(A) louder than passenger trains. A noise level of 10 dB corresponds to ten times more energy released through sound. For this reason, when allocating the number of persons affected by harmful or annoying traffic noise, the distance travelled (in km) to transport freight by road or railway is multiplied by a factor of 8 or 2.5 respectively.

The eco-factor for freight and passenger transport per distance covered (see Tab. 121) is calculated by applying the eco-factor per person affected by harmful or annoying traffic noise in Tab. 117 to Tab. 119.

The number of persons affected by harmful or annoying road noise is based on the vehicle kilometres travelled to transport freight by road (independently of the truck size and load capacity).

Tab. 117: Eco-factor for road noise, in UBP per person affected by harmful or annoying noise (HAP)

	Edition 2021	Q	Notes	Edition 2013
Normalisation (HAP/a)	821 164	B	Takes account of road, railway and aircraft noise	803 882
Current flow (HAP/a)	716 317	A	(BAFU 2019a)	715 754
Critical flow (HAP/a)	424 507	b	(BAFU 2019a)	436 058
Weighting (–)	2,85			2,69
Eco-factor (UBP/HAP)	**3 500 000**			3 400 000

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 118: Eco-factor for railway noise, in UBP per person affected by harmful or annoying noise (HAP)

	Edition 2021	Q	Notes	Edition 2013
Normalisation (HAP/a)	821 164	B	Takes account of road, railway and aircraft noise	803 882
Current flow (HAP/a)	45 411	A	(BAFU 2019a)	60 934
Critical flow (HAP/a)	22 553	b	(BAFU 2019a)	32 754
Weighting (–)	4,05			3,46
Eco-factor (UBP/HAP)	**4 900 000**		Railway noise	4 300 000

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 119: Eco-factor for aircraft noise, in UBP per person affected by harmful or annoying noise (HAP)

	Edition 2021	Q	Notes	Edition 2013
Normalisation (HAP/a)	821 164	B	Takes account of road, railway and aircraft noise	803 882
Current flow (HAP/a)	59 436	A	(BAFU 2019a)	27 194
Critical flow (HAP/a)	24 382	b	(BAFU 2019a)	15 042
Weighting (–)	5,94			3,27
Eco-factor (UBP/HAP)	**7 200 000**		Aircraft noise	4 100 000

Q = data quality; for explanation, see Part 2, Chapter 6

Tab. 120: Elementary flows for implementation of the noise eco-factor at the inventory level

Elementary flow name		
Road noise caused by passenger cars*	vkm	Noise, road, passenger car
Road noise caused by trucks	vkm	Noise, road, lorry
Railway noise caused by passenger transportation	pkm	Noise, rail, passenger train
Railway noise caused by cargo transportation	tkm	Noise, rail, freight train
Aircraft noise caused by passenger transportation	pkm	Noise, aircraft, passenger
Aircraft noise caused by freight transportation	tkm	Noise, aircraft, freight

vkm: vehicle-kilometre, pkm: passenger-kilometre, tkm: tonne-kilometre;
* For the assessment of noise by motorcycles, see Tab. 123

While the number of persons affected by harmful or annoying road noise has remained almost unchanged, there has been a significant decrease in those affected by railway noise and a significant increase in those affected by aircraft noise. Moreover, the difference in the average noise level between trucks and passenger cars has decreased slightly, while that between freight trains and passenger trains has declined significantly. The eco-factor for road passenger transport is therefore slightly higher, while that for road freight transport is almost 15% lower. The eco-factor for passenger transport by rail has increased by 50% and that for freight transport by rail has decreased by two thirds, while those for passenger and freight transport by air are almost three times as high as in 2013.

Furthermore, the option of a differentiated assessment of quiet or particularly loud vehicles should be provided. Tab. 122 shows the average noise emissions of different means of transport. We assume that the average eco-factors derived for road traffic noise apply to average passenger cars and trucks. If the dB values of the means of transport to be inventoried are known, the noise

Tab. 121: Calculation of the noise eco-factor of various means of transport in UBP/vkm, UBP/pkm and UBP/tkm

It shows the number of persons affected by harmful or annoying road, railway and aircraft noise (HA persons), and the allocated distance travelled in 2015 to transport freight and people.

	Unit	Road traffic		Railway traffic		Air traffic	
		People	**Freight**	**People**	**Freight**	**People**	**Freight**
Number of HA persons	HAP	716 317		45 411		59 436	
Distance travelled 2015	vkm	$5,87\times10^{10}$	$6,36\times10^{9}$	$1,94\times10^{8}$	$2,85\times10^{7}$	$8,75\times10^{9}$	$1,95\times10^{9}$
Number of HA persons	HAP/vkm	$6,54\times10^{-6}$	$5,23\times10^{-5}$	$1,71\times10^{-4}$	$4,28\times10^{-4}$	$5,55\times10^{-6}$	$5,55\times10^{-6}$
Number of HA persons	HAP/vkm	$6,54\times10^{-6}$	$5,23\times10^{-5}$				
Number of HA persons	HAP/pkm			$1,63\times10^{-6}$		$5,55\times10^{-7}$	
Number of HA persons	HAP/tkm				$9,81\times10^{-7}$		$5,55\times10^{-6}$
Eco-factors vehicle kilometre	UBP/vkm	**23**	**180**				
Eco-factors passenger kilometre	UBP/pkm			**8,0**		**4,0**	
Eco-factors tonne kilometre	UBP/tkm				**4,8**		**40**

HAP: persons affected by harmful or annoying noise, vkm: vehicle kilometre, pkm: passenger kilometre, tkm: tonne kilometre
To allocate the number of highly annoyed persons to passenger and freight transportation by road and railway, the distance travelled to transport freight is multiplied by a factor of 8 or 2.5, as the noise level of trucks and freight trains is around 4 dB higher than the noise level of passenger cars and passenger trains.

Tab. 122: Average noise emissions of the means of transport

Means of transportation		**Noise level**	**Notes**
Road, passenger cars	dB(A)	71	Lmax, according to SonROAD18, free flowing traffic at 50 km/h
Road, trucks	dB(A)	80	
Railway, ICN, 140 kmh	dB(A)	56,5	Leq (16h) according to SonRail webtool, single pass, distance: 1 meter with moderate rail roughness and concrete sleepers
Railway, freight train (container, composite brake blocks, 4 axles, 20m, 1 engine)	dB(A)	60,7	
Airplane, A320 (average medium or short-haul plane), flex power take-off	dB(A)	46,9	Leq (16h), distance: 300 metres, from Empa measurements
Airplane, A330-3 (average long-haul plane), flex power take-off	dB(A)	50,3	

kilometres can be multiplied by the appropriate factor in accordance with Tab. 123. The formula published in Doka (2003a) is used here.

For instance, if the vehicle to be assessed is 3 dB quieter (noise level -3 dB) than the average vehicle, the vehicle kilometre of noise to be used in the inventory analysis should be reduced by half (factor 0.5; see Tab. 123). Thus, driving 1 km with a 3 dB quieter car causes 0.5 km of 'noise, road, passenger cars'.

The vehicle kilometre of noise to be used for the noise emissions of motorcycles can be determined in the same way, by establishing the difference between the noise level of the average passenger car and the noise level of a motorcycle. This makes it possible to read the correction factor in Tab. 123 and calculate the vehicle kilometre of motorcycle noise.

Tab. 123: Factor by which noise kilometres must be multiplied for an appropriate level difference from the average (see Tab. 122)

The formula for determining the factor is:

Factor = $10^{(\text{level change}/10)}$, according to Doka (2003a),

based on the road traffic noise model Sonroad 1997 of EMPA 1997.

Level change (dB)	Factor
− 5	0,32
− 4	0,40
− 3	0,50
− 2	0,63
− 1	0,79
0	1,00
+ 1	1,26
+ 2	1,58
+ 3	2,00
+ 4	2,51
+ 5	3,16
+ 6	3,98
+ 7	5,01
+ 8	6,31
+ 9	7,94
+ 10	10,00

16 Selected methodological issues

16.1 Inventory method for FSC forest

FSC forest is a special form of forestry. This type of land use is not covered by the extended CORINE nomenclature. It is therefore recommended that the land use be broken down into defined types of land use. In the case of FSC forest, it should be divided into areas of managed forest and areas of unmanaged forest (see also Tab. 94). FSC forest is ultimately inventoried according to the proportions of each type of land use or management intensity.

16.2 Inventory method for CO_2 emission certificates

International and national standards on greenhouse gas inventories and carbon footprints of products and companies are clear about the role of certificates (Carbon Trust & DEFRA 2011; WBCSD & WRI 2011a, b; EN 15804 2019; International Organization for Standardization (ISO) 2013): CO_2 emission certificates are a reduction measure and may not be offset against generated emissions in product and company inventories.

16.3 Dealing with guarantees of origin for energy products

Guarantees of origin (GOs) prove that purchased electricity has been generated to a certain quality standard (power from renewable sources). These certificates need to be considered in different ways, depending on the circumstances. The following scenarios may arise:

- A company buys electricity and GOs independently of each other.
- A company buys electricity and GOs together, i.e. the purchased electricity is generated at the same power plant from which the GOs are bought.

For companies that buy power on the liberalised market, the purchase of GOs must be combined with the purchase of electricity. The verified purchase of GOs and electricity from the same power plants entitles these companies to use the corresponding power plant mix when inventorying their products.

If these companies buy electricity and GOs separately, the electricity mix of the purchased power (physical production) must be used. If the electricity mix is not known, the Swiss consumer mix should be used. Justified exemptions are possible for companies that are bound by the supply monopoly.

The GOs may be indicated separately as an improvement measure.

The rules and procedures set out here also apply mutatis mutandis to biogas certificates and biogas guarantees of origin.

16.4 Environmental handprints

In the discussion about the environmental footprint of products and services, there is an increasing focus on how any positive effects can be presented, as well as negative environmental impacts. The most commonly used term in this context is ‘handprint’. A recent example would be the life cycle assessment rules for buildings published by the Finnish Ministry of the Environment (Ympäristöministeriö 2020).

They propose quantifying as handprints the emissions potentially avoided through the export of electricity generated in the building and through the future recycling of construction materials at the end of the building’s useful life, as well as the biogenic carbon stored in renewable raw materials. At the same time, they stipulate that the two variables, i.e. the footprint and the handprint, must be kept strictly separate and not offset. Separate limit values are defined for the footprint and the handprint: these are maximum thresholds in the case of the footprint and minimum thresholds in the case of the handprint.

Determining the size of handprints requires scenarios, in particular for the definition of the environmental and energy efficiency of the average technology (manufacture, operation and disposal). That is why handprints are uncertain and speculative. We therefore recommend following the Finnish model and quantifying the potential environmental handprints separately from the environmental footprints and defining independent targets for the two indicators. We recommend binding targets for the environmental footprint and voluntary targets for the handprint.

16.5 Circular economy indicators

In recent years, indicators have been developed to quantify the circularity (recyclability) of a product or service (De Pascale et al. 2020). To be able to estimate the environmental benefits of recyclable products, a comparative life cycle assessment is required: in one version, the product is manufactured using primary raw materials; in the other it is recycled, and the recovered secondary raw materials are used in production. As with evaluating handprints, the use of (future) scenarios is essential. We advise caution when it comes to indicators such as ‘proportion of recyclate in the product’ or ‘proportion of recyclable materials’.

17 Unassessed environmental impacts

17.1 Non-ionising radiation

Non-ionising radiation is divided into low- and high-frequency radiation, infrared radiation, visible light and ultraviolet radiation. Low-frequency electric and magnetic fields are generated, for example, by overhead lines for trams and trains, power transmission lines and household electrical appliances such as televisions. High-frequency radiation is produced by television and radio transmitters, mobile phone masts, mobile phones, radar systems and microwave ovens.

The Federal Act and Ordinance on Protection against the Risks associated with Non-Ionising Radiation and with Sound specify the maximum tolerated radiation levels (Swiss Federal Council 2019a, b).

The effect of non-ionising radiation on humans depends on the intensity and frequency of the radiation. The impact of very intense radiation, which is not usually present in our environment, has been scientifically proven. However, as scientific knowledge currently stands, it is unclear whether and to what extent the weak non-ionising radiation present in everyday life is harmful to health in the long term.[39]

Given the lack of clarity about its damaging effects, the fact that it varies greatly from place to place and time to time, and the lack of suitable life cycle inventories, it is not currently possible to derive an eco-factor for non-ionising radiation.

17.2 Ecosystem services

Ecosystem services can be grouped into four types (Staub et al. 2011). A distinction is made depending on whether an ecosystem service is:

- directly usable (e.g. a recreational service based on hunting, collection and observation of species living in the wild);
- an input factor for the production of market goods by industry (e.g. natural supply of production support services: pollination and biological pest control);
- an intermediate ecosystem service contributing to final ecosystem services (e.g. CO_2 storage);
- conducive to the creation of a natural/healthy living environment (e.g. quietness).

In all, Staub et al. (2011) distinguish 23 indicators for representing ecosystem services. It is very challenging to assign the impacts of pollutant emissions to air, water and soil and of the extraction or use of resources to a reduction in ecosystem services based on a causal link, or even to quantify this reduction. In the case of some indicators (e.g. quietness), there is a risk of double counting (the eco-factor for 'noise emissions' is also used, among other things, to quantify damage to the ecosystem service 'quietness').

Because of the complex interdependencies involved, and the lack of data and targets, no eco-factors were developed in this area.

17.3 VOC emissions to groundwater

In addition to other substances, volatile organic compound (VOC) concentrations in groundwater have been observed as part of NAQUA's activities (NAQUA 2019) for around 20 years. According to this report, VOCs are mainly released into the environment during the handling of fuels and solvents and as a result of accidents, and can thus enter the groundwater. In addition, these substances enter the atmosphere in the form of combustion residues or through the volatilisation of fuels or solvents. They can then enter the groundwater through seepage of precipitation and surface water. In the case of groundwater contamination through chlorinated hydrocarbons, contaminated sites are often the cause. The Waters Protection Ordinance (WPO 1998, 2020) sets out numerical requirements for various VOC substances and substance groups in groundwater that is used as drinking water. In 2014, the numerical requirement for volatile halogenated hydrocarbons (VHHs) of 1 mg/l was exceeded at least

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[39] *www.bafu.admin.ch/bafu/de/home/themen/elektrosmog/fachinformationen.html* (in German) (Accessed: 4 December 2020)

once during the year at almost 4% of the tested monitoring wells. Moreover, traces of VHHs below this threshold were detected in around one quarter of the monitoring wells. For other VOCs, such as MAHs, PAHs, MTBEs and ETBEs, the limit values were not exceeded and the number of monitoring sites at which these substances were detected was lower. Only for 1,4-dioxane was a value in excess of 1 mg/l measured at two monitoring sites, although in both cases the value was below the maximum of 6 mg/l set in the Ordinance on Drinking Water and Water in Public Baths and Shower Facilities (DWBSO; Federal Department of Home Affairs (FDHA), 2020) (NAQUA 2019).

As there is no information about the quantities of VOCs emitted to groundwater, an eco-factor cannot be calculated. It should be noted that MAHs, PAHs and MTBEs/ETBEs do not represent a nationwide problem for groundwater quality. VHHs are still among the substances that significantly impair groundwater quality by exceeding the numerical requirement of the WPO at 4% of the monitoring sites. These are primarily substances that entered the environment in the second half of the 20th century through the careless handling of solvents and cleaning agents and are still present in groundwater today due to their longevity. The use of VHHs has since been restricted or strictly regulated. As a result of these measures, the production and use of VHHs has been declining for about two decades (NAQUA 2019). For this reason, establishing eco-factors for VOCs in groundwater is not considered urgent.

17.4 Micropollutants in water bodies

Micropollutants are man-made substances that enter water bodies and drinking water. As individual substances or often as a cocktail of several substances, they are problematic for aquatic organisms and pollute drinking water resources. They originate from a variety of everyday products such as medicines, personal care products, pesticides or other chemicals. There are thousands of different micropollutants in water bodies. Eco-factors have been derived for a selection of micropollutants from the groups of heavy metals, endocrine disruptors, POPs, AOXs and PAHs. According to the Federal Council's 'Environment Switzerland 2018' report (FOEN 2018), micropollutants from settlement areas, industry and commerce represent a major challenge. For this reason, these substances will be given further attention in the next revision and the list of eco-factors will be expanded, especially for medicines and antibiotics.

17.5 Salinisation

When food and other consumer goods (for instance, lithium batteries) are imported into Switzerland, foreign soil salinisation is present throughout the value creation chains. As salinisation is not an environmental problem in Switzerland, there is no legislation governing it. International agreements must be used instead.

Salinisation can have two causes: ion deposition and water abstraction. The latter overlaps to some extent with the 'water use' indicator. For an assessment, ion deposition is basically considered a pollutant emission via salinisation.

Existing methodological approaches (Feitz & Lundie 2002; Leske & Buckley 2003, 2004a, b) are not detailed or broad enough to be applied. Moreover, we are not aware of any more recent work or quantitative national or international targets.

17.6 Erosion

In the context of life cycle assessments, erosion is referred to as an important environmental impact. The data situation on erosion in agriculture has improved significantly. The loss of soil per kg of harvested quantity has been analysed and quantified for each region (van Zelm et al. 2017). However, this information has not yet been incorporated into the life cycle inventories of agricultural products in leading LCA databases. Moreover, the legal basis (BAFU & BLW 2013) does not include binding quantitative targets.

17.7 Noise from machinery and stationary sources

Eco-factors have not yet been prepared for noise from construction machinery, leaf and hay blowers, lawnmowers, construction sites, wind turbines, and commercial and industrial installations. The impacts of these sources of noise are limited to local areas. Accordingly, the (required) abatement measures are also defined locally. As a result, it is difficult to determine Swiss eco-factors for noise from these sources.

17.8 Underwater noise

Increasing underwater noise from ships and exploration for natural resources under the sea floor is forcing marine mammals out of their habitats and has the potential to mask biological signals, trigger behavioural responses and physiological effects, and increase marine mammal injury and mortality.

There are various international initiatives on underwater noise (International Ocean Noise Coalition (IONC); European Coalition for Silent Oceans (ECSO)). OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) has also addressed this topic in recent years, carrying out and documenting extensive surveys in the North Sea (OSPAR Commission 2017c) and publishing guidance on the monitoring and assessment of underwater noise (OSPAR Commission 2017a).

Due to a lack of international agreements or laws with quantitative targets, it was – as previously – not possible to derive an eco-factor in this fourth revision.

17.9 Light pollution

The infiltration of our living environment by artificial light, known colloquially as light pollution, can lead to migratory birds on the wing at night becoming disorientated and flying off course. Similarly, local light sources can affect nocturnal animals, fragmenting their habitat, shrinking their territory and reducing their food supply.

The FOEN is currently consulting on an enforcement aid to address this (BAFU 2017), aimed at helping to prevent unnecessary light emissions in the design, approval and operation of lighting. Based on Article 11 of the Environmental Protection Act, the enforcement aid is geared towards individual projects and contains neither statements nor data on the current situation in Switzerland or on possible targets for the country as a whole. Consequently, the present report does not include an eco-factor for light emissions.

18 Annex

A1 Conversion factors for emissions

Tab. 124: Conversion factors for emissions of nitrogen and phosphorous compounds and for COD/DOC

	Mass, rounded (g/mol)	
NO_X als NO_2	46	1 g NO_2 corresponds to 0,3 g NO_X-N
NH_3	17	1 g NH_3 corresponds to 0,82 g NH_3-N
NH_4^+	18	1 g NH_4^+ corresponds to 0,78 g NH_4^+-N
NO_3^-	62	1 g NO_3^- corresponds to 0,23 g NO_3^--N
N_2O	44	1 g N_2O corresponds to 0,64 g N_2O-N
PO_4^{3-}	95	1 g PO_4^{3-} corresponds to 0,33 g PO_4^{3-}-P
P_2O_5	142	1 g P_2O_5 corresponds to 0,44 g P_2O_5-P
COD	–	1 g COD corresponds to 0,3 g DOC (rough approximation)

A2 Eco-factors for greenhouse gases and ozone-depleting substances

When substances have both a GWP and an ODP, the factor resulting in the higher eco-factor is used. The bold face of values in the table indicates whether the GWP or the ODP was used for the calculation. The GWP values are based on IPCC (IPCC 2013a), the ODP values on UNEP (UNEP 2007).

Tab. 125: Eco-factors for greenhouse gases and ozone-depleting substances

	Formula	**CAS No**	**GWP (CO_2–eq)**	**ODP (R11–eq)**	**Eco-factor 2021 (UBP/g)**	**Eco-factor 2013 (UBP/g)**	**Basis 2013**
Carbon dioxide	CO_2	124-38-9	**1**	–	**1**	0,46	GWP
Carbon dioxide + **	CO_2 +	124-38-9	**2,5 *** **	–	**2,5**	0,46	GWP
Carbon monoxide	CO	630-08-0	**1,57**	–	**1,6**	0,72	GWP
Methane fossil	CH_4	74-82-8	**30**	–	**30**	12	GWP
Methane biogen	CH_4	74-82-8	**28**	–	**28**	12	GWP
Nitrous oxide	N_2O	10024-97-2	**265**	–	**270**	140	GWP
Chlorofluorocarbons (CFCs)							
CFC-11	CCl_3F	75-69-4	4 660	**1**	**25 000**	8 500	ODP
CFC-12	CCl_2F_2	75-71-8	10 200	**1**	**25 000**	8 500	ODP
CFC-13	$CClF_3$	75-72-9	13 900	**1**	**25 000**	8 500	ODP
CFC-111	C_2Cl_5F	354-56-3	–	**1**	**25 000**	8 500	ODP
CFC-112	$C_2Cl_4F_2$	76-12-0	–	**1**	**25 000**	8 500	ODP
CFC-113	CCl_2FCClF_2	76-13-1	5 820	**0,8**	**20 000**	6 800	ODP
CFC-114	$CClF_2CClF_2$	76-14-2	8 590	**1**	**25 000**	8 500	ODP
CFC-115	CF_3CClF_2	76-15-3	7 670	**0,6**	**15 000**	5 100	ODP
CFC-211	C_3Cl_7F	422-78-6	–	**1**	**25 000**	8 500	ODP
CFC-212	$C_3Cl_6F_2$	3182-26-1	–	**1**	**25 000**	8 500	ODP
CFC-213	$C_3Cl_5F_3$	2354-06-5	–	**1**	**25 000**	8 500	ODP
CFC-214	$C_3Cl_4F_4$	29255-31-0	–	**1**	**25 000**	8 500	ODP
CFC-215	$C_3Cl_3F_5$	4259-43-2	–	**1**	**25 000**	8 500	ODP
CFC-216	$C_3Cl_2F_6$	661-97-2	–	**1**	**25 000**	8 500	ODP
CFC-217	C_3ClF_7	422-86-6	–	**1**	**25 000**	8 500	ODP
Hydrofluorocarbons (HFCs)							
HFC-23	CHF_3	75-46-7	**12 400**	–	**12 000**	6 800	GWP
HFC-32	CH_2F_2	75-10-5	**677**	–	**680**	310	GWP
HFC-41	CH_3F	593-53-3	**116**	–	**120**	42	GWP
HFC-125	CHF_2CF_3	354-33-6	**3 170**	–	**3 200**	1 600	GWP
HFC-134	CHF_2CHF_2	359-35-3	**1 120**	–	**1 100**	510	GWP
HFC-134a	CH_2FCF_3	811-97-2	**1 300**	–	**1 300**	660	GWP
HFC-143	CHF_2CH_2F	430-66-0	**328**	–	**330**	160	GWP
HFC-143a	CF_3CH_3	420-46-2	**4 800**	–	**4 800**	2 100	GWP
HFC-152	CH_2FCH_2F	624-72-6	**16**	–	**16**	24	GWP

* Assessed with the eco-factor for ozone creation potential (POCP), as that value is higher

** Carbon dioxide and other climate-impacting compounds from aviation

*** not according to GWP100, the other climate-impacting effects are expressed as multiples of the CO_2 impact according to Switzerland's long-term climate strategy

	Formula	CAS No	GWP (CO_2–eq)	ODP (R11–eq)	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)	Basis 2013
HFC-152a	CH_3CHF_2	75-37-6	**138**	–	**140**	57	GWP
HFC-161	CH_3CH_2F	353-36-6	**4**	–	**4**	5,5	GWP
HFC-227ea	CF_3CHFCF_3	431-89-0	**3 350**	–	**3 400**	1 500	GWP
HFC-236cb	$CH_2FCF_2CF_3$	677-56-5	**1 210**	–	**1 200**	620	GWP
HFC-236ea	CHF_2CHFCF_3	431-63-0	**1 330**	–	**1 300**	630	GWP
HFC-236fa	$CF_3CH_2CF_3$	690-39-1	**8 060**	–	**8 100**	4 500	GWP
HFC-245ca	$CH_2FCF_2CHF_2$	679-86-7	**716**	–	**720**	320	GWP
HFC-245fa	$CHF_2CH_2CF_3$	460-73-1	**858**	–	**860**	470	GWP
HFC-365mfc	$CF_3CH_2CF_2CH_3$	406-58-6	**804**	–	**800**	370	GWP
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	138495-42-8	**1 650**	–	**1 700**	750	GWP
Partially halogenated chlorofluorocarbons (HCFCs)							
HCFC-21	$CHCl_2F$	75-43-4	148	**0,04**	**1 000**	340	ODP
HCFC-22	$CHClF_2$	75-45-6	**1 760**	0,055	**1 800**	830	GWP
HCFC-31	CH_2FCl	593-70-4	–	**0,02**	**500**	170	ODP
HCFC-121	$CHCl_2CCl_2F$	354-14-3	–	**0,04**	**1 000**	340	ODP
HCFC-122	$CHCl_2CClF_2$	354-21-2	59	**0,08**	**2 000**	680	ODP
HCFC-123	$CHCl_2CF_3$	306-83-2	79	**0,02**	**500**	170	ODP
HCFC-124	$CHFClCF_3$	2837-89-0	527	**0,022**	**550**	280	GWP
HCFC-131	CH_2ClCCl_2F	359-28-4	–	**0,05**	**1 300**	430	ODP
HCFC-133a	CH_2ClCF_3	75-88-7	–	**0,06**	**1 500**	510	ODP
HCFC-141	$CH_2ClCHClF$	430-57-9	–	**0,07**	**1 800**	600	ODP
HCFC-141b	CH_3CFCl_2	1717-00-6	782	**0,11**	**2 800**	940	ODP
HCFC-142b	CH_3CF_2Cl	75-68-3	**1 980**	0,065	**2 000**	1 100	GWP
HCFC-225ca	$CF_3CF_2CHCl_2$	422-56-0	127	**0,025**	**630**	210	ODP
HCFC-225cb	$CClF_2CF_2CHClF$	507-55-1	525	**0,033**	**830**	280	ODP
HCFC-253	$C_3H_4F_3Cl$	460-35-5	–	**0,03**	**750**	260	ODP
HCFC-261	$CH_3CClFCH_2Cl$	420-97-3	–	**0,02**	**500**	170	ODP
HCFC-271	C_3H_6FCl	430-55-7	–	**0,03**	**750**	260	ODP
Perfluorocarbons (PFCs)							
Methane, perfluoro- (HFC-14)	CF_4	75-73-0	**6 630**	–	**6600**	3 400	GWP
Ethane, perfluoro- (HFC-116)	C_2F_6	76-16-4	**11 100**	–	**11 000**	5 600	GWP
Propane, octafluoro- (HFC-218)	C_3F8	76-19-7	**8 900**	–	**8 900**	4 100	GWP
Propane, hexafluorcyclo-	c-C_3F_6	931-91-9	**9 200**	–	**9 200**	8 000	GWP
Butane, decafluoro-	C_4F_{10}	355-25-9	**9 200**	–	**9 200**	4 100	GWP
Butane, octafluorcyclo-	c-C_4F_8	115-25-3	**9 540**	–	**9 500**	4 700	GWP
Pentane, dodecafluoro-	C_5F_{12}	678-26-2	**8 550**	–	**8 600**	4 200	GWP
Hexane, tetradecafluoro-	C_6F_{14}	355-42-0	**7 910**	–	**7 900**	4 300	GWP
PFC-9-1-18	$C_{10}F_{18}$		**7 190**	–	**7 200**	3 500	GWP
PFPMIE	$CF_3OCF(CF_3)CF_2O$-CF_2OCF_3		**9 710**	–	**9 700**	4 700	GWP

* Assessed with the eco-factor for ozone creation potential (POCP), as that value is higher

** Carbon dioxide and other climate-impacting compounds from aviation

*** not according to GWP100, the other climate-impacting effects are expressed as multiples of the CO_2 impact according to Switzerland's long-term climate strategy

	Formula	CAS No	GWP (CO_2–eq)	ODP (R11–eq)	Eco-factor 2021 (UBP/g)	Eco-factor 2013 (UBP/g)	Basis 2013
Brominated hydrocarbons							
Methane, bromo-	CH_3Br	74-83-9	2	**0,6**	**15 000**	5 100	ODP
Methane, dibromo-	CH_2Br_2	74-95-3	**1**	–	**1**	0,71	GWP
Methane, bromchloro-	CH_2BrCl	74-97-5	–	**0,12**	**3 000**	1 000	ODP
Methane, bromfluoro-	CH_2FBr	373-52-4	–	**0,73**	**18 000**	6 200	ODP
Methane, bromdifluoro-	$CHBrF_2$	1511-62-2	376	**0,74**	**19 000**	6 300	ODP
Methane, dibromfluoro-	$CHFBr_2$	1868-53-7	–	**1**	**25 000**	8 500	ODP
Halon 1211 (Methane, bromochlorodifluoro-)	$CBrClF_2$	353-59-3	1 750	**3**	**75 000**	26 000	ODP
Halon 1301 (Methane, bromotrifluoro-)	$CBrF_3$	75-63-8	6 290	**10**	**250 000**	85 000	ODP
Halon 2402 (Ethane, 1,2-dibromo-1,1,2,2-tetrafluoro-)	$C_2Br_2F_4$	124-73-2	1 470	**6**	**150 000**	51 000	ODP
Chlorinated hydrocarbons							
Methane, tetrachloro-, (R-10)	CCl_4	56-23-5	1 730	**1,1**	**28 000**	9 400	ODP
Chloroform, (R-20)	$CHCl_3$	67-66-3	**16**	–	**16**	– *	GWP
Methane, monochloro-, (R-40)	CH_3Cl	74-87-3	**12**	–	**12**	– *	GWP
Methane, dichloro-, (R-30)	CH_2Cl_2	75-09-2	**9**	–	**9**	– *	GWP
Ethane, 1,1,1-trichloro-, (R-140)	CH_3CCl_3	71-55-6	160	**0,1**	**2 500**	850	ODP
Other halogenated hydrocarbon compounds							
Methane, trifluoriodo-	CF_3I	2314-97-8	–	–	**0**	0,18	GWP
Ethanol, 2,2,2-trifluoro-	CF_3CH_2OH	75-89-8	**20**	–	**20**	26	GWP
1-propanol, 2,2,3,3,3-pentafluoro-	$CF_3CF_2CH_2OH$	422-05-9	**19**	–	**19**	19	GWP
2-propanol, 1,1,1,3,3,3-hexafluoro-	$(CF_3)_2CHOH$	920-66-1	**182**	–	**180**	90	GWP
Nitrogen trifluoride	NF_3	7783-54-2	**16 100**	–	**16 000**	7 900	GWP
Sulphur, pentafluoro(trifluoromethyl)-	SF_5CF_3	373-80-8	**17 400**	–	**17 000**	8 100	GWP
Sulphur hexafluoride	SF_6	2551-62-4	**23 500**	–	**24 000**	10 000	GWP
Ethers and halogenated ether compounds							
Ether, dimethyl-	CH_3OCH_3	115-10-6	–	–	**– ***	– *	GWP
Ether, methyl perfluoroisopropyl-	$(CF_3)_2CFOCH_3$	22052-84-2	**363**	–	**360**	160	GWP
HCFE-235da2	$CF_3CHClOCHF_2$	26675-46-7	**491**	–	**490**	160	GWP
HFE-125	CF_3OCHF_2	3822-68-2	**12 400**	–	**12 000**	6 900	GWP
HFE-134	CHF_2OCHF_2	1691-17-4	**5 560**	–	**5 600**	2 900	GWP
HFE-227ea	$CF_3CHFOCF_3$	2356-61-8	**6 450**	–	**6 500**	710	GWP

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** Carbon dioxide and other climate-impacting compounds from aviation

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A3 PAHs (polycyclic aromatic hydrocarbons)

The following table contains a list of the most common PAHs. The list is not conclusive. The eco-factor to be used can be found in Sections 9.10.5, 9.10.6 and 10.10.4.

Tab. 126: PAHs (polycyclic aromatic hydrocarbons)

PAK No	Name	CAS-Nr.	Molekulargewicht	Synonyme
8	Acenaphthene	83-32-9	154	1,2-Dihydroacenaphthylene; 1,8-Ethylenenaphthalene
7	Acenaphthylene	208-96-8	152	Acenaphthalene
15	Anthracene	120-12-7	178	Anthracin
38	Benz(a)anthracene	56-55-3	228	1,2-Benzanthracene; 1,2-Benzanthrene; Benzo[b]phenanthrene; 2,3-Benzophenanthrene; Tetraphene; Naphthanthracene
74	Benzo(a)pyrene	50-32-8	252	Benzo[def]chrysene; 3,4-Benzopyrene; 6,7-Benzopyrene; 1,2-Benzpyrene; 4,5-Benzpyrene
69	Benzo(b)fluoroanthene	205-99-2	252	3,4-Benz[e]acephenanthrylene; Benzo[b]fluoranthene; Benzo[e]fluoranthene; 2,3-Benzofluoranthene; 3,4-Benzofluoranthene;
120	Benzo(ghi)perylene	191-24-2	276	1,12-Benzoperylene
71	Benzo(k)fluoroanthene	207-08-9	252	11,12-Benzofluoranthene; 8,9-Benzofluoranthene; 2,3:1›,8 -Binaphthylene; Dibenzo[b,jk]fluorene
39	Chrysene	218-01-9	228	Benzo[a]phenanthrene; 1,2-Benzophenanthrene
130	Dibenz(a,h)anthracene	53-70-3	278	1,2:5,6-Benz[a]anthracene; 1,2:5,6-Benzanthracene; 1,2,5,6-Dibenzoanthracene
18	Fluoroanthene	206-44-0	202	Benzo[jk]fluorene; Idryl; 1,2-(1,8-Naphthalenediyl)benzene; Benz[a]acenaphthylene; 1,2-Benzoacenaphthylene
11	Fluorene	86-73-7	166	o-Biphenylenemethane; Diphenylenemethane; 9H-Fluorene; 2,2 -Methylenebiphenyl; 2,3-Benzidene; o-Biphenylmethane
113	Indeno(1,2,3-cd)pyrene	193-39-5	276	1,10-(1,2-Phenylene)pyrene; 1,10-(o-Phenylene)pyrene; o-Phenylenepyrene; 2,3-(o-Phenylene)pyrene; 2,3-Phenylenepyrene
4	Naphthalene	91-20-3	128	Naphthalin
14	Phenanthrene	85-01-8	178	Phenanthrin
21	Pyrene	129-00-0	202	Benzo[def]phenanthrene; Pyren

A4 Eco-factors for persistent organic pollutants (POPs)

This is a list of all POPs considered to be emissions to surface waters. The substances, characterisation and eco-factors were determined by Ruiz et al. (2012). The CAS number is standard.

Tab. 127: Persistent organic pollutants (POPs), emitted to surface waters

Name	CAS No	BCF (l/kg)	Characterisation factor (kg 2,4,6-Tribromphenol-eq./kg)	Eco-factor 2021 (UBP/g)
1,1,2,2-Tetrachloroethane	79-34-5	14	0,06	3 300
1,1'-Bianthracene -9,9',10,10 -tetrone, 4,4'-diamino-	4051-63-2	3 890	15,85	930 000
1,2,4-Benzenetricarboxylic acid, tris(2-ethylhexyl) ester	3319-31-1	19	0,08	4 600
1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-, 2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl ester	20566-35-2	87	0,35	21 000
1,2-Benzenedicarboxylic acid, di-c6-10-alkyl esters	68515-51-5	617	2,51	150 000
1,2-Benzenedicarboxylic acid, dioctadecyl ester	14117-96-5	3	0,01	760
1,3,5-Triazine, 2,4-dimethoxy-6-(1-pyrenyl)-	3271-22-5	2 570	10,47	620 000
1,3,5-Triazine-2,4,6(1H,3H,5H)-trione, 1,3,5-tris[[3,5-bis(1,1-dimethylethyl)-4-hydroxyphenyl]methyl]-	27676-62-6	3	0,01	760
1,3,5-Triazine-2,4,6(1H,3H,5H)-trione, 1,3,5-tris[[4-(1,1-dimethylethyl)-3-hydroxy-2,6-dimethylphenyl]methyl]-	40601-76-1	3	0,01	760
1,3-Eicosanedione, 1-phenyl-	58446-52-9	170	0,69	41 000
1,3-Isobenzofurandione, 4,5,6,7-tetrachloro-	117-08-8	537	2,19	130 000
1,3-Propanediol, 2,2 -[oxybis(methylene)]bis[2-(hydroxymethyl)-	126-58-9	3	0,01	760
1,3-Propanediol, 2-ethyl-2-(hydroxymethyl)-	77-99-6	3	0,01	760
1,3-Propanedione, 1,3-diphenyl-	120-46-7	5	0,02	1 300
1,4:7,10-Dimethanodibenzo a,e cyclooctene, 1,2,3,4,7,8,9,10,13,13,14,14-dodeca chloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-	13560-89-9	107	0,44	26 000
10:2 FTOH (10:2 fluorotelomer alcohol)	865-86-1	2 234	9,10	540 000
12H-Phthaloperin-12-one	6925-69-5	24	0,10	5 800
13-Docosenamide, (Z)-	112-84-5	661	2,69	160 000
14H-Benz 4,5 isoquino 2,1-a perimidin-14-one	6829-22-7	145	0,59	35 000
1H-Indene-1,3(2H)-dione, 2-(3-hydroxy-2-quinolinyl)-	7576-65-0	240	0,98	58 000
1H-Isoindol-1-one, 3,3'-(1,4-phenylenediimino)bis 4,5,6,7-tetrachloro-	5590-18-1	3 802	15,49	910 000
1H-Isoindol-3-amine, 1-imino-	3468-11-9	3	0,01	760
1H-Isoindole-1,3(2H)-dione, 2- (trichloromethyl)thio -	133-07-3	35	0,14	8 500
1H-Isoindole-1,3(2H)-dione, 2,2 -(1,2-ethanediyl) bis[4,5,6,7-tetrabromo-	32588-76-4	562	2,29	130 000

Name	CAS No	BCF (l/kg)	Characterisation factor (kg 2,4,6-Tribromphenol-eq./kg)	Eco-factor 2021 (UBP/g)
1H-Isoindole-1,3(2H)-dione, 3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thio]-	133-06-2	32	0,13	7 800
1H-Isoindole-1,3(2H)-dione, 4,5,6,7-tetrachloro-2-[2-(4,5,6,7-tetrachloro-2,3-dihydro-1,3-dioxo-1H-inden-2-yl)-8-quinol	30125-47-4	95	0,39	23 000
1-Propanol, 2-chloro-, phosphate (3:1)	6145-73-9	6	0,02	1 300
2,4,6(1H,3H,5H)-Pyrimidinetrione, 5,5'-(1H-isoindole-1,3(2H)-diylidene)bis-	36888-99-0	3	0,01	760
2,4,6(1H,3H,5H)-Pyrimidinetrione, 5-[(2,3-dihydro-6-methyl-2-oxo-1H-benzimidazol-5-yl)azo]-	72102-84-2	10	0,04	2 400
2,4,6-Tribromophenol	118-79-6	245	1,00	59 000
2,4,8,10-Tetraoxa-3,9-diphosphaspiro 5.5 undecane, 3,9-bis 2,4-bis(1,1-dimethylethyl)phenoxy -	26741-53-7	162	0,66	39 000
2,4'-Dichlorobiphenyl	34883-43-7	6 902	28,12	1 700 000
2,5-Pyrrolidinedione, 3-dodecyl-1-(2,2,6,6-tetramethyl-4-piperidinyl)-	79720-19-7	562	2,29	130 000
2H-1-Benzopyran-6-ol, 3,4-dihydro-2,5,7,8-tetramethyl-2-(4,8,12-trimethyltridecyl)-	10191-41-0	39	0,16	9 300
2H-Pyran-2,4(3H)-dione, 3-acetyl-6-methyl-	520-45-6	3	0,01	760
2-Naphthalenecarboxamide, 4- (2,5-dichlorophenyl)azo -N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-	6992-11-6	10	0,04	2 400
2-Naphthalenecarboxamide, 4-[[5-[[[4-(aminocarbonyl)phenyl]amino]carbonyl]-2-methoxyphenyl]azo]-N-(5-chloro-2,4-dimetho	59487-23-9	10	0,04	2 400
2-Naphthalenecarboxamide, N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-4- 2-methoxy-5- (phenylamino)carbonyl	12225-06-8	10	0,04	2 400
2-Naphthalenecarboxamide, N,N'-(2-chloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxy-	5280-78-4	10	0,04	2 400
2-Naphthalenecarboxamide, N,N'-(2-chloro-1,4-phenylene)bis[4-[(4-chloro-2-nitrophenyl)azo]-3-hydroxy-	35869-64-8	10	0,04	2 400
2-Naphthalenecarboxamide, N,N'-1,4-phenylenebis[4-[(2,5-dichlorophenyl)azo]-3-hydroxy-	3905-19-9	10	0,04	2 400
2-n-Octyl-4-isothiazolin-3-one	26530-20-1	19	0,08	4 600
2-Thiophenecarboxylic acid, 4-cyano-5-[[5-cyano-2,6-bis[(3-methoxypropyl)amino]-4-methyl-3-pyridinyl]azo]-3-methyl-, me	72968-71-9	10	0,04	2 400
3,3'-((2,5-Dimethyl-p-phenylene)bis(imino(1-acetyl-2-oxoethylene)azo))bis(4-chloro-N-(5-chloro-o-tolyl)benzamide)	5280-80-8	10	0,04	2 400
3H-Dibenz f,ij isoquinoline-2,7-dione, 3-methyl-6- (4-methylphenyl)amino -	81-39-0	112	0,46	27 000
3H-Pyrazol-3-one, 4- (1,5-dihydro-3-methyl-5-oxo-1-phenyl-4H-pyrazol-4-ylidene)methyl -2,4-dihydro-5-methyl-2-phenyl-	4702-90-3	389	1,58	93 000
3H-Pyrazol-3-one, 4,4'-[(3,3'-dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-(4-methylphenyl)-	15793-73-4	10	0,04	2 400
4,5-Dichloro-2-octyl-3(2H)-isothiazolone	64359-81-5	110	0,45	26 000

Name	**CAS No**	**BCF (l/kg)**	**Characterisation factor (kg 2,4,6-Tribromphenol-eq./kg)**	**Eco-factor 2021 (UBP/g)**
4,7-Methano-1H-isoindole-1,3(2H)-dione, 2,2 -(1,2-ethanediyl) bis[5,6-dibromohexahydro-	52907-07-0	9	0,04	2 200
4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	355	1,45	85 000
5,9,14,18-Anthrazinetetrone, 6,15-dihydro-	81-77-6	1 514	6,17	360 000
7-Oxa-3,20-diazadispiro[5.1.11.2]heneicosan-21-one, 2,2,4,4-tetramethyl-	64338-16-5	7 586	30,90	1 800 000
8:2 FTOH (8:2 fluorotelomer alcohol)	678-39-7	12 190	49,65	2 900 000
9,10-Anthracenedione, 1-(methylamino)-	82-38-2	62	0,25	15 000
9,10-Anthracenedione, 1,1'- (6-phenyl-1,3,5-triazine-2,4-diyl)diimino bis-	4118-16-5	26	0,11	6 300
9,10-Anthracenedione, 1,4-bis (4-methylphenyl)amino -	128-80-3	513	2,09	120 000
9,10-Anthracenedione, 1-hydroxy-4- (4-methylphenyl)amino -	81-48-1	1 585	6,46	380 000
9-Octadecenamide, (Z)-	301-02-0	372	1,51	89 000
Acetamide, 2-cyano-2-[2,3-dihydro-3-(tetrahydro-2,4,6-trioxo-5(2H)-pyrimidinylidene)-1H-isoindol-1-ylidene]-N-methyl-	76199-85-4	3	0,01	760
Adipate, bis(2-ethylhexyl)-	103-23-1	955	3,89	230 000
Anthra 2,1,9-def:6,5,10-d'e'f' diisoquinoline-1,3,8,10(2H,9H)-tetrone, 2,9-dimethyl-	5521-31-3	263	1,07	63 000
Anthracene	120-12-7	2 765	11,26	660 000
Antioxidant MD-1024	32687-78-8	3 236	13,18	780 000
Azamethine Yellow 2GLT	5045-40-9	2 042	8,32	490 000
Benzamide, 3,3'-[(2-chloro-5-methyl-1,4-phenylene)bis[imino(1-acetyl-2-oxo-2,1-ethanediyl)azo]]bis[4-chloro-N-[2-(4-chl	79953-85-8	10	0,04	2 400
Benzamide, N-[4-(aminocarbonyl)phenyl]-4-[[1-[[(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)amino]carbonyl]-2-oxopropyl]azo]	74441-05-7	10	0,04	2 400
Benzenamine, 4-(1-methyl-1-phenylethyl)-N- 4-(1-methyl-1-phenylethyl)phenyl -	10081-67-1	2 399	9,77	580 000
Benzenamine, N-phenyl-, reaction products with 2,4,4-trimethylpentene	68411-46-1	12 589	51,28	3 000 000
Benzene (as BTEX)	71-43-2	9	0,04	2 100
Benzene, 1,1 -[1,2-ethanediylbis(oxy)]bis[2,4,6-tribromo-	37853-59-1	1 175	4,79	280 000
Benzene, 1,1 -oxybis-, octabromo deriv.	32536-52-0	1 950	7,94	470 000
Benzene, 1,1'-(1-methylethylidene)bis 3,5-dibromo-4-(2,3-dibromopropoxy)-	21850-44-2	81	0,33	19 000
Benzene, 1,2,4,5-tetrabromo-3,6-bis(pentabromophenoxy)-	58965-66-5	3	0,01	760
Benzene, ethyl-	100-41-4	53	0,22	13 000
Benzene, pentabromomethyl-	87-83-2	19 055	77,62	4 600 000
Benzenepropanamide, N,N -1,6-hexanediylbis[3,5-bis(1,1-dimethylethyl)-4-hydroxy-	23128-74-7	107	0,44	26 000
Benzenepropanoic acid, 3-(1,1-dimethylethyl)- -[3-(1,1-dimethylethyl)-4-hydroxyphenyl]-4-hydroxy- -methyl-, 1,2-ethaned	32509-66-3	4	0,02	1 000

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Benzenepropanoic acid, 3-(1,1-dimethylethyl)-4-hydroxy-5-methyl-, 1,2-ethanediylbis(oxy-2,1-ethanediyl) ester	36443-68-2	513	2,09	120 000
Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, 1,6-hexanediyl ester	35074-77-2	10	0,04	2 300
Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, thiodi-2,1-ethanediyl ester	41484-35-9	46	0,19	11 000
Benzo(a)pyrene	50-32-8	8 241	33,57	2 000 000
Benzo(b)fluoranthene	205-99-2	5 189	21,14	1 200 000
Benzo(k)fluoranthene	207-08-9	10 116	41,20	2 400 000
Benzoic acid, 2-[[3-[[(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl) amino]carbonyl]-2-hydroxy-1-naphthalenyl]azo]-, butyl est	31778-10-6	10	0,04	2 400
Benzoxazole, 2- 4- 2- 4-(2-benzoxazolyl)phenyl ethenyl phenyl -5-methyl-	5242-49-9	4 074	16,59	980 000
Benzoxazole, 2,2 -(1,4-naphthalenediyl)bis-	5089-22-5	5 248	21,38	1 300 000
Benzoxazole, 2,2 -(2,5-thiophenediyl)bis[5-(1,1-dimethylethyl)-	7128-64-5	2 138	8,71	510 000
Benzoxazole, 2,2'-(1,2-ethenediyldi-4,1-phenylene)bis-	1533-45-5	7 586	30,90	1 800 000
Bisbenzimidazo 2,1-b:2',1'-i benzo lmn 3,8 phenanthroline-8,17-dione	4424-06-0	490	2,00	120 000
Bisphenol A	80-05-7	72	0,30	17 000
Butanamide, 2,2'- (3,3'-dichloro 1,1'-biphenyl -4,4'-diyl)bis(azo) bis N-(2,4-dimethylphenyl)-3-oxo-	5102-83-0	10	0,04	2 400
Butanamide, 2,2'-[1,2-ethanediylbis(oxy-2,1-phenyleneazo)]bis[N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxo-	77804-81-0	10	0,04	2 400
BZ NO 153	35065-27-1/ 38380-05-1	77 446	315,46	1 9000 000
C,i, solvent yellow 14	842-07-9	10	0,04	2 400
Cresyl diphenyl phosphate	26444-49-5	66	0,27	16 000
Cyclododecane, hexabromo-	25637-99-4	5 754	23,44	1 400 000
Cyclohexane, 1,2,3,4,5-pentabromo-6-chloro-	87-84-3	603	2,45	140 000
Decabromodiphenyl oxide	1163-19-5	42	0,17	10 000
Decanedioic acid, bis(1,2,2,6,6-pentamethyl-4-piperidinyl) ester	41556-26-7	724	2,95	170 000
Decanedioic acid, bis(2,2,6,6-tetramethyl-4-piperidinyl) ester	52829-07-9	380	1,55	91 000
Decanedioic acid, bis(2-ethylhexyl) ester	122-62-3	105	0,43	25 000
D-Glucitol	50-70-4	3	0,01	760
Dichloromethane	75-09-2	2	0,01	440
Diisononyl phthalate	28553-12-0	229	0,93	55 000
Dimethylphenol phosphate (3:1)	25155-23-1	661	2,69	160 000
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1746-01-6	13 804	56,23	3 300 000
Diundecyl phthalate	3648-20-2	21	0,09	5 100
Diuron	330-54-1	23	0,09	5 500
EtFOSA (N-ethyl perfluorooctane sulfonamide)	4151-50-2	13 366	54,44	3 200 000
Ethane, 1,2-dichloro-	107-06-2	2	0,01	480

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Ethanediamide, N-(2-ethoxyphenyl)-N -(2-ethylphenyl)-	23949-66-8	126	0,51	30 000
Ethanol, 2,2 -[(1-methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxy]]bis-	4162-45-2	7 762	31,62	1 900 000
Ethanol, 2-butoxy-, phosphate (3:1)	78-51-3	21	0,09	5 000
Ethene, tetrachloro-	127-18-4	83	0,34	20 000
Ethylene oxide	75-21-8	3	0,01	760
HBCD (Hexabromocyclododecane)	3194-55-6	32 584	132,72	7 800 000
HCFC-141b (1,1-dichlorofluoroethane)	1717-00-6	13	0,05	3 200
HCFC-142b (1-chloro-1,1-difluoroethane)	75-68-3	8	0,03	1 800
Hexanedioic acid, diisononyl ester	33703-08-1	269	1,10	65 000
Indeno(1,2,3-cd)pyrene	193-39-5	32 137	130,90	7 700 000
MeFOSA (N-methyl perfluorooctane sulfonamide)	31506-32-8	6 339	25,82	1 500 000
Melamine	108-78-1	3	0,01	760
Methanone, 2-hydroxy-4-(octyloxy)phenyl phenyl-	1843-05-6	200	0,81	48 000
Methanone, (2,4-dihydroxyphenyl)phenyl-	131-56-6	11	0,04	2 600
Methanone, (2-hydroxy-4-methoxyphenyl)phenyl-	131-57-7	38	0,15	9 100
Naphthalene	91-20-3	69	0,28	19 000
Nonanedioic acid, bis(2-ethylhexyl) ester	103-24-2	182	0,74	44 000
Octadecanamide	124-26-5	513	2,09	120 000
Octadecanoic acid, 1,2,3-propanetriyl ester	555-43-1	3	0,01	760
Octadecanoic acid, butyl ester	123-95-5	158	0,65	38 000
Octadecanoic acid, diester with 1,2,3-propanetriol	1323-83-7	3	0,01	760
Octadecanoic acid, ester with 2,2-bis(hydroxymethyl)-1,3-propanediol	8045-34-9	3 020	12,30	720 000
Octadecanoic acid, octadecyl ester	2778-96-3	3	0,01	760
Octadecyl 3,5-bis(tert-butyl)-4-hydroxybenzenep*	2082-79-3	6	0,02	1 400
Oxirane, 2,2 -[(1-methylethylidene)bis(4,1-phenyleneoxymethylene)]bis-	1675-54-3	158	0,65	38 000
PBDE-100 (2,2',4,4',6-pentabromodiphenyl ether)	189084-64-8	6 324	25,76	1 500 000
PBDE-28 (2,4,4'-tribromodiphenyl ether)	41318-75-6	6 714	27,35	1 600 000
PBDE-47 (2,2',4,4'- tetrabromodiphenyl ether)	5436-43-1	32 584	132,72	7 800 000
PBDE-99 (2,2',4,4',5-pentabromodiphenyl ether)	60348-60-9	15 136	61,65	3 600 000
PCB 105 (2,3,3',4,4'-Pentachlorobiphenyl)	32598-14-4	140 605	572,73	34 000 000
PCB 110 (2,3,3',4',6-Pentachlorobiphenyl)	38380-03-9	51 168	208,42	12 000 000
PCB 118 (2,3',4,4',5-Pentachlorobiphenyl)	31508-00-6	184 502	751,53	44 000 000
PCB 123 (2,3',4,4',5'-Pentachlorobiphenyl)	65510-44-3	196 789	801,58	47 000 000
PCB 138 (2,2',3,4,4',5'-Hexachlorobiphenyl)	35065-28-2	67 143	273,49	16 000 000
PCB 149 (2,2',3,4',5',6-Hexachlorobiphenyl)	38380-04-0	111 173	452,84	27 000 000
PCB 158 (2,3,3',4,4',6-Hexachlorobiphenyl)	74472-42-7	37 584	153,09	9 000 000
PCB 160 (2,3,3',4',5,6-Hexachlorobiphenyl)	41411-62-5	143 219	583,38	34 000 000
PCB 180 (2,2',3,4,4',5,5'-Heptachlorobiphenyl)	35065-29-3	4 920	20,04	1 200 000
PCB 194 (2,2',3,3',4,4',5,5'-Octachlorobiphenyl)	35694-08-7	1 343	5,47	320 000

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PCB 199 (2,2',3,3',4,5,5',6'-Octachlorobiphenyl)	52663-75-9	644	2,62	150 000
PCB 28 + 31 (2,4,4'-Trichlorobiphenyl + 2,4',5-Trichlorobiphenyl)	7012-37-5/16606-02-3	18 793	76,55	4 500 000
PCB 5 (2,3-dichlorobiphenyl)	16605-91-7	6 095	24,83	1 500 000
PCB 52 (2,2',5,5'-Tetrachlorobiphenyl)	35693-99-3	40 644	165,56	9 700 000
PCB 70 (2,3',4',5-Tetrachlorobiphenyl)	32598-11-1	52 119	212,30	12 000 000
PCB 90 + 101 (2,2',3,4',5-Pentachlorobiphenyl + 2,2',4,5,5'-Pentachlorobiphenyl)	68194-07-0/37680-73-2	167 880	683,83	40 000 000
Pcb-18	37680-65-2	15 631	63,67	3 700 000
Pentabromodiphenyl ether	32534-81-9	15 136	61,65	3 600 000
Pentaerythritol	115-77-5	3	0,01	760
Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)	6683-19-8	2	0,01	520
PFBA (perfluorobutanoic acid)	375-22-4	3	0,01	760
PFBS (perfluorobutane sulfonate)	375-73-5	3	0,01	760
PFDA (perfluorodecanoic acid)	335-76-2	56	0,23	13 000
PFHpA (perfluoroheptanoic acid)	375-85-9	6	0,02	1 300
PFHxA (perfluorohexanoic acid)	307-24-4	3	0,01	760
PFHxS (perfluorohexane sulfonate)	355-46-4	3	0,01	760
PFNA (perfluorononanoic acid)	375-95-1	10	0,04	2 400
PFOA (Perfluorooctanoic acid)	335-67-1	3	0,01	760
PFOS (Perfluorooctanesulfonic acid)	1763-23-1	3	0,01	760
PFPA (pentafluoropropionic anhydride)	356-42-3	10	0,04	2 300
Phenol, 2-(2H-benzotriazol-2-yl)-4-(1,1,3,3-tetramethylbutyl)-	3147-75-9	5 888	23,99	1 400 000
Phenol, 2-(2H-benzotriazol-2-yl)-4-(1,1-dimethylethyl)-6-(1-methylpropyl)-	36437-37-3	6 761	27,54	1 600 000
Phenol, 2-(2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylethyl)-	3846-71-7	3 802	15,49	910 000
Phenol, 2-(2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylpropyl)-	25973-55-1	6 026	24,54	1 400 000
Phenol, 2-(2H-benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)-	70321-86-7	3 715	15,13	890 000
Phenol, 2-(2H-benzotriazol-2-yl)-4-methyl-	2440-22-4	324	1,32	78 000
Phenol, 2-(5-chloro-2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylethyl)-	3864-99-1	10 233	41,68	2 500 000
Phenol, 2-(5-chloro-2H-benzotriazol-2-yl)-6-(1,1-dimethylethyl)-4-methyl-	729335	1 288	5,25	310 000
Phenol, 2,2 -methylenebis[6-(1,1-dimethylethyl)-4-methyl-	119-47-1	3 715	15,13	890 000
Phenol, 2,2'-thiobis 6-(1,1-dimethylethyl)-4-methyl-	90-66-4	1 950	7,94	470 000
Phenol, 2,4-bis(1,1-dimethylethyl)-, phosphite (3:1)	31570-04-4	3	0,01	760
Phenol, 2,4-dibromo-	615-58-7	62	0,25	15 000
Phenol, 2,6-bis(1,1-dimethylethyl)-4-ethyl-	4130-42-1	1 230	5,01	290 000
Phenol, 2,6-bis(1,1-dimethylethyl)-4-methyl-	128-37-0	646	2,63	150 000

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Phenol, 4- 4,6-bis(octylthio)-1,3,5-triazin-2-yl amino -2,6-bis(1,1-dimethylethyl)-	991-84-4	3	0,01	760
Phenol, 4,4 -(1-methylethylidene)bis[2,6-dibromo-	79-94-7	10 471	42,65	2 500 000
Phenol, 4,4 ,4 -(1-methyl-1-propanyl-3-ylidene)tris[2-(1,1-dimethylethyl)-5-methyl-	1843-03-4	13	0,05	3 100
Phenol, 4,4 -butylidenebis[2-(1,1-dimethylethyl)-5-methyl-	85-60-9	759	3,09	180 000
Phenol, 4,4 -thiobis[2-(1,1-dimethylethyl)-5-methyl-	96-69-5	1 950	7,94	470 000
Phenol, 4,4',4"-[(2,4,6-trimethyl-1,3,5-benzenetriyl)tris(methylene)]	1709-70-2	3	0,01	760
Phenol, nonyl-, phosphite (3:1)	26523-78-4	3	0,01	760
Phosphate, tris(2-chloroethyl)-	115-96-8	1	0,00	150
Phosphonic acid, [[3,5-bis(1,1-dimethylethyl)-4-hydroxyphenyl] methyl]-, diethyl ester	976-56-7	132	0,54	32 000
Phosphonous acid, [1,1 -biphenyl]-4,4 -diylbis-, tetrakis[2,4-bis(1,1-dimethylethyl)phenyl] ester	38613-77-3	3	0,01	760
Phosphoric acid, triethyl ester	78-40-0	3	0,01	760
Phosphoric acid, tris(2-ethylhexyl) ester	78-42-2	30	0,12	7 200
Phosphorous acid, diisodecyl phenyl ester	25550-98-5	245	1,00	59 000
Phosphorous acid, isodecyl diphenyl ester	26544-23-0	603	2,45	140 000
Phosphorous acid, triphenyl ester	101-02-0	10 965	44,66	2 600 000
Phthalate, butyl-benzyl-	85-68-7	617	2,51	150 000
Phthalate, dibutyl-	84-74-2	437	1,78	100 000
Phthalate, diisodecyl-	26761-40-0	76	0,31	18 000
Phthalate, diisooctyl-	27554-26-3	708	2,88	170 000
Phthalate, dioctyl-	117-81-7	1 698	6,92	410 000
Pigment red 149	4948-15-6	8 913	36,30	2 100 000
Pigment yellow 83	5567-15-7	10	0,04	2 400
Propanedioic acid, [[3,5-bis(1,1-dimethylethyl)-4-hydroxyphenyl] methyl]butyl-, bis(1,2,2,6,6-pentamethyl-4-piperidinyl)	63843-89-0	263	1,07	63 000
Propanoic acid, 3,3 -thiobis-, didodecyl ester	123-28-4	15	0,06	3 600
Propanoic acid, 3,3'-thiobis-, dioctadecyl ester	693-36-7	3	0,01	760
Quino 2,3-b acridine-7,14-dione, 2,9-dichloro-5,12-dihydro-	3089-17-6	891	3,63	210 000
Quino[2,3-b]acridine-7,14-dione, 5,12-dihydro-	1047-16-1	1	0,00	230
Quino[2,3-b]acridine-7,14-dione, 5,12-dihydro-2,9-dimethyl-	980-26-7	5	0,02	1 200
Quinoline, 1,2-dihydro-2,2,4-trimethyl-	147-47-7	71	0,29	17 000
Sorbitan, monododecanoate	1338-39-2	56	0,23	13 000
Soybean oil, epoxidised	8013-07-8	3	0,01	760
Sulfur hexafluoride	2551-62-4	4	0,02	940
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	1 259	5,13	300 000
Toluene	108-88-3	25	0,10	6 100
Tributylphosphate	126-73-8	30	0,12	7 200
Trichlorobenzenes	12002-48-1	262	1,07	63 000

Name	CAS No	BCF (l/kg)	Characterisation factor (kg 2,4,6-Tribromphenol-eq./kg)	Eco-factor 2021 (UBP/g)
Trichloroethene	79-01-6	15	0,06	3 500
Trichloromethane	67-66-3	7	0,03	1 600
Tricresyl phosphate	1330-78-5	162	0,66	39 000
Triphenylphosphate	115-86-6	74	0,30	18 000
Tris(1,3-dichloroisopropyl) phosphate	13674-87-8	18	0,07	4 300
Xylene	1330-20-7	58	0,24	14 000

A5 Plant protection products

Tab. 128: Full list of PPP eco-factors

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
(E,Z)-2,13-Octadecadienyl acetate	0086252-74-6	5 160 000	12
(E,Z)-octadeca-3,13-dienyl acetate	0053120-26-6	5 160 000	12
1-Decanol	0000112-30-1	10 600	0,024
1-methylcyclopropene / 1-MCP	–	2 260 000	5,1
1-Naphthaleneacetic acid	0000086-87-3	10 000	0,023
1-Naphthylacetic acid	–	10 900 000	25
1h-Purin-6-amine, n-(phenylmethyl)-	0001214-39-7	8.1	0,000019
2-(1-naphthyl) Acetamide	0000086-86-2	2 260 000	5,1
2,4-D	0000094-75-7	3 900 000	8,9
6-benzyladenine	–	2 260 000	5,1
Abamectin	0071751-41-2	5 160 000	12
Acephate	0030560-19-1	44 000 000	100
Acequinocyl	–	388 000	0,88
Acetamide	0000060-35-5	4 450 000	10
Acetamiprid	0135410-20-7	4 390 000	10
Acetochlor	0034256-82-1	667 000	1,5
Acibenzolar-S-methyl	0135158-54-2	1 240 000	2,8
Aclonifen	0074070-46-5	4 060 000	9,2
Alachlor	0015972-60-8	943 000	2,1
Alanycarb	–	3 460 000	7,9
Aldicarb	0000116-06-3	15 500 000	35
Aldrin	0000309-00-2	44 000 000	100
alpha-Cypermethrin	0067375-30-8	3 250 000	7,4
alpha-Pinene	–	4 910	0,011
Aluminium oxide	–	1 240 000	2,8
Aluminium phosphide	0020859-73-8	13 500 000	31
Ametoctradin	–	870 000	2
Ametryn	0000834-12-8	1 240 000	2,8
Amidosulfuron	0120923-37-7	2 580 000	5,9
Aminopyralid	–	10 900 000	25
Amisulbrom	–	870 000	2
Amitraz	0033089-61-1	193 000	0,44
Anthraquinon	0000084-65-1	2 250	0,0051
Asulam	0003337-71-1	391 000	0,89
Essential oils	–	4 910	0,011
Atrazin	0001912-24-9	16 600 000	38
Azaconazole	–	870 000	2
Azadirachtin A+B	0011141-17-6	153 000	0,35
Azinphos-methyl	0000086-50-0	8 690 000	20

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Azoxystrobin	0131860-33-8	1 040 000	2,4
Rosin	0008050-09-7	4 910	0,011
Tree wax	–	4 910	0,011
Beflubutamid	0113614-08-7	815 000	1,9
Benalaxyl	–	487 000	1,1
Benalaxyl-M	0071626-11-4	487 000	1,1
Benazolin	0003813-05-6	8 510	0,019
Benomyl	0017804-35-2	536 000	1,2
Benoxacor	–	10 900 000	25
Bensulfuron methyl ester	0083055-99-6	1 170 000	2,7
Bensultap	0017606-31-4	2 220	0,005
Bentazon	0025057-89-0	1 960 000	4,5
Benthiavalicarb	0413615-35-7	661 000	1,5
Benthiavalicarb-isopropyl	–	753 000	1,7
Benzoic acid	0000065-85-0	168 000	0,38
Benzovindiflupyr	–	16 300 000	37
Benzyl-Dodecyl-Dimethyl-Ammonium-Bromid	–	3 870 000	8,8
beta-Cyfluthrin	–	9 740 000	22
Bifenazat	–	388 000	0,88
Bifenox	0042576-02-3	73 200	0,17
Bifenthrin	0082657-04-3	942 000	2,1
Bitertanol	0055179-31-2	3 620 000	8,2
Bixafen	–	16 300 000	37
Boscalid	0188425-85-6	55 500	0,13
Brodifacoum	0056073-10-0	532	0,0012
Bromadiolone	0028772-56-7	302 000	0,69
Bromopropylate	0018181-80-1	2 080 000	4,7
Bromoxynil	0001689-84-5	1 750 000	4
Bromuconazole	0116255-48-2	870 000	2
Bupirimate	0041483-43-6	202 000	0,46
Buprofezin	0069327-76-0	19 800 000	45
Butafenacil	–	3 530 000	8
Butralin	0033629-47-9	416 000	0,95
Calciumcyanamide	–	10 900 000	25
Calciumphosphide	0001305-99-3	302 000	0,69
Capric acid	–	4 910	0,011
Caprylic acid	–	4 910	0,011
Captan	0000133-06-2	273 000	0,62
Carbamic acid, (3,4-diethoxyphenyl)-, 1-methylet	0087130-20-9	12 900	0,029
Carbaryl	0000063-25-2	10 500 000	24
Carbendazim	0010605-21-7	12 600 000	29
Carbetamide	0016118-49-3	28 700	0,065
Carbofuran	0001563-66-2	34 600 000	79

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Carbosulfan	0055285-14-8	20 700 000	47
Carboxin	0005234-68-4	74 300	0,17
Carfentrazone-ethyl	0128639-02-1	431 000	0,98
Chlorantraniliprol	–	5 160 000	12
Chlorfenvinphos	0000470-90-6	44 000 000	100
Chloridazon	0001698-60-8	401 000	0,91
Chlorimuron-ethyl	0090982-32-4	10 900 000	25
Chlormequat	0007003-89-6	1 570 000	3,6
Chlormequat	0007003-89-6	1 570 000	3,6
Chlormequat chloride	0000999-81-5	19 700	0,045
Chlorophacinone	–	302 000	0,69
Chlorophen	–	5 720 000	13
Chlorothalonil	0001897-45-6	5 650 000	13
Chlorotoluron	0015545-48-9	127 000	0,29
Chlorpropham	0000101-21-3	2 870 000	6,5
Chlorpyrifos	0002921-88-2	29 600 000	67
Chlorpyrifos-ethyl	–	4 590 000	10
Chlorpyrifos-methyl	0005598-13-0	8 400 000	19
Chlorsulfuron	0064902-72-3	3 460 000	7,9
Chlorthal	0002136-79-0	163 000	0,37
Choline chloride	0000067-48-1	1 660	0,0038
Cinidon-ethyl	0142891-20-1	10 900 000	25
Clethodim	0099129-21-2	10 900 000	25
Clodinafop-propargyl	0105512-06-9	2 820 000	6,4
Clofentezine	0074115-24-5	5 160 000	12
Clomazone	0081777-89-1	197 000	0,45
Clopyralid	0001702-17-6	30 900	0,07
Cloquintocet-mexyl	0099607-70-2	10 900 000	25
Cloransulam-methyl	0147150-35-4	10 900 000	25
Clothianidin	0210880-92-5	4 390 000	10
Cyanamid	0000420-04-2	44 300	0,1
Cyanazine	0021725-46-2	30 000 000	68
Cyazofamid	0120116-88-3	815 000	1,9
Cyclanilide	0113136-77-9	2 260 000	5,1
Cycloxydim	0101205-02-1	21 500	0,049
Cyflufenamid	0180409-60-3	815 000	1,9
Cyfluthrin	0068359-37-5	16 700 000	38
Cyhexatin	–	44 900	0,1
Cymoxanil	0057966-95-7	52 600	0,12
Cypermethrin	0052315-07-8	9 190 000	21
Cypermethrin high-cis	–	9 740 000	22
Cyproconazole	0094361-06-5	162 000	0,37
Cyprodinil	0121552-61-2	661 000	1,5

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Cyromazin	–	9 450 000	21
d-Carvon	0002244-16-8	4 910	0,011
Daminozide	0001596-84-5	27 500	0,063
Dazomet	0000533-74-4	42 400	0,096
Decadiencarbonsäuremethylester	–	201 000	0,46
Deltamethrin	0052918-63-5	761 000	1,7
Desmedipham	0013684-56-5	81 400	0,19
Diafenthiuron	0080060-09-9	5 160 000	12
Diazinon	0000333-41-5	44 000 000	100
Diazinon	0000333-41-5	44 000 000	100
Dicamba	0001918-00-9	572 000	1,3
Dichlobenil	0001194-65-6	20 200	0,046
Dichlorprop-P	0015165-67-0	6 090 000	14
Dichlorvos (DDVP)	0000062-73-7	15 600 000	36
Diclofop	0040843-25-2	2 820 000	6,4
Diclofop-methyl	0051338-27-3	31 300	0,071
Dicofol	0000115-32-2	44 000 000	100
Dicrotophos	0000141-66-2	44 000 000	100
Diethofencarb	0087130-20-9	12 900	0,029
Difenoconazol	0119446-68-3	870 000	2
Difethialon	–	302 000	0,69
Diflubenzuron	0035367-38-5	991 000	2,3
Diflufenican	0083164-33-4	17 200	0,039
Diflufenzopyr-sodium	0109293-98-3	10 900 000	25
Dimefuron	0034205-21-5	3 140 000	7,1
Dimethachlor	0050563-36-5	89 000	0,2
Dimethenamid	0087674-68-8	3 920 000	8,9
Dimethenamid-P	0163515-14-8	10 900 000	25
Dimethoate	0000060-51-5	4 750 000	11
Dimethomorph	0110488-70-5	661 000	1,5
Dimethyl decylammoniumchlorid	–	3 870 000	8,8
Dinocap	0039300-45-3	76 300	0,17
Dinoseb	0000088-85-7	30 700 000	70
Dipropylthiocarbamic acid S-ethyl ester	0000759-94-4	3 600 000	8,2
Diquat	0000231-36-7	44 000 000	100
Diquat dibromide	0000085-00-7	44 000 000	100
Dithianon	0003347-22-6	4 440 000	10
Diuron	0000330-54-1	14 300 000	32
DNOC	0000534-52-1	663 000	1,5
Dodemorph	0001593-77-7	26 400	0,06
Dodine	0002439-10-3	4 280	0,0097
Iron(II) sulfate	0013463-43-9	7 930	0,018
Iron(III) phosphate	0010045-86-0	10 900 000	25

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Emamectinbenzoat	–	13 500 000	31
Endosulfan	0000115-29-7	4 930 000	11
Endothall	0000145-73-3	878 000	2
Epoxiconazole	0106325-08-0	870 000	2
Esfenvalerate	0066230-04-4	28 200 000	64
Acetic acid	0000064-19-7	292	0,00066
Ethalfluralin	0055283-68-6	573 000	1,3
Ethanol, 2-butoxy-	0000111-76-2	1 540 000	3,5
Ethephon	0016672-87-0	3 560 000	8,1
Ethofumesate	0026225-79-6	106 000	0,24
Ethoprop	0013194-48-4	44 000 000	100
Ethylene	–	2 260 000	5,1
Etofenprox	0080844-07-1	101 000	0,23
Etoxazol	0153233-91-1	870 000	2
Etridiazole	0002593-15-9	176 000	0,4
Eucalyptus oil	–	4 910	0,011
Famoxadone	0131807-57-3	10 900 000	25
Fenamidon	0161326-34-7	661 000	1,5
Fenazaquin	0120928-09-8	5 160 000	12
Fenbuconazole	0114369-43-6	4 320 000	9,8
Fenbutatin oxide	0013356-08-6	241 000	0,55
Fenhexamid	0126833-17-8	1 240 000	2,8
Fenitrothion	0000122-14-5	2 170 000	4,9
Fenoxaprop	0095617-09-7	2 820 000	6,4
Fenoxaprop ethyl ester	0066441-23-4	3 900	0,0089
Fenoxaprop-P ethyl ester	0071283-80-2	354	0,0008
Fenoxaprop-P-ethyl	0071283-80-2	354	0,0008
Fenoxycarb	0072490-01-8	3 460 000	7,9
Fenpiclonil	0074738-17-3	1 680 000	3,8
Fenpropathrin	0039515-41-8	35 100 000	80
Fenpropidin	0067306-00-7	21	0,000047
Fenpropimorph	0067306-03-0	661 000	1,5
Fenpyrazamin	–	1 040 000	2,4
Fenpyroximate	0111812-58-9	16 300 000	37
Fentin acetate	0000900-95-8	44 000 000	100
Fentin hydroxide	0000076-87-9	44 000 000	100
Fatty acids (total)	0068938-07-8	4 910	0,011
Fatty acids	–	4 910	0,011
Fatty acids (potassium salts)	–	4 910	0,011
Fatty acids C7-C18	–	4 910	0,011
Fipronil	0120068-37-3	44 000 000	100
Flamprop-m-isopropyl	0063782-90-1	10 900 000	25
Flazasulfuron	0104040-78-0	2 580 000	5,9

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Flonicamid	0158062-67-0	815 000	1,9
Florasulam	0145701-23-1	870 000	2
Fluazifop-P-butyl	0079241-46-6	7 780	0,018
Fluazinam	0079622-59-6	134 000	0,31
Flucarbazone sodium salt	0181274-17-9	10 900 000	25
Fludioxonil	0131341-86-1	1 040 000	2,4
Flufenacet	0142459-58-3	10 900 000	25
Flumetsulam	0098967-40-9	10 900 000	25
Flumioxazin	0103361-09-7	10 900 000	25
Fluometuron	0002164-17-2	4 790 000	11
Fluopicolide	–	625 000	1,4
Fluopyram	–	31 700 000	72
Fluorochloridone	0061213-25-0	224 000	0,51
Fluoroglycofen-ethyl	0077501-90-7	3 580 000	8,1
Fluoxastrobin	0361377-29-9	1 040 000	2,4
Flupyrsulfuron-methyl-sodium	0144740-54-5	2 580 000	5,9
Fluquinconazole	0136426-54-5	870 000	2
Flurenol	0000467-69-6	371 000	0,84
Flurenol	–	371 000	0,84
Flurochloridon	–	10 900 000	25
Fluroxypyr	0069377-81-7	331 000	0,75
Flurtamone	0096525-23-4	10 900 000	25
Flusilazole	0085509-19-9	870 000	2
Flutolanil	0066332-96-5	3 360 000	7,6
Flutolanil	0066332-96-5	3 360 000	7,6
Fluxapyroxad	–	16 300 000	37
Folpet	0000133-07-3	2 300 000	5,2
Fomesafen	0072178-02-0	44 000 000	100
Foramsulfuron	0173159-57-4	2 580 000	5,9
Fosetyl	0039148-24-8	1 240 000	2,8
Fuberidazole	0003878-19-1	22 900	0,052
Fuberidazole	0003878-19-1	22 900	0,052
Furathiocarb	–	3 460 000	7,9
Gibberellin A3	0000077-06-5	18 200	0,041
Gibberellinsäure A4+A7	–	18 200	0,041
Glufosinate	0051276-47-2	10 900 000	25
Glutaraldehyd	–	6 140 000	14
Glyphosat	0001071-83-6	440 000	1
Spearmint oil	–	4 910	0,011
Guazatine	–	1 040 000	2,4
Halauxifen-methyl	–	3 530 000	8
Halosulfuron-methyl	0100784-20-1	2 580 000	5,9
Haloxyfop-(R)-Methylester	0072619-32-0	2 820 000	6,4

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Haloxyfop-ethoxyethyl	0087237-48-7	574	0,0013
Heptenophos	0023560-59-0	177 000	0,4
Hexaconazol	–	870 000	2
Hexaconazole	0079983-71-4	870 000	2
Hexaflumuron	–	3 140 000	7,1
Hexythiazox	0078587-05-0	943 000	2,1
Hymexazol	0010004-44-1	22 400	0,051
Imazalil	0035554-44-0	77 900	0,18
Imazalil	0035554-44-0	77 900	0,18
Imazamox	0114311-32-9	106 000	0,24
Imazapyr	0081334-34-1	559	0,0013
Imazethapyr	0081335-77-5	572 000	1,3
Imidacloprid	0138261-41-3	7 550 000	17
Indoxacarb	0173584-44-6	753 000	1,7
Iodosulfuron	0185119-76-0	2 580 000	5,9
Iodosulfuron-methyl-Natrium	0144550-36-7	2 580 000	5,9
Ioxynil	0001689-83-4	98 200	0,22
Iprodione	0036734-19-7	3 650 000	8,3
Iprovalicarb	0140923-17-7	6 190	0,014
Isoproturon	0034123-59-6	811 000	1,8
Isoxadifen-ethyl	0163520-33-0	10 900 000	25
Isoxaflutole	0141112-29-0	10 900 000	25
Japan Myths Oil	–	4 910	0,011
Green soap	–	4 910	0,011
Potassium alum	–	1 240 000	2,8
Potassium iodide	–	30 800	0,07
Potassium nitrate	0007757-79-1	302 000	0,69
Potassium phosphonate	–	661 000	1,5
Potassium thiocyanat	–	302 000	0,69
Kaolinite	0001332-58-7	5 160 000	12
Kresoxim-methyl	0143390-89-0	1 040 000	2,4
Kresoxim-methyl	0143390-89-0	1 040 000	2,4
Synthetic resin dispersion	–	4 910	0,011
Copper	0007440-50-8	20 300 000	46
Copper (as 19% oxychloride, 6.5% carbonate basic and 14.3% lime preparation)	0012069-69-1	2 490 000	5,7
Copper (as hydroxide)	0020427-59-2	13 200 000	30
Copper (as lime preparation)	0008011-63-0	4 070 000	9,3
Copper (as octanoate)	–	3 590 000	8,2
Copper (as oxychloride)	0001332-65-6	6 050 000	14
Copper (as oxysulfate)	0007758-98-7	12 200 000	28
Lactofen	0077501-63-4	10 900 000	25
Lambda-Cyhalothrin	0091465-08-6	6 350 000	14

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Lecithin	0008002-43-5	5 160 000	12
Glue	–	4 910	0,011
Lenacil	0002164-08-1	2 600 000	5,9
Limonene	–	4 910	0,011
Lindane	0000058-89-9	44 000 000	100
Linuron	0000330-55-2	32 400 000	74
Lufenuron	0103055-07-8	3 140 000	7,1
Magnesium phosphide	0012057-74-8	302 000	0,69
Malathion	0000121-75-5	47 700	0,11
Maleic hydrazide	0000123-33-1	53 500	0,12
Maleic hydrazide	–	18 500	0,042
Mancozeb	0008018-01-7	1 340 000	3
Mandipropamid	0374726-62-2	815 000	1,9
Maneb	0012427-38-2	715 000	1,6
MCPA	0000094-74-6	44 000 000	100
MCPB	0000094-81-5	662 000	1,5
Mecoprop	0000093-65-2	10 900 000	25
Mecoprop-P	0016484-77-8	16 800	0,038
Mefenpyr-Diethyl	0135590-91-9	10 900 000	25
Mepanipyrim	0110235-47-7	661 000	1,5
Mepiquat	0015302-91-7	5 040 000	11
Mepiquat chloride	0024307-26-4	21	0,000047
Mepronil	0055814-41-0	1 040 000	2,4
Mesosulfuron-methyl	0208465-21-8	2 580 000	5,9
Mesotrione	0104206-82-8	10 900 000	25
Metalaxil	0057837-19-1	1 430 000	3,3
Metalaxyl-M	0070630-17-0	233 000	0,53
Metaldehyd	0000108-62-3	17 300	0,039
Metaldehyde (tetramer)	0009002-91-9	10 900 000	25
Metam-sodium dihydrate	0000137-42-8	6 200 000	14
Metamitron	0041394-05-2	6 220	0,014
Metazachlor	0067129-08-2	28 900	0,066
Metconazole	0125116-23-6	870 000	2
Methabenzthiazuron	0018691-97-9	538 000	1,2
Methamidophos	0010265-92-6	27 700 000	63
Methidathion	0000950-37-8	44 000 000	100
Methiocarb	0002032-65-7	4 890 000	11
Methomyl	0016752-77-5	10 600 000	24
Methomyl	0016752-77-5	10 600 000	24
Methoxyfenozide	0161050-58-4	1 360 000	3,1
Methylbutenol	0000115-18-4	1 180	0,0027
Metiram	0009006-42-2	48	0,00011
Metobromuron	0003060-89-7	54 900	0,12

Name	**CAS No**	**Eco-factor 2021 (UBP/kg)**	**Characterisation factor kg glyphosate-eq./kg**
Metolachlor	0051218-45-2	834 000	1,9
Metosulam	0139528-85-1	870 000	2
Metoxuron	0019937-59-8	5 990	0,014
Metrafenone	0220899-03-6	1 040 000	2,4
Metribuzin	0021087-64-9	2 010 000	4,6
Metsulfuron-methyl	0074223-64-6	528 000	1,2
Milbemectin	0051596-10-2 (milbemycin A3) + 051596-11-3 (milbemycin A4)	5 160 000	12
Milbemectin	0051596-10-2	5 160 000	12
Mineral oil / Petroleum oils	–	4 910	0,011
Mixture of vegetable oils, resin and fats	–	4 910	0,011
Monocrotophos	0006923-22-4	44 000 000	100
Monolinuron	0001746-81-2	1 260 000	2,9
Monosodium acid methanearsonate	0002163-80-6	46 900	0,11
Myclobutanil	0088671-89-0	960 000	2,2
N,N-Diallyldichloracetamid	–	10 900 000	25
Naled	0000300-76-5	694 000	1,6
Napropamide	0015299-99-7	772 000	1,8
Sodium fluorosilicate	0016893-85-9	302 000	0,69
Rosins	0008050-09-7	4 910	0,011
Nicosulfuron	0111991-09-4	2 580 000	5,9
Nitrothal-isopropyl	0010552-74-6	36 000	0,082
Norflurazon	0027314-13-2	1 030 000	2,4
Novaluron	0116714-46-6	3 140 000	7,1
Octan acids (as Na and Fe salt)	–	2 290 000	5,2
Oleum foeniculi	–	4 910	0,011
Oleic acid	–	4 910	0,011
Orange oil	–	4 910	0,011
Orbencarb	0034622-58-7	185 000	0,42
Orthophenylphenol	0000090-43-7	164 000	0,37
Oryzalin	0019044-88-3	5 950 000	14
Oxadiargyl	0039807-15-3	10 900 000	25
Oxadixyl	0077732-09-3	40 700	0,093
Oxamyl	0023135-22-0	4 220 000	9,6
Oxasulfuron	–	2 580 000	5,9
Oxychinolin	0000148-24-3	543	0,0012
Oxydemeton methyl	0000301-12-2	268 000	0,61
Oxyfluorfen	0042874-03-3	8 750 000	20
Paclobutrazol	0076738-62-0	919 000	2,1
Paraffin oil	0068938-07-8	4 910	0,011
Paraquat	0004685-14-7	3 650 000	8,3

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Parathion	0000056-38-2	13 200 000	30
Parathion-methyl	0000298-00-0	3 780 000	8,6
Perfume oil	–	4 910	0,011
Nonanoic acid	0000112-05-0	4 660	0,011
Penconazole	0066246-88-6	8 040 000	18
Pencycuron	0066063-05-6	4 730	0,011
Pendimethalin	0040487-42-1	1 510 000	3,4
Penoxsulam	–	3 530 000	8
Penthiopyrad	–	16 300 000	37
Permethrin	0052645-53-1	187 000	0,43
Pethoxamid	0106700-29-2	815 000	1,9
Phenmedipham	0013684-63-4	56 500	0,13
Phorate	0000298-02-2	44 000 000	100
Phosalon	0002310-17-0	2 630 000	6
Phosmet	0000732-11-6	7 450 000	17
Picloram	0001918-02-1	1 060 000	2,4
Picoxystrobin	0117428-22-5	1 040 000	2,4
Pinoxaden	0243973-20-8	10 900 000	25
Piperonyl butoxid	0000051-03-6	723 000	1,6
Pirimicarb	0023103-98-2	672 000	1,5
Pirimiphos-methyl	0029232-93-7	27 200 000	62
Prochloraz	0067747-09-5	23 600 000	54
Procymidone	0032809-16-8	1 150 000	2,6
Profenofos	0041198-08-7	19 100 000	43
Prohexadione-Calcium	0127277-53-6	18 200	0,041
Prometryn	0007287-19-6	6 000 000	14
Propachlor	0001918-16-7	249 000	0,57
Propamocarb	0024579-73-5	569	0,0013
Propamocarb-hydrochlorid	0025606-41-1	1 240	0,0028
Propanil	0000709-98-8	193 000	0,44
Propaquizafop	0111479-05-1	10 900 000	25
Propargite	0002312-35-8	1 000 000	2,3
Propiconazole	0060207-90-1	7 850 000	18
Propineb	0012071-83-9	2 580 000	5,9
Propoxycarbazone-sodium	0181274-15-7	10 900 000	25
Propyzamide	0023950-58-5	28 000 000	64
Proquinazid	0189278-12-4	661 000	1,5
Prosulfocarb	0052888-80-9	7 760	0,018
Prosulfuron	0094125-34-5	4 500 000	10
Prothioconazole	0178928-70-6	870 000	2
Pymetrozine	0123312-89-0	31 700 000	72
Pyraclostrobin	0175013-18-0	1 040 000	2,4
Pyraflufen-ethyl	0129630-19-9	10 900 000	25

Name	CAS No	Eco-factor 2021 (UBP/kg)	Characterisation factor kg glyphosate-eq./kg
Pyrethrin	0000121-29-9	16 900 000	38
Pyrethrine	0000121-21-1	11 400	0,026
Pyridate	0055512-33-9	100	0,00023
Pyrifenox	0088283-41-4	548 000	1,2
Pyrimethanil	0053112-28-0	32 100	0,073
Pyriproxyfen	0095737-68-1	10 200 000	23
Pyrithiobac sodium salt	0123343-16-8	10 900 000	25
Pyroxsulam	–	870 000	2
Quassia extract	–	5 160 000	12
Quinclorac	0084087-01-4	359 000	0,82
Quinmerac	0090717-03-6	858	0,002
Quinoclamine	0002797-51-5	831 000	1,9
Quinoxyfen	0124495-18-7	661 000	1,5
Quizalofop ethyl ester	0076578-14-8	15 100 000	34
Quizalofop-P-ethyl	0100646-51-3	2 820 000	6,4
Canola oil	0068938-07-8	4 910	0,011
Canola oil methyl ester	0067762-38-3	4 910	0,011
Rimsulfuron	0122931-48-0	2 580 000	5,9
Rotenon	0000083-79-4	1 630 000	3,7
S-Metolachlor	0087392-12-9	1 420 000	3,2
Sheep fat	–	4 910	0,011
Sulphur	0007704-34-9	37 600	0,085
Calcium polysulfide	–	24 100	0,055
Aluminium sulfate	–	10 600	0,024
Sesame oil refined	–	4 910	0,011
Sethoxydim	0074051-80-2	115 000	0,26
Silthiofam	0175217-20-6	55 500	0,13
Simazin	0000122-34-9	44 000 000	100
Sodium oleate	0000143-19-1	5 160 000	12
Sojalecithin	0008002-43-5	5 160 000	12
Sojaöl epoxidiert	–	4 910	0,011
Spinetoram	–	5 160 000	12
Spinosad	0168316-95-8	5 160 000	12
Spirodiclofen	0148477-71-8	5 160 000	12
Spirotetramat	–	5 160 000	12
Spiroxamine	0118134-30-8	1 040 000	2,4
Starane	0081406-37-3	6 870	0,016
Streptomycin sulfate	0003810-74-0	10 900 000	25
Sulcotrione	0099105-77-8	10 900 000	25
Sulfentrazone	0122836-35-5	10 900 000	25
Sulfosate	0081591-81-3	164 000	0,37
Sulfosulfuron	0141776-32-1	2 580 000	5,9
Sulfoxaflor	–	5 160 000	12

Name	**CAS No**	**Eco-factor 2021 (UBP/kg)**	**Characterisation factor kg glyphosate-eq./kg**
Sulfuric acid	0007664-93-9	37 600	0,085
Sulfuric acid, iron (2+) salt (1:1)	0007720-78-7	339 000	0,77
Sulfurylfluorid	–	11 800	0,027
tau-Fluvalinat	0102851-06-9	9 740 000	22
Tebuconazole	0080443-41-0	870 000	2
Tebufenozide	0112410-23-8	2 520 000	5,7
Tebufenpyrad	0119168-77-3	16 300 000	37
Tebupirimphos	0096182-53-5	5 160 000	12
Tebutam	0035256-85-0	421 000	0,96
Teflubenzuron	0083121-18-0	17 500 000	40
Tefluthrin	0079538-32-2	507 000	1,2
Tembotrione	0335104-84-2	10 900 000	25
Tepraloxydim	0149979-41-9	21 500	0,049
Terbacil	0005902-51-2	15 600 000	36
Terbufos	0013071-79-9	44 000 000	100
Terbuthylazine	0005915-41-3	8 440 000	19
Terbutryn	0000886-50-0	44 000 000	100
Terpineol	–	30 800	0,07
Tetramethrin	–	9 740 000	22
Thiabendazole	0000148-79-8	5 930 000	13
Thiacloprid	0111988-49-9	4 390 000	10
Thiamethoxam	0153719-23-4	4 390 000	10
Thidiazuron	0051707-55-2	646 000	1,5
Thiencarbazone	–	3 530 000	8
Thifensulfuron-methyl	0079277-27-3	5 620 000	13
Thiobencarb	0028249-77-6	468 000	1,1
Thiocyclam hydrogen oxalat	–	5 160 000	12
Thiophanate-methyl	0023564-05-8	15 000	0,034
Thiophanate-methyl	–	4 210 000	9,6
Thiram (TMTD)	0000137-26-8	2 290 000	5,2
Tolclofos-methyl	0057018-04-9	2 080 000	4,7
Tolylfluanid	–	1 240 000	2,8
Tralkoxydim	0087820-88-0	21 500	0,049
Tralomethrin	0066841-25-6	135 000	0,31
Triadimenol	0055219-65-3	2 790 000	6,4
Triallate	0002303-17-5	16 500 000	37
Triasulfuron	0082097-50-5	28 700 000	65
Triazamat	0112143-82-5	3 460 000	7,9
Triazoxid	0072459-58-6	3 270 000	7,4
Tribenuron	0106040-48-6	3 140 000	7,1
Tribenuron-methyl	0101200-48-0	4 550 000	10
Tribufos	0000078-48-8	44 000 000	100
Trichlorfon	0000052-68-6	8 390 000	19

Name	**CAS No**	**Eco-factor 2021 (UBP/kg)**	**Characterisation factor kg glyphosate-eq./kg**
Triclopyr	0055335-06-3	297 000	0,68
Tridemorph	0081412-43-3	661 000	1,5
Trifloxystrobin	0141517-21-7	1 040 000	2,4
Triflumizole	0068694-11-1	1 430 000	3,3
Trifluralin	0001582-09-8	18 500 000	42
Triflusulfuron-methyl	0126535-15-7	2 580 000	5,9
Trinexapac-ethyl	0095266-40-3	35 900	0,082
Triticonazole	–	870 000	2
Tritosulfuron	–	2 580 000	5,9
Valifenalate	–	6 190	0,014
Vamidothion	0002275-23-2	716 000	1,6
Vinclozolin	0050471-44-8	3 860 000	8,8
Mineral oil (petroleum)	–	4 910	0,011
Wintergreen oil	–	4 910	0,011
Wool wax (from sheeps' wool)	–	4 910	0,011
zeta-Cypermethrin	0052315-07-8	9 190 000	21
Zineb	0012122-67-7	232 000	0,53
Zinc phosphide	–	302 000	0,69
Ziram	0000137-30-4	1 430 000	3,3
Zoxamide	0156052-68-5	625 000	1,4
1,1,2,2-tetrachloroethane	79-34-5	0.06	3 300

A6 Eco-factors for land use

The values for country-specific PDFs (potentially disappeared fractions) for the characterisation were taken from Chaudhary and Brooks (Chaudhary & Brooks 2018), and the eco-factors were derived from these. The characterisation factors are based on 'settlement area' in Switzerland as the reference land use (with a PDF of 1.87E-15).

The extent of the differentiation in intensity is not the same as the existing elementary flows and CORINE+ categories. The existing elementary flows and CORINE+ categories were assigned to the following categories provided by Chaudhary and Brooks, with the associated eco-factors.

Tab. 129: Potential species loss, characterisation factors and eco-factors for land use in Switzerland

Land use	PDF	Charact. factor (m^2a SA-eq./m^2a)	Eco-factor 2021 (UBP/m^2a)	Eco-factor 2013 (UBP/m^2a)
Land use categories according to Chaudhary and Brooks				
Managed forests, intense use	1,61E-15	0,86	540	120
Managed forests, light use	0,00E+00	0	0	30
Managed forests, minimal use	0,00E+00	0	0	0
Plantation, minimal use	1,83E-15	0,98	610	120
Plantation, light use	1,89E-15	1,01	630	120
Plantation, intense use	1,96E-15	1,05	660	120
Pasture, minimal use	1,26E-15	0,68	420	80
Pasture, light use	1,43E-15	0,76	480	80
Pasture, intense use	1,58E-15	0,84	530	230
Cropland, minimal use	1,30E-15	0,70	440	100
Cropland, light use	1,51E-15	0,81	510	290
Cropland, intense use	1,55E-15	0,83	520	420
Urban, minimal use	1,12E-15	0,60	370	0
Urban, light use	1,67E-15	0,90	560	180
Urban, intense use	1,87E-15	1,00	630	300

Tab. 130: Potential species loss, characterisation factors and eco-factors for land use in Switzerland

CORINE+	Land use	PDF		Charact, factor (m^{2}a SA-eq,/m^{2}a)	Eco-factor 2021 (UBP/m^{2}a)	Eco-factor 2013 (UBP/m^{2}a)
Settlement areas						
111	Urban fabric, continuous, >80% sealed	1.87E-15	a)	1	**630**	300
112	Urban fabric, discontinuous, <80% sealed	1.67E-15	b)	0,90	**560**	180
113	Urban fallow		c)		**370**	0
114	Rural settlement	1.67E-15	b)	0,90	**560**	180
121	Industrial or commercial units	1.87E-15	a)	1	**630**	300
121a	Industrial area, continuous, >80% sealed	1.87E-15	a)	1	**630**	300
121b	Industrial area, discontinuous, <80% sealed	1.67E-15	b)	0,90	**560**	180
122	Road and rail networks and associated land	1.87E-15	a)	1	**630**	300
122a	Road networks	1.87E-15	a)	1	**630**	300
122b	Road embankments and associated land (min. 100m width)	1.67E-15	b)	0,90	**560**	180
122c	Rail networks	1.87E-15	a)	1	**630**	300
122d	Rail embankments and associated land (min. 100m width)	1.67E-15	b)	0,90	**560**	180
122e	Rail fallow	1.12E-15	c)	0,60	**370**	30
124	Airports	1.87E-15	a)	1	**630**	180
125	Industrial fallow	1.12E-15	c)	0,60	**370**	0
131	Mineral extraction site	1.87E-15	a)	1	**630**	300
132	Dump site	1.87E-15	a)	1	**630**	300
133	Construction site	1.87E-15	a)	1	**630**	300
134	Mining fallow	1.12E-15	c)	0,60	**370**	0
14	Artificial, non-agricultural areas with vegetation	1.12E-15	c)	0,60	**370**	180
141	Green urban areas	1.12E-15	c)	0,60	**370**	180
142	Sport and leisure facilities	1.12E-15	c)	0,60	**370**	180
Agricultural areas						
21	Arable land	1.55E-15	a)	0,83	**520**	420
211	Arable land, non-irrigated	1.55E-15	a)	0,83	**520**	420
211a	Arable land, non-irrigated, conventional	1.55E-15	a)	0,83	**520**	420
211b	Arable land, non-irrigated, IP	1.55E-15	a)	0,83	**520**	420
211c	Arable land, non-irrigated, organic	1.51E-15	b)	0,81	**510**	150
211d	Arable land, non-irrigated, fibre/energy crops	1.55E-15	a)	0,83	**520**	420
211e	Arable land, non-irrigated, fallow	1.30E-15	c)	0,7	**440**	150
211f	Arable land, non-irrigated, artificial meadow	1.55E-15	a)	0,83	**520**	290
22	Permanent crops	1.51E-15	b)	0,81	**510**	290
221	Permanent crops, vineyard	1.51E-15	b)	0,81	**510**	290
221a	Permanent crops, vineyard, intensive	1.55E-15	a)	0,83	**520**	290
221b	Permanent crops, vineyard, non-intensive	1.30E-15	c)	0,7	**440**	100
222	Permanent crops, fruit trees and berry plantations	1.51E-15	b)	0,81	**510**	290

SA: Settlement area
a) Allocation of management intensity ‘intense use’, categories in Tab. 126
b) Allocation of management intensity ‘light use’, categories in Tab. 126
c) Allocation of management intensity ‘minimal use’, categories in Tab. 126

CORINE+	Land use	PDF		Charact, factor (m²a SA-eq,/m²a)	Eco-factor 2021 (UBP/m²a)	Eco-factor 2013 (UBP/m²a)
222a	Permanent crops, orchards, conventional	1.51E-15	b)	0,81	**510**	290
222b	Permanent crops, orchards, organic	1.30E-15	c)	0,7	**440**	100
231	Pastures and meadows	1.43E-15	b)	0,76	**480**	230
231a	Pastures and meadows, intensive	1.58E-15	a)	0,84	**530**	230
231b	Pastures and meadows, less intensive	1.26E-15	c)	0,68	**420**	81
231c	Pastures and meadows, organic	1.26E-15	c)	0,68	**420**	81
243a	Heterogeneous agricultural lands	1.30E-15	c)	0,7	**440**	270
245	Agricultural fallow with hedgerows	1.30E-15	c)	0,7	**440**	81
244	Agroforestry lands	1.30E-15	c)	0,7	**440**	140
Forests and shrub						
311	Forest, broad-leafed	0	b)	0	**0**	30
311a	Forest, broad-leafed, plantations	1.83E-15	c)	0,98	**610**	120
311b	Forest, broad-leafed, semi-natural	0	c)	0	**0**	0
312	Forest, coniferous	0	b)	0	**0**	30
312a	Forest, coniferous, plantations	1.83E-15	c)	0,98	**610**	120
312b	Forest, coniferous, semi-natural	0	c)	0	**0**	0
313	Forest, mixed	0	b)	0	**0**	30
313a	Forest, mixed broad-leafed/coniferous	0	b)	0	**0**	30
313b	Forest, mixed coniferous/broad-leafed	0	b)	0	**0**	30
313c	Forest, mixed, plantations	1.83E-15	c)	0,98	**610**	120
314	Forest, forest edge	0	c)	0	**0**	0
321	Shrub and/or herbaceous vegetation, grassland, semi-natural	0	c)	0	**0**	0
322	Shrub and/or herbaceous vegetation, moors and heathland	0	c)	0	**0**	0
323	Shrub and/or herbaceous vegetation, sclerophyllous vegetation	0	c)	0	**0**	0
324	Shrub and/or herbaceous vegetation, transitional woodland/shrub	0	c)	0	**0**	0
325	Shrub and/or herbaceous vegetation, hedgerows	0	c)	0	**0**	0
Other uses						
–	Unknown use	1,67 E–15	b)	0,90	**560**	110

SA: Settlement area

a) Allocation of management intensity ‘intense use’, categories in Tab. 126

b) Allocation of management intensity ‘light use’, categories in Tab. 126

c) Allocation of management intensity ‘minimal use’, categories in Tab. 126

The country-specific PDF and UBP data used for the eco-factors are available to download as an Excel list. The following list shows a selection of countries for comparison purposes.

Compared with Switzerland, the values are higher for ecoregions with a higher number of species and vulnerability or, conversely, lower for regions with a lower number of species and vulnerability.

Tab. 131: 2021 eco-factors for land use in selected countries

Land use Eco-factor 2021 (UBP/m²a)	Sweden	France	Switzerland	Brazil	India
Land use categories according to Chaudhary and Brooks					
Managed forests, intense use	100	370	540	1 870	1 970
Managed forests, light use	0	0	0	1 780	1 890
Managed forests, minimal use	0	0	0	210	20
Plantation, minimal use	100	440	610	1 960	2 170
Plantation, light use	100	450	630	2 000	2 240
Plantation, intense use	100	480	660	2 060	2 330
Pasture, minimal use	90	340	420	1 990	1 990
Pasture, light use	90	380	480	2 030	2 100
Pasture, intense use	90	410	530	2 060	2 190
Cropland, minimal use	70	330	440	1 990	1 690
Cropland, light use	80	380	510	2 040	1 910
Cropland, intense use	80	390	520	2 040	1 940
Urban, minimal use	90	250	370	1 880	1 650
Urban, light use	100	410	560	2 040	2 140
Urban, intense use	100	460	630	2 090	2 310

A7 Eco-factors for primary mineral resources (minerals and metals)

In the current version of the eco-factors, resource extraction is assessed, rather than dissipative use. In case studies where the use of primary mineral resources is important, it should be ensured that only dissipative use (see Section 13.4.7) is assessed.

Tab. 132: Characterisation factors and eco-factors for dissipative use of primary mineral resources (minerals and metals), with characterisation based on ultimate reserves (amount present in the earth's crust)

	Characterisation (kg Sb-eq./kg)	Eco-factor 2021 (UBP/kg)
Aluminium, 24% in bauxite, 11% in crude ore, in ground	0,000000025	0,0038
Antimony, in ground	1,0	150 000
Barite, 15% in crude ore, in ground	0,0000085	1,3
Borax, in ground	0,00028	42
Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	3,6	540 000
Cerium, 24% in bastnasite, 2.4% in crude ore, in ground	0,000020	2,9
Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	0,00079	120
Cinnabar, in ground	2,3	350 000
Cobalt, in ground	0,00025	37
Colemanite, in ground	0,00026	39
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	0,021	3 200
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	0,021	3 200
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	0,021	3 200
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	0,021	3 200
Europium, 0.06% in bastnasite, 0.006% in crude ore, in ground	0,00029	43
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	0,000013	1,9
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	0,000013	1,9
Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground	0,000064	9,5
Gallium, 0.014% in bauxite, in ground	0,00000042	0,063
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	1 370	200 000 000
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	1 370	200 000 000
Gold, Au 1.4E-4%, in ore, in ground	1 370	200 000 000
Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	1 370	200 000 000
Gold, Au 4.3E-4%, in ore, in ground	1 370	200 000 000
Gold, Au 4.9E-5%, in ore, in ground	1 370	200 000 000
Gold, Au 6.7E-4%, in ore, in ground	1 370	200 000 000
Gold, Au 7.1E-4%, in ore, in ground	1 370	200 000 000
Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 1.4E-2%, in ore, in ground	1 370	200 000 000
Hafnium, in ground	0,0000039	0,58
Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	0,11	16 000
Iron, 46% in ore, 25% in crude ore, in ground	0,00000069	0,10
Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground	0,000026	3,8

	Characterisation (kg Sb-eq./kg)	Eco-factor 2021 (UBP/kg)
Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	0,019	2 800
Lithium, 0.15% in brine, in ground	0,000026	3,8
Magnesite, 60% in crude ore, in ground	0,00000018	0,026
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	0,000025	3,7
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	0,17	26 000
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	0,17	26 000
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	0,17	26 000
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	0,17	26 000
Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	0,17	26 000
Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground	0,000022	3,2
Nickel, 1.13% in sulfides, Ni 0.76% and Cu 0.76% in crude ore, in ground	0,00082	120
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	0,00082	120
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	966	140 000 000
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	966	140 000 000
Phosphorus, 18% in apatite, 12% in crude ore, in ground	0,000071	11
Phosphorus, 18% in apatite, 4% in crude ore, in ground	0,000071	11
Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground	0,000097	14
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	971	140 000 000
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	971	140 000 000
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	0,0028	420
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	0,0028	420
Rhenium, in crude ore, in ground	1 050	160 000 000
Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground	0,000077	11
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	8,64	1 300 000
Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	8,64	1 300 000
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	8,64	1 300 000
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	8,64	1 300 000
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	8,64	1 300 000
Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	8,64	1 300 000
Sulphur, in ground	0,00016	23
Stibnite, in ground	0,057	8 400
Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground	0,0013	190
Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	170	25 000 000
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	0,082	12 000
TiO_2, 54% in ilmenite, 2.6% in crude ore, in ground	0,00000038	0,056
TiO_2, 95% in rutile, 0.40% in crude ore, in ground	0,00000038	0,056
Ulexite, in ground	0,00027	39
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	0,0028	410
Zirconium, 50% in zircon, 0.39% in crude ore, in ground	0,000026	3,9

A8 Country-specific eco-factors for freshwater consumption

The country-specific eco-factors listed in the following tables are only to be used for specific or sufficiently detailed life cycle inventories. The characterisation factor from AWARE is given for agricultural, non-agricultural use and 'unknown'. The factor is an average for the country and can normally be used. The eco-factor is obtained by multiplying the characterisation factor by the uncharacterised eco-factor of 23 UBP/m^3.

Tab. 133: Eco-factors for freshwater consumption

	CF AWARE			Eco–factor 2021 (UBP/m^3)			Eco-factor 2013 (UBP/m^3)
Country	Agricultural	Non–agricultural	Unknown	Agricultural	Non–agricultural	Unknown	
Afghanistan	58,639	31,636	57,935	1 300	730	1 300	1 200
Albania	36,575	9,070	34,163	840	210	790	19
Algeria	66,209	37,030	64,172	1 500	850	1 500	2 700
American Samoa	0,000	4,418	4,418	–	100	100	–
Andorra	64,952	13,272	56,331	1 500	310	1 300	–
Angola	4,579	9,912	5,789	110	230	130	0,18
Anguilla	0,000	22,372	22,372	–	510	510	–
Antigua and Barbuda	10,348	4,883	5,760	240	110	130	–
Argentina	37,597	4,193	30,141	860	96	690	15
Armenia	87,549	43,724	85,753	2 000	1 000	2 000	1 300
Aruba	0,000	0,000	0,000	–	–	–	–
Australia	72,790	25,406	71,081	1 700	580	1 600	20
Austria	1,279	1,143	1,246	29	26	29	21
Azerbaijan	86,823	44,410	84,629	2 000	1 000	1 900	1 200
Bahrain	8,163	9,040	8,727	190	210	200	91 000
Bangladesh	3,010	2,343	2,986	69	54	69	8,2
Barbados	17,511	7,600	9,707	400	170	220	5 500
Belarus	3,761	2,989	3,364	86	69	77	54
Belgium	2,208	1,204	1,374	51	28	32	1 100
Belize	1,258	1,048	1,088	29	24	25	0,63
Benin	5,495	7,200	6,324	130	170	150	0,23
Bhutan	1,064	0,765	1,021	24	18	23	0,18
Bolivia	3,466	1,685	2,891	80	39	66	0,1
Bosnia and Herzegovina	1,336	1,016	1,175	31	23	27	0,78
Botswana	13,036	33,044	21,713	300	760	500	2,4
Brazil	2,653	1,899	2,275	61	44	52	0,48
British Virgin Islands	23,411	13,241	14,619	540	300	340	–
Brunei	0,205	0,179	0,183	5	4	4	–
Bulgaria	27,992	9,469	26,695	640	220	610	790
Burkina Faso	16,842	19,564	18,201	390	450	420	59

		CF AWARE			Eco–factor 2021 (UBP/m^3)		Eco-factor 2013 (UBP/m^3)
Country	**Agricultural**	**Non–agricultural**	**Unknown**	**Agricultural**	**Non–agricultural**	**Unknown**	
Burundi	10,682	65,193	29,112	250	1 500	670	5
Cambodia	9,434	3,347	8,565	220	77	200	0,2
Cameroon	11,147	3,956	7,140	260	91	160	0,11
Canada	8,377	2,686	6,578	190	62	150	2,4
Cape Verde	26,095	8,333	24,813	600	190	570	51
Central African Republic	14,748	9,698	8,881	340	220	200	–
Chad	12,317	35,812	21,603	280	820	500	0,7
Chile	83,202	35,142	81,380	1 900	810	1 900	1,4
China	45,847	27,081	42,471	1 100	620	980	360
Colombia	2,247	0,780	1,421	52	18	33	0,34
Comoros	5,432	9,801	9,679	120	230	220	0,66
Congo	0,715	0,563	0,569	16	13	13	0,000029
Congo, Democratic Republic of the	1,874	9,382	7,709	43	220	180	–
Costa Rica	2,054	0,652	1,083	47	15	2	5,4
Ivory Coast	6,371	5,866	6,018	150	130	140	2,9
Croatia	1,917	1,354	1,586	44	31	36	0,34
Cuba	3,857	2,991	3,657	89	69	4	380
Cyprus	76,643	48,664	75,680	1 800	1 100	1 700	530
Czech Republic	1,898	1,693	1,827	44	39	42	160
Denmark	2,037	1,989	2,034	47	46	47	120
Djibouti	13,145	34,404	20,925	300	790	480	–
Dominica	12,596	5,818	6,881	290	130	160	–
Dominican Republic	12,068	4,027	10,185	280	93	230	260
East Timor	11,263	3,328	9,604	260	77	220	–
Ecuador	7,988	2,162	6,727	180	50	150	12
Egypt	95,674	98,401	95,965	2 200	2 300	2 200	6 100
El Salvador	1,587	1,710	1,664	36	39	38	28
Equatorial Guinea	0,000	0,289	0,289	–	7	7	0,0043
Eritrea	44,681	36,041	44,065	1 000	830	1 000	82
Estonia	1,328	1,071	1,092	31	25	25	190
Ethiopia	27,397	28,534	28,985	630	660	670	20
Falkland Islands	0,000	5,388	5,388	–	120	120	–
Faroe Islands	0,000	1,439	1,439	–	33	33	–
Fiji	3,007	1,073	2,093	69	25	48	0,078
Finland	1,519	1,732	1,672	35	40	38	2,1
France	9,487	3,051	8,151	220	70	190	210
French Guiana	0,465	0,494	0,477	11	11	11	–
Gabon	0,943	0,411	0,443	22	9	10	–
Georgia	83,104	24,507	75,948	1 900	560	1 700	5,7
Germany	1,778	1,117	1,312	41	26	30	420
Ghana	16,837	16,074	16,438	390	370	380	3,3

		CF AWARE			Eco–factor 2021 (UBP/m^3)		Eco-factor 2013 (UBP/m^3)
Country	**Agricultural**	**Non–agricultural**	**Unknown**	**Agricultural**	**Non–agricultural**	**Unknown**	
Gibraltar	48,066	30,985	46,163	1 100	710	1 100	–
Greece	69,360	28,348	68,036	1 600	650	1 600	160
Greenland	0,000	0,000	0,000	–	–	–	–
Grenada	8,333	13,474	11,822	190	310	270	–
Guadeloupe	9,947	6,951	9,524	230	160	220	–
Guatemala	1,156	1,099	1,117	27	25	26	6,6
Guinea	10,086	20,965	15,387	230	480	350	0,49
Guinea Bissau	2,705	2,647	2,699	62	61	62	0,3
Guyana	0,957	0,455	0,935	22	10	21	0,44
Haiti	6,184	4,467	5,962	140	100	140	70
Honduras	0,918	1,080	0,981	21	25	23	1,5
Hungary	1,288	1,164	1,264	30	27	29	28
Iceland	0,000	1,083	1,083	–	25	2	0,009
India	30,494	21,306	29,836	700	490	690	1 300
Indonesia	23,935	8,926	21,814	550	210	500	30
Iran	66,851	40,144	66,282	1 500	920	1 500	4 400
Iraq	58,975	36,664	58,664	1 400	840	1 300	4 500
Ireland	1,636	0,792	0,797	38	18	18	2,2
Isle of Man	0,000	4,977	4,977	–	110	110	–
Israel	87,031	54,971	84,872	2 000	1 300	2 000	12 000
Italy	46,401	16,678	43,214	1 100	380	990	540
Jamaica	11,658	6,302	8,685	270	140	200	37
Japan	0,597	0,573	0,589	14	13	14	420
Jersey	0,000	13,542	13,542	–	310	310	–
Jordan	79,028	49,902	77,682	1 800	1 100	1 800	3 200
Kazakhstan	52,801	27,580	50,599	1 200	630	1 200	870
Kenya	11,286	28,989	21,268	260	670	490	76
Kuwait	47,083	71,024	58,941	1 100	1 600	1 400	20 000 000
Kyrgyzstan	63,434	55,859	62,959	1 500	1 300	1 400	410
Laos	5,959	3,797	5,752	140	87	130	1,6
Latvia	1,458	1,245	1,258	34	29	29	1,3
Lebanon	86,899	50,712	83,418	2 000	1 200	1 900	700
Lesotho	15,416	25,311	18,609	350	580	430	0,87
Liberia	1,272	0,646	0,681	29	15	16	0,0057
Libya	46,464	27,972	46,116	1 100	640	1 100	500 000
Liechtenstein	0,930	0,714	0,761	21	16	18	–
Lithuania	1,697	1,269	1,313	39	29	30	87
Luxembourg	0,990	0,722	0,774	23	17	18	3,6
Macedonia	53,718	18,203	48,894	1 200	420	1 100	250
Madagascar	7,727	2,308	7,381	180	53	170	18
Malawi	5,225	6,618	5,483	120	150	130	30

	CF AWARE			Eco–factor 2021 (UBP/m^3)			Eco-factor 2013 (UBP/m^3)
Country	**Agricultural**	**Non–agricultural**	**Unknown**	**Agricultural**	**Non–agricultural**	**Unknown**	
Malaysia	0,588	0,517	0,557	14	12	13	5
Mali	16,450	28,002	17,971	380	640	410	41
Malta	68,780	46,190	65,103	1 600	1 100	1 500	11 000
Martinique	17,088	2,540	14,725	390	58	340	–
Mauritania	96,766	52,614	90,440	2 200	1 200	2 100	190
Mauritius	0,777	3,446	3,337	18	79	77	660
Mayotte	0,000	0,000	0,000	–	–	–	–
Mexico	36,291	14,450	33,578	830	330	770	290
Moldova	2,234	2,007	2,176	51	46	50	260
Monaco	5,051	1,727	3,042	120	40	70	–
Mongolia	18,960	30,624	21,854	440	700	500	2,1
Montenegro	1,235	0,848	1,168	28	20	27	–
Montserrat	0,000	10,451	10,451	–	240	240	–
Morocco	88,057	54,031	87,353	2 000	1 200	2 000	1 800
Mozambique	7,076	5,470	6,988	160	130	160	0,11
Myanmar	5,692	1,777	5,464	130	41	130	7,7
Namibia	10,791	34,688	22,043	250	800	510	0,42
Nepal	13,821	17,890	14,185	320	410	330	21
Netherlands	1,589	0,957	1,202	37	22	28	130
New Caledonia	0,000	3,460	3,460	–	80	80	–
New Zealand	8,281	1,689	6,613	190	39	150	2
Nicaragua	1,636	0,875	1,345	38	20	31	0,41
Niger	7,068	18,566	8,662	160	430	200	47
Nigeria	7,998	9,819	8,923	180	230	210	12
North Korea	2,783	2,195	2,716	64	50	62	–
Norway	0,691	0,780	0,757	16	18	17	0,57
Oman	12,298	31,825	14,388	280	730	330	8 500
Panama	0,938	0,634	0,660	22	15	15	0,089
Papua New Guinea	1,043	0,454	0,476	24	10	11	–
Paraguay	1,124	1,587	1,376	26	36	32	0,02
Peru	29,280	13,242	27,787	670	300	640	0,98
Philippines	7,915	2,213	6,982	180	51	160	280
Poland	2,100	1,998	2,016	48	46	46	360
Portugal	52,269	17,082	50,884	1 200	390	1 200	110
Puerto Rico	21,655	2,078	9,385	500	48	220	190
Qatar	43,145	60,071	49,512	990	1 400	1 100	560 000
Raunion	2,324	12,014	7,393	53	280	170	–
Romania	4,193	1,737	3,984	96	40	92	10
Russia	20,769	3,663	12,517	480	84	290	2,1
Rwanda	68,891	75,294	74,859	1 600	1 700	1 700	2,4
Samoa	0,000	0,910	0,910	–	21	21	–

	CF AWARE			Eco–factor 2021 (UBP/m^3)			Eco-factor 2013 (UBP/m^3)
Country	**Agricultural**	**Non–agricultural**	**Unknown**	**Agricultural**	**Non–agricultural**	**Unknown**	
San Marino	17,748	6,090	15,657	410	140	360	–
Sao Tome and Principe	30,116	25,577	30,079	690	590	690	–
Saudi Arabia	18,298	28,365	18,561	420	650	430	930 000
Senegal	80,818	52,791	78,380	1 900	1 200	1 800	31
Serbia	3,597	2,304	3,762	83	53	87	–
Sierra Leone	1,336	0,809	1,133	31	19	26	0,091
Singapore	0,000	0,926	0,926	–	21	21	–
Slovakia	1,288	1,192	1,274	30	27	29	1,8
Slovenia	1,180	1,087	1,174	27	25	27	8,4
Solomon Islands	0,000	0,860	0,860	–	20	20	–
Somalia	70,989	47,006	66,456	1 600	1 100	1 500	480
South Africa	40,760	21,134	38,353	940	490	880	600
South Korea	0,747	1,066	0,894	17	25	21	1 300
Spain	80,760	31,411	79,334	1 900	720	1 800	810
Sri Lanka	23,198	5,036	22,170	530	120	510	580
Saint Kitts and Nevis	6,385	4,319	4,586	150	99	110	–
Saint Lucia	43,426	14,144	41,547	1 000	330	960	–
Saint Pierre and Miquelon	0,000	16,067	16,067	–	370	370	–
Saint Vincent and the Grenadines	0,000	9,233	9,233	–	210	210	–
Sudan	53,293	49,453	52,936	1 200	1 100	1 200	590
Suriname	0,665	0,584	0,655	15	13	15	0,29
Svalbard and Jan Mayen	0,000	45,427	45,427	–	1 000	1 000	–
Swaziland	1,546	2,816	1,825	36	65	42	510
Sweden	2,776	1,694	2,117	64	39	49	2,2
Switzerland	1,320	0,737	0,965	30	17	22	23
Syria	79,169	48,473	78,587	1 800	1 100	1 800	860
Taiwan	2,047	2,614	2,226	47	60	51	–
Tajikistan	72,470	49,130	71,581	1 700	1 100	1 600	140
Tanzania	6,719	29,056	13,706	150	670	320	28
Thailand	7,301	3,946	6,982	170	91	160	160
The Bahamas	0,000	27,356	27,356	–	630	630	–
Gambia	6,452	13,642	10,966	150	310	250	0,76
Togo	9,166	10,944	10,352	210	250	240	1,3
Tonga	0,000	12,675	12,675	–	290	290	–
Trinidad and Tobago	57,217	22,719	25,685	1 300	520	590	35
Tunisia	69,811	40,114	68,911	1 600	920	1 600	3 700
Turkey	58,043	22,241	56,460	1 300	510	1 300	290
Turkmenistan	67,641	44,235	66,817	1 600	1 000	1 500	1 600
Turks and Caicos Islands	0,000	12,662	12,662	–	290	290	–
Uganda	78,969	87,902	86,915	1 800	2 000	2 000	0,24
Ukraine	37,651	6,238	32,486	870	140	750	730
United Arab Emirates	11,548	47,272	15,200	270	1 100	350	6 800 000

		CF AWARE			Eco–factor 2021 (UBP/m^3)		Eco-factor 2013 (UBP/m^3)
Country	**Agricultural**	**Non–agricultural**	**Unknown**	**Agricultural**	**Non–agricultural**	**Unknown**	
United Kingdom	3,341	1,248	1,612	77	29	37	75
United States of America	35,715	9,087	33,127	820	210	760	230
Uruguay	0,582	0,469	0,542	13	11	12	6,6
Uzbekistan	73,093	50,214	72,113	100	1 200	1 700	6 500
Vanuatu	0,000	2,053	2,053	–	47	47	–
Venezuela	6,929	4,585	5,954	160	110	140	0,52
Vietnam	17,750	4,725	12,098	410	110	280	82
British Virgin Islands	23,411	13,241	14,619	540	300	340	–
Western Sahara	0,000	56,095	56,334	–	1 300	1 300	–
Yemen	46,982	48,633	47,017	1 100	1 100	1 100	28 000
Zambia	5,324	6,714	5,625	120	150	130	2,6
Zimbabwe	4,027	10,123	4,684	93	230	110	420
Svalbard and Jan Mayen	0,000	45,427	45,427	–	1 000	1 000	–
Swaziland	1,546	2,816	1,825	36	65	42	510
Global (GLO)	45,737	20,304	42,954	1 100	470	990	320
Regions	0,000	0,000	0,000	–	–	–	–
RER	48,950	5,919	40,964	1 100	140	940	320
Europe–CH	48,962	5,951	41,019	1 100	140	940	320
RAF	73,084	59,282	71,601	1 700	1 400	1 600	17
RAS	44,436	22,846	42,213	1 000	530	970	220
RLA	37,846	6,348	31,090	870	150	720	19 000
RNA	35,503	8,808	32,724	820	200	750	610
RME	60,264	40,971	59,812	1 400	940	1 400	–
ENTSOE	49,974	5,688	42,520	1 100	130	980	–
BRIC	36,904	21,702	34,769	850	500	800	–
BRICS	36,970	21,701	34,828	850	500	800	–
OECD	47,305	8,744	42,832	1 100	200	990	–
OECD+BRIC	40,833	17,456	37,764	940	400	870	–
OECD+BRICS	40,828	17,489	37,765	940	400	870	–
CS	5,343	3,291	5,613	120	76	130	5,9
PS	85,693	54,016	83,750	2 000	1 200	1 900	–
OCEANIA	70,649	19,478	68,296	1 600	450	1 600	20
NORDEL	–	–	–	–	–	35	–

A9 Eco-factors for marine fish resources

Tab. 134: Normalisation flow calculated from the import of fishery products sorted by ISSCAAP group sorted by contribution to the normalisation flow

ISSCAAP group	Product group	Import in tonnes	Product to live weight (-)	CF live weight	Wild capture share	Discard rate	CF discard	Characterisation in 1,000 tonnes PA-eq.	Contribution to normalisation
Total	**Total**	**69701**						**2629**	
Clams, cockles, arkshells	Clams, cockles and ark shells, live, fresh or chilled	257	2,18	46,7	8,3%	13,2%	9,21	2,23	0,1%
Flounders, halibuts, soles	Flat fish, fillets, fresh or chilled	1 049	2,18	65,7	84,7%	9,8%	9,21	129	4,9%
	Flat fish, fillets, frozen	423	2,18	65,7	84,7%	9,8%	9,21	52	2,0%
	Sole (Solea spp,), fresh or chilled	238	2,18	65,7	84,7%	9,8%	9,21	29,3	1,1%
	Turbots (Psetta maxima), fresh or chilled	143	2,18	309	84,7%	9,8%	9,21	81,6	3,1%
Lobsters, spiny-rock lobsters	Lobsters (Homarus spp,), live, fresh or chilled	168	2,63	68,7	99,4%	32,4%	9,21	31,5	1,2%
Miscellaneous coastal fishes	Seabream (Sparidae), fresh or chilled	1 195	1,47	93,2	85,8%	9,8%	9,21	142	5,4%
	Seabass (Dicentrarchus spp,), fresh or chilled	793	1,79	498	10,0%	9,8%	9,21	70,9	2,7%
Miscellaneous marine crustaceans	Other crustaceans, prepared or preserved	82	2,18	23,7	100,0%	32,4%	9,21	4,76	0,2%
	Other crustaceans, whether in shell or not, frozen	64	2,18	23,7	100,0%	32,4%	9,21	3,72	0,1%
	Crustaceans dried, salted or in brine, smoked, for human consumption, nei	32	2,18	23,7	100,0%	32,4%	9,21	1,86	0,1%
	Crustaceans live, fresh or chilled, for human consumption, nei	14	2,18	23,7	100,0%	13,2%	9,21	0,759	0,0%
Miscellaneous pelagic fishes	Other fish, whole or in pieces, prepared or preserved	3 808	2,18	17,8	97,0%	6,2%	9,21	148	5,6%
	Other fish, whole or in pieces, prepared or preserved	3 446	2,18	17,8	97,0%	6,2%	9,21	134	5,1%
	Prepared or preserved fish, excl, whole or in pieces	2 074	2,18	17,8	97,0%	6,2%	9,21	80,6	3,1%
	Other freshwater or saltwater fish, fresh or chilled	1 796	2,18	17,8	97,0%	6,2%	9,21	69,8	2,7%
	Fish fillets, fresh or chilled, nei	1 517	2,18	17,8	97,0%	6,2%	9,21	58,9	2,2%
	Fish oils, other than liver oils	1 413	2,18	17,8	97,0%	6,2%	9,21	54,9	2,1%

ISSCAAP group	Product group	Import in tonnes	Product to live weight (-)	CF live weight	Wild capture share	Discard rate	CF discard	Characterisation in 1,000 tonnes PA-eq.	Contribution to normalisation
	Meals of fish or crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption	1056	2,18	1	97,0%	9,8%	9,21	4,24	0,2%
	Fish fillets, frozen, nei	720	2,18	17,8	97,0%	6,2%	9,21	28	1,1%
	Fish waste	624	2,18	17,8	97,0%	6,2%	9,21	24,2	0,9%
Mussels	Mussels, live, fresh or chilled	1 538	1	195	3,8%	13,2%	9,21	11,5	0,4%
	Mussels, prepared or preserved	257	2,18	195	3,8%	13,2%	9,21	4,2	0,2%
	Mussels, frozen	129	2,18	195	3,8%	13,2%	9,21	2,11	0,1%
	Mussels, dried, salted or in brine; smoked	51	2,18	195	3,8%	13,2%	9,21	0,834	0,0%
Oysters	Oysters, live, fresh, chilled	454	1	84,6	2,4%	13,2%	9,21	0,933	0,0%
Salmons, trouts, smelts	Pacific, Atlantic and Danube salmon, fillets, fresh or chilled	3 895	2,18	28,1	28,9%	9,8%	9,21	71,2	2,7%
	Salmons, including fillets, smoked	3 294	2,18	28,1	28,9%	9,8%	9,21	60,2	2,3%
	Atlantic and Danube salmon, fresh or chilled	3 143	2,18	28,1	28,9%	9,8%	9,21	57,5	2,2%
	Pacific, Atlantic and Danube salmon, fillets, frozen	1 870	2,18	28,1	28,9%	9,8%	9,21	34,2	1,3%
	Salmon, prepared or preserved	688	2,18	28,1	28,9%	9,8%	9,21	12,6	0,5%
	Atlantic and Danube salmon, frozen	302	1,3	28,1	28,9%	9,8%	9,21	3,3	0,1%
Scallops, pectens	Scallops, including queen scallop, frozen	259	2,18	32,2	26,2%	13,2%	9,21	4,93	0,2%
Shrimps, prawns	Other shrimps and prawns, whether in shell or not, frozen	4 626	2,8	19,9	91,2%	32,4%	9,21	271	10,3%
	Other shrimps and prawns, prepared or preserved	1 990	2,8	19,9	91,2%	32,4%	9,21	116	4,4%
	Shrimps and prawns, prepared or preserved, not in airtight containers	1 427	2	19,9	91,2%	32,4%	9,21	59,6	2,3%
Tunas, bonitos, billfishes	Tunas, skipjack and Atlantic bonito, prepared or preserved	9 181	1,44	16,4	99,4%	9,8%	9,21	227	8,6%
Rest		13 938						540	20,5%

Tab. 135: Characterisation factors (CFs) and eco-factors per kg live weight of the most commonly fished species for the different FAO fishing areas; sorted by catch in descending order of quantity; PA: Peruvian anchovy (lead fish resource, 'reference substance')

FAO fishing area (number)	Name	Scientific name	CF fishing area PA-eq, / kg	CF fish type PA-eq, / kg	Eco-factor fishing area UBP / kg	Eco-factor fish type UBP / kg	Fishing volume Tonnes	Stock in tonnes
Northwest Atlantic (21)	Northern prawn	Pandalus borealis	39,4	43,8	39 700	44 200	217 000	613 000
	Atlantic herring	Clupea harengus	14,7	1,73	14 900	1 750	207 000	1 030 000
	American sea scallop	Placopecten magellanicus	17,9	17,9	18 000	18 000	204 000	1 540 000
	Atlantic menhaden	Brevoortia tyrannus	7,02	7,03	7 080	7 100	181 000	1 340 000
	American lobster	Homarus americanus	50,5	50,5	51 000	51 000	153 000	452 000
	Ocean quahog	Arctica islandica	14,4	14,4	14 500	14 500	117 000	767 000
	Atlantic surf clam	Spisula solidissima	10,3	10,3	10 400	10 400	103 000	1 550 000
	Queen crab	Chionoecetes opilio	0,712	2,03	719	2 050	97 600	6 560 000
	Greenland halibut	Reinhardtius hippoglossoides	135	65,9	136 000	66 500	61 900	275 000
	Atlantic cod	Gadus morhua	21,8	1,19	22 000	1 200	53 400	413 000
Northeast Atlantic (27)	Atlantic herring	Clupea harengus	1,27	1,73	1 280	1 750	1 440 000	8 910 000
	Atlantic cod	Gadus morhua	1,05	1,19	1 060	1 200	1 290 000	8 230 000
	Atlantic mackerel	Scomber scombrus	2,6	2,77	2 630	2 800	1 170 000	4 070 000
	Blue whiting(=Poutassou)	Micromesistius poutassou	1,87	1,9	1 880	1 920	1 070 000	4 610 000
	Capelin	Mallotus villosus	4,12	5,22	4 150	5 260	526 000	2 890 000
	European sprat	Sprattus sprattus	4,47	6,9	4 510	6 960	457 000	1 940 000
	Sandeels(=Sandlances) nei	Ammodytes spp	49,3	49,3	49 700	49 700	291 000	772 000
	Saithe(=Pollock)	Pollachius virens	8,07	8,87	8 140	8 950	289 000	1 400 000
	Haddock	Melanogrammus aeglefinus	6,25	7,29	6 300	7 350	283 000	1 720 000
	Atlantic horse mackerel	Trachurus trachurus	41,8	46,6	42 100	47 000	161 000	419 000
Western Central Atlantic (31)	Gulf menhaden	Brevoortia patronus	2,72	2,72	2750	2 750	475 000	2 760 000
	Round sardinella	Sardinella aurita	142	21,3	143 000	21 500	58 900	87 400
	American cupped oyster	Crassostrea virginica	74,8	63,4	75 500	64 000	57 600	249 000
	Northern brown shrimp	Penaeus aztecus	25,5	28	25 700	28 300	54 400	387 000
	Calico scallop	Argopecten gibbus	1000	1000	1 010 000	1 010 000	47 600	39 600
	Blue crab	Callinectes sapidus	128	68,7	129 000	69 300	45 100	154 000
	Northern white shrimp	Penaeus setiferus	74,8	74,8	75 400	75 400	41 900	198 000
	Stromboid conchs nei	Strombus spp	173	176	174 000	177 000	34 500	984 000
	Caribbean spiny lobster	Panulirus argus	55,7	89,3	56 200	90 100	29 000	191 000
	Atlantic seabob	Xiphopenaeus kroyeri	1,9	8,32	1 920	8 400	28 200	2 200 000

FAO fishing area (number)	Name	Scientific name	CF fishing area PA-eq, / kg	CF fish type PA-eq, / kg	Eco-factor fishing area UBP / kg	Eco-factor fish type UBP / kg	Fishing volume Tonnes	Stock in tonnes
Eastern Central Atlantic (34)	European pilchard(=Sardine)	Sardina pilchardus	7,13	8,67	7 190	8 750	861 000	2 040 000
	Sardinellas nei	Sardinella spp	15,6	21,4	15 800	21 600	379 000	646 000
	Bonga shad	Ethmalosa fimbriata	49,9	49,9	50 400	50 400	363 000	357 000
	Atlantic chub mackerel	Scomber colias	45	80,8	45 400	81 600	296 000	339 000
	Jack and horse mackerels nei	Trachurus spp	34,1	51	34 400	51 500	266 000	998 000
	Round sardinella	Sardinella aurita	11,6	21,3	11 700	21 500	222 000	578 000
	Skipjack tuna	Katsuwonus pelamis	40,5	6,43	40 800	6 480	213 000	467 000
	Madeiran sardinella	Sardinella maderensis	33,2	33,2	33 500	33 500	189 000	482 000
	Yellowfin tuna	Thunnus albacares	18	9,65	18 100	9 740	82 700	452 000
	Bigeye tuna	Thunnus obesus	36,5	35,2	36 900	35 500	50 500	284 000
Mediterranean and Black Sea (37)	European anchovy	Engraulis encrasicolus	3,72	5,38	3 750	5 430	292 000	1 830 000
	European pilchard(=Sardine)	Sardina pilchardus	11,2	8,67	11 300	8 750	191 000	811 000
	European sprat	Sprattus sprattus	143	6,9	144 000	6 960	65 300	130 000
	Striped venus	Chamelea gallina	85,1	110	85 900	111 000	43 700	186 000
	Sardinellas nei	Sardinella spp	67,1	21,4	67 700	21 600	42 500	150 000
	Jack and horse mackerels nei	Trachurus spp	1000	51	1 010 000	51 500	25 600	23 900
	Bogue	Boops boops	96,6	271	97 400	273 000	21 600	90 400
	Mediterranean horse mackerel	Trachurus mediterraneus	157	167	158 000	169 000	21 300	88 800
	European hake	Merluccius merluccius	118	26,3	119 000	26 500	21 000	88 800
	Atlantic bonito	Sarda sarda	246	300	248 000	303 000	17 100	68 500
Southwest Atlantic (41)	Argentine shortfin squid	Illex argentinus	2,99	2,99	3 020	3 020	800 000	3 820 000
	Argentine hake	Merluccius hubbsi	3,99	3,99	4 030	4 030	340 000	2 530 000
	Argentine red shrimp	Pleoticus muelleri	223	223	225000	225 000	125 000	427 000
	Whitemouth croaker	Micropogonias furnieri	62,3	64,6	62 800	65 200	97 300	238 000
	Patagonian grenadier	Macruronus magellanicus	37,1	59,3	37 400	59 800	66 200	366 000
	Patagonian squid	Loligo gahi	220	168	222 000	169 000	46 900	141 000
	Patagonian scallop	Zygochlamys patagonica	373	373	376 000	376 000	35 800	82 000
	Skipjack tuna	Katsuwonus pelamis	137	6,43	138 000	6 480	25 000	76 200
	Longtail Southern cod	Patagonotothen ramsayi	530	530	534 000	534 000	23 800	40 700
	Acoupa weakfish	Cynoscion acoupa	93,2	93,2	94 100	94 100	20 000	88 900

FAO fishing area (number)	Name	Scientific name	CF fishing area PA-eq, / kg	CF fish type PA-eq, / kg	Eco-factor fishing area UBP / kg	Eco-factor fish type UBP / kg	Fishing volume Tonnes	Stock in tonnes
Southeast Atlantic (47)	Cape horse mackerel	Trachurus capensis	3,35	3,35	3 380	3 380	360 000	2 210 000
	Sardinellas nei	Sardinella spp	34,9	21,4	35 200	21 600	145 000	745 000
	Southern African pilchard	Sardinops ocellatus	18	18	18 100	18 100	120 000	696 000
	Cunene horse mackerel	Trachurus trecae	120	209	121 000	210 000	85 300	219 000
	Whitehead's round herring	Etrumeus whiteheadi	267	267	269 000	26 900	26 500	41 600
	Dentex nei	Dentex spp	604	661	610 000	667 000	18 400	72 300
	Bigeye tuna	Thunnus obesus	36,5	35,2	36 900	35 500	13 300	284 000
	Blue shark	Prionace glauca	2,75	13,3	2 770	13 400	12 600	1 240 000
	Snoek	Thyrsites atun	327	181	330 000	183 000	12 500	40 400
	Southern meagre(=Mulloway)	Argyrosomus hololepidotus	1 000	1 000	1 010 000	1 010 000	11 100	11 600
Western Indian Ocean (51)	Indian oil sardine	Sardinella longiceps	23	29,1	23 200	29 400	507 000	620 000
	Yellowfin tuna	Thunnus albacares	11,7	9,65	11 800	9 740	314 000	1 120 000
	Skipjack tuna	Katsuwonus pelamis	11,1	6,43	11 200	6 480	269 000	1 180 000
	Indian mackerel	Rastrelliger kanagurta	38,2	90,4	38 500	91 200	164 000	274 000
	Bombay-duck	Harpadon nehereus	48,4	66,4	48 800	67 000	130 000	217 000
	Giant tiger prawn	Penaeus monodon	18	44,2	18 100	44 600	110 000	643 000
	Longtail tuna	Thunnus tonggol	86,6	108	87 400	109 000	104 000	219 000
	Narrow-barred Spanish mackerel	Scomberomorus commerson	82,6	65,6	83 300	66 100	88 900	200 000
	Kawakawa	Euthynnus affinis	113	39,3	114 000	39 700	77 100	159 000
	Jacks, crevalles nei	Caranx spp	460	530	464 000	534 000	72 300	147 000
Eastern Indian Ocean (57)	Hilsa shad	Tenualosa ilisha	32	32	32 300	32 300	265 000	380 000
	Indian mackerels nei	Rastrelliger spp	44,2	39,3	44 600	39 700	176 000	264 000
	Skipjack tuna	Katsuwonus pelamis	11,1	6,43	11 200	6 480	148 000	1 180 000
	Indian mackerel	Rastrelliger kanagurta	293	90,4	295 000	91 200	113 000	82 300
	Short mackerel	Rastrelliger brachysoma	118	37,4	119 000	37 700	98 100	121 000
	Giant tiger prawn	Penaeus monodon	62,7	44,2	63 200	44 600	94 800	309 000
	Blood cockle	Anadara granosa	48,5	84,6	48 900	85 300	90 600	585 000
	Yellowfin tuna	Thunnus albacares	11,7	9,65	11 800	9 740	88 100	1 120 000
	Indian oil sardine	Sardinella longiceps	130	29,1	131 000	29 400	80 500	104 000
	Kawakawa	Euthynnus affinis	77,6	39,3	78 300	39 700	72 300	185 000

FAO fishing area (number)	Name	Scientific name	CF fishing area PA-eq, / kg	CF fish type PA-eq, / kg	Eco-factor fishing area UBP / kg	Eco-factor fish type UBP / kg	Fishing volume Tonnes	Stock in tonnes
Northwest Pacific (61)	Alaska pollock(=Walleye poll,)	Theragra chalcogramma	0,849	1,1	856	1 110	1 860 000	13 800 000
	Japanese anchovy	Engraulis japonicus	3,26	3,26	3 290	3 290	1 350 000	2 680 000
	Largehead hairtail	Trichiurus lepturus	2,4	3,55	2 420	3 580	1 150 000	4 220 000
	Pacific chub mackerel	Scomber japonicus	1,39	2,53	1 400	2 550	1 150 000	6 230 000
	Akiami paste shrimp	Acetes japonicus	5,47	5,56	5 520	5 610	562 000	2 630 000
	Gazami crab	Portunus trituberculatus	14,4	14,4	14 500	14 500	557 000	1 630 000
	Pacific saury	Cololabis saira	14,6	17,2	14 800	17 300	461 000	741 000
	Seerfishes nei	Scomberomorus spp	14,9	19	15 100	19 100	447 000	2 360 000
	Pacific herring	Clupea pallasii	5,25	6,97	5 300	7 040	432 000	1 740 000
	Japanese pilchard	Sardinops melanostictus	5,3	5,3	5 350	5 350	400 000	1 780 000
Northeast Pacific (67)	Alaska pollock(=Walleye poll,)	Theragra chalcogramma	1,54	1,1	1 550	1 110	1 430 000	6 970 000
	Pacific cod	Gadus macrocephalus	10,3	14,3	10 300	14 400	323 000	1 520 000
	North Pacific hake	Merluccius productus	14,5	16,5	14 600	16 700	258 000	810 000
	Pink(=Humpback) salmon	Oncorhynchus gorbuscha	8	21,7	8 070	21 800	248 000	1 070 000
	Yellowfin sole	Limanda aspera	14,7	14,8	14 800	14 900	145 000	852 000
	Sockeye(=Red) salmon	Oncorhynchus nerka	19,3	32,7	19 400	33 000	118 000	490 000
	Chum(=Keta=Dog) salmon	Oncorhynchus keta	104	22,6	105 000	22 800	61 400	156 000
	Pacific herring	Clupea pallasii	49,2	6,97	49 600	7 040	57 200	317 000
	Rock sole	Lepidopsetta bilineata	101	102	102 000	103 000	53 600	204 000
	Pacific ocean perch	Sebastes alutus	177	184	178 000	185 000	50 000	313 000
Western Central Pacific (71)	Skipjack tuna	Katsuwonus pelamis	3,37	6,43	3 400	6 480	1 710 000	4 420 000
	Yellowfin tuna	Thunnus albacares	7,2	9,65	7 270	9 740	509 000	1 650 000
	Kawakawa	Euthynnus affinis	21,2	39,3	21 300	39 700	214 000	560 000
	Short mackerel	Rastrelliger brachysoma	21,5	37,4	21 700	37 700	203 000	406 000
	Indian mackerel	Rastrelliger kanagurta	94,2	90,4	95 100	91 200	200 000	193 000
	Bigeye scad	Selar crumenophthalmus	51,4	55,1	51 800	55 600	184 000	250 000
	Indian mackerels nei	Rastrelliger spp	34,4	39,3	34 700	39 700	154 000	279 000
	Narrow-barred Spanish mackerel	Scomberomorus commerson	45,4	65,6	45 800	66 100	147 000	345 000
	Frigate tuna	Auxis thazard	35	37,7	35 300	38 000	146 000	421 000
	Goldstripe sardinella	Sardinella gibbosa	40,8	57,9	41 100	58 400	143 000	248 000

FAO fishing area (number)	Name	Scientific name	CF fishing area PA-eq, / kg	CF fish type PA-eq, / kg	Eco-factor fishing area UBP / kg	Eco-factor fish type UBP / kg	Fishing volume Tonnes	Stock in tonnes
Eastern Central Pacific (77)	Pacific thread herring	Opisthonema libertate	22,7	24,4	22 900	24 600	299 000	480 000
	Skipjack tuna	Katsuwonus pelamis	18,5	6,43	18 600	6 480	213 000	930 000
	Yellowfin tuna	Thunnus albacares	10,1	9,65	10 200	9 740	198 000	1 020 000
	Pacific anchoveta	Cetengraulis mysticetus	1 000	916	1 010 000	925 000	164 000	21 000
	California pilchard	Sardinops caeruleus	46,4	72	46 800	72 600	146 000	343 000
	Opalescent inshore squid	Loligo opalescens	1,18	1,18	1 190	1 190	98 900	2 370 000
	Californian anchovy	Engraulis mordax	195	195	197 000	197 000	83 200	151 000
	Bigeye tuna	Thunnus obesus	30,3	35,2	30 500	35 500	70 400	375 000
	Pacific chub mackerel	Scomber japonicus	81	2,53	81 700	2 550	48 400	161 000
	Red-eye round herring	Etrumeus teres	842	56,9	850 000	57 400	32 100	37 600
Southwest Pacific (81)	Blue grenadier	Macruronus novaezelandiae	8,73	9,51	8 800	9 590	164 000	1 220 000
	Jack and horse mackerels nei	Trachurus spp	55,8	51	56 300	51 500	46 700	484 000
	Southern blue whiting	Micromesistius australis	64,4	108	65 000	109 000	37 100	145 000
	Snoek	Thyrsites atun	123	181	124 000	183 000	30 000	94 700
	Wellington flying squid	Nototodarus sloanii	119	119	120 000	120 000	21 200	114 000
	Pink cusk-eel	Genypterus blacodes	196	203	198 000	205 000	15 700	65 800
	Albacore	Thunnus alalunga	77,5	38,1	78 100	38 500	12 400	174 000
	Greenback horse mackerel	Trachurus declivis	574	585	579 000	590 000	12 200	30 900
	Oreo dories nei	Oreosomatidae	1 000	1 000	1 010 000	1 010 000	10 900	46 300
	Skipjack tuna	Katsuwonus pelamis	3,37	6,43	3 400	6 480	10 100	4 420 000
Southeast Pacific (87)	Anchoveta(=Peruvian anchovy)	Engraulis ringens	1	1	1 010	1 010	4 370 000	9 320 000
	Jumbo flying squid	Dosidicus gigas	8,76	9,05	8 840	9 130	996 000	2 680 000
	Araucanian herring	Strangomera bentincki	15,4	15,4	15 500	15 500	405 000	678 000
	Chilean jack mackerel	Trachurus murphyi	3,34	3,34	3 370	3 370	389 000	3 110 000
	Skipjack tuna	Katsuwonus pelamis	18,5	6,43	18 600	6 480	221 000	930 000
	Pacific chub mackerel	Scomber japonicus	38,9	2,53	39 200	2 550	187 000	438 000
	South Pacific hake	Merluccius gayi	131	131	132 000	132 000	88 500	164 000
	Yellowfin tuna	Thunnus albacares	10,1	9,65	10 200	9 740	83 500	1 020 000
	Common dolphinfish	Coryphaena hippurus	143	269	144 000	272 000	68 700	91 700
	Eastern Pacific bonito	Sarda chiliensis	27,8	29,6	28 000	29 800	57 500	403 000

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Abbreviations

a
Annum, year

ADP
Abiotic Depletion Potential

AMD
Availability Minus Demand

AOX
Adsorbable organic halogen compounds

AP
Acidification Potential

ATW
Alpha-toxic waste

AUE
Office for Environment and Energy (of the Canton of Basel-Stadt)

AWARE
Available Water Remaining

BAFU / FOEN
Bundesamt für Umwelt / Federal Office for the Environment

BAG / FOPH
Bundesamt für Gesundheit / Federal Office of Public Health

BaP
Benzo(a)pyrene

BAZL / FOCA
Bundesamt für Zivilluftfahrt / Federal Office of Civil Aviation

BCF
Bioconcentration factor

BDP
Biodiversity Damage Potential

BFE / FOE
Bundesamt für Energie / Federal Office of Energy

BFS / FSO
Bundesamt für Statistik / Federal Statistical Office

BRIC
Brazil, Russia, India and China

BRICS
Brazil, Russia, India, China and South Africa

BOD
Biochemical oxygen demand

CAS
Chemical Abstracts Service

CF
Characterisation factor

CFCs
Chlorofluorocarbons

COD
Chemical oxygen demand

CORINE
Coordination of Information on the Environment

CTU
Comparative Toxic Unit. CTUh refers to human toxicity, CTUe to ecotoxicity.

DALY
Disability Adjusted Life Year

DOC
Dissolved organic carbon

DQR
Data quality guidelines

DSF
Depleted Stock Fraction

EDP
Ecosystem Damage Potential

ENSI
Swiss Federal Nuclear Safety Inspectorate

EPD
Environmental Product Declaration

EPA
Environmental Protection Agency (USA)

eq.
Equivalent

FAO
Food and Agriculture Organization of the United Nations

FSC
Forest Stewardship Council

GESAMP
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

GWP100
Global warming potential

HAP
Highly annoyed person (by noise)

HLW
High-level radioactive waste

HFCs
Partially halogenated hydrofluorocarbons

HCFCs
Partially halogenated CFCs

IARC
International Agency for Research on Cancer

IAWR
International Association of Waterworks in the Rhine Basin

ICPR
International Commission for the Protection of the Rhine

IONC
International Ocean Noise Coalition

IPCC
Intergovernmental Panel on Climate Change

ISO
International Organization for Standardization

km
Kilometre

LMLW
Low-level and medium-level radioactive wastes

MAH
Monocyclic aromatic hydrocarbons

MJ
Megajoule (106 joules)

MJe
Megajoule in the form of electrical energy

MJt
Megajoule in the form of thermal energy

MSY
Million species year

NABO
Swiss Soil Monitoring Network

NADUF
National Long-Term Surveillance of Swiss Rivers

Nagra
National Cooperative for the Disposal of Radioactive Waste

NAQUA
National Groundwater Monitoring

NMVOC
Non-methane volatile organic compounds (excl. methane and CFCs), see also VOC

OAPC
Ordinance on Air Pollution Control

OAPEC
Organization of Arab Petroleum Exporting Countries

ODP
Ozone depletion potential

OECD
Organisation for Economic Co-Operation and Development

OSPAR
Oslo and Paris Commission

PA
Peruvian anchovy

PAHs
Polycyclic aromatic hydrocarbons

PCB
Polychlorinated biphenyl

PCDDs
Polychlorinated dibenzo-p-dioxins

PCDFs
Polychlorinated dibenzofurans

PDF
Potentially disappeared fraction (of species)

PFCs
Perfluorocarbons

PFOS
Perfluorooctane sulfonate

PJ
Petajoule (1015 joules)

pkm
Passenger-kilometres

PM10
Particle with a diameter of less than 10 micrometres

PM2.5
Particle with a diameter of less than 2.5 micrometres

POPs
Persistent organic pollutants

PSI
Paul Scherrer Institut

PPP
Plant protection product

ReCiPe
Initial letters of the organisations RIVM Radboud University, CML and PRé (which initially developed the method of the same name)

RTI
Radiotoxicity index

SA
Settlement area

Sb
Antimony

SETAC
Society for Environmental Toxicology and Chemistry (Brussels, Belgium)

SF
Spent fuel elements

TEQ
Toxicity-equivalent

TJ
Terajoule (1012 joules)

tkm
Tonne kilometres

TOC
Total Organic Carbon (carbon bound in organic molecules).

TVA
Technical Ordinance on Waste

UBP
Eco-point (DE: Umweltbelastungspunkt)

UNECE
United Nations Economic Commission for Europe

UNEP
United Nations Environment Programme

UVEK / DETEC
Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation / Federal Department of the Environment, Transport, Energy and Communications

VHH
Volatile halogenated hydrocarbons

vkm
Vehicle kilometres

VOCs
Volatile organic compounds

WHO
World Health Organization

WPO
Waters Protection Ordinance

WULCA
Water use in Life Cycle Assessment

ZZL
Central interim storage facilities

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