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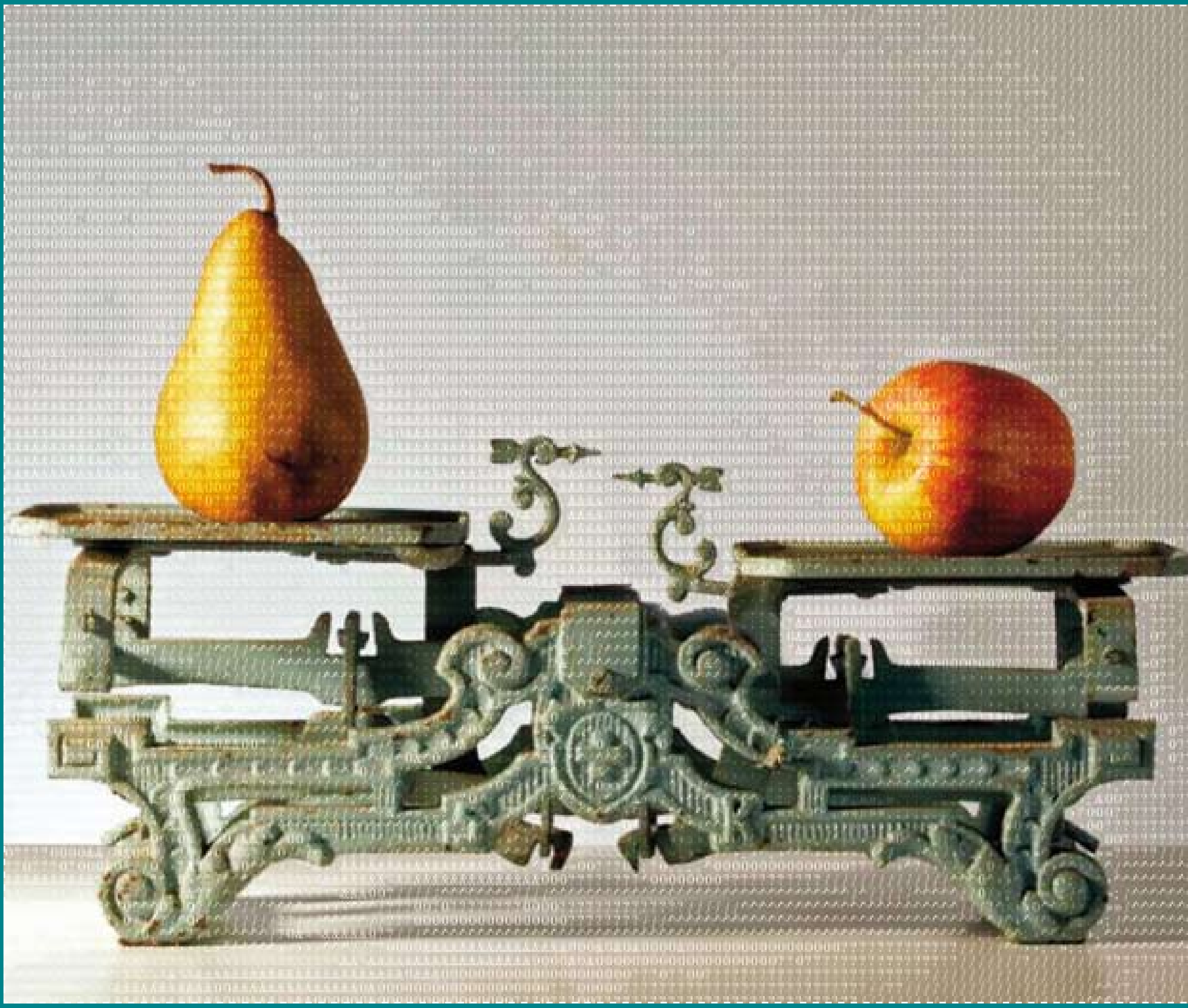
> The Ecological Scarcity Method Eco-Factors 2006

A method for impact assessment in LCA



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The eco-factors were determined on the basis of the latest data available in 2006 on ambient loads and levels in Switzerland, and in accordance with the environmental quality targets and limit values established in Swiss law at that time.

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> Abstracts

Applied within the context of a life cycle assessment (LCA), the ecological scarcity method allows for the assessment of the impacts generated by the releases of pollutants and extraction of resources identified in a life cycle inventory analysis. Eco-factors, expressed as eco-points per unit of pollutant emission or resource extraction, are the key parameter used by the method. The publication sets out how the eco-factors are determined, reflecting, on the one hand, the current emission situation, and, on the other hand, Swiss national policy targets as well as international targets supported by Switzerland. New statutory and political settings, new findings and experience, and the changing emission situation make it essential to adapt the eco-factors regularly. The present edition adjusts the eco-factor formula to the structure of the relevant ISO standard, updates the figures on which existing eco-factors are based, and takes account of new substances and resources.

Keywords:
LCA
eco-factors
assessment of impacts
life cycle inventory
eco-points

Die Methode der ökologischen Knappheit ermöglicht im Rahmen einer Ökobilanzierung die Wirkungsabschätzung von Sachbilanzen. Zentrale Grösse der Methode sind die Ökofaktoren, welche die Umweltbelastung einer Schadstoffemission resp. Ressourcenentnahme in der Einheit Umweltbelastungspunkte pro Mengeneinheit angeben. Die Publikation beschreibt die Herleitung der Ökofaktoren, die einerseits die aktuelle Emissionssituation und anderseits die schweizerischen oder von der Schweiz mitgetragenen internationalen Emissionsziele widerspiegeln. Aufgrund neuer gesetzlicher und politischer Rahmenbedingungen, neuer Erkenntnisse und Praxiserfahrungen sowie der sich ändernden Emissionssituation ist eine regelmässige Anpassung der Ökofaktoren nötig. Mit der vorliegenden Ausgabe wurden die Ökofaktorformel an die Struktur der ISO-Norm angepasst, die Datengrundlagen der bestehenden Ökofaktoren aktualisiert sowie neue Stoffe und Ressourcen berücksichtigt.

Stichwörter:
Ökobilanzierung
Ökofaktoren
Wirkungsabschätzung
Sachbilanzen
Umweltbelastungspunkte

La méthode de la saturation écologique permet d’évaluer l’impact des inventaires de cycle de vie lors d’un écobilan. Les écofacteurs constituent les variables centrales de la méthode: ils représentent la charge environnementale due à l’émission d’un polluant ou à la consommation d’une ressource, exprimée en unités de charge écologique (ou écopoints) par quantité de matière. La présente publication décrit comment les écofacteurs ont été obtenus, reflétant à la fois le niveau des émissions actuelles et les objectifs de la Suisse en la matière, qu’ils soient nationaux ou qu’ils découlent d’accords internationaux auxquels notre pays a adhéré. Les écofacteurs doivent régulièrement être mis à jour, pour tenir compte de la mutation du contexte légal et politique, des nouvelles connaissances et de l’expérience pratique accumulées, ainsi que de l’évolution des émissions elles-mêmes. La réédition actuelle a permis d’adapter la formule de l’écofacteur à la structure de la norme ISO 14040, de mettre à jour la base de données pour les écofacteurs existants et de prendre en compte de nouvelles substances et ressources.

Mots-clés:
écobilan
écofacteurs
impact des inventaires
écopoints

Nel quadro di un ecobilancio, il metodo della saturazione ecologica permette di valutare l'impatto degli inventari del ciclo di vita dei prodotti. Gli ecofattori costituiscono la variabile centrale di tale metodo: indicano l'impatto ambientale dovuto all'emissione di inquinanti o al consumo di risorse, che viene espresso in unità di impatto ambientale (o ecopunti) per quantità di materia. La presente pubblicazione illustra le modalità di calcolo degli ecofattori, le quali rispecchiano contemporaneamente il livello attuale delle emissioni e gli obiettivi della Svizzera in materia, siano essi nazionali o sostenuti dalla Svizzera nell'ambito di convenzioni internazionali. Gli ecofattori devono essere aggiornati periodicamente in seguito ai cambiamenti del contesto legale e politico, alle acquisizioni di nuove conoscenze, all'esperienza pratica accumulata e all'evoluzione delle emissioni. In questa nuova edizione, le formule degli ecofattori sono state adeguate alla struttura prevista dalla norma ISO 14040, i dati di basi degli ecofattori esistenti sono stati attualizzati e, infine, sono state incluse nuove sostanze e risorse.

Parole chiave:
ecobilancio
ecofattori
impatto ambientale
ecopunti

> Foreword

Upon the entry into force on 1 July 2008 of the amended legislation governing mineral oil taxation (comprising the Mineral Oil Tax Act and the Mineral Oil Tax Ordinance), Switzerland became the first country to introduce binding minimum environmental and social standards for the promotion of fuels produced from renewable feedstocks. Promotion takes the form of a reduction in mineral oil tax. Under the new legislation, fuels from renewable feedstocks are only eligible for such tax relief if proof of their positive aggregate environmental impact has been furnished and they were produced under socially acceptable conditions. The Ordinance on Proof of the Positive Aggregate Environmental Impact of Fuels from Renewable Feedstocks (Biofuels Life Cycle Assessment Ordinance, BLCAO) sets out how such proof is to be furnished and assessed. As a part of its assessment process, the Swiss Federal Office for the Environment (FOEN) performs an environmental life cycle assessment (LCA). The LCA is based on the ecological scarcity method, which rates environmental impacts using an “eco-points” (EP) metric. As a result, this LCA method is attracting widespread interest.

The ecological scarcity method was originally developed upon a private initiative in 1990, and has been updated once in the intervening period. FOEN recognizes the method and has been instrumental in its methodological refinement, providing data on the state of the environment and information on the applicable environmental targets enshrined in statute.

In view of the growing relevance of LCA, and especially of the eco-points method, as a decision support tool for policymaking, it is important that this method is not only available to expert circles, but is also made accessible to a wider public. This is why FOEN has supplemented the report on the ecological scarcity method – already published by Öbu, providing updated and partly new ecofactors for the 2006 reference year – with a detailed “synoptic overview”. In order that the method is more readily comprehensible abroad as well, from where such fuels may be imported, this expanded report is now also published in English.

The version last published by FOEN as No. 297 in its “Schriftenreihe Umwelt” publication series under the German title “Bewertung in Ökobilanzen mit der Methode der ökologischen Knappheit, Ökofaktoren 1997” was no longer up to date. In the meantime, the political and statutory setting had changed, as had emissions situations. Measures taken since then have delivered emissions reductions; new environmental targets have been adopted. An overhaul of the method was due.

This latest revision integrates expertise from three realms: policy knowledge about environmental targets and present environmental situations from FOEN, the experience and needs of users of LCA studies from the Öbu network and further companies and, finally, expertise in LCA performance from specialized consultancies. Numerous individuals supported the project team by contributing their knowledge and providing data. Several organizations and firms conducted extensive practical tests, contributed LCA user feedback and provided significant financial support. FOEN extends its warmest thanks to all these partners and to the project team.

Gérard Poffet
Vice Director
Federal Office for the Environment (FOEN)

> Zusammenfassung

Ökobilanzen von Produkten, Prozessen oder Unternehmen bestehen gemäss der Norm ISO 14040 aus den vier Phasen

- Festlegung des Ziels und des Untersuchungsrahmens,
- Sachbilanz (Ökoinventar),
- Wirkungsabschätzung und
- Interpretation (Auswertung).

Bei der Methode der ökologischen Knappheit erfolgt die Wirkungsabschätzung von Sachbilanzen (Life Cycle Inventories) nach dem «Distance-to-target»-Prinzip. Zentrale Grösse der Methode sind die Ökofaktoren, welche die Umweltbelastung einer Schadstoffemission resp. Ressourcenentnahme in der Einheit Umweltbelastungspunkte pro Mengeneinheit angeben. Bei der Bestimmung der Ökofaktoren spielen einerseits die aktuelle Emissionssituation und andererseits die schweizerischen oder die von der Schweiz mitgetragenen internationalen Ziele die wesentliche Rolle. Diese Methode wurde erstmals 1990 publiziert.

Die in der ersten Aktualisierung (Brand et al. 1998) für verschiedene Umwelteinwirkungen vorgeschlagenen Ökofaktoren werden von einem breiten Kreis angewendet. Neue wissenschaftliche Erkenntnisse, neue gesetzliche und politische Grundlagen, neue internationale Abkommen, Entwicklungen im Rahmen der Internationalen Normierung sowie die Erfahrungen aus der Praxis haben die nun vorliegende Überarbeitung nötig gemacht. Im Rahmen dieser Überarbeitung wurde die Ökofaktor-Formel an die Struktur der ISO-Norm angepasst (Elemente Charakterisierung, Normierung, Gewichtung). Die Auswahl der bewerteten Stoffe wurde nochmals erweitert. Die Daten- und Informationsgrundlagen der bestehenden Ökofaktoren wurden überprüft und aktualisiert. Nachfolgend werden die wichtigsten Änderungen zusammengefasst:

- In der **Ökofaktor-Formel** wird durch eine leicht veränderte mathematische Darstellung der Charakterisierungsschritt neu explizit aufgeführt, und für die Normierung werden neu wie heute üblich die aktuellen Emissionen herangezogen. Dadurch wird der Gewichtungsfaktor (Verhältnis von aktuellem Fluss zu kritischem Fluss) quadratisch dargestellt. Im Ergebnis sind die alte und neue Formeldarstellung bei gleicher Datengrundlage identisch.
- Bei **CO_2 und Energie** wird das Fernziel des Bundes (1 Tonne CO_2 beziehungsweise 2000 W pro Kopf) auf einen in der Gesetzgebung üblichen Zeithorizont von 2030 interpoliert.
- Bei den Luftschadstoffen werden zusätzlich Ökofaktoren für **Benzol, Dioxin und Dieselruss** unter Anwendung des im Umweltschutzgesetz verankerten Vorsorgeprinzips bereitgestellt.
- Bei den **Schwermetallemissionen** (sowohl in die Luft als auch in den Boden) wird neu die langfristige Erhaltung der Bodenfruchtbarkeit als Ziel verwendet.

- Die Ökofaktoren können bei Bedarf und Datenverfügbarkeit neu auf der Basis von regionalen Knappheiten ermittelt werden. Dieses Prinzip wird für **Phosphor** in schweizerischen Oberflächengewässern angewendet.
- Aktuelle Forschungsresultate erlauben das Bereitstellen eines Ökofaktors (inkl. Charakterisierung) für **hormonaktive Substanzen** (östrogene Aktivität) in Gewässer. Damit wird erstmals dem zunehmend wichtigen Bereich der Mikroverunreinigungen in Gewässern Rechnung getragen.
- Auf der Basis internationaler Abkommen zum Schutze der Nordsee können neu auch Ökofaktoren für die Einleitung **radioaktiver Isotope in die Meere** bereit gestellt werden (ebenfalls mit Charakterisierung).
- In manchen Gegenden der Welt ist **Süsswasser** eine knappe Ressource. Deshalb werden neu Ökofaktoren eingeführt, die sich an der regionalen Knappheit dieser Ressource orientieren.
- In der Schweiz werden die abbaubaren Kiesreserven (auf Grund der zulässigen Landnutzung) zunehmend knapp. Darum wurde neu ein Ökofaktor für **Kies** eingeführt.
- Neu werden Ökofaktoren für die **Landbeanspruchung** ausgewiesen. Die Charakterisierung erfolgt auf der Basis der Auswirkungen von Landnutzungen auf die Pflanzenbiodiversität.
- Neu wird der in **Reaktordeponien** einzulagernde Abfall über den im Abfall enthaltenen Kohlenstoff bewertet. Das bisher bei allen Deponietypen verwendete Prinzip der Bewertung des Deponievolumens wird fallen gelassen. Das Deponievolumen wird lediglich verwendet zur Bewertung der Endlagerung von **radioaktiven Abfällen** und der Untertagedeponie von **Sonderabfällen.**

Übersicht Ökofaktoren 2006

Die folgende Tabelle zeigt die Ökofaktoren gemäss der Schweizer Situation. Faktoren für weitere Substanzen, die mittels Charakterisierung bestimmt wurden, sind in den Anhängen aufgeführt (Anh. A2 bis A5). Die Spalte «Normierungsfluss» stellt die heutige Emissionssituation (gemäss den 2006 verfügbaren Daten) dar. Die Spalte «Aktueller Fluss» stellt die Referenzgrösse dar. Sie ist meist identisch mit dem Normierungsfluss. Die Spalte «Kritischer Fluss» repräsentiert das politisch gesetzte Ziel. Ist der kritische Fluss grösser als der aktuelle Fluss, unterschreitet die aktuelle Situation das Ziel.

Tab. A > Übersicht Ökofaktoren 2006

	Normierungsfluss		Aktueller Fluss	Kritischer Fluss		Ökofaktor 2006	UBP pro
Emissionen in die Luft							
CO_2	53 034 000	t CO_2-eq	45 436 000	11 183 000[1]	t CO_2	0.31	g CO_2-eq
Ozonschichtabbauende Substanzen	391	t R11-eq	391	188	t R11-eq	11 000	g R11-eq
NMVOC	116 000	t	116 000	81 000	t	18	g
NO_x	91 000	t	91 000	45 000	t	45	g
NH_3 (als N)	44 000	t	44 000	25 000	t	70	g N
SO_2	19 000	t SO_2-eq	19 000	25 000	t	30	g SO_2-eq
PM2.5–10	22 000	t	9 255	5 048[2]	t	150	g
PM2.5	22 000	t	12 745	6 952[2]	t	150	g
Dieselruss	3 400	t	3 400	450	t	17 000	g
Benzol	1 055	t	1 055	525	t	3 800	g
Dioxine und Furane	67.5	g	67.5	34.5	g	5.7E+10	g
Blei	91	t	91	58[3]	t	27 000	g
Cadmium	2.00	t	2.00	2.08[3]	t	460 000	g
Quecksilber	1.02	t	1.02	2.22	t	210 000	g
Zink	560	t	560	359[3]	t	4 400	g
Emissionen in Oberflächengewässer							
Stickstoff (als N)	31 360	t	24 827	17 510	t	64	g N
Phosphor (als P)	1 694	t	28.6	20	mg/m³	1 200	g P
CSB	47 700	t	47 700	144 000	t	2.3	g
Arsen	8.6	t	10.5	40	mg/kg	8 000	g
Blei	32	t	38	100	mg/kg	4 400	g
Cadmium	0.61	t	0.42	1.0	mg/kg	290 000	g
Chrom	25	t	44	100	mg/kg	7 600	g
Kupfer	74	t	51	50	mg/kg	14 000	g
Nickel	84	t	38	50	mg/kg	6 800	g
Quecksilber	0.20	t	0.21	0.50	mg/kg	880 000	g
Zink	167	t	182	200	mg/kg	5 000	g
Radioaktive Emissionen	2 000	GBq C14-eq	96	64.1	TBq	1 100	kBq C14-eq
AOX (als Cl^-)	288	t	288	1 200	t	200	g Cl
Chloroform	1.5	t	0.04	0.60	mg/m³	1 500	g
PAK	0.144	t	0.004	0.1	mg/m³	11 000	g
Benzo(a)pyren (BaP)	0.048	t	0.001	0.01	mg/m³	210 000	g
Hormonaktive Stoffe	5.0	kg E2-eq	5.0	24.0	kg E2-eq	8 700 000	g E2-eq
Emissionen in Grundwasser							
Stickstoff (als N)	34 000	t	34 000	17 000	t	120	g N

	Normierungsfluss		Aktueller Fluss	Kritischer Fluss		Ökofaktor 2006	UBP pro
Emissionen in den Boden							
Blei	79.9	t	30.3	19.4	g/ha.a	31 000	g
Cadmium	2.98	t	1.25	1.30	g/ha.a	310 000	g
Kupfer	120	t	73.4	58.0	g/ha.a	13 000	g
Zink	870	t	473	303	g/ha.a	2 800	g
Pflanzenschutzmittel (PSM)	1 507	t PSM-eq	1 577	1 500	t	730	g PSM-eq
Ressourcen							
Primärenergieträger	1 030	PJ-eq	1 169	636 1	PJ	3.3	MJ-eq
Landnutzung, Siedlungsfläche	3 378	km².a-eq	2 791	3 224	km².a	220	m²a-eq
Süsswasser Schweiz	2.57	km³	2.57	10.7	km³	22	m³
Süsswasser OECD	2.57	km³	1 020	2 040	km³	97	m³
Kies	34 000 000	t	34 000 000	34 000 000	t	0.029	g
Abfälle							
C in Reaktordeponie	97 410	t	97 410	79 420	t	15	g C
Sonderabfälle in Untertagedeponien	36 900	t	36 900	36 900	t	27	g
hochradioaktive Abfälle	218	m³	218	109	m³	18 000	cm³
Schwach-/mittelradioaktive Abfälle	1 230	m³	1 230	615	m³	3 300	cm³

[1] Wert emittelt durch Interpolation zwischen Zielsetzung 2010 und 2050

[2] Wert abgeleitet aus kritischem Fluss PM10 und Anteil PM2.5

[3] Wert ermittelt auf Basis Verhältnis aktueller zu kritischer Fluss der Emissionen in Boden

Zeitlicher Bezugsrahmen: es liegen die im Jahr 2006 verfügbaren aktuellsten Daten zu Grunde.

Genauigkeit: Die Flüsse sind für eine optimale Rückverfolgbarkeit nicht gerundet, sondern wie in den verwendeten Quellen angegeben.

Die Knappheitsfaktoren sind auf zwei signifikante Stellen gerundet.

> Résumé

Selon la norme ISO 14040, l'analyse du cycle de vie de produits, de processus ou d'entreprise est structurée en 4 phases:

- détermination des buts et des cadres de recherche,
- analyse de l'inventaire,
- évaluation de l'impact
- interprétation.

La méthode de la saturation écologique permet d'évaluer l'impact des inventaires de cycle de vie, selon le principe de leur distance à la cible (en anglais, "distance to target"). Les écofacteurs constituent les variables centrales de la méthode: ils représentent la charge environnementale due à l'émission d'un polluant ou à la consommation d'une ressource, exprimée en unités de charge écologique (ou écopoints) par quantité de matière. Leur calcul se base principalement sur le niveau actuel des émissions ainsi que sur les objectifs environnementaux de la Suisse, qu'ils soient nationaux ou qu'ils découlent d'accords internationaux auxquels notre pays a adhéré.

Les écofacteurs proposés selon la première actualisation pour les différents impacts environnementaux (Brand et al. 1998) sont de plus en plus employés. L'actualisation présente est devenue nécessaire suite aux nouveaux résultats scientifiques, aux nouveaux fondements légaux et politiques, aux nouveaux accords internationaux, aux expériences pratiques et aux développements des normes internationales. La formule de l'écofacteur a été structurellement adaptée et inclue les éléments: charactérisation, normalisation et pondération. Le choix des matières analysées a été élargi et les bases de données et d'informations des facteurs existants ont été verifiées et actualisées. Voici un bref résumé des changements les plus importants qui ont eu lieu:

- La formule de l'écofacteur a été légèrement remaniée au niveau de sa représentation mathématique. La charactérisation a été introduite et la normalisation se base sur les émissions actuelles. Le facteur de pondération (ratio des flux actuels versus des flux critiques) est élevé au carré. En employant la nouvelle formule ou l'ancienne avec une même base de données, les écofacteurs restent identiques.
- Pour le CO_2 et l'énergie, les buts (1 tonne de CO_2 ou de 2000 W par habitant) à long terme de la confédération ont été interpolés à 2030 selon l'horizon prévu par la législation.
- En ce qui concerne les polluants atmosphériques, des écofacteurs supplémentaires ont été établis pour le benzène, la dioxine et les particules de diesel. Ceux-ci se basent sur le principe de précaution dicté dans la loi sur la protection de l'environnement.
- Pour les émissions atmosphériques et terrestres des métaux lourds, les buts ont été alignés à ceux utilisés pour la conservation à long terme de la fertilité des sols.

- Les écofacteurs peuvent, si le besoin se fait ressentir et si les données sont disponibles, être établis selon les spécificités régionales. Ce principe est appliqué au phosphor présent dans les eaux de surface en Suisse.
- Les résultats scientifiques actuels ont permis l'établissement d'un écofacteur sur les micro-polluants (mesurant l'activité oestrogénique) introduits dans les eaux. Ainsi, pour la première fois, les calculs portent aussi sur les micro-polluants qui deviennent de plus en plus importants.
- Sur la base des accords internationaux pour la protection de la mer du Nord, de nouveaux écofacteurs ont été créés pour l'introduction des isotopes radioactifs en mer (la charactérisation y est inclue).
- Dans certaines régions du monde, les eaux douces sont une ressource limitée. Pour cette raison, un écofacteur portant sur ces limites régionales a été introduit.
- Les réserves de gravier en Suisse diminuent (selon les zones autorisées) de plus en plus et un nouvel écofacteur lui a été alloué.
- Nouvellement des écofacteurs sont déterminés pour l'utilisation du sol. La caractérisation se fait sur la base des impacts de l'utilisation des sols sur la biodiversité des plantes.
- Les déchets bioactives sont dorénavant évalués selon leur teneur carbonique. Jusqu'à présent seul le volume de tous les déchets déchargés était pris en compte. Le volume de stockage reste uniquement employé pour le stockage souterrain des déchets radioactifs et des déchets spéciaux.

Aperçu des écofacteurs 2006

Le tableau suivant montre les écofacteurs selon la situation suisse. Des écofacteurs supplémentaires, définis par la normalisation, se trouvent dans les annexes de 2 à 5. La colonne «flux de normalisation» présente la situation actuelle des émissions. La colonne «flux actuel» sert de référence et est la plupart du temps égale au flux de normalisation. La colonne des «flux critiques» représente les buts politiques. Si le flux critique est supérieur au flux actuel, la situation actuelle correspond au but politique.

Tab. A > Aperçu des écofacteurs 2006

	Flux de normalisation		Flux actuel	Flux critique		Ecofacteur 2006	UBP par
Emissions dans l'air							
CO$_2$	53 034 000	t CO$_2$-eq	45 436 000	11 183 000[1]	t CO$_2$	0.31	g CO$_2$-eq
Substances appauvrissant la couche d'ozone	391	t R11-eq	391	188	t R11-eq	11 000	g R11-eq
NMVOC	116 000	t	116 000	81 000	t	18	g
NO$_x$	91 000	t	91 000	45 000	t	45	g
NH$_3$ (en N)	44 000	t	44 000	25 000	t	70	g N
SO$_2$	19 000	t SO$_2$-eq	19 000	25 000	t	30	g SO$_2$-eq
PM2.5–10	22 000	t	9 255	5 048[2]	t	150	g
PM2.5	22 000	t	12 745	6 952[2]	t	150	g
Particules de diesel	3 400	t	3 400	450	t	17 000	g
Benzène	1 055	t	1 055	525	t	3 800	g
Dioxines et Furanes	67.5	g	67.5	34.5	g	5.7E+10	g
Plomb	91	t	91	58[3]	t	27 000	g
Cadmium	2.00	t	2.00	2.08[3]	t	460 000	g
Mercure	1.02	t	1.02	2.22	t	210 000	g
Zinc	560	t	560	359[3]	t	4 400	g
Emissions dans les eaux de surface							
Azote (comme N)	31 360	t	24 827	17 510	t	64	g N
Phosphore (en P)	1 694	t	28.6	20	mg/m^3	1 200	g P
DCO	47 700	t	47 700	144 000	t	2.3	g
Arsenic	8.6	t	10.5	40	mg/kg	8 000	g
Plomb	32	t	38	100	mg/kg	4 400	g
Cadmium	0.61	t	0.42	1.0	mg/kg	290 000	g
Chrome	25	t	44	100	mg/kg	7 600	g
Cuivre	74	t	51	50	mg/kg	14 000	g
Nickel	84	t	38	50	mg/kg	6 800	g
Mercure	0.20	t	0.21	0.50	mg/kg	880 000	g
Zinc	167	t	182	200	mg/kg	5 000	g
Emissions radioactives	2 000	GBq C14-eq	96	64.1	TBq	1 100	kBq C14-eq
AOX (en Cl$^-$)	288	t	288	1 200	t	200	g Cl
Chloroforme	1.5	t	0.04	0.60	mg/m^3	1 500	g
HAP	0.144	t	0.004	0.1	mg/m^3	11 000	g
benzo[a]pyrène	0.048	t	0.001	0.01	mg/m^3	210 000	g
Perturbateurs endocriniens	5.0	kg E2-eq	5.0	24.0	kg E2-eq	8 700 000	g E2-eq
Emissions dans les eaux souterraines							
Azote (en N)	34 000	t	34 000	17 000	t	120	g N

	Flux de normalisation		Flux actuel	Flux critique		Ecofacteur 2006	UBP par
Emissions dans le sol							
Plomb	79.9	t	30.3	19.4	g/ha.a	31 000	g
Cadmium	2.98	t	1.25	1.30	g/ha.a	310 000	g
Cuivre	120	t	73.4	58.0	g/ha.a	13 000	g
Zinc	870	t	473	303	g/ha.a	2 800	g
Pesticides	1 507	t PSM-eq	1 577	1 500	t	730	g PSM-eq
Ressources							
Source d'énergie primaire	1 030	PJ-eq	1 169	636 [1]	PJ	3.3	MJ-eq
Affectation des sols, agglomération	3 378	km².a-eq	2 791	3 224	km².a	220	m²a-eq
Eaux douces suisses	2.57	km³	2.57	10.7	km³	22	m³
Eaux douces OCDE	2.57	km³	1 020	2 040	km³	97	m³
Gravier	34 000 000	t	34 000 000	34 000 000	t	0.029	g
Déchets							
C dans les décharges	97 410	t	97 410	79 420	t	15	g C
Déchets spéciaux dans les décharges souterraines	36 900	t	36 900	36 900	t	27	g
Déchets fortement radioactifs	218	m³	218	109	m³	18 000	cm³
Déchets faiblement et moyennement radioactif	1 230	m³	1 230	615	m³	3 300	cm³

[1] Valeur calculée par interpolation entre les buts pour 2010 et 2050

[2] Valeur deduite du flux critique PM10 et en partie de PM2.5

[3] Valeur calculée de la relation entre flux actuel et flux critique des émissions dans le sol.

Cadre temporel: les chiffres sont basées sur les données disponibles en 2006.

Précision des données: Les flux ne sont pas arrondis, pour faciliter leurs traçabilité dans les publications sources. Les facteurs de pondération, par contre, sont arrondis à deux chiffres significatifs.

> Summary

According to ISO Standard 14040, the life cycle assessment (LCA) of products, processes or companies comprises four phases:

- > Goal and scope definition
- > Inventory analysis
- > Impact assessment and
- > Interpretation.

The “ecological scarcity” method permits impact assessment of life cycle inventories according to the “distance to target” principle. Eco-factors, expressed as eco-points per unit of pollutant emission or resource extraction, are the key parameter used by the method. With that method, eco-factors are determined by the current emissions situation and, secondly, by the political targets set by Switzerland or by international policy and supported by Switzerland. The method was first published in 1990.

The eco-factors proposed for various environmental impacts in the first update of the method (Brand et al. 1998) are used widely. The fresh update presented here became necessary to reflect new scientific findings, new statutory and political targets, new international agreements, developments in international standarization and experience gathered in practice. As a part of this revision, the eco-factor formula has been adjusted to the structure of the ISO standard (with its elements of charactization, normalization and weighting). The set of substances assessed has been further enlarged. The data and information on which the existing eco-factors were based was checked and updated. The key changes made are as follows:

- > The mathematical representation of the **ecofactor formula** has been slightly modified. The characterization step is now made explicit. In addition, normalization is now based on current emissions, as has become common practice. As a consequence the weighting factor (ratio of current to critical flow) is squared. With both the old and new formula representation, the resulting eco-factors remain identical if the data is the same.
- > With regard to **CO_2 and energy,** the long-term target of the Swiss confederation (1 tonne CO_2 or 2000 W per capita) was interpolated for the year 2030, which is a common time horizon of Swiss legislation.
- > With regard to air pollutants, new eco-factors were determined for **benzene, dioxin and diesel soot,** based on the precautionary principle enshrined in the Swiss Environmental Protection Act.
- > For **heavy metal emissions** (both to air and to soil), the long-term maintenance of soil fertility is now used as the new target.
- > Eco-factors can now be defined according to regional scarcities, if needed and if regional data are available. This principle is applied to **phosphorus and emissions** to Swiss surface waters.

- Recent reesearch findings allow the establishment of an eco-factor (incl. characterization) for **endocrine disruptors** (measured as oestrogen activity) in waters. Account is thus taken for the first time of micropollutants in waters, an issue that is gaining importance.
- A further new feature is that eco-factors can be established for discharges of **radioactive isotopes** to the seas (again including characterization); this is based on international agreements for the protection of the North Sea.
- In some parts of the world **freshwater** is a scarce resource. Therefore new eco-factors have been introduced that are oriented to the regional scarcity of this resource.
- In Switzerland, extractable **gravel** reserves are becoming decreasing scarce (due to permissible land uses). A new eco-factor for **gravel** was therefore introduced.
- New eco-factors were introduced for **land use.** Characterization is based on the impacts of land uses upon plant biodiversity.
- A new feature concerning the assessment of **bioreactive landfills** is that the wastes consigned to them are assessed on the basis of their carbon content. Previously, landfill types were assessed on the basis of landfill volume; this practice has been discontinued. Landfill volume is now only used to assess the final storage of **radioactive wastes** and underground disposal of **hazardous wastes.**

Overview of eco-factors for 2006

The following table lists the eco-factors according to the Swiss situation. Annexes A2 to A5 present the factors for further substances determined by characterization. The **"normalization flow"** column states today's emission situation (in accordance with the data available in 2006). The **"current flow"** column presents the reference quantity, which in most cases is identical to the normalization flow. The **"critical flow"** column represents the **political target.** If the critical flow is larger than the current flow, then today's situation is in accordance with the target.

Tab. A > Overview of eco-factors for 2006

	Normalization flow		Current flow	Critical flow		Ecofactor 2006	UBP per
Emissions to air							
CO_2	53 034 000	t CO_2-eq	45 436 000	11 183 000 [1]	t CO_2	0.31	g CO_2-eq
Ozone-depleting substances	391	t R11-eq	391	188	t R11-eq	11 000	g R11-eq
NMVOC	116 000	t	116 000	81 000	t	18	g
NO_x	91 000	t	91 000	45 000	t	45	g
NH_3 (as N)	44 000	t	44 000	25 000	t	70	g N
SO_2	19 000	t SO_2-eq	19 000	25 000	t	30	g SO_2-eq
PM2.5–10	22 000	t	9 255	5 048 [2]	t	150	g
PM2.5	22 000	t	12 745	6 952 [2]	t	150	g
Diesel soot	3 400	t	3 400	450	t	17 000	g
Benzene	1 055	t	1 055	525	t	3 800	g
Dioxins and Furans	67.5	g	67.5	34.5	g	5.7E+10	g
Lead	91	t	91	58 [3]	t	27 000	g
Cadmium	2.00	t	2.00	2.08 [3]	t	460 000	g
Mercury	1.02	t	1.02	2.22	t	210 000	g
Zinc	560	t	560	359 [3]	t	4 400	g
Emissions to surface waters							
Nitrogen (as N)	31 360	t	24 827	17 510	t	64	g N
Phosphorus (as P)	1 694	t	28.6	20	mg/m³	1 200	g P
COD	47 700	t	47 700	144 000	t	2.3	g
Arsenic	8.6	t	10.5	40	mg/kg	8 000	g
Lead	32	t	38	100	mg/kg	4 400	g
Cadmium	0.61	t	0.42	1.0	mg/kg	290 000	g
Chromium	25	t	44	100	mg/kg	7 600	g
Copper	74	t	51	50	mg/kg	14 000	g
Nickel	84	t	38	50	mg/kg	6 800	g
Mercury	0.20	t	0.21	0.50	mg/kg	880 000	g
Zinc	167	t	182	200	mg/kg	5 000	g
Radioactive emissions	2 000	GBq C14-eq	96	64.1	TBq	1 100	kBq C14-eq
AOX (as Cl^-)	288	t	288	1 200	t	200	g Cl
Chloroform	1.5	t	0.04	0.60	mg/m³	1 500	g
PAHs	0.144	t	0.004	0.1	mg/m³	11 000	g
Benzo(a)pyrene	0.048	t	0.001	0.01	mg/m³	210 000	g
Endocrine disruptors	5.0	kg E2-eq	5.0	24.0	kg E2-eq	8 700 000	g E2-eq
Emissions to groundwater							
Nitrogen (as N)	34 000	t	34 000	17 000	t	120	g N

	Normalization flow		Current flow	Critical flow		Ecofactor 2006	UBP per
Emissions to soil							
Lead	79.9	t	30.3	19.4	g/ha.a	31 000	g
Cadmium	2.98	t	1.25	1.30	g/ha.a	310 000	g
Copper	120	t	73.4	58.0	g/ha.a	13 000	g
Zinc	870	t	473	303	g/ha.a	2 800	g
Plant protection products	1 507	t PPP-eq	1 577	1 500	t	730	g PPP-eq
Resources							
Primary energy carriers	1 030	PJ-eq	1 169	636 [1]	PJ	3.3	MJ-eq
Land use, settlement area	3 378	km^2.a-eq	2 791	3 224	km^2.a	220	m^{2}a-eq
Freshwater Switzerland	2.57	km^3	2.57	10.7	km^3	22	m^3
Freshwater OECD	2.57	km^3	1 020	2 040	km^3	97	m^3
Gravel	34 000 000	t	34 000 000	34 000 000	t	0.029	g
Wastes							
C to landfill	97 410	t	97 410	79 420	t	15	g C
Hazardous wastes to underground repositories	36 900	t	36 900	36 900	t	27	g
High-level radioactive wastes	218	m^3	218	109	m^3	18 000	cm^3
Low/medium-level radioactive wastes	1 230	m^3	1 230	615	m^3	3 300	cm^3

[1] Value calculated by interpolation between targets for 2010 and 2050

[2] Value derived from PM10 critical flow and PM2.5 proportion

[3] Value calculated from ratio of current to critical flow of emissions to soil

Temporal reference: The figures are based on the data available in 2006.

On data accuracy: The flows are not rounded, thus allowing for optimal traceability in source texts. Scarcity and weighting factors are rounded to two digits.

> Synoptic overview

Introduction

The Swiss Mineral Oil Tax Ordinance[1] amended as per 1 July 2008 states: “For tax relief to apply to fuels from renewable resources, proof must be furnished that these fuels meet the minimum criteria for positive aggregate environmental impact.” This is the first time that life cycle assessment (LCA) of a product – in this case of “biogenic” fuels – is required explicitly at the level of a statutory ordinance. As it can be expected that the growing importance of LCA will generate greater interest in the underlying methodology beyond expert circles, the Swiss Federal Office for the Environment (FOEN) has produced this synoptic overview in order to make accessible to an interested public the content of the technical publication “Life Cycle Assessment: The Ecological Scarcity Method – Eco-Factors 2006” (“Ökobilanzen: Methode der ökologischen Knappheit – Ökofaktoren 2006” (Öbu SR 28/2008)). The first part of this abridged version presents the life cycle assessment method, while the second part explains the general procedure by which eco-factors are derived. The third and largest part discusses the individual pollutants and resources rated with an eco-factor.

Life cycle assessment

Life cycle assessment (LCA) is a decision-support tool for companies, organizations and public authorities wishing to analyse the environmental aspects of processes, products, sites or entire companies. LCA studies can be used to identify the environmental relevance of processes and the potential to optimize them, deliver the fundamentals for decisions on which options to choose, furnish evidence of environmental performance, and raise awareness of environmental issues among participants and stakeholders. An LCA records and assesses the environmental impacts arising throughout the life cycle of a product. The life cycle encompasses the extraction of resources, their processing to semi-finished goods, the manufacture of products, their use across their service life, and the final disposal or recycling processes. Transports required between the individual life cycle stages are also taken into account. LCA studies are preformed in the following four steps:

1. **Definition of the goal and scope of the study**
   The goal of the study is defined, for instance to produce a comparison of returnable and non-returnable mineral water packaging. The definition of the functional unit and the question of system boundaries are essential when defining the scope of the study: What is an appropriate and fair basis for the comparison? How far does the study of the subject go? Are, for instance, the construction of the factory and the manufacture of the machinery taken into account? How is the recycling of packag-

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[1] Mineralölsteuerverordnung (MinöStV) of 20 November 1996 (amended as per 1 July 2008). The details of the criteria are regulated in the DETEC Ordinance on Proof of the Positive Aggregate Environmental Impact of Fuels from Renewable Feedstocks – Biofuels Life Cycle Assessment Ordinance, BLCAO (Verordnung des UVEK über den Nachweis der positiven ökologischen Gesamtbilanz von Treibstoffen aus erneuerbaren Rohstoffen – Treibstoff-Ökobilanzverordnung, TrÖbiV).

ing materials modelled? Which impact assessment methods are chosen to quantify the environmental impacts related to returnable and non-returnable packaging systems? The assumptions made and constraints imposed upon the study are made explicit in this step.

2. **Generation of a life cycle inventory**
   Inventory analysis records the quantities of resources, semi-finished products, energy carriers and services required and the pollutants released by each individual process required to manufacture a product. The outcome of this analysis could for instance be that the manufacture of the product under review releases, among other things, 130 kg carbon dioxide (CO_2), 3 kg methane (CH_4) and 45 grams of nitrogen oxides (NO_x) across the entire life cycle. To produce an inventory analysis it is necessary to collect detailed environmental and product data, which are often listed in datasets of life cycle inventory databases.

3. **Assessment of impacts**
   In the impact assessment step, the findings of the inventory analysis are assessed with regard to their environmental and health impacts. This is done in several substeps. The resource consumption and pollutant emissions identified in the inventory analysis can be aggregated to a single or several indicators by means of assessment factors applying classification, characterisation, normalisation and weighting or just classification and characterisation. In the first substep, classification, resources extracted and pollutants emitted are classified according to the environmental impacts caused. For instance, carbon dioxide and methane are grouped in the "climate change" category. In the second substep, characterisation, the relative contribution of the substances grouped in one class is quantified relative to a reference substance. For instance, the relative global warming potential of the different greenhouse gases (carbon dioxide and methane in the above example) is determined and added on the basis of a uniform metric (CO_2-equivalents in the present case). In our example, the climate change impact is 199 kg CO_2-equivalents (applying the following characterisation factors: 1 kg CO_2-equivalents per kg CO_2 and 23 kg CO_2-equivalents per kg methane).
   In a third step, normalisation, characterised environmental impacts caused by a product are put in relation to the total impacts occurring worldwide, in a region (Europe) or a nation (Switzerland). These impacts may be expressed as annual totals or on an annual per capita basis (resulting in 0.02 person years, applying 10 tons CO_2-equivalents per year and person). Finally, the normalised impacts caused by a product are further aggregated using weighting factors.

4. **Interpretation and recommendation for action**
   Indicators and aggregate environmental impacts quantified using a common metric can be compared to alternative products or processes, or to company LCAs performed previously. The results can be used to derive a recommendation in line with the targets set (e.g. for a decision on which option to choose, or for a process optimization), or to provide evidence of environmental performance (e.g. reduction of greenhouse gas emissions). Sensitivity analyses are carried out to test the robustness of the results, and contribution analyses help to identify environmental hot spots.

Eco-factors

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

Characterization captures the relative harmfulness of a pollutant emission or resource extraction vis-à-vis a reference substance within a given impact category (global warming potential, acidification potential, radioactivity etc.). The factors are based upon scientific findings. For instance, the radiative forcing (global warming potential) of methane (CH_4) is 23 times higher than that of carbon dioxide (CO_2). Sulphur hexafluoride (SF_6), which is used to insulate electric components, even has a global warming potential 22 000 times that of CO_2. It is common practice to express the characterized quantity in equivalents of the reference substance. In the case of greenhouse gases, these are CO_2-equivalents (CO_2-eq). Methane has a characterization factor of 23 kg CO_2-eq, meaning that 1 kg methane has the same impact as 23 kg CO_2, and accordingly the eco-factor is 23 times that of CO_2.

Normalization quantifies the contribution of a unit of pollutant or resource use to the total current load/pressure in a region (in this case the whole of Switzerland) per year. If, for instance, 100 000 tonnes of a substance are released annually, then the contribution of 10 grams is small. If, in contrast, only 70 grams are released in total, then the same contribution of 10 grams is very large. The smaller the normalization flow, the larger the eco-factor will tend to be.

Weighting expresses the relationship between the current pollutant emission or resource consumption (current flow) and the politically determined emission or consumption targets (critical flow). The more the overall load of a substance exceeds the politically determined critical flow, i.e. the environmental protection target, the more eco-points are assigned per unit (e.g. gram) to a substance. Any growth of the current flow leads to exponential growth of the weighting factor, as does any reduction in the critical flow (tightening of legal/political targets). Any reduction in the current flow or any increase in the critical flow (due to a relaxation of environmental targets) leads to an exponential reduction of the weighting factor.

The following formula governs calculation of the eco-factor:

$$\text{Eco-factor} = \underbrace{K}_{\substack{\text{Characterization} \\ \text{(optional)}}} \cdot \underbrace{\frac{1 \cdot EP}{F_n}}_{\text{Normalization}} \cdot \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \cdot \underbrace{c}_{\text{Constant}}$$

K = **Characterization factor** of a pollutant or of a resource
F_n = **Normalization flow:** Current annual flow, with Switzerland as system boundary
F = **Current flow:** Current annual flow in the reference area
F_k = **Critical flow:** Critical annual flow in the reference area
c = **Constant (10^{12}/a):** Serves to obtain readily presentable numerical quantities
EP = **Eco-point:** The unit of environmental impact assessed

“Flow” refers to the load of a pollutant, the quantity of a resource consumed, or the level of an environmental impact characterized.

If the eco-factors are applied to production processes abroad, it needs to be taken into account that the given eco-factors **weight every emission as if it were taking place in Switzerland.** Thus, the actual level of emissions remaining constant, shifting a process to another country does not affect the impact assessment result. Where required and where data availability permits, **eco-factors can be regionalized.** For instance, an agricultural product produced in North Africa is then assessed with a regional weighting term (current flow in region over critical flow for region, e.g. freshwater consumption) and a normalization to Swiss conditions (normalization flow for Switzerland). This makes it possible to conduct an assessment of the regional scarcity situation in a manner permitting comparison with the Swiss eco-factors. The present publication contains the data for assessing water use abroad. For certain pollutants whose loads vary greatly from site to site, such as phosphorus emitted to surface waters, a regional differentiation can be performed within Switzerland in the same manner.

One and the same pollutant can generate different environmental impacts. It follows that different eco-factors based upon different political targets could be assigned to that pollutant. For instance, ammonia emissions to air could be assessed on the basis of an explicit reduction target for nitrogen or, alternatively, on the basis of their acidification potential. In such cases the principle applied is that **assessment is based on the strictest political target and thus the highest eco-factor is used.**

Depending upon whether a certain pollutant is emitted to water, air or soil, different eco-factors may result depending upon the specific political and statutory emission targets. Hence in some cases **the same pollutant is addressed in several contexts** in the following; this applies notably to the heavy metals.

A principle in preparing LCA studies is that **every emission only scores once.** This takes place when a substance first crosses the boundary from the anthropo-technosphere to the natural environment (or vice versa in the case of resource extraction). Further substance and material flows within the natural environment – including substances that originated in the anthroposphere – are not taken into account, as otherwise these would be counted double.

A **characterization** is acceptable under the terms of this methodology if it is in line with the intention of the legislator. Moreover, the characterization should be scientifically recognized and it should be possible to derive it from political targets. In the case of greenhouse gases, only the CO_2 reduction target is enshrined in law, but the intention of the legislator is to contribute to limiting global climate change. It is therefore appropriate in this case to differentiate according to global warming potential and to assign a characterization factor to each individual substance. In the case of volatile organic compounds (NMVOCs), in contrast, characterization is not appropriate, because the legislator has imposed a uniform levy upon all pollutants in this category (the Swiss VOC levy).

Assessing emissions and resources

The following sections briefly set out the environmental and health impacts of the pollutant emissions and resource extractions assessed. They further present emission sources, the derivation of critical flows from statutory texts, emission and consumption trends, and differences to earlier assessments. The synoptic table contained in the “Summary” section of the full publication provides a reference listing the figures for current and critical flows and the eco-factors. Reference is made to the corresponding sections of the full publication for more detailed data.

The selection of substances is guided by their environmental and political relevance. As environmental policy has by no means set targets for all substances, the selection of environmental impacts assessed is limited. Hence no assessment is provided of emissions that have little environmental relevance in Switzerland and Europe (e.g. sulphate in waters) or for which not enough knowledge is available (e.g. noise).

Substances are classified according to the environmental compartment they enter when leaving the anthropo-technosphere. This synopsis of the publication presents emissions to air, waters and soil, then assesses resource extractions and, finally, the landfilling and underground storage of wastes.

Emissions to air

The airborne pollutants assessed with an eco-factor were selected according to their environmental relevance for the whole of Switzerland. Air pollution control measures have led to a drop in emissions in recent years. Thus in some cases impacts within Switzerland are of subordinate importance. It needs to be taken into account, however, that the eco-factors are applied not only to Swiss processes, but also to processes taking place abroad. An eco-factor is therefore retained for substances which may be unproblematic in Switzerland, but have the potential to continue to be environmentally relevant abroad.

CO_2 and further greenhouse gases

Modelling shows that the global mean temperature can be expected to rise by 1.4 to 5.8 °C between 1990 and 2100, and the sea level can be expected to rise by 10 to 90 cm. Moreover, more extreme weather events are anticipated, and more precipitation or greater aridity depending upon region. This is caused by the human-induced amplification of the greenhouse effect. Reducing greenhouse gas emissions is therefore a priority target of Swiss environmental policy. 86 % of the impact of greenhouse gas emissions is attributable to carbon dioxide (CO_2), around 7 % to methane (CH_4) and some 6 % to nitrous oxide (N_2O). Although the global warming potential of chlorinated and fluorinated hydrocarbons and of sulphur hexafluoride (SF_6) can, as such, be several thousand times greater than that of CO_2, in Switzerland their contribution to the impacts is small (slightly above 1 %) – their current flow is relatively small.

The Swiss CO_2 Act stipulates a reduction by 10 % from the 1990 level for fuels. This would result in a critical flow of 36.96 million t CO_2 per year. The Swiss Federal Council (Bundesrat) envisages the "2000 watt society" as a long-term target, which implies a maximum emission of 1 t CO_2 per person and year. The resulting target would be 8.06 million t CO_2 for the year 2050, given the anticipated population at that time. To calculate the critical flow, these two emission targets are interpolated to a time horizon to 2030. This results in an eco-factor that is higher by half than that determined in 1997.

CO_2-equivalents (abbreviated to CO_2-eq) are used as the metric for all climate-relevant emissions. The global warming potential of the other greenhouse gases can be determined via characterization factors (see Table 8, Section 3.2.6).

Ozone-depleting substances

The ozone layer is located in the stratosphere, at an altitude between 15 and 50 km. This layer protects life on Earth from a part of the ultraviolet radiation of the sun. Volatile substances containing chlorine and/or bromine atoms cause depletion of the ozone layer. The resultant elevated UV radiation causes an increase in skin cancers and eye diseases in humans, and is mutagenic in all organisms.

The most important ozone-depleting substances are CFCs (chlorofluorocarbons), halons and carbon tetrachloride (CCl_4). HCFCs (partially halogenated CFCs) have the same effect, but in a significantly weaker form. At the same time, CFCs and HCFCs are contributors to human-induced climate change. If a substance is both a greenhouse gas and an ozone-depleting substance, then the higher of the two eco-factors is used.

A substance labelled internationally as R11 provides the reference. The eco-factors of the other ozone-depleting substances can be determined by means of characterization factors (see Section 3.3.6, Table 14) and are expressed as R11-equivalents (R11-eq).

The new eco-factor is substantially larger than that of 1997. This is partly because measured data have now replaced earlier estimates. A further reason is that an absolute ban on ozone-depleting substances will enter into force in the foreseeable future, leading to a smaller critical flow.

Volatile organic compounds (NMVOCs)

Non-methane volatile organic compounds (NMVOCs) comprise volatile organic compounds (VOCs) with the exception of the greenhouse gas methane. VOCs include largely harmless as well as highly toxic and carcinogenic compounds. NMVOCs are important precursors to ground-level ozone (also known as summer smog), which can harm human health and plants. Some individual VOCs – such as benzene and dioxins – receive their own specific eco-factors because of their great harmfulness to human health.

The introduction of the Swiss VOC levy in 2000, together with increasingly strict emission rules for vehicles, has contributed to a steep reduction in emissions. As the current flow has been reduced and the critical flow has remained unchanged, the eco-factor is significantly below that of 1997. The trend towards lower emissions is expected to continue.

Nitrogen oxides (NO_x)

Nitrogen oxides are formed above all when fossil energy carriers are burnt. Transport is the main source, accounting for 58 % of emissions in 2000. Further sources of nitrogen oxides include construction machines and agricultural and silvicultural machines (12 %), combustion facilities/furnaces (6 %) and commercial and industrial processes (24 %). Nitrogen loads cause soils and waters to acidify. This severely endangers sensitive ecosystems. Moreover, it promotes nitrophilous plants, which can lead to a reduction of plant diversity and to the loss of ecologically valuable ecosystems such as oligotrophic grassland and open submerged swards.

Nitrogen dioxide (NO_2) and the secondary particles formed from nitrogen oxides are particularly harmful to human health. They can cause respiratory tract diseases or cardiac arrhythmia, and can reduce life expectancy. Nitrogen oxides are important precursors in the formation of ground-level ozone, which in turn impairs health.

Measures adopted since 1985 have succeeded in reducing NO_x emissions significantly. However, to comply with limit values emissions still need to be reduced by some 60 %. The planned tightening of rules will then lead to a further drop. The eco-factor is one-third lower than in 1997, as the current flow has dropped while the critical flow has remained the same.

Ammonia (NH_3)

Ammonia is formed in livestock management and when mineral nitrogen fertilizers are applied. Agriculture is the main generator of emissions, accounting for 93 %. Because of its nitrogen content, ammonia contributes to the acidification and over-fertilization of soils and waters. Its mode of effect is similar to that of nitrogen oxides (see above).

The critical flow corresponds to the target set in 2005 by the Swiss Federal Commission for Air Hygiene, which in turn corresponds to the lower value of the range of targets set in 1999 by the Swiss Federal Council (Bundesrat). The critical flow is thus set slightly lower than in 1997, while the current flow has dropped significantly. A slightly smaller eco-factor results.

Sulphur dioxide (SO_2)
and further acidifying substances

Sulphur dioxide 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 of aerosols.

Determination of the critical flow is based on the international Sulphur Protocol, which has been ratified by Switzerland. The protocol sets an emissions target which corresponds to a reduction of 78 % from the 1980 baseline. The eco-factor for SO_2 is significantly smaller than in 1997, which is attributable to the reduction in current SO_2 emissions with the critical flow remaining constant.

Sulphur dioxide makes by far the largest contribution to acidification. Specific eco-factors can be determined by means of characterization factors for further acidifying substances such as hydrogen fluoride, phosphoric acid and hydrogen sulphide (see Section 3.7.6, Table 20).

PM10 and diesel soot

PM10 is a mixture of soot, resuspended road dust, particles from the abrasion of pavings and tyres and substances attached to these (sulphate, nitrate, ammonium, organic carbon). PM is the abbreviation of "particulate matter", while the number gives the size of the particles (in micrometres). PM10 means that the particle size is below 10 micrometres. PM10 can enter the lung because of the small size of the particles. Numerous studies prove the correlation between PM10 levels in ambient air and complaints and diseases of the respiratory tract.

The harmfulness of the particles depends upon their size and composition. PM2.5–10 (size between 2.5 and 10 micrometres) can cause coughing, asthma attacks and other diseases of the respiratory tract. PM2.5 (size < 2.5 micrometres) remains in the lung much longer and accumulates there, as it is not readily coughed up. It can cause cardiac arrhythmia and cardiovascular diseases. Diesel soot particles, which count among the ultrafine particles (PM0.1), can enter the bloodstream and the lymphatic system via the lung. They are considered carcinogenic and are thus particularly hazardous to human health.

Although it must be assumed that PM2.5 is more harmful than PM2.5–10, the legislator has not distinguished between the two. A distinction is made, in contrast, between PM10 and diesel soot. Accordingly, in addition to the previous eco-factor for PM10, a new one for diesel soot has been introduced. The critical flow for PM10 was determined on the basis of the limit values established by the Swiss Federal Ordinance on Air Pollution Control (Luftreinhalteverordnung). While PM10 emissions have dropped since 1997, the eco-factor is nonetheless higher because of the lower critical flow. No threshold value has been established for diesel soot, but the Ordinance on Air Pollution Control requires that as much is done to reduce emissions of carcinogenic substances as technology and operating conditions will allow, providing this is economically acceptable (precautionary principle). The introduction of stricter standards and the possibility of using particle filters results in the critical flow stated in the table. Because of the major human health impact of diesel soot particles, the eco-factor for diesel soot is 100 times higher than that for PM10.

Benzene

Benzene enters the atmosphere when mineral oil products are burnt. Small quantities of the substance are already contained in crude oil, and further benzene is formed during refining. Motorized transport is the source of three-quarters of all benzene emissions in Switzerland.

Benzene is taken into the body via the respiratory tract, and is stored in fatty tissue. As women have a higher body fat ratio than men, the impacts of this pollutant are greater for women. There is unequivocal evidence that benzene harms blood formation and that long-term exposure can lead to leukaemia. Furthermore, it must be assumed that benzene is mutagenic.

Even small quantities of benzene are harmful to human health. According to FOEN benzene emissions would need to be brought down to 100 t per year if the acceptable risk is not to be exceeded. This reduction target is not achievable today by measures that are economically acceptable and feasible in terms of technology and operating conditions. Reduction targets for specific emission sources for the years 2010 and 2030 are therefore used to determine the critical flow. The new eco-factor is 100 times higher than in the earlier assessment, when benzene was classed as an NMVOC; this is justified in view of its carcinogenic effect.

Dioxins and furans

Polychlorinated dibenzodioxins and dibenzofurans (PCDD and PCDF, usually simply termed dioxins and furans) are chlorinated aromatic hydrocarbons. There are in total 76 polychlorinated dioxins and 135 polychlorinated furans. The substances differ in their numbers and positions of chlorine atoms. They are formed in technological but also in natural combustion processes in the presence of chlorine. They accumulate in the food chain and some are highly toxic to humans and animals. Dioxins impair embryonal development in several ways. In particular, they appear to give rise to miscarriage, deformity of (genital) organs, and intellectual deficits.

As a result of continuous improvements in flue gas purification in industry, the burning of wastes and treated wood in private households will become the main source of emissions in the near future in relative terms. Applying the precautionary principle – under which the measures that are technologically and operationally feasible and economically acceptable are the standard – it is possible to halve the current flow. The critical flow was set accordingly. The eco-factor for dioxins and furans is very high. This is an expression of the low emission quantities in the order of several grams per year, and further reflects the great harmfulness of these substances and the available reduction options.

Lead

Lead emissions damage animals and plants. Lead harms soil fertility and accumulates in food chains. In humans it can impair blood formation and can cause developmental disorders in children.

Because lead was blended into petrol from the 1950s onwards, lead emissions rose sharply. This trend has reversed thanks to the emergence of unleaded petrol from 1970 onwards. Further uses of lead include batteries, paints and lead for bullets. The presently remaining emissions are caused largely by waste incineration plants and the steel industry.

A new feature of the present eco-factor is that it is derived from soil protection targets – this approach is based on statements made in the Swiss Federal Ordinance on Air Pollution Control. Heavy metal emissions to air that are finally deposited and enter the soil are weighted in the same way as direct lead emissions to soil. This new derivation results in an eco-factor that is around ten times higher than the previous one.

Cadmium

Cadmium is taken in mainly via the respiratory tract. Even small quantities are toxic to humans and animals if exposure is chronic. The heavy metal accumulates in the body, where it can cause cancer and disturbs storage of other, vital metals. The consequences of chronic cadmium exposure can include diseases of the respiratory tract, kidney damage, and anaemia due to iron deficiency. Moreover, cadmium is toxic to plants and microorganisms and impairs soil fertility.

As a result of measures implemented in waste incineration and in the metal industry to reduce airborne emissions, cadmium emissions have dropped significantly since 1980. The main applications of cadmium were alloys and the production of dry batteries and colouring pigments. Today, the use of cadmium is banned for many applications.

No critical flow can be derived from the ambient limit values set by the Swiss Federal Ordinance on Air Pollution Control. Therefore, as in the case of lead, a critical flow is derived from soil protection targets. Despite a trend towards lower emissions, the new derivation results in an eco-factor that is about four times higher than the 1997 eco-factor.

Mercury

Mercury is highly toxic to humans and animals. It is taken in via the respiratory tract and accumulates in various organs. It is also toxic to plants and microorganisms and impairs soil fertility. Industry and commerce are the principal generators of mercury emissions. Emissions have dropped steadily in recent years; no further reduction is expected.

The strictest target of the Swiss Federal Council is to reduce emissions to the level of 1950. This value is taken as the critical flow. The eco-factor has almost doubled from 1997.

Zinc

Zinc exposure impairs plant growth. While emissions from industry and commerce are dropping, those from road transport are rising. Tyre and road wear is the main source of emissions, presently accounting for two-thirds. If the trend towards increasing zinc emissions from transport persists, it is to be expected that overall emissions will rise again.

No critical flow can be derived from the ambient limit values of the Air Pollution Control Ordinance. Therefore, as in the case of lead, a critical flow is derived from soil protection targets. The new derivation results in an eco-factor that is more than eight times higher compared to the previous eco-factor.

Emissions to surface waters

The eco-factors used to weight emissions to surface waters are based on loads that apply to the whole of Switzerland, and thus reflect an average situation. To perform an exact appraisal, it is necessary to take account of regional circumstances, notably the size of water bodies affected, which in view of the volume of work involved has only been performed for phosphorus. Separate eco-factors have been determined for emissions to groundwater.

Effluent treatment measures have led to a drop in emissions in the last decades. Thus in some cases impacts within Switzerland are of lesser importance. It needs to be taken into account, however, that the eco-factors are applied not only to Swiss processes, but also to processes taking place abroad. An eco-factor is therefore retained for substances which may be unproblematic in Switzerland, but have the potential to continue to be environmentally relevant abroad. This is the case if pollutant emissions are regulated by the international agreements on the protection of the Rhine or of the North Sea to which Switzerland is a signatory.

Nitrogen (N)

The sources of nitrogen emissions to waters are fertilizers from agriculture and effluents from industry, commerce and households. More than 90 % of anthropogenic total nitrogen inputs to surface waters consist of nitrate and ammonium or ammonia. Nitrogen loading is not a general problem anymore in Switzerland in ecological terms. It remains a concern in the North Sea, however, where its consequences – elevated algal growth and fish mortality (see phosphorus) – are issues.

Although the contribution of Switzerland to overall pollution of the Rhine is small, Switzerland has signed the declaration of intent of North Sea states. This envisages halving phosphorus and nitrogen inputs from the 1985 baseline. The target envisaged for 1995 has not yet been achieved to this day for nitrogen. The reduction achieved by 2003 was 29 %. The target is taken as the basis for setting the critical flow for total nitrogen. The eco-factor for nitrogen has dropped slightly, as nitrogen loading has been reduced substantially since 1997.

Phosphorus (P)

Elevated phosphorus loads lead to elevated algal growth in lakes and seas. Decomposition of dead algae in the deep water layers requires oxygen, which is then not available to other organisms. Oxygen deficiency and fish mortality result. Phosphorus (or phosphate) enters waters mainly through erosion and runoff from arable land. As a result, lakes in areas where agriculture is intensive are affected most severely.

The above-mentioned target of halving inputs to the North Sea has been achieved for phosphorus, but the protection target for Swiss lakes, in contrast, has not yet been achieved throughout the country. The loads of individual lakes vary widely, so that a regional differentiation was performed (see Table 33, Section 4.3.4).

The connection of households and commercial enterprises to sewage treatment plants and the ban on phosphates in textile detergents have succeeded in greatly reducing phosphorus loading over the last two decades. In agriculture, too, the situation has improved slightly, as in integrated agricultural production only the amount of phosphorus can be applied that is taken up by the crops. As a result, phosphorus concentrations have dropped even in the most severely polluted lakes. This relaxation of the phosphorus problem results in a substantially lower eco-factor.

Organic matter (COD)

In principle, all organic substances exert pressure on waters by requiring oxygen for their decomposition which is then no longer available to the fauna. A part of the organic matter comes from natural sources, and another from effluents. The principle is established in law that the organic matter arising in effluent must be reduced to the extent that no ecological detriment results for waters. In view of the available oxygen levels in waters, the residual load coming from effluent treatment facilities is non-critical in most cases. The toxicity of many organic substances is therefore of greater ecological relevance; this, however, is not taken into account here.

The critical flow can be derived from the Swiss Water Protection Ordinance, which requires that the organic matter arising in effluent is reduced to a level at which no ecological detriment results for waters. From an ecological perspective, downstream from the points of discharge of effluents organic matter should consume a maximum of 30 % of the average quantity of oxygen dissolved in water. The critical flow can thus be calculated on the basis of total runoff. Chemical oxygen demand (COD) is generally taken as the metric for the concentration of organic matter in waters. Other measures can be converted into COD values (see Table 35, Section 4.4.4).

Broad-scale effluent treatment, in combination with provisions governing effluent discharges, have led to a reduction of organic matter in waters. As a result of the lower current flow, the eco-factor is lower than in 1997.

Arsenic and heavy metals

Heavy metals and arsenic damage the aquatic ecosystem by accumulating in organisms, where they can cause growth impairments and metabolic disturbances. They propagate through the food chain. In Switzerland these substances are not a serious problem in the concentrations observed. If arsenic is ingested over long periods through drinking water, it can promote cancers of the skin and of the urinary bladder, but also other forms of cancer.

The Water Protection Ordinance sets limit values for seven environmentally relevant heavy metals: lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), mercury (Hg) and zinc (Zn). The Convention on the Protection of the Rhine, to which Switzerland is a signatory, sets stricter standards for heavy metals, so that these are taken as the basis for calculating the critical flow. The resultant eco-factors are substantially higher than those of 1997.

Radioactive emissions

One possible effect of radioactive radiation is to disturb or destroy the cell functions of organisms (somatic effects), which can cause cancer. Another potential effect is to change the genes of the cells (mutagenic effects). The eco-factor takes account of these two effects. It does not take account of the effects of radioactive radiation upon ecosystems, nor of the potential impacts of accident-related releases of large quantities of radioactive substances.

The emissions of Swiss nuclear power plants are well below the limit values. The eco-factor set out here refers only to the discharge of radioactivity to seawater by the reprocessing plants at La Hague (F) and Sellafield (GB), where fuel elements from Swiss nuclear power plants were reprocessed until July 2006. This eco-factor is defined for the first time here, as the reduction targets for the protection of the North Sea supported by Switzerland were only defined in recent years. Table 41 (Section 4.6.7) lists eco-factors for inputs of selected isotopes to the sea.

Adsorbable organic halogens (AOXs)

AOXs are a sum parameter of adsorbable organic halogenated substances that can be of both human and natural origin. They include substances such as chlorinated non-aromatic hydrocarbons (e.g. chloroform), chlorinated aromatic hydrocarbons, polychlorinated biphenyls (PCBs) and certain pesticides. Pulp production is a major source of AOX emissions. Overall, AOX contamination of surface waters in Switzerland has declined substantially in recent years.

The environmental impact of the compounds grouped as AOXs varies widely. However, subdividing AOXs into distinct, homogeneous substance classes or even individual substances would only be practicable to a limited extent. A single eco-factor for all AOXs is therefore a necessary compromise. As AOXs now only play a minor role in water resources protection, a more exact determination is not of prime concern. A separate eco-factor is only derived for chloroform.

An important criterion of toxicity is the propensity of a substance to accumulate in organisms. The more highly chlorinated a substance is, the more toxic it is. The eco-factor is therefore defined in relation to chlorine, i.e. it rises in step with the number of chlorine atoms.

The international association of waterworks in the Rhine catchment area IAWR has set a non-legally-binding emissions target for AOXs, which corresponds to the standards required for potable water supply. This provides a basis for calculating the critical flow. As the current flow has dropped while the critical flow has remained the same, the eco-factor is lower than in 1997.

Chloroform

Chloroform is a substance within the AOX group that was formerly in widespread use. It was used as a dry-cleaning agent, and as a solvent and disinfectant. Chloroform is considered potentially carcinogenic and is banned today, with very few exemptions. As a result, loads have dropped substantially. The weighting factor is determined from the measured current concentration and the critical concentration. The critical concentration results from the target value established by the Convention on the Protection of the Rhine. The resulting new eco-factor for chloroform is several times higher than that for the other AOXs.

Polycyclic aromatic hydrocarbons (PAHs)

PAH emissions are the result of combustion processes and of abrasion particles being washed from roads. Some PAHs are highly toxic and carcinogenic. As they occur exclusively in suspended matter, their distribution depends upon the concentration of suspended solids in waters. The most frequent PAHs are compiled in Annex 3.

Previously there was no eco-factor for PAHs as the available data did not suffice. The weighting factor is calculated from the measured current concentration and the critical concentration in accordance with the target value established by the agreement on the protection of the Rhine. The eco-factor reflects the harmfulness of certain PAHs and the small quantities discharged to waters.

A separate eco-factor is established for benzo(a)pyrene. All other PAHs are assessed using a generic PAH eco-factor, as the available data does not suffice to conduct a further characterization of individual substances.

Benzo(a)pyrene (BaP)

BaP is a PAH (see above). It is formed in the incomplete combustion of organic material, e.g. in furnaces and engines, but also in cigarettes. BaP pollution in waters stems largely from wood preservatives containing creosote, for instance from railway sleepers. Today, the use of creosote is only permitted – with restrictions – for commercial applications. BaP is certainly carcinogenic in animals, and probably in humans. The procedure for deriving the eco-factor is analogous to that for the other PAHs. Its eco-factor is about twice that of the other PAHs; this is justified because BaP is highly toxic and carcinogenic.

Endocrine disruptors

Hormones are chemical messengers between tissues and cells that regulate processes in the body. Endocrine disruptors are hormonally active exogenous substances with the capacity to disrupt the hormone system (also termed endocrine system). They are already effective in small quantities. As hormonal processes are similar in many organisms, a single endocrine disruptor can impact upon very many different organisms. Fertility disturbances have been proven in numerous aquatic and terrestrial animal species. Concentrations of endocrine disruptors that cause feminization effects in male fishes have been found close to the discharge points of sewage treatment plants. This disrupts via the food chain the reproductive capacity of, for instance, the otter Lutra lutra, which has led to the species becoming severely endangered in Switzerland. In humans, substances that disrupt the reproductive endocrine system are considered responsible for developmental abnormalities of embryos, reduced fertility, and breast, testicular and prostate cancer. Intake of the substances can be via the digestive system, the skin or the lungs.

A hormonally active effect is attributed to a broad range of chemicals. It has been proven for the following substances: natural and artificial oestrogens, various pesticides containing organochlorine compounds, certain industrial chemicals used in plastics, various dioxins and furans, organotin compounds from anti-fouling ship paints among other sources, and certain UV filter substances contained in sun lotions. It must be expected that many substances have not yet been identified as endocrine disruptors, as many of the chemicals presently on the market have not yet been tested for their hormonally active effect.

As no statutory limit values have yet been established for endocrine disruptors, calculation of the eco-factor uses a target value below which expert judgement holds that no chronic effects should occur. Assessment of endocrine disruptors takes the oestrogen potential of E2 (17-oestradiol) as reference. The eco-factors of further endocrine disruptors can be determined by means of characterisation factors shown in Table 50 (Section 4.11.6.).

Emissions to groundwater

Strict quality standards apply to Swiss groundwater, as 80 % of drinking water comes from this source. The eco-factors only assess nitrate because this is the only substance for which quantifiable data is presently available. In addition, however, plant protection products and volatile halogenated hydrocarbons are relevant groundwater contaminants to which quantified standards apply (plant protection products exceed the standards set by the Swiss Water Protection Ordinance at some 10 % of the monitoring wells operated by the Swiss groundwater monitoring system; the standards for volatile halogenated hydrocarbons are exceeded at around 7 % of the wells).

Nitrogen (nitrate)

The main source of nitrate pollution is nitrogen fertilizer applied to fields, which is readily washed out from the soil into groundwater. In areas where farming practices are intensive, nitrate concentrations in groundwater are measured that exceed the 25 mg/l limit set by the Swiss Water Protection Ordinance, and in some cases even exceed the 40 mg/l tolerance value for drinking water. FOEN calls for the nitrate flow of 1990 to be halved; this delivers the critical flow. In contrast to nitrate in surface waters, nitrate in groundwater continues to be problematic; the eco-factor is thus higher than the eco-factor for nitrogen loading of surface waters, but has not changed from 1997.

Emissions to soil

The aim of the various statutes adopted at national level is to maintain soil fertility over the long term. In addition to the pollutant loads addressed in this section, soil fertility is also endangered by the paving-over of soils, by erosion, and by compaction due to machine use. These factors are assessed partly via the “land use” eco-factor.

The quality of soils in Switzerland is impaired by various substance-related impacts. These include acidification, overfertilization and loading with heavy metals and organic pollutants. Soils are polluted on the one hand directly by substance inputs from plant protection and fertilization activities, but also indirectly through the deposition of airborne pollutants (heavy metals, nitrogen). Non-point airborne inputs to soils are assessed at the point of their emission to air.

Substance loads generated by agriculture are inventoried at the point where they no longer contribute to agricultural use of soils. For nitrate this is when it is washed into the groundwater, for phosphate when eroded or washed into surface waters, and for ammonia and nitrous oxide when emitted to air. These substances are therefore treated in the corresponding sections. As a result, the present section only addresses heavy metals and plant protection products, as these are already pollutants when they enter the soil.

Heavy metals
(lead, cadmium, copper, zinc)

Heavy metals impair plant growth and disturb soil fertility. Because plants can build available heavy metals into their biomass, these accumulate in food chains. If heavy metals are ingested at high doses and over longer periods, this can lead to chronic poisoning. Cleaning up soils contaminated with heavy metals requires major resource inputs.

In order to maintain soil fertility over the long term, the article specifying the purpose of the Swiss Soil Pollution Ordinance states that no accumulation of heavy metals in soils must occur, meaning that inputs can at most be equal to outputs from soil. The calculation of current loads was based on spot-check measurements. This new manner of derivation leads to substantially higher eco-factors for the above-mentioned heavy metals, as the eco-factor now only applies for non-settlement areas. The increase is most striking for lead, which is due to the rather generous ambient limit values previously set. Copper and zinc have an almost identical eco-factor. For cadmium – the current flow is smaller than the critical flow – the increase in the eco-factor compared to 1997 is minor.

Plant protection products

Plant protection products include crop protectants and plant growth regulators, as well as postharvest protection products. These can be substances, preparations, organisms or other agents. The eco-factor assessment only addresses chemical-synthetic plant protection products. These are applied above all in open arable farming, and in fruit growing and viticulture.

The associated environmental problems are a function of the primary effects, the quantities and rates of degradation of the active agents, and the types and behaviour of degradation products and residues. They can have unintended adverse effects upon biodiversity in the areas on which they are applied, also affecting spiders, myriapoda and birds. Because plant protection products are dispersed directly or with the wind by being attached to soil particles, they are also detectable in mountain lakes and in rainfall. Human health impacts arise notably in drinking water use.

The Swiss Federal Office for Agriculture had set itself the target of reducing the application of plant protection products by 30 % by the year 2005 from the 1990/1992 baseline. The use of novel plant protection products that are effective in small quantities, in combination with extensification programmes and the expansion of organic farming practices, has led to a marked drop in consumption, resulting in a slightly lower eco-factor. That trend will continue.

Characterization is performed with reference to the standard dose of an average plant protection product (PPP) applied in Switzerland, the PPP-equivalent (PPP-eq). The 20 active agents most sold in Switzerland and the approximately 80 pesticides listed in the ecoinvent v1.2 life cycle inventory database are characterized (see the full list in Annex 4).

Resources

In the past, the ecological scarcity approach only took account of the consumption of energy resources. Now, for the first time, it embraces further resources – namely freshwater, gravel and land use – as these are increasingly considered ecologically scarce. In addition, a further new feature is that a distinction is made in the energy resource category between renewable (limited rate of replenishment) and non-renewable (limited stock) energies. An eco-factor is assigned to renewable energies as it must be assumed that for them, too, there is an upper limit to use.

Energy resources

The long-term target of becoming a "2000 watt society", as envisaged by the Swiss Federal Council, calls not only for a reduction in energy consumption, but also for an increase in the contribution made by renewable energy sources: Of the 2000 watts per person, 1500 are to come from renewable sources. As a consequence renewable energies need to supply three times more energy than the non-renewable sources. It follows from this political evaluation that 3 MJ of energy from renewable sources are rated with the same weight as 1 MJ from non-renewable sources. The weight assigned to non-renewable energies is appreciably higher than in the past, while renewable energies retain practically the same value. The eco-factor for renewable energy, which was previously only applied to hydropower, now also applies to all other types of energy production. In a manner similar to the approach taken for greenhouse gases, an interim target is interpolated for the year 2030 on the basis of the long-term target to be achieved by 2050.

The overview table states the average eco-factor for non-renewable energy resources in EP/MJ-eq, while Table 65 (Section 7.2.7) lists in detail the individual primary energy carriers. The eco-factor for energy consumption only assesses the scarcity of the energy resource. The other environmental impacts generated by the emissions from energy use are captured by means of the eco-factors for emissions to air, water and soil.

Land use

Land-use statistics break down the area of Switzerland, which totals 41 286 km^2, into the following types of use: settlement and urban areas (buildings, transportation areas, recreational and open green spaces, landfills, building sites), agriculturally utilized areas (grassland, arable land, orchards), wooded areas (forest, shrub forest, woods), unproductive areas (rock, ice, lakes, rivers, glaciers).

The overall settlement area is growing at a rate of around one square metre per second, mostly at the expense of agricultural land in the Swiss plateau (the Mittelland region of Switzerland). This is driven by a growing population, in combination with growing levels of land take per person. The target of the Swiss government set out in the 2002 strategy for a sustainable Switzerland is to meet further demand wherever possible by means of inward development, i.e. improved utilization of existing settlement areas. Sparing use should be made of soils, and action should be taken to counter urban sprawl. Specifically, for a future population of 8.06 million, settlement area is to be stabilized over the longer term at a level of 400 m^2 per inhabitant. This delivers the critical flow.

Land use is characterized in terms of the plant diversity of a land-use type. The "settlement area" land-use type taken as basis for characterization is a mixture of highly disparate types of area, ranging from urban green spaces to industrial estates. The metric is the settlement area utilized during a year (settlement-area-and-year equivalent, SA*a-eq). Land-use forms exhibiting great plant diversity, such as agricultural fallows or forest margins, are assigned a negative impact factor in view of their positive environmental effect. Table 67 (Section 7.3.6) states the eco-factors of selected individual land-use types, while Annex 5 provides the full list.

Gravel

Gravel in mineral deposits is an important material for the formation and protection of groundwater. Gravel extracted from deposits is used mainly in the construction industry, especially as a concrete aggregate and in road and railway subgrades. Gravel resources are replenished very slowly: Only around 1 % of Switzerland's annual gravel consumption is formed anew in rivers in the same period. Moreover, the quality of gravel deposits differs widely, and the extractable quantity is much smaller than the resource. Hence an eco-factor was newly introduced.

As the quantity extracted annually ranges between 30 and 40 million tonnes, the gravel reserves designated for extraction in Switzerland suffice for 15 to 20 years. Although the resource is finite, the current quantity extracted is tolerated by the responsible cantonal spatial planning authorities. The critical flow thus corresponds to the current flow. The eco-factor for gravel, now set for the first time, captures a special case in the realm of land-use concerns: the level of gravel extraction that is legally and environmentally acceptable.

Freshwater

Switzerland is in the fortunate position of commanding over more than enough clean water. Nonetheless, in its 2002 strategy for a sustainable Switzerland, the Swiss Federal Council, noting the global freshwater problems, calls for sparing use of this resource, too, for Switzerland.

Freshwater is scarce in some regions of the world, while in others there is a surplus. Eco-factors are determined on the one hand for specific countries (for Switzerland and further OECD states), and on the other hand for six different scarcity situations (low, moderate, medium, high, very high and extreme). This permits – depending upon the life cycle inventory available from case to case – a highly differentiated analysis. It is thus possible for the first time – for instance in life cycle assessments of foods – to take account of the actually observed water scarcity in a region of origin. When required to explore specific issues, users of the method can themselves derive regional or local eco-factors. If, in contrast, water consumption data is not available with a sufficient degree of differentiation, the average for OECD countries, which is also calculated here, can be used as a first approximation.

In accordance with the OECD procedure, the scarcity of freshwater resources is measured as the share of gross consumption in the available renewable water resource. Gross consumption comprises drinking water requirements and water extractions for agricultural irrigation and industrial processes. The available renewable resource is calculated from annual precipitation on the area of the state, plus inflows from neighbouring states, minus evaporation. The OECD considers a moderate to medium pressure on water resources to be tolerable. On that basis, the critical flow is set as being a gross water consumption that amounts to 20 % of the available renewable freshwater resource.

The annual available water resource in Switzerland is 53.5 km³. The tolerable pressure on Swiss water resources is 20 % of the available resource, which amounts to 10.7 km³ per year. Gross consumption in Switzerland is 2.57 km³ per year (around 350 m³ per capita and year or 1000 litres per capita and day), which corresponds to just below 5 % of the available renewable water resource. Although there is thus no water scarcity in Switzerland, local water shortages can arise in summer. The eco-factor stated here does not capture such temporarily and spatially limited situations.

The available renewable resources of all OECD states total 10 300 km³ per year. The tolerable pressure on water resources is 2050 km³ per year. Gross consumption is 1020 km³, which is just below 10 % of the available renewable resource. While in general this translates into a “low” level of water scarcity, the eco-factor for the average of all OECD states is nonetheless higher than that for Switzerland by a factor of 5. Annex 6 lists the data and eco-factors for the individual OECD states.

Numerous other countries have “low” to “medium” water scarcity, corresponding to eco-factors spanning a factor of around 40. In contrast, there is almost a factor of 1000 between the eco-factors in the “low” and “extreme” categories. This reflects the severe over-exploitation in arid regions such as Saudi-Arabia, where more freshwater (especially groundwater) is utilized than is available from precipitation and inflows. Table 72 (Section 7.5.5) lists the eco-factors for the categories of the scarcity scale, while Table 74 (Section 7.5.7) classes a representative selection of states on that scale.

Wastes

In the following, we discuss the eco-factor for substances in aboveground bioreactive landfills, for hazardous wastes stored underground, and for radioactive wastes.

Carbon in bioreactive landfills

The Environmental Protection Act stipulates that wastes with a potential to cause long-term problems must not be stored in landfills in Switzerland. The indicator for the reaction potential of waste is its carbon (C) content, which should be kept as low as possible. Wastes deposited in aboveground landfills are therefore assessed on the basis of their carbon content. Slags contain an estimated 4 % C, while the average for other wastes consigned to bioreactive landfills is 15 %. 661 500 tonnes of slags are consigned annually to such landfills, plus 473 000 tonnes of other wastes. The current C flow can be calculated from these figures.

According to FOEN, the target for the C content in bioreactive landfill wastes is 7 %, from which the critical flow can be determined. The eco-factor is listed here for the first time. Wastes consigned to landfills for inert materials or to landfills for stabilized residues contain practically no reactive organic material, and are not taken into account in the annual flows on which the eco-factor is based.

Hazardous wastes
in underground landfills

There are no underground landfills in Switzerland. Of the 1.1 million tonnes of hazardous wastes arising annually, 90 % are treated within the country. Around one-third is incinerated. The remainder is either recycled, consigned to physical-chemical treatment or stored in a landfill for stabilized residues.

The remaining 10 % of hazardous wastes are exported. Of this, in turn, one-third is made up of the filter dusts from municipal solid waste incineration plants, which are stored in underground landfills. As these wastes cannot be stored expediently within Switzerland, the current flow is tolerated and is equated with the critical flow for weighting purposes. The present eco-factor, which is slightly higher than that of 1997, relates exclusively to these stored hazardous wastes.

Radioactive wastes
in final repositories

Electricity produced by nuclear power plants generates radioactive wastes that must eventually be consigned to final storage. The hazardousness of radioactive wastes depends upon their persistence (half-life), and on the type and intensity of their radiation. The Swiss strategy for a final repository classes radioactive wastes in two categories:

1. Short-lived low-level and medium-level wastes present a low degree of hazard after a relatively short period. A necessary shut-in time of 500 years is anticipated.
2. Long-lived medium-level wastes (LMLW), high-level wastes (HLW) and spent fuel elements must be stored safely for at least 100 000 years.

The Swiss Nuclear Power Act establishes that radioactive wastes arising in Switzerland must be disposed of within the country. No decision on a site for the required final repository is to be expected in the near future.

Including the encasement materials and assuming that the service lives of nuclear power plants are extended from 40 to 60 years, around 8300 m^3 spent fuel elements, around 1000 m^3 HLW from reprocessing and 3460–7260 m^3 LMLW will arise in Switzerland. Overall, therefore, the deep repository will need to accept around 16 000 m^3 long-lived high-level and medium-level radioactive wastes. Storage volume in the order of 115 000 m^3 is envisaged for the final storage of short-lived low-level and medium-level wastes, the bulk of which also comes from the operation and decommissioning of nuclear power plants.

There is no political consensus on the tolerable quantity of radioactive wastes. There would be an argument for setting the tolerable level at the level of the current flow, but also for setting it at zero. For the purposes of determining the eco-factor, the critical flow is set at half the current flow as a first approximation. This reflects the current situation, in which efforts are under way with regard to a final repository, but no specific construction project is in progress. The eco-factor has not changed from 1997 for short-lived low-level and medium-level wastes. For fuel elements, LMLW and HLW it has been re-assessed at 40 % of the previous value due to the larger expected volume of wastes as a result of the extension of the service lives of nuclear power plants by 50 %.

Noise

Noise pollution is an ubiquitous problem that severely affects the cities in particular. The main sources are road and rail vehicles, agricultural and silvicultural machines, aircraft, motorboats, building sites, shooting ranges and sports facilities. The Swiss Noise Abatement Ordinance defines the noise target that is to be achieved – in analogy to the precautionary principle – as what technology and operating conditions will allow providing this is economically acceptable. A further goal is that there should be no severe nuisance to the affected public.

The basic problem in assessing noise is that, in contrast to substance emissions, sound quickly dissipates and is therefore always locally contained. A further problem is that assessment can only be performed on the basis of the ambient situation, which, moreover, is conditioned by subjective perceptions. An assessment method has albeit been developed within the context of the ecological scarcity methodology for road traffic noise; this, however, is not readily transferable to noise from other sources and would, in its original form, lead to a one-sided assessment of road traffic. As there is thus no generally recognized method for assessing noise in life cycle assessments, no eco-factor was derived for the present.

1 > Introduction

1.1 Position of the ecological scarcity method in relation to life cycle assessment (LCA)

The ecological scarcity method makes it possible to weight environmental impacts within the context of a life cycle assessment of products, processes or entire organizations (production sites, companies, etc.).

The method requires as input parameters the outcomes of a life cycle inventory analysis. The result is a weighting of these inventory analysis results, expressed as "eco-points" (EP). In other words, the inventory analysis parameters (e.g. CO_2 emissions) are multiplied by the respective eco-factor (310 EP/kg CO_2 in this case) in order to receive the eco-points of the parameters in question. These eco-points can then be added up to deliver an aggregate score.

For a company or other stakeholders, it can be highly informative to assess the environmental impacts of products or of a company in this manner, as the eco-points reflect the priorities of public environmental policy. The results of such an assessment can support decision-making in product development, and in management, procurement and consultancy.

1.2 Terminology

The method presented in this report is known under various names, including "ecological scarcity method", "ecoscarcity method" and "eco-points method" (or, in German: Methode der ökologischen Knappheit, Methode BUWAL 133, Stoffflussmethode, Ökopunktmethode, UBP-Methode and others). In this publication, **"ecological scarcity method"** is used to designate the method. The established name for the *measure* of ecological scarcity is "eco-points" (EP; in German: Umweltbelastungspunkte, UBP).

1.3 Structure of the report

The report commences with a presentation of the fundamentals of the ecological scarcity method in Chapter 2. The formula used to calculate the eco-factors is explained, and further specified in sections on derivation rules (Section 2.2), on application (Section 2.3) and on data quality (Section 2.4). The derivations of the specific eco-factors are presented in Chapter 3 onwards, whereby the characterizations used are explained separately in the preceding Section 2.5.

The structure of the methodology chapter, and that of the sections on the individual eco-factors, is organized around the basic elements of the formula representation or calculation sequence. This results in the following structure:

1. Ecological relevance (only in the chapters on the individual eco-factors)
2. Characterization (insofar as applied)
3. Normalization
4. Weighting (with sections presenting the current and critical flows)
5. Eco-factor
6. Application guidance (where necessary)

2 > Methodological fundamentals

2.1 The ecological scarcity method

2.1.1 The basic principle

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

Weighting is based primarily on environmental protection targets set at national level and, in some cases, international level. Such 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 to sustainability as far as possible.

Weighting is conducted on the basis of the goals set by Swiss environmental policy; here – as in the determination of target values – local and global impact categories are converted to the Swiss level. The method can also be applied to other regions. Thus, for instance, eco-factors have already been developed for Holland, Norway, Sweden (Nordic Council of Ministers 1995, Table A22 / A23), Belgium (SGP 1994) and Japan (Miyazaki et al. 2004).

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

The method converts the various environmental impacts into points, so that these values can be added and compared. The eco-factors thus have the formal nature of a utility value analysis, whereby they can be determined from the current environmental situation (current flow), the target situation aimed at by environmental policy (critical flow) and the calculation algorithm (see Section 2.1.3).

2.1.2 Previous formula and derivation of the new 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 LCAs for packaging materials published by BUWAL, the precursor agency from which BAFU/FOEN emerged, in 1984 (Ahbe et al. 1990).

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

$$\text{Eco-factor} = \frac{1\,EP}{F_k} \cdot \frac{F}{F_k} \cdot c \qquad (1)$$

F = Current flow: current annual pollutant load or resource extraction, in Switzerland

F_k = Critical flow: critical annual pollutant load or resource extraction, in Switzerland

c = 10^{12}/a

EP = Eco-point (the unit of the evaluated result)

In the update performed by Brand et al. (1998) the formula was retained unchanged. The following reasons have now prompted a mathematical reformulation and careful modernization of this formula:

- The international LCA Standard ISO 14042 prescribes the basic structure of impact assessment. As set out in Section 2.1.3, the aim is to largely comply with these prescriptions.
- Environmental concerns can vary greatly in time and place. This is, for instance, the case for the freshwater resource, which is very scarce in some regions of the world, but available in surplus in others. As there is no water scarcity in Switzerland, there was until now no eco-factor for the freshwater resource. As a result, these aspects, which may be of environmental relevance, could not yet be taken into account in LCA studies of foods and resources from arid regions (e.g. tomatoes from southern Spain, or cotton from India). The new formula permits both regional and temporal differentiation.

As the new representation is based on a mathematical reformulation, great continuity is ensured, whereby

- if the critical and current flows of a pollutant are unchanged, then the same eco-factor results from the revised formula as it did from the original formula,
- the linear dependence of the eco-factor (as a percentage of the critical flow) upon the ratio of the current to the critical flow remains,

- the characterization applied in the past of pollutants that have the same type of impact (e.g. GWP and CO_2) remains, but is facilitated through systematization,
- application of the eco-factors can proceed as in the past, through provision of a table listing the eco-factors for 2006, with which the inventory analysis outcomes can be weighted.

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

With the previous formula (1), normalization was initially performed on the basis of the critical flow and weighting then performed using the ratio of F to F_k. Equation (2) shows the form extended by the current flow F/F. Reconfiguration of the coefficients leads finally to equation (3), the starting point for the new eco-factor formula (4), which is explained in the following section.

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

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

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

2.1.3 Ecological scarcity and eco-factor calculation

The formula

The ecological scarcity method weights environmental impacts – i.e. pollutant emissions and resource extractions – with “eco-factors”. The eco-factor is derived from environmental law or corresponding political targets. In its basic form, it can be structured in accordance with ISO Standard 14042 in three elements

- characterization
- normalization and
- weighting

(International Organization for Standardization (ISO) 2000). The starting point for the new eco-factor formula is equation (3) as set out above.

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

$$\text{Eco-factor} = \underbrace{K}_{\substack{\text{Characterization}\\ \text{(optional)}}} \cdot \underbrace{\frac{1 \cdot \text{EP}}{F_n}}_{\text{Normalization}} \cdot \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \cdot \underbrace{c}_{\text{constant}} \tag{4}$$

with: **K** = **Characterization factor** of a pollutant or of a resource
Flow = Load of a pollutant, quantity of a resource consumed, or level of an environmental pressure characterized
F_n = **Normalization flow:** current annual flow, with Switzerland as system boundary
F = **Current flow:** current annual flow in the reference area
F_k = **Critical flow:** critical annual flow in the reference area
c = Constant (10^{12}/a)
EP = **Eco-point:** the unit of the assessed result

Characterization

Characterization factors are determined for pollutants and resources that can be allocated to a specific environmental impact (for instance, global warming). Here the effect of a certain pollutant (e.g. the global warming potential of methane) is placed in relation to the effect of a reference substance (carbon dioxide in this case). Section 2.2.4 discusses the rules for applying the characterization. Characterization was already introduced in the previous version of the ecological scarcity method (climate change, ozone depletion, acidification and primary energy).

Normalization

Normalization serves to adjust the scarcity situation (weighting) to the present pollutant emissions or resource extractions in a region. ISO 14042 and the relevant SETAC publications also proposed conducting normalization on the basis of the present flows of a region.

Scarcity (weighting) is a dimensionless quantity determined exclusively by the ratio of the current to the critical flow, but not by the absolute values of these flows. Normalization adjusts (normalizes) the assessment to Swiss conditions. Therefore **normalization is performed on the basis of the annual pollutant emissions or resource extractions for the whole of Switzerland.**

Weighting

The final weighting of pollutants or resources or of characterized environmental impacts is performed on the basis of their “distance-to-target” – or **“ecological scarcity”.** To do this, the method uses on the one hand the total present flows of an environmental pressure (current flows) and, on the other hand, the flows of the same environmental pressure considered to be the maximum permissible level within the context of environmental policy goals (critical flows). Depending upon the way the specific environmental target or environmental legislation is formulated, either individual substances or (characterized) environmental impacts are considered.

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

Weighting is a dimensionless quantity determined exclusively by the **ratio of the current to critical flow.** The absolute level of the flows has no influence whatsoever upon the weighting. Thus, regardless of whether, for instance, there is a current flow of 2000 t/a and a critical flow of 1000 t/a or of 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

The factor 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 eco-factor

The unit in which the eco-factor is expressed is “eco-point (EP) per unit of environmental pressure”, e.g. “30 EP per gram SO_2”, or “eco-points (EP) per unit of environmental impact”, e.g. “0.31 EP per gram CO_2-equivalent”.

The new representation of the formula now makes it possible to determine eco-factors that are differentiated temporarily and spatially, and to determine eco-factors for subgroups of certain pollutants – all of which are fully compatible with the basic scheme and with the annual eco-factors for Switzerland and can thus be combined seamlessly. The following sections present the options for differentiation.

2.1.4 Regionalization of eco-factors

The breakdown of the eco-factor into characterization, normalization and weighting terms now 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. Normalization is performed on the basis of the current flow of the region to which the eco-factor is to apply, which, in our case, is Switzerland (see equation (5)). Equation (5) corresponds to equation (1) if Region 1 is identical to Switzerland.

$$\textit{Eco-factor}^{Region\,1} = K \cdot \frac{1 \cdot EP}{F_n^{\,CH}} \cdot \left(\frac{F^{\,Region\,1}}{F_k^{\,Region\,1}} \right)^2 \cdot c \qquad (5)$$

with: K = Characterization factor of a pollutant or of a resource

F_n^{CH} = Normalization flow: current annual load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, with Switzerland as system boundary

$F^{Region\ 1}$ = Current flow: current annual load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, with Region 1 as system boundary

$F_k^{\text{Region 1}}$ = Critical flow: critical annual load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, with Region 1 as system boundary
c = $10^{12}/a$
EP = Eco-point (the unit of the assessed result)

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

1. A weighting factor determined for a certain region can be normalized to Switzerland and thus integrated in the assessment. For instance, a regional weighting factor can be calculated for freshwater consumption in North Africa on the basis of the current and critical flows there. Account can thus be taken of the much greater scarcity of freshwater in North Africa compared to Switzerland. Normalization to the current Swiss flow results in an eco-factor compatible with Swiss eco-factors which represents the scarcity situation in North Africa. Using this eco-factor, water consumption taking place in North Africa 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 the whole of Switzerland. For instance, the state of Swiss waters varies greatly. Lakes in the central plateau (Mittelland), such as the Greifensee or the Hallwilersee, have greater phosphorus pollution levels than, for instance, the Brienzersee or Lake Constance. Measures taken to improve the situation in lakes where pollution levels are previously higher lead to a greater reduction of environmental impacts.
3. In cases where Swiss environmental policy is guided by binding international objectives, weighting factors can be calculated for regions larger than Switzerland on the basis of these goals. Such weighting factors applying to, for instance, the European level, are then normalized to the Swiss situation. Thus, for instance, Switzerland has agreed with the North Sea states that nitrogen discharges to the North Sea be reduced by half from 1985 levels.

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

$$\textit{Eco-factor}^{\text{CH}} = \textit{Eco-factor}^{\text{Region 1}} * r_1 + \textit{Eco-factor}^{\text{Region 2}} * r_2. \qquad (6)$$

with: r_1 = Share of the current flow of Region 1 in the current flow of the whole of Switzerland
r_2 = Share of the current flow of Region 2 in the current flow of the whole of Switzerland

Through the quadratic function of the weighting factor, an eco-factor differentiated in this manner will tend to carry greater weight than the corresponding, uniform eco-factor. Spatial differentiation is thus not mathematically neutral, but gives greater weight to regions where environmental pressure is higher.

2.1.5 Temporal differentiation of eco-factors

In a similar fashion, the new formula representation permits temporal differentiation of weighting and thus of the eco-factor. For instance, a future assessment of noise could distinguish between different times of day. In the same vein, for certain airborne pollutants a distinction could be made for the current and critical flows in specific periods, such as the summer and winter halves of the year (cf. equation (7)).

$$\textit{Eco-factor}^{\textit{Period 1}} = K \cdot \frac{1 \cdot EP}{F_n^{\,Year}} \cdot \left(\frac{F^{\,\textit{Period 1}}}{F_k^{\,\textit{Period 1}}} \right)^2 \cdot c \tag{7}$$

with: K = Characterization factor of a pollutant or of a resource
F_n^{Year} = Normalization flow: current annual load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, with Switzerland as system boundary
$F^{\text{Period 1}}$ = Current flow: current load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, during Period 1 (e.g. in daytime or in summer half of year), with Switzerland as system boundary
$F_k^{\text{Period 1}}$ = Critical flow: critical load of a pollutant, quantity of a resource consumed or level of an environmental pressure characterized, during Period 1 (e.g. in daytime or in summer half of year), with Switzerland as system boundary
c = 10^{12}/a
EP = Eco-points (the unit of the assessed result)

The resulting eco-factors can then in turn be weighted, and aggregated to form a daily or annual average. This is illustrated for the example of two periods:

$$\textit{Eco-factor}^{\text{Year}} = \textit{Eco-factor}^{\text{Period 1}} * p_1 + \textit{Eco-factor}^{\text{Period 2}} * p_2 \tag{8}$$

with: 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 would also be conceivable, such as four periods in accordance with the four seasons of the year.

Here again, as in regional differentiation, situations in which the current flow is substantially above 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.

2.1.6 Eco-factors for pollutant sub-groups

In certain cases, the legislator has adopted an environmental target for a group of pollutants (such as PM10), but not for individual sub-groups that may be analysed separately in inventories or which users of the method may wish to examine separately for other reasons (as such PM2.5). In such a situation all sub-groups should receive the same eco-factor as the entire group, as the applicable environmental law provides no grounds for differentiation[2]. It follows that the formation of pollutant sub-groups (PM2.5 and PM2.5–10) – when the same environmental target applies to all sub-groups – must have no influence upon the level of the eco-factor.

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

Eco-factors for parts of a pollutant group can now be formed by using the flow of the entire pollutant group for normalization in the eco-factor formula; in the above case this would be the annual PM10 load across the whole of Switzerland.

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

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

$$\textit{Eco-factor}^{PM2.5} = K \cdot \frac{1 \cdot EP}{F_n^{PM10}} \cdot \left(\frac{F^{PM\,2.5}}{F_k^{PM\,2.5}} \right)^2 \cdot c \qquad (9b)$$

$$\textit{Eco-factor}^{PM2.5\text{-}10} = K \cdot \frac{1 \cdot EP}{F_n^{PM10}} \cdot \left(\frac{F^{PM\,2.5-10}}{F_k^{PM\,2.5-10}} \right)^2 \cdot c \qquad (9c)$$

Inconsistent artefacts that previously arose when subdividing pollutant groups can thus 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 then be broken out of the group and analysed separately. In the PM10 emissions group, for instance, this is the case for diesel soot emissions.

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[2] This applies despite the fact that one must assume that PM2.5 will tend to be more harmful than the entirety of PM10.

2.2 Principles governing the derivation of eco-factors

2.2.1 Taking account of natural background levels

Wherever possible, only anthropogenic flows are considered for the calculation of eco-factors (for instance, nitrogen in waters). Natural background pollution is outside of the system boundary.

2.2.2 Aggregate parameters

Parameters that aggregate several substances (e.g. NMVOC, total nitrogen) are used if the environmental policy targets are only formulated for the aggregate parameter or if the ecological effect of the individual substances is similar. If an aggregate parameter is in widespread use in 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 designated separately in addition in life cycle inventory databases and are thus assessed twice. Therefore assessment should proceed at the level of the individual active substances wherever possible.

2.2.3 Precautionary principle

The precautionary principle is defined and handled in slightly different ways depending upon the source, the country and the issue at hand. What is common to all definitions, however, is that the principle applies when there is no conclusive scientific evidence of cause-effect mechanisms but there are indications that make a threat to human or animal health or to the environment appear probable (BAG et al. 2003).

The article setting out the aim of the Swiss Environmental Protection Act (EPA) makes explicit mention of 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 certain environmental compartments. For example, individual sensitivity to exposure to ozone or other airborne pollutants varies widely. Nonetheless, effects below the threshold of no harm or for which no such threshold has been defined must only be reduced to the extent that this is operationally (technically) feasible and economically viable. The situation is different if the threshold of no harm is exceeded – that restriction then does not apply and mitigation action must be taken. Federal Swiss agencies other than FOEN can have slightly different definitions (BAG et al. 2003, pp. 8ff). Their specifications, however, have little relevance to the derivation of eco-factors.

2.2.4 Using characterization factors

The fundamental condition determining the application of characterization factors is that **characterization matches the intention of the legislator.** Thus, for instance, the Swiss CO_2 Act only regulates CO_2 emissions, but with the intention of reducing the Swiss contribution to climate change. Characterization is thus appropriate. In addition, the following applies:

a) The characterization factors used should be scientifically recognized.
b) The characterization factors can be derived from political targets.

2.2.5 Determination of normalization

The current flows on which weighting is based are generally identical to the flows that are to be used for normalization. If, however, characterization is performed or a regional or temporal differentiation is carried out, the current flow will differ from the normalization flow if the environmental target was not also formulated on the basis of the characterized emissions. The characterized flow comprises only those substance flows whose eco-factors are determined through the characterization. In accordance with the principle of the highest eco-factor (Section 2.2.11), eco-factors must always be assessed in relation to the strictest target. If another target is stricter for a flow, normalization must no longer contain this flow.

Certain rules must be observed when deriving the normalization flows:

> As a priority, the current annual loads in Switzerland should be used. This applies particularly and without exception in cases where eco-factors 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 are to be used, which are converted to “Swiss” loads through the ratio of the European/global to the Swiss population.
> If these are not known, the annual loads of a specific industrialized nation are to be used, again corrected by the population ratio.

In the case of pollutants and resources that are characterized in a first step, the characterized annual impacts must be used for normalization.

2.2.6 Determination of weighting

The new representation of the formula results in a new, independent weighting term with the ratio of F to F_k squared. The effect of this quadratic weighting is that slight exceedances of the critical flow receive a much smaller weight than large exceedances: If, for instance, the current flow is 10 % above the critical flow ($F = 1.1\ F_k$), this gives a weighting factor of 1.21. If the current flow is 40 % above the critical flow ($F = 1.4\ F_k$), this gives a weighting factor around 2, and if exceedance of the critical flow is 100 % (F = 2 F_k) the weighting factor is 4.

National annual flows are generally used for weighting. Depending upon 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. In accordance with the environmental targets and in a manner matching the normalization, the flows are quantified either as individual substances or as environmental pressures.

The weighting term is unitless. The current and critical flows must therefore be expressed in the same units.

The weighting function remains quadratic when eco-factors are differentiated spatially or temporarily. This differs from the proposal made by Dinkel et al. (2004), where the weighting factor is linear for regionalized eco-factors.

Current flow

Current flows are always to be determined with regard to the reduction target. The reference for the current and critical flows should be the same. For instance, the Swiss CO_2 Act only refers to CO_2 emissions from certain sources, whereas the Kyoto Protocol embraces all greenhouse gases. The current flow must be calculated in accordance with the target or the critical flow. In most cases the current flow is identical to the normalization flow.

Critical flow

Critical flows are generally based upon binding political targets (which in turn can be based on scientific findings). These are primarily protection targets established by law (annual loads, ambient levels). Where no statutory provisions exist, critical flows are based upon political statements of intent with as binding a nature as possible (for instance, the stated intent to limit settlement area, which provides a basis for assessing land use).

2.2.7 Determination of the eco-factor

Through characterization, normalization and weighting, the eco-factors capture political and statutory evaluations of the ecological relevance of pollutants. For instance, the emissions of various heavy metals to air, soil and water are assessed with specific eco-factors, which (ideally) are 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.

2.2.8 Temporal aspects of eco-factor determination

Stipulations enshrined in statutes, such as ambient limit values for airborne pollutants, generally do not set any explicit time horizon apart from transitional provisions. Their provisions apply from their entry into force onwards. When political goals are set, in contrast, specific targets can be defined for certain points in time. With its report on sustainable development in Switzerland (Schweizerischer Bundesrat 2002a), the Swiss Federal Council underscores that it aims for a long-term perspective, as already stipulated in the Federal Constitution of the Swiss Confederation (Art. 73). Moreover, the preamble to the Federal Constitution notes responsibility towards future generations.

In cases where there are several political targets with (very) different time horizons for the determination of an eco-factor, then, on the basis of an appraisal of the current political situation, either one of the points in time should be selected or an interpolation performed to an intermediate point in time (cf. determination of the eco-factor for CO_2, Section 3.2).

2.2.9 Time lag between current flows and future impacts

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

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

The situation is somewhat different for pressures that are generated by processes today but will only arise in the very distant future. The long-term emissions from landfills (modelled in the ecoinvent data to 60 000 years in the future) generated by today's wastes are such an example.

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 possibly never arise. With sufficient engineering effort, landfills can be cleaned up at practically any time. It is therefore acceptable to either only partly take 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 established in environmental law. A deviating assessment of long-term emissions is therefore conceivable in principle, as both these goals and targets and also the exposure situation at the point in time of occurrence of the long-term emissions can differ substantially from the present situation.

It needs to be checked carefully in each case how long-term emissions are treated in life cycle inventory data. It depends upon this whether a more differentiated analysis and assessment of long-term emissions is required.

2.2.10 Spatial aspects

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

Where there is a uniform limit value across Switzerland for pollutants but the pollution situation varies greatly from region to region, it is appropriate to perform a differentiation. For airborne pollutants, the differences are usually too small or cannot be quantified. For water pollutants, in contrast, relevant and quantifiable differences in levels of pollution can arise (e.g. phosphorus in lakes, see Section 4.3). In such cases, regionalized eco-factors should be applied as a basis for determining the eco-factor for the whole of Switzerland (see also Section 2.1.4).

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

There are several possible ways of deriving some eco-factors. For instance, 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 thus performed on the basis of the dominant assessable environmental pressures.

2.3 Principles governing the application of eco-factors

2.3.1 Selection of substances

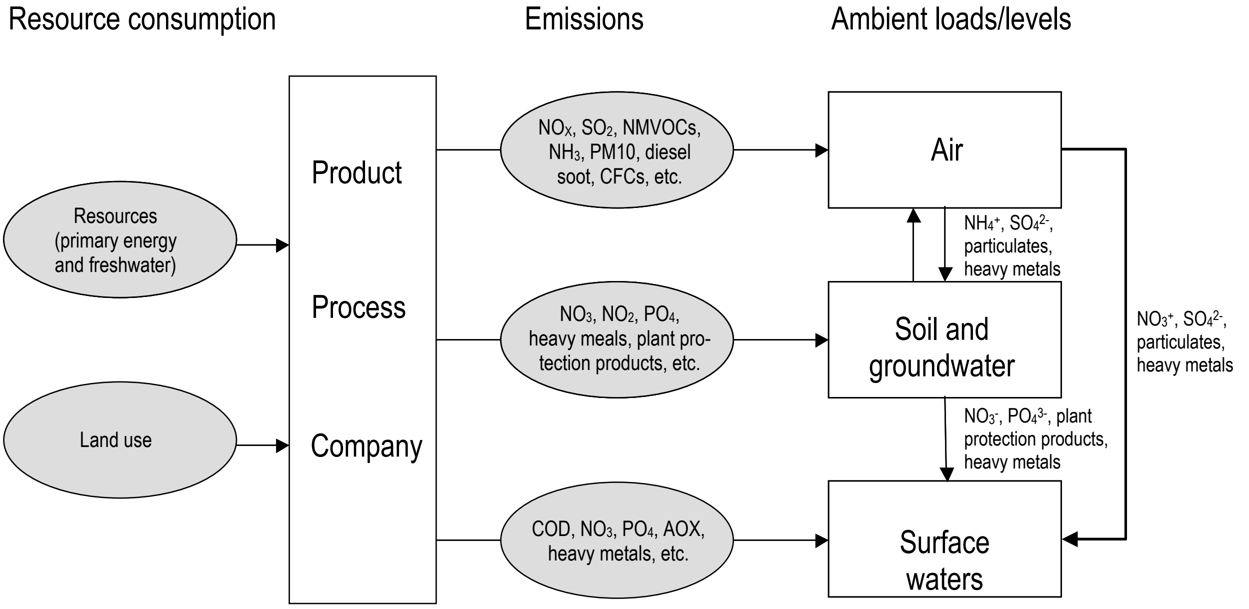
The selection of substances is guided by their ecological and political relevance. This limits the list of environmental pressures that can be weighted. For environmental policy by no means set targets for all substances, especially not for those that have little environmental relevance in Switzerland and Europe (such as sulphate emissions to waters) or for which knowledge is lacking (such as noise). Nonetheless, through more rigorous use of characterization, the substance list has been extended substantially compared to that presented by Brand et al. (1998).

Most of the eco-factors given in the previous report (Brand et al. 1998) continue to be determined, but some are now derived differently. For instance, wastes in surface landfills are no longer assessed on the basis of a special volume eco-factor. A new feature is the assessment of the carbon content of wastes consigned to bioreactive landfills.

Substances are inventoried at the point of passage from the technosphere to the ecosphere. This boundary is not always clearly defined – especially that between soil and groundwater. A more detailed discussion of this boundary is provided in Section 6.1.2 in the chapter on soil. Tab. 1 provides a schematic overview showing the points at which environmental pressures are assessed with eco-factors (fields shaded grey). Each emission should only be assessed once – at its first passage from the technosphere to the ecosphere. Further substance flows within the ecosphere, including those of substances that originally came from the anthropo-technosphere, are not taken into account, as otherwise double counting would occur.

Fig. 1 > Overview of system boundaries

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



2.3.2 Spatial and temporal validity of the eco-factors

Life cycle inventories of product systems generally comprise globally distributed emissions and consumption. Care must therefore be taken when applying the eco-factors that each emission is weighted as if it were taking place in Switzerland (with the exception of freshwater insofar as the life cycle inventory is differentiated accordingly, and of radioactive emissions to the North Sea). Through this approach, the shift of a process to another country does not affect the outcome of an LCA, if the absolute emission level is the same. When environmental impacts have a globally uniform effect, 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 extraction can differ from region to region (e.g. water pollutant emissions). The regionalization of eco-factors presented above makes it possible to take account of such differences.

In practice, however, taking systematic account of specific regional circumstances for a product LCA generally entails major effort, due to a lack of information on the specific environmental situation and the environmental policy goals applying there. This would require an independent and systematic definition of eco-factors for that region. It is indeed conceivable that an eco-factor which is of particular relevance to an LCA is adjusted to the specific regional scarcities in a manner similar to a sensitivity analysis (e.g. specific pollutant emissions to water in a region in which pollution levels are very high or very low). Such "private" or scientifically based eco-factors must, however, be interpreted with great caution.

Such an approach can also be taken when interpreting a site audit as a part of the environmental management activities of a company, or when assessing the on-site impacts of a locally defined project (such as a major road or railway construction project).

As the eco-factors reflect present environmental targets, their informative value declines with time. On the other hand, a comparison of the 1997 eco-factors to those of 2006 shows that most of the political targets, i.e. the critical flows, have changed little.

Time elapses until an environmental issue is reflected in political targets. Target values therefore rarely encapsulate the most recent scientific findings. In the same vein, the current flows are often based on extrapolation of past values. The eco-factors must therefore continue to be updated in future at regular intervals. Online updating, e.g. on the Internet, does not however appear expedient, as a "daily quotation" of eco-factors would presumably engender more uncertainty than accuracy.

2.4 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. 1 > Indicators of the quality or binding nature of data

Quality indicator	Uncertainty attaching to the current flow
A	<20 %
B	20 to 40 %
C	>40 %

Indicator of 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 or expert estimate
c	Modelling assumption of advisory group

2.5 Characterization

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

The characterization factors are based on scientific knowledge of the relative effect in terms of the environmental impact characterized. In the case of greenhouse gases, for instance, the characterization value of 296 kg CO_2-eq./kg N_2O for nitrous oxide (N_2O) means that 1 kg N_2O has the same global warming impact as 296 kg CO_2.

In the ecological scarcity method, applying characterization is permissible if the corresponding environmental impact played a key role when the target was set. In the case of greenhouse gases, for instance, only a CO_2 reduction target is enshrined in statute. As, however, the intention of the legislator is to thereby contribute to limiting global climate change, applying global warming potential values is possible and appropriate.

Characterization is not, however, appropriate in every theoretically conceivable case. It should not be applied in cases where the environmental impact of the characterization does not match the intention of the legislator with regard to the way the reduction target (or the limit or target value) was set. For instance, the Swiss legislator has adopted a uniform VOC levy. Characterizing individual NMVOCs according to their photochemical oxidation potential (POCP) is therefore not appropriate.

The new formula representation introduces an explicit characterization term (K). Characterization had partly already been used in previous reports on eco-points (Brand et al. 1998), but had not been introduced formally in the EP formula. Tab. 2 lists the characterizations used in the present report and compares them to those of EP97.

Tab. 2 > Characterization methods used in EP97 and EP06

	Abbr.	Reference unit	Implementation		
			EP97	EP06	Source 2006
Global warming potential	GWP	CO_2-eq.	Yes	Sec. 3.2	IPCC 2001
Ozone depletion potential	ODP	R11-eq.	Yes	Sec. 3.3	UNEP 2000
Acidification potential	AP	SO_2-eq.	Partly	Sec. 3.7	Guinée et al. 2001
Characterization of radioactive emissions		C-14-eq.	No	Sec. 4.6	Frischknecht et al. 2000
Characterization of endocrine disruptors		E2-eq.	No	Sec. 4.11	Rutishauser et al. 2004
Characterization of plant protection products	PPP	PPP-eq.	No	Sec. 6.3	based on the Danish indicator in OECD 2001
Characterization of primary energy resources		MJ-eq.	No	Sec. 7.2	Schweizerischer Bundesrat 2002b
Ecosystem damage potential through land use	EDP	Settlement area eq.	No	Sec. 7.3	Köllner 2001

The sources cited relate to EP06

3 > Emissions to air

3.1 Introduction

3.1.1 Selection of substances

The report on “Human-induced air pollutant emissions in Switzerland from 1900 to 2010” (BUWAL 1995) quantifies the emissions of 17 different pollutants and allocates them to four source groups: transport, industry and commerce, agriculture and forestry, and households. Air pollutants are selected on the basis of their ecological relevance for the whole of Switzerland. In addition, eco-factors are calculated for greenhouse gases and ozone-depleting substances by means of characterization.

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

Tab. 3 compiles the air pollutants assessed with an eco-factor. It further states, in broad categories, which impacts the pollutants have and which of these are significant in determining the eco-factor.

Tab. 3 > Impact mechanisms of the air pollutants assessed

	Environmental								Human						Notes
	Global warming potential (GWP)	Ozone depletion potential (ODP)	Ozone precursor 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	Characterization	
CO_2 and further greenhouse gases	#	x	x											GWP	
Ozone-depleting substances	x	#	x											ODP	
NMVOCs			#			x			x	x		x	x	POCP	
Nitrogen oxides (NO_X)			*	*	*	x			x					-	Targets are designed to protect human health, fauna and flora
Ammonia (NH_3)				*	*			x						-	Targets are designed to protect ecosystems Alternative assessment via AP
SO_2 and further acidifying substances					#	x		x	x					AP	
Particulates (excl. diesel soot)									#	x			x	-	Derivation from Swiss Air Pollution Control Ordinance
Diesel soot	x								x	#				-	Application of precautionary principle
Benzene			x							#	(x)		x	-	Application of precautionary principle
Dioxins/furans										#		x	x	(I-TEQ)	Application of precautionary principle
Lead (Pb)						x	#						x	-	Emissions to air are assessed using the weighting factor for soil, as the greatest scarcity prevails there
Cadmium (Cd)							#		x	x		(x)	x	-	dito
Zinc (Zn)						x	#						x	-	dito

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

3.2 CO_2 and further greenhouse gases

3.2.1 Environmental impact

Human-induced amplification of the greenhouse effect is assumed to be a causal contribution to the global warming by 0.4 to 0.8 °C and simultaneous rise in sea level by 10 to 20 cm that has taken place in the past 100 years (IPCC 2001, p. 2; Schweizerischer Bundesrat 1997). Modelling shows that the global mean temperature can be expected to rise by 1.4 to 5.8 °C between 1990 and 2100, and the sea level can be expected to rise by 10 to 90 cm. Furthermore, more precipitation and Extremee events are expected, with regionally disparate patterns. It is thought that the global temperature has never changed at a comparable rate over the past 10000 years (IPCC 2001, p. 15; Schweizerischer Bundesrat 1997).

The Swiss Sustainable Development Strategy (Schweizerischer Bundesrat 2002a) states reduction of CO_2 emissions as a priority goal of environmental policy. Several measures are in place or in preparation (the “Energie Schweiz” energy action plan for Switzerland, a CO_2 levy, implementation of the Kyoto Protocol) that shall contribute to reducing CO_2 emissions. Aviation fuels are also to be covered in future, within the framework of an international agreement.

The gases with the greatest global warming impact are CO_2, CH_4 (methane) and N_2O (nitrous oxide). In addition, various chlorinated and fluorinated hydrocarbons (CFCs, HCFCs, HFCs, PFCs) and SF_6 have a direct radiative forcing effect. While the global warming impact of the latter substances can be several thousand times greater than that of CO_2, their contribution to the overall emissions inventory of Switzerland is small (Tab. 5).

3.2.2 Characterization

The group of greenhouse gases comprises the substances that contribute to global climate change, be it to a greater or a lesser degree. To exert their effect as greenhouse gases, they must enter the atmosphere.

The latest publication by the IPCC (2001) provides the reference for the global warming potentials (GWPs) of the various gases. The reference substance is carbon dioxide (CO_2). When the need arises, the GWP potentials are adjusted to new scientific findings, and new substances are characterized. The values depend upon the period of time over which the effects are summated. It is common practice to apply the GWP_{100} values (integrated over 100 years; Tab. 4, full list in Annex A2) – this is also applied for characterization in the present report.

Tab. 4 > Global warming potential of the substances regulated under the Kyoto and Montreal Protocols

		GWP100	
		Used in this report (IPCC 2001) (CO_2-eq.)	Used in the Kyoto Protocol (Houghton et al. 1996) (CO_2-eq.)
Carbon dioxide	CO_2	1	1
Methane	CH_4	23	21
Nitrous oxide	N_2O	296	310
Chlorofluorocarbons	CFCs/HCFCs	120–14 000	90–8 100
Partially halogenated fluorocarbons	HFCs	12–12 000	140–11 700
Perfluorinated hydrocarbons	PFCs	5 700–11 900	6 500–9 200
Sulphur hexafluoride	SF_6	22 200	23 900

The current IPCC report (IPCC 2001) rates the relative radiative forcing of individual gases in most cases higher than was the case in the Second Assessment Report of 1996 (Houghton et al. 1996). It is the GWP values of the latter on which national greenhouse gas emissions inventories are based. The changes in the GWPs are due above all to advances in the radiative forcing model.

Some greenhouse gases also damage the ozone layer. Their ozone depletion potential is therefore also assessed. The higher of the resultant eco-factors is then applied. Other environmental impacts of greenhouse gases (such as the herbicidal effect of the decomposition products of fluorocarbons) are not taken into account here.

3.2.3 Normalization

By signing the Kyoto Protocol, Switzerland has committed to reducing its greenhouse gas emissions. Although the reduction target established by the Swiss CO_2 Act exclusively refers to carbon dioxide, the Swiss Federal Council makes it clear in its memorandum on the CO_2 Act (Schweizerischer Bundesrat 1997) and in its Sustainable Development Strategy (Schweizerischer Bundesrat 2002a) that the goal of Swiss climate policy is to reduce the emissions of all greenhouse gases.

As characterization is performed using the current GWPs (IPCC 2001), normalization is also performed with the overall flow of greenhouse gases calculated with these GWPs. This leads to a normalization flow of 53 034 million t CO_2-eq/a (see Tab. 5).

Tab. 5 > Greenhouse gas emissions in Switzerland

according to FOEN (2006), weighted with the GWP 100 values according to IPCC (2001)

	GWP_{100} (IPCC 2001) (CO_2-eq.)	Emissions in 2004 (1000 t CO_2-eq)	Share in overall greenhouse gas emissions
CO_2	1	45436	86 %
CH_4	23	3661	6.9 %
N_2O	296	3075	5.8 %
HFCs	12–12000	618	1.2 %
PFCs	5700–11900	67	0.1 %
SF_6	22200	176	0.3 %
Total		53034	100 %

3.2.4 Weighting

There are two political targets for CO_2 or greenhouse gases in Switzerland: One is based on the Kyoto Protocol, which is operationalized in the shape of the Swiss CO_2 Act and aims at reducing CO_2 emissions by 10 % by the year 2010 from the 1990 baseline. The other follows from the mention made in the memorandum to the CO_2 Act (Schweizerischer Bundesrat 1997) that the 10 % reduction will not suffice to stabilize CO_2 concentrations in the atmosphere, and that a long-term reduction of 70–80 % is in fact necessary.

There is a certain incongruence between these two very different targets, which apply to quite different target times. As both targets are positioned on the same reduction path but apply to different points in time, it is not possible here to apply the principle that where there are several reduction targets the largest resulting eco-factor is used. Moreover, using a target that is in the distant future would greatly over-stress the severity and urgency compared to other environmental problems. On the other hand, the first target has by now become very short-term (4 years) and also does not sufficiently reflect the severity of global warming. An appropriate eco-factor must therefore be situated between these two endpoints.

The draft Swiss Electricity Supply Act states the year 2030 as target date for the share of renewable energies in Swiss electricity generation. This can be interpreted as the present time horizon with which policymakers operate in relation to climate and energy issues.

Current and critical flow for the 2010 time horizon (CO_2 Act)

The reduction target established by the CO_2 Act relates exclusively to the carbon dioxide emissions of fuels used to produce energy. The Act does not cover other sources. The baseline year is 1990. The current flow is thus smaller than that listed in Tab. 5. It figures 41.1 million t CO_2/a (BUWAL 2005b, Table 2).

The CO_2 Act defines a reduction for fuels of 10 % from the 1990 baseline. This results in a critical flow of 37.0 million t CO_2/a (BUWAL 2005b).

Current and critical flow for the 2050 time horizon (Sustainable Development Strategy)

As the critical flow relates to CO_2 emissions (and not to the CO_2-equivalents of all Kyoto greenhouse gases) the current flow must also be determined on the basis of CO_2 emissions only. This comprises all sources, but not the land-use change and forestry sector (e.g. forest sinks). It follows from the national greenhouse gas emissions inventory (FOEN 2006) that the current flow of carbon dioxide in 2004 in Switzerland is 45 436 million t CO_2 (Tab. 5).

The 1 t CO_2 target is a part of the vision of a 2000 watt society, and is also stated in the Swiss Sustainable Development Strategy (Schweizerischer Bundesrat 2002a). Different points in time for attaining that goal are stated in various studies: 2050, 2100 or 2150 (Koschenz & Pfeiffer 2005; Spreng & Semadeni 2001; Würsten 2003). The most stringent variant is used here, i.e. the year 2050.

A resident Swiss population of 8.06 million is assumed for the year 2050 (intermediate scenario of the BFS (2006). This results in a critical flow of 8.06 million t CO_2/a for 2050.

3.2.5 Eco-factor for CO_2

Eco-factors of the endpoints

Tab. 6 > Calculation of the CO_2 eco-factors for the two endpoints – 2010 and 2050

	Target 2010	Q	Target 2050	Q	Notes
Normalization (1000 t CO_2-eq./a)	53 034	A	53 034	A	Emissions according to FOEN (2006), but with GWPs in accordance with IPCC (2001)
Current flow (1000 t CO_2/a)	41 130*	A	45 436	A	(BUWAL 2005b; FOEN 2006)
Critical flow (1000 t CO_2/a)	36 960*	a	8 060	b	see text
Weighting (-)	1.24		31.8		
Eco-factor (EP/g CO_2-eq.)	0.023		0.60		Basis for interpolation

Q=data quality; for explanation see Section 2.4
* only carbon dioxide from fuels used to produce energy

The calculation of the eco-factors for 2010 and 2050 shows that they differ by a factor of around 25. These two endpoint eco-factors are interpolated to the year 2030 in a next step. The two targets are thus adjusted to the time horizon commonly applied by the Swiss legislator.

Tab. 7 > Eco-factor for CO_2 and further greenhouse gases in EP/g CO_2-equivalents[3]

The eco-factor has risen by around 50 % from 1997.

Interpolated eco-factor

	Situation 2006	Q	Notes	Situation 1997
Normalization (1000 t CO_2-eq./a)	53 034	A	Emissions according to FOEN (2006), but with GWPs in accordance with IPCC (2001)	-
Current flow (1000 t CO_2/a)	-			44 200
Critical flow (1000 t CO_2/a)	-			15 000
Weighting (-)	16.5		Calculated from interpolated eco-factor and normalization	-
Eco-factor (EP/g CO_2-eq.)	0.31		Interpolated eco-factor	0.2

Q=data quality; for explanation see Section 2.4

3.2.6 Eco-factors for further greenhouse gases

Taken together, the further greenhouse gases contribute around 15 % of the global warming impact attributable to Switzerland (Tab. 5). Their eco-factors are determined via characterization using GWP_{100} values (IPCC 2001; cf. Tab. 8 and the detailed list in A2).

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

Tab. 8 > Eco-factors for several greenhouse gases, calculated from the weighting factor for CO_2

	Formula	GWP	Eco-factor 2006 (EP/g)	Basis in 2006	Eco-factor 1997 (EP/g)	Basis in 1997
Carbon dioxide	CO_2	1	0.31	GWP	0.2	GWP
Methane	CH_4	23	7.1	GWP	4.2	GWP
Nitrous oxide	N_2O	296	92	GWP	62	GWP
HCFC -22	$CHClF_2$	1 700	610	ODP*	300	GWP
HCFC -142b	CH_3CF_2Cl	2 400	740	GWP*	360	GWP
HFC -125	CHF_2CF_3	3 400	1 100	GWP	560	GWP
HFC -134a	CH_2FCF_3	1 300	400	GWP	260	GWP
Sulphur hexafluoride	SF_6	22 200	6 900	GWP	4 800	GWP

The detailed list is in A2.
* The eco-factor can be determined both on the basis of the GWP and the ODP; the higher of the two is used and listed here.

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[3] Interpolation to 2030

3.2.7 Eco-factors from global warming for carbon monoxide (CO) and diesel soot (Black Carbon)

For carbon (C), an eco-factor can be derived on the basis of the indirect global warming potential of carbon monoxide. IPCC (2001) mentions a range of 1 to 3 kg CO_2-eq/kg CO for the GWP_{100} of CO. In stoichiometric terms, 1.57 kg CO_2 are formed from 1 kg CO. This value is taken for the GWP_{100} of CO. An eco-factor of 0.49 EP/g results.

Diesel soot (termed “Black Carbon” by the IPCC) also has a global warming impact, as do all aerosols. The GWP for Black Carbon is 800 to 2000 (IPCC 2001, Chapter 5). The eco-factor that results is, however, substantially lower than the eco-factor derived from human health effects (cf. Section 3.8.4).

3.3 Ozone-depleting substances

3.3.1 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 layer therefore increases, among other things, the skin cancer rate and eye diseases in humans, and the rate of mutation in all organisms. In addition, it accelerates aging in plastic polymers.

The most important ozone-depleting substances are CFCs (chlorofluorocarbons), halons and carbon tetrachloride (CCl_4). HCFCs (partially halogenated CFCs) have the same effect, but in a significantly weaker form. At the same time, CFCs and HCFCs are contributors to human-induced climate change (cf. Section 3.2).

3.3.2 Characterization

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 taken as unit. ODP values are determined in an internationally binding form in the Montreal Protocol. Tab. 9 presents a selection, while A2 gives the entire list. This list is expanded to include new substances as required. The status of the year 2000 is used for characterization (UNEP 2000).

Halogenated hydrocarbons that contain no chlorine or bromine atoms, but contain e.g. fluorine (HFCs) have no ozone-depleting effect. Most ozone-depleting substances also have a global warming potential. It is a principle of the ecological scarcity method that the higher of the two resulting eco-factors is used (cf. Section 2.2.11).

Tab. 9 > Ozone depletion potentials of a number of important substances

		ODP (kg R11-eq./kg)
CFCs	R11	1
	R12	1
	R115	0.6
HCFCs	R22	0.055
	R124	0.022
	R141b	0.11
Halons	Halon 1211	3
	Halon 1301	10
	Bromomethane	0.6
Solvents	1,1,1- trichloroethane	0.1
	Tetrachloromethane	1.1

cf. also A2

3.3.3 Normalization

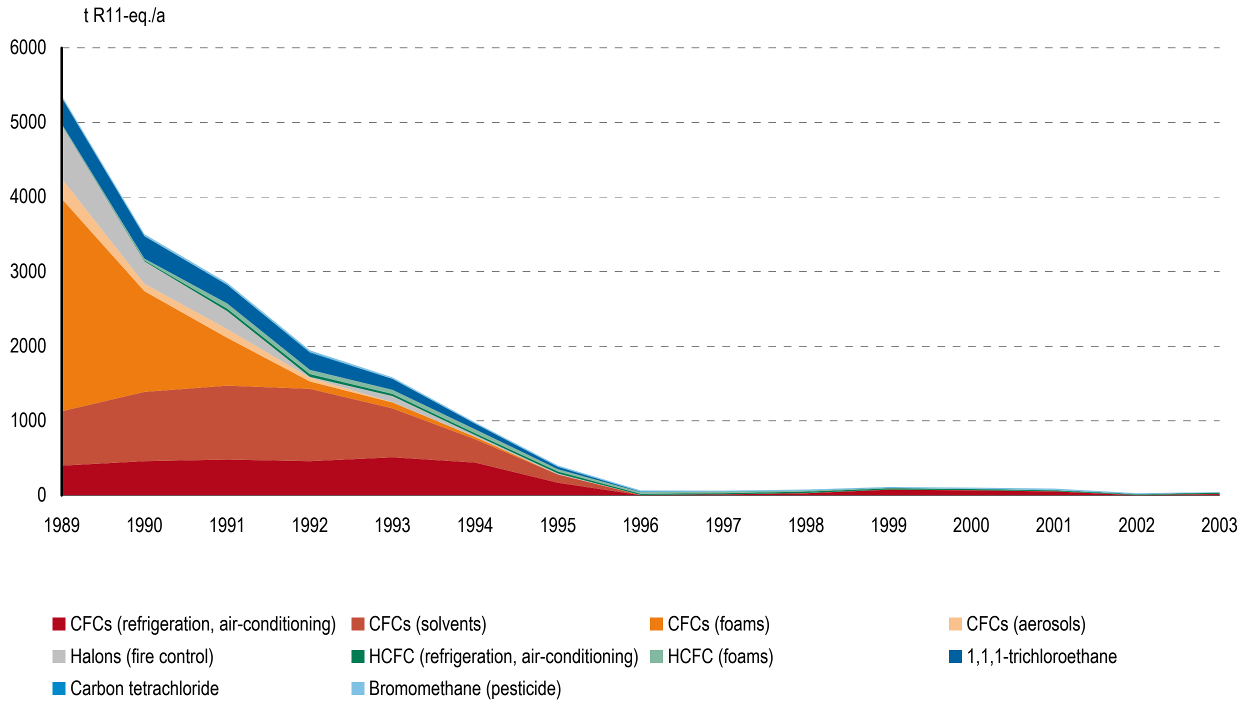
The ozone-depleting substances are characterized. As the environmental target is based on the characterized values, the normalization flow is identical to the characterized current flow.

3.3.4 Weighting

Current flow

Swiss **imports** of ozone-depleting substances have been surveyed by FOEN since 1986 and are well known (cf. Fig. 2 and Tab. 10). No ozone-depleting substances are produced in Switzerland. HCFCs are now only permitted in existing refrigeration systems until 2015. Here R-22 is the main refrigerant used. Refilling equipment with halons is prohibited in Switzerland since 2003. CFCs are completely prohibited in foams since 1992 and in refrigeration systems since 2004.

Fig. 2 > Development of Swiss imports of ozone-depleting substances from 1989 to 2003, measured in R11-eq.



source: FOEN

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

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

Tab. 10 > Average imports of ozone-depleting substances in tonnes and in tonnes R11-equivalent over the period from 2001 to 2003

	Imports to Switzerland: average over 2001–2003 period	
	(t/a)	(t R11-eq./a)
CFCs		
Refrigerants	27	27
Solvents	1.3	1.3
Foaming agents (insulation)	0	0
Aerosol propellants	0	0
HCFCs		
Refrigerants (mainly R22)	229	13
Foaming agents (insulation)	32	2.9
Further substances		
Halons (for fire control)	0	0
Trichloroethane (as solvent)	1.0	0.1
Tetrachloromethane (in laboratories)	2.2	2.4
Bromomethane (as pesticide)	17	10
Total	310	57

source: FOEN

Empa has been conducting a measurement programme for halogenated gases in the atmosphere since 2000 on the Jungfraujoch mountain. Empa has found that emissions of the main ozone-depleting substances are dropping (Reimann et al. 2004). The calculation of the current flow (Tab. 11) uses the average value of these measurements over the period from 2001 to 2003, and the HCFC-22 and tetrachloromethane import data from the import statistics gathered by FOEN; these figures cover more than 90 % of the overall ozone-depleting impact[4, 5].

The national halon register[6] reports a stock of around 200 tonnes in 2005 for the halon 1301 (this is estimated to be 80 % of the real stock). Emissions through triggering fire extinguishers are on the scale of 0.2 % to 0.6 % of the stock, which would amount to a figure of between 500 and 1500 kg emissions to air. The difference to the measurements performed by Empa (see Tab. 11) can probably be explained by unrecorded stocks. The figures provided by the Empa measurements (Reimann et al. 2004) are used here.

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[4] The appraisal is based on the global production volume of halogenated hydrocarbons (AFEAS 2004, AFEAS (2004) Annual Global Fluorocarbon Production (Excel Sheet), retrieved 6.6.2005 from http://www.afeas.org/., where the contribution of CFC-113 and CFC-114, which are not taken into account in the present report, is around 12 %. As these substances have been banned in Switzerland for some time, it can be assumed that their contributions are substantially smaller. The contribution of other CFCs and HCFCs not taken into account is well below 1 %.

[5] As HCFC-22 can now only be used to refill existing equipment, the imported quantity corresponds roughly to the emitted quantity. Tetrachloromethane is mostly used in small quantities in laboratories, and has little relevance to the emissions balance.

[6] Personal communication by B. Horisberger (FOEN) of 15.8.2006

Tab. 11 > Swiss emissions of the most important ozone-depleting substances in t/a and as R11-eq./a

		Stock reduction for the year 2005					
		Total		as emissions to air		through disposal	
		(t/a)	(t R11-eq./a)	(t/a)	(t R11-eq./a)	(t/a)	(t R11-eq./a)
CFCs							
CFC -11	CCl_3F	278	278	167	167	111	111
CFC -12	CCl_2F_2	167	167	100	100	67	67
CFC -115	CF_3CClF_2	6.1	3.7	3.7	2.2	2.4	1.5
HCFCs							
HCFC -22	$CHClF_2$	280	15	229	13	51	2.8
HCFC -124	$CHFClCF_3$	6.5	0.1	5.3	0.1	1.2	0.03
HCFC -141b	CH_3CFCl_2	156	17	74	8	82	9.0
Halons							
Halon 1211	$CBrClF_2$	20	61	6.7	20	14	41
Halon 1301	$CBrF_3$	19	192	6.3	63	13	129
Methane, bromo-	CH_3Br	31	19	19	11	12	7.5
Solvents							
Ethane, 1,1,1-trichloro-	CH_3CCl_3	47	5	39	3.9	8.6	0.86
Methane, tetrachloro – *	CCl_4	2.7	2.9	2.2	2.4	0.5	0.53
Total		1 015	761	652	391	363	370

* HCFC-22 and tetrachloromethane emissions are not measured. The FOEN import statistics provide approximate values (Tab. 10)

The current flow of 391 t R11-eq. per year is therefore a good approximation for the Swiss emissions to air of ozone-depleting substances.

Critical flow

The Swiss Chemicals Risk Reduction Ordinance (Chemikalien-Risikoreduktions-Verordnung, ChemRRV) prohibits the production, importation and use of ozone-depleting substances. Exemptions regarding importation and use are presently only in place for the maintenance of existing HCFC refrigeration equipment and for the recycling of HCFC refrigerants (transitional period until 2015).

The provisions of the ChemRRV have led to a sharp reduction in emissions of ozone-depleting substances (Fig. 2). However, the stocks formed mainly in building insulation materials (CFC-11, HCFCs) will release considerable amounts in the coming decades. Emissions will therefore only drop slowly.

The ChemRRV 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.

The tolerated emissions are taken as a basis for determining the critical flow. As these decline gradually, choice of the reference year is decisive. The transitional provisions (i.e. the exemptions for HCFC use in existing refrigeration equipment) terminate in 2015.

Hence in the following an estimation is performed of the emissions of ozone-depleting substances that are to be anticipated in 2015. This proceeds from the current flows listed in Tab. 11, whereby the following assumptions are made for the derivation of the reduction:

- CFC-12 and CFC-115 were used mainly in refrigeration equipment. The last transitional period for these two substances ends in 2008. Therefore zero emissions of these substances are expected for 2015.
- Emissions from insulating material amount to around 1 % of the stock. For refrigeration systems, a leakage rate of around 10 % is expected.[7]
- CFCs and HCFCs in insulating material are consigned to disposal in the course of building and equipment refurbishment. It is assumed that the stock (and thus also the emissions to air) are thus reduced by 0.8 % (CFCs) and 1.4 % (HCFCs) annually (these assumptions are identical to those made in the previous report (Brand et al. 1998)).
- An annual reduction rate of around 7 % to 9 % can be concluded for halon 1211 and halon 1301 from the figures of the national halon register on disposal quantities (there is a ban on refilling) and the emissions to air derived from the Empa measurements on the Jungfraujoch (Reimann et al. 2004). The mean of these two values is used, i.e. 8 %.
- Building on the assumptions made, an annual reduction in emissions by 1.8 % (CFCs) and 2.4 % (HCFCs) is anticipated for the substances that are in the meantime only present in insulating material. These two values are applied to the emissions of CFC-11 and HCFC-141b.
- For the other HCFCs, the annual reduction is determined from the mean of the reduction of emissions to air (5.5 %) and the annual percentage disposed (1.4 %). This results in an annual emissions reduction of 6.9 %.
- From 2006 onwards, bromomethane is only used in chemical synthesis processes. Only a slow reduction and small quantities emitted can therefore be expected. As a first approximation, the rate of reduction of CFC-11 is used here.
- For solvents, the rate of reduction of HCFC-22 is applied. This is purposeful as the solvents listed and HCFC-22 can at present still be used under certain conditions.

Tab. 12 presents in detail the derivation of the critical flow. It follows that the emissions to be expected in 2015, i.e. the critical flow, figure 188 t R11-eq.

It is further apparent that the assumptions made on HCFCs and on solvents have minor relevance to the assessment of the critical flow. Their ozone depletion potential (see Tab. 9) is substantially smaller, while their emission quantities are on the same scale (cf. also Tab. 11).

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[7] Personal communication by B. Horisberger (FOEN) of 10.8.2006

Tab. 12 > Assessment of Swiss emissions of the main ozone-depleting substances in 2015, in t/a and as R11-eq./a

	Reduction rate of the stock	Stock reduction for the year 2015					
		Total		as emissions to air		through disposal	
	per year	(t/a)	(t R11-eq./a)	(t/a)	(t R11-eq./a)	(t/a)	(t R11-eq./a)
CFCs							
CFCs -11	1.8 %	224	224	134	134	90	90
CFCs -12	-	0	0	0	0	0	0
CFC-115	-	0	0	0	0	0	0
HCFCs							
HCFC-22*	6.9 %	119	7	97	5	22	1.2
HCFC-124	6.9 %	2.8	0.1	2.3	0.05	0.5	0.01
HCFC-141b	2.4 %	117	13	56	6	61	6.8
Halons							
Halon 1211	8.0 %	7.4	22	2.5	7	5.0	15
Halon 1301	8.0 %	7.1	71	2.3	23	4.7	47
Methane, bromo-	1.8 %	25	15	15	9	10	6.0
Solvents							
Ethane, 1,1,1-trichloro-	6.9 %	20	2.0	16	1.6	3.7	0.4
Methane, tetrachloro- *	6.9 %	1.1	1.2	0.92	1.0	0.2	0.2
Total		523	354	326	188	197	166

* The figures for HCFC-22 and tetrachloromethane are based on data in the import statistics maintained by FOEN.

3.3.5 Eco-factor for ozone-depleting substances

Tab. 13 > Eco-factor for R11-equivalents in EP/g R11-eq

	Situation 2006	Q	Notes	Situation 1997
Normalization (t R11-eq./a)	391			
Current flow (t R11-eq./a)	391	B	Based on data in Reimann et al. (2004)	1470
Critical flow (t R 11-eq./a)	188	b	Assessed on basis of tolerated emissions as set out in text	850
Weighting (-)	4.33			
Eco-factor (EP/g R11-eq./a)	11000			2000

Q = data quality; for explanation cf. Section 2.4

The new factor is substantially higher than that of 1997, which is partly attributable to the new method of determining emission loads. This is now based on real measured data. Rough estimates of the stocks of ozone-depleting substances are no longer necessary. On the one hand, the consumption of ozone-depleting substances has dropped sharply, while, on the other hand, the absolute ban will enter into force in the foreseeable future. A substantially higher eco-factor is therefore plausible.

3.3.6 Eco-factor for further ozone-depleting substances

The eco-factor for further ozone-depleting substances can be derived from the characterization values for the ozone depletion potential (ODP) and the eco-factor for R11-equivalents derived in Section 3.3.5.

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

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.

Tab. 14 > Eco-factors for ozone-depleting substances, stated in EP/g of substance

	Formula	ODP (kg R11-eq/kg)	Eco-factor 2006 (EP/g)	Basis in 2006	Eco-factor 1997 (EP/g)	Basis in 1997
CFC-11	CCl_3F	1	11 000	ODP*	2 000	ODP
CFC-12	CCl_2F_2	1	11 000	ODP*	2 000	ODP
CFC-111	C_2Cl_5F	1	11 000	ODP	2 000	ODP
HCFC-123	$CHCl_2CF_3$	0.02	220	ODP*	40	ODP
HCFC-142b	CH_3CF_2Cl	0.065	740	GWP*	360	GWP
HCFC-225ca	$CF_3CF_2CHCl_2$	0.025	280	ODP*	-	
Halon 1211	$CBrClF_2$	3	33 000	ODP*	6 000	ODP
Halon 1301	$CBrF_3$	10	110 000	ODP*	20 000	ODP
Methane, bromo-	CH_3Br	0.6	6 600	ODP*	1 400	ODP

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

3.3.7 Implementation in the ecoinvent v2.0 dataset

The substance “halogenated solvents, chlorinated” is assessed with the eco-factor of R22.

3.4 NMVOCs and further substances with photochemical ozone creation potential

3.4.1 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 (VOC Verordnung, VOCV) defines VOCs as *"organic compounds with a vapour pressure of at least 0.1 mbar at 20 °C or with a boiling point of at most 240 °C at 1013.25 mbar"*. NMVOCs (non-methane volatile organic compounds) are VOCs excluding the gas methane.

Together 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 upon 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 weighted with separate eco-factors.

3.4.2 Characterization

Photochemical ozone creation potential (POCP) is a measure of the contribution of a molecule to ozone formation and could provide a starting point for characterization. However, as the Swiss VOC Ordinance intentionally makes no distinction between different NMVOC substances, characterization is not appropriate.

3.4.3 Normalization

The current flow already relates to the whole of Switzerland. Normalization is therefore identical to the current flow.

3.4.4 Weighting

Current flow

Annual NMVOC emissions in Switzerland rose from 70 000 to 324 000 tonnes over the period from 1950 to 1985. Emissions have been dropping since 1985. In 1995 they figured 211 000 tonnes (BUWAL 1991, p. 74). The introduction of the VOC levy in 2000, in combination with increasingly stricter emission rules for vehicles, has contributed to a further halving of emissions to a current level of just under 116 000 t/a (BUWAL 2003f; BUWAL 2005a).

Critical flow

The Swiss Federal Air Pollution Control Ordinance sets ambient limit values for ozone (O_3). These are presently often exceeded, especially in conurbations and in rural areas (BUWAL 1997b, p. 20).

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 the limit values, BUWAL (1989, p. 247) states that NMVOC emissions need to be reduced by more than 75 % from their peak level reached in the 1980s. This results in a critical flow for NMVOCs of 81 000 t/a.

The Swiss air pollution control strategy stipulates as a minimum target for NMVOCs a reduction to the level of 1960 (145 000 t/a; (BUWAL 1991, p. 75; BUWAL 1996a)). In addition, the environment ministers of Germany, Liechtenstein, Switzerland and Austria adopted on 23 August 1993 in Graz a declaration setting the target of reducing NMVOC emissions by 70–80 % from the level of the 1980s (Graz 1993, p. 2). This results in a maximum emission level of 64 800 to 97 200 t/a (BUWAL 1996a, p. 33). The mean value of this target range corresponds to the critical flow derived above.

3.4.5 Eco-factor for NMVOCs

Tab. 15 > Eco-factor for volatile organic compounds (excl. methane and CFCs) in EP/g NMVOC

	Situation 2006	Q	Notes	Situation 1997
Normalization (t NMVOC/a)	116 000	B		
Current flow (t NMVOC/a)	116 000	A	(BUWAL 2005a)	211 000
Critical flow (t NMVOC/a)	81 000	a	(Künzler 2004, BUWAL 2005d)	81 000
Weighting (-)	2.05			
Eco-factor (EP/g NMVOC)	18			32

Q = data quality; for explanations see Section 2.4

The eco-factor has dropped substantially from 1997, as the current flow has been reduced while the critical flow has remained unchanged. It can be assumed that emissions will continue to drop in future.

3.5 Nitrogen oxides (NO_x)

3.5.1 Environmental impact

Nitrogen oxide loads cause many forms of pressure and damage. As a result of their acidifying effect, sensitive ecosystems are severely endangered. Moreover, nitrophilous plants are promoted, which can lead to a reduction of plant diversity and to 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 disrhythmia are direct effects. Over the longer term, this reduces life expectancy. 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 1996c; BUWAL 2005c).

3.5.2 Normalization

The given target is to reduce the quantity of NO_x emitted (stated as NO_2), and no characterization is performed. The normalization flow is therefore identical to the current flow.

3.5.3 Weighting

Current flow

Nitrogen oxides are formed above all when fossil energy carriers are burnt. Transport is the main source, accounting for 58 % of emissions in 2000. Further anthropogenic sources of nitrogen oxides include construction machines and agricultural and silvicultural machines (12 %), combustion facilities/furnaces (6 %) and certain commercial and industrial processes (24 %) (BUWAL 2005c).

Annual NO_x emissions in Switzerland (measured as NO_2) rose from 31 300 t to 179 000 t over the period from 1950 to 1985. Emissions have been declining since 1985 (BUWAL 1991, p. 72). Thanks to the measures taken, NO_x emissions have dropped substantially. The current flow in 2005 is just under 91 000 t/a (BUWAL 2005a).

Critical flow

The Swiss Air Pollution Control Ordinance stipulates ambient limit values for nitrogen dioxide (NO_2) and ozone (O_3). These were set such that, if 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, in some cases substantially, while in rural areas they are generally complied with. The ambient limit values for ozone, in contrast, are frequently exceeded above all in rural areas and in conurbations (BUWAL 1997b, p. 20).

Substantial emissions reductions are therefore essential in order to comply with the ambient limit values. A report produced by the Swiss Federal Commission for Air Hygiene (BUWAL 2005c) states that NO_x emissions would need to be reduced by around 40 % (from their 2000 level) in order for the ambient limit value for NO_2 to be complied with. Compliance with the ambient limit value for O_3 requires a reduction by around 60 %. The latter target is used to determine the critical flow, as it is stricter. This reduction also has the effect of reducing the contribution to over-fertilization to a level acceptable over the longer term (BUWAL 1996c). In (BUWAL 2005a) the O_3 target is taken as a basis for defining the NO_x target value. The critical flow corresponds to this BUWAL target.

3.5.4 Eco-factor for NO_x

Tab. 16 > Eco-factor for nitrogen oxides in EP/g NO_X as NO_2

	Situation 2006	Q	Notes	Situation 1997
Normalization (t NO_x as NO_2/a)	91 000	A		
Current flow (t NO_x as NO_2/a)	91 000	A	(BUWAL 2005a)	136 000
Critical flow (t NO_x as NO_2/a)	45 000	a	(BUWAL 2005a)	45 000
Weighting (-)	4.09			
Eco-factor (EP/g NO_x as NO_2)	45			67

Q = data quality; for explanation see Section 2.4

The eco-factor is one-third lower than in 1997, as the current flow has dropped while the critical flow has remained the same. The planned further tightening of emission standards in the transport sector can be expected to deliver a further drop.

3.6 Ammonia (NH_3)

3.6.1 Sources and environmental impact

Agriculture is the main source of ammonia, accounting for 93 %. Ammonia forms on the one hand in livestock management (animal housing, farmyard manure storage and field application) and, on the other hand, is emitted when mineral nitrogen fertilizers are applied (BUWAL 2005c).

Ammonia contributes to the acidification and over-fertilization of aquatic and terrestrial ecosystems, leading to longer-term direct and indirect changes to ecosystems. Because of the complexity of the processes, the effects of elevated nitrogen loading are difficult to predict. They include increased sprout growth and greater susceptibility to parasites, and the promotion of nitrophilous plants, thus displacing endemic plant species. Ecosystems recover only very slowly from over-fertilization, if at all (BUWAL 1996c; BUWAL 2005c).

Ammonia also contributes to the formation of secondary particles, which causes human health impacts. Moreover, ammonia in air promotes the formation of sulphuric acid (H_2SO_4) from sulphur dioxide (SO_2) (BUWAL 1996c; BUWAL 2005c).

3.6.2 Normalization

The reduction target relates to the over-fertilizing impact and to the acidifying impact of ammonia. No characterization is performed. The normalization flow is therefore identical to the current flow.

3.6.3 Weighting

Current flow

Ammonia emissions rose gradually from the early 20th century onwards, peaking in 1980. Since then, emissions have dropped. In 2005 they totalled 44 000 t NH_3-N/a (corresponding to 53 400 t NH_3/a) (BUWAL 2004b; BUWAL 2005d).

Critical flow

According to BUWAL (1996c, p. 34), ecological considerations would require a long-term reduction of the mean overall deposition of nitrogen compounds to 10 kg N/(ha*a). Proceeding from this deposition target for total nitrogen and from the goal for nitrogen oxides, and taking account of the input-output inventories of the various N compounds, an ecologically based goal for ammonia emissions of 25 000 to 30 000 t NH_3-N is derived in (BUWAL 1996c, p. 34). The Swiss Federal Council (Schweizerischer Bundesrat) affirmed this goal in 1999 in its report on air hygiene measures (Schweizerischer Bundesrat 1999).[8] The Swiss Federal Commission for Air Hygiene states a reduction target of 25 000 t NH_3-N (i.e. 30 400 t NH_3) (BUWAL 2005c, p. 129). This value is used for the critical flow.

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[8] Reduction of ammonia emissions by 40–50 % from 1995 (60,200 t NH_3).

3.6.4 Eco-factor for NH_3

Tab. 17 > Eco-factor for ammonia in EP/g NH_3-N and in EP/g NH_3

	Situation 2006	Q	Notes	Situation 1997
Normalization (t NH_3-N/a)	44 000	B		
Current flow (t NH_3-N/a)	44 000	B	(BUWAL 2005d)	70 700
Critical flow (t NH_3-N/a)	25 000	a	(BUWAL 2005c)	33 400
Weighting (-)	3.098			
Eco-factor (EP/g NH_3-N)	70			63
Eco-factor (EP/g NH_3)	57.65			

Q = data quality; for explanation see Section 2.4

The eco-factor has dropped slightly as the current flow has already dropped appreciably while the critical flow is set only slightly lower.

A further way to derive an eco-factor for ammonia would be characterization via the acidification potential (Section 3.7.6). The eco-factor derived here using the direct reduction target is, however, higher and is therefore applied.

Thanks to reductions already achieved in ammonia emissions, the current flow is dropping slightly from its previous value. A major reduction potential is available in, among other fields, agriculture through low-emission animal housing and slurry storage as well as optimized slurry application to fields. If this and other technical options are exploited, it is possible to reduce emissions by 30–40 % (BUWAL 2004b).

3.7 SO_2 and further acidifying substances

3.7.1 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 of aerosols (BUWAL 1995, Table 2.1).

3.7.2 Characterization

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

Tab. 18 > Characterization factors for the acidification potential in accordance with Guinée et al. (2001, as per April 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
Sulphuric acid	H_2SO_4	0.65
Hydrogen sulphide	H_2S	1.88
Nitrogen oxides	NO_x (as NO_2)	0.7

3.7.3 Normalization

The target for sulphur dioxide is based on its acidifying effect. The other acidifying substances (cf. Tab. 20 in 3.7.6) would also need to be taken into account for the normalization flow. Separate targets have been established for NO_x and NH_3, which is why these two substances are not included in the normalization. Due to a lack of data, however, the other acidifying substances could not be taken into account for the calculation of the normalization flow. It can, however, be assumed that sulphur dioxide makes by far the largest contribution and that the stated normalization flow of around 19 000 t SO_2-eq./a only slightly underestimates the real situation (see Tab. 20).

3.7.4 Weighting

Current flow

Annual SO_2 emissions in Switzerland rose from 46200 to 116000 tonnes over the period from 1950 to 1980. Emissions have been dropping since 1980 (BUWAL 1991, p. 70). In 2006 they figured around 19000 t/a (BUWAL 2005d).

Critical flow

The Swiss Air Pollution Control Ordinance establishes ambient limit values for sulphur dioxide. Emission levels today are now less than half of those considered to be the maximum acceptable level of 46200 t/a (as of 1950; (BUWAL 1991, p. 70)) as stated in the Swiss air pollution control strategy (BUWAL 1996a).

The protection of ecosystems against acidification is also regulated by the UN/ECE (United Nations / Economic Commission for Europe) Sulphur Protocols. The Swiss parliament ratified the second sulphur protocol in 1997. This establishes in Article 2 as a long-term target that sulphur loads are to remain below the critical loads for ecosystems (UN/ECE 1994; UNECE 1999). In (Amann et al. 1991, p. 17) these critical emission levels are documented for each country. For Switzerland, a critical flow of 25000 t was calculated, which corresponds to a reduction of 78 % from the 1980 level, or 25 % from the 1995 level (Schweizerischer Bundesrat 1999).

The target that follows from the Sulphur Protocol is stricter and is therefore used as critical flow.

3.7.5 Eco-factor for SO_2

Tab. 19 > Eco-factor for sulphur dioxide in EP/g SO_2

	Situation 2006	Q	Notes	Situation 1997
Normalization (t SO_2-eq./a)	19000	A	see text	
Current flow (t SO_2/a)	19000	A	((BUWAL 2005d)	34300
Critical flow (t SO_2/a)	25000	a	(BUWAL 2005d)	25400
Weighting (-)	0.578			
Eco-factor (EP/g SO_2-eq.)	30			53

Q = data quality; for explanation see Section 2.4

The eco-factor for SO_2 is substantially lower than it was in 1997. This is because current SO_2 emissions have dropped almost by half, while the critical flow has not changed.

3.7.6 Eco-factors for further acids

Further substances are responsible for the acidification of ecosystems in addition to sulphur dioxide. An eco-factor can be derived for further substances by using the acidification potential, which characterizes the relative acidification attributable to a substance in relation to SO_2 (see Section 3.7.2).

The eco-factors only assess the acidifying effect, as they are linked to SO_2 via the characterization. No account is taken of the further effects of individual acids. Ammonia and nitrogen oxide are weighted more strongly by their specific reduction targets (cf. Sections 3.5 and 3.6), so that the eco-factor established there applies.

Tab. 20 > Eco-factors for substances with acidifying potential in EP/g acid, characterized with reference to sulphur dioxide

		Acidification potential (kg SO_2-eq./kg)	Eco-factor 2006 (EP/g)	Notes	Eco-factor 1997 (EP/g)
Ammonia	NH_3	1.88		The eco-factor from direct derivation is higher (cf. Section 3.6)	63
Hydrogen fluoride	HF	1.6	48		85
Phosphoric acid	H_3O_4P	0.98	29		-
Nitric acid	HNO_3	0.51	15		-
Hydrochloric acid	HCl	0.88	26		47
Sulphuric acid	H_2SO_4	0.65	20		-
Hydrogen sulphide	H_2S	1.88	56		-
Nitrogen oxides	NO_x	0.7		The eco-factor from direct derivation is higher (cf. Section 3.5)	67

for weighting and normalization see Tab. 19

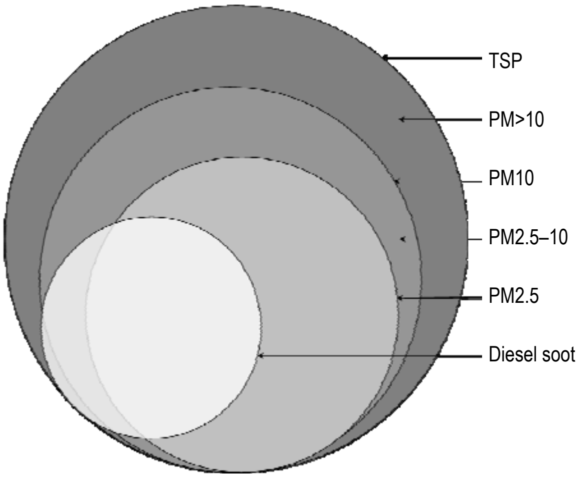
3.8 Particulate matter (I): PM10, PM2.5 and PM2.5–10

3.8.1 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) (BUWAL 2001c).

An eco-factor for PM10 has been established in the past (Brand et al. 1998). The harmfulness of particles depends on the one hand upon their size and on the other upon their composition. Account is taken of size by determining additional eco-factors for PM2.5 and PM2.5–10. The legislator, however, has not yet introduced this differentiation. The derivation of the new eco-factor for diesel soot, in contrast, is determined primarily by the composition – which means the carcinogenicity – of the particles. Furthermore, it is thought that in the case of diesel soot in particular toxicity correlates more closely with particle number than with absolute mass.

Fig. 3 > Schematic of particle sizes and their relationships



TSP: Total Suspended Particles

Epidemiological studies have shown that the 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 which can move beyond the larynx and enter the lung. 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 (BUWAL 1996b, p. 9). For instance, it has been shown in the National Research Programme 26 (People, Health, Environment) that if the long-term exposure increases by 10 micrograms PM10 per m^3 the risk of various diseases of the respiratory tract rises by 30 to 60 %.

Recent scientific findings show that the risk presented by different aerosols varies in magnitude. **Diesel soot emissions** – defined as elemental carbon (EC)[9] (Jenk 2005) – are presently considered carcinogenic and particularly hazardous to health. Diesel soot particles consist of tiny spherical tar particles. Typical diesel soot particles have a diameter of 0.1–0.2 µm, but can also be larger. Further carcinogenic organic substances adsorb on the particle surface, but their carcinogenicity is negligible compared to that of the particles (Yetergil 1997, pp. 38ff). It is assumed that in the case of diesel engines without particle filters and in the case of furnaces / combustion processes, elemental carbon accounts for approx. 90 % of the total mass of particle emissions, while in the case of internal combustion engines the proportion is approx. 3 % (Jenk 2005). Soot particles also have a global warming impact (termed Black Carbon in IPCC (2001)), which this is small compared to the hazard to health (see Section 3.2.7).

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 fraction **(PM2.5)** correlates more with cardiac disrhythmia and an increased incidence of cardiovascular diseases. These fine particles remain much longer in the lung and accumulate there, as they are not readily coughed up. Ultrafine particles (PM0.1) – **diesel soot particles** are on this scale – can enter the bloodstream and the lymphatic system via the lung. Over time they are decomposed by the immune system and excreted (BUWAL 2001c).

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

At present there are two reduction targets for particles: 1) for PM10 and 2) for diesel soot. 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 political or statutory level.

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[9] According to the new SUVA definition, soot only comprises elemental carbon (EC), while the earlier definition also included organic carbon (OC). The present report only considers EC as soot.

3.8.2 Normalization

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

3.8.3 Weighting

Current flow

The data situation for **PM10** loads has been substantially improved vis-à-vis Brand et al. (1998). The current flow of 22 000 t/a is based on the BUWAL report SRU 379 (BUWAL 2005d). PM10 emissions from abrasion and resuspension are difficult to quantify. Ongoing research projects are designed to improve the assessment basis in this regard over the medium term. It must be assumed that, with the exception of road and rail transport, the present emission estimates of PM10 from abrasion and resuspension are systematically too high. As the update is based on estimated values, a degree of uncertainty remains in this regard.

Scarcely any emission inventories are available for primary **PM2.5.** BUWAL UM 169 (BUWAL 2003d, Table 13) contains emission estimates for 2000 (13 332 t) and 2010 (12 158 t, with "business as usual" scenario); this is based upon ambient measurements. The mean – 12 745 t for primary PM2.5 – is adopted as the current flow for 2005.

The current flow for **PM2.5–10** results from the difference of the annual loads for PM2.5 and 10, and figures 9255 t.

Critical flow

The Swiss Air Pollution Control Ordinance (Luftreinhalteverordnung, LRV) stipulates 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 in response to a recommendation by the Swiss Federal Commission for Air Hygiene in view of the health impacts of fine particulate exposure (BUWAL 1996b). According to BUWAL (2005d) the emission target is approx. 12 000 tonnes PM10 per year.

There is no limit value for **PM2.5** in Switzerland. However, as it is a subgroup of PM10, the same target can be applied, i.e. the critical flow is 6952 t/a.

The reduction target for PM10 is also taken for the **PM2.5–10** fraction, i.e. the critical flow is 5048 t/a.

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

Tab. 21 > Eco-factor for PM10 in EP/g PM10

	Situation 2006	Q	Notes	Situation 1997
Normalization (t PM10/a)	22 000	B		
Current flow (t PM10/a)	22 000	B	PM10 emissions with diesel soot	36 000
Critical flow (t PM10/a)	12 000	a	(BUWAL 2005d)	18 000
Weighting (-)	3.36			
Eco-factor (EP/g PM10)	150			110

Q = Data quality; for explanation see Section 2.4

Tab. 22 > Eco-factors for PM2.5 in EP/g PM2.5

	Situation 2006	Q	Notes	Situation 1997
Normalization (t PM2.5/a)	22 000	B	Applying target for PM10	
Current flow (t PM2.5/a)	12 745	B	(BUWAL 2003d), PM2.5 emissions incl. diesel soot	-
Critical flow (t PM2.5/a)	6 952	a		-
Weighting (-)	3.36			
Eco-factor (EP/g PM2.5)	150			110

Q = Data quality; for explanation see Section 2.4

Tab. 23 > Eco-factor for PM2.5–10 in EP/g PM2.5–10

	Situation 2006	Q	Notes	Situation 1997
Normalization (t PM2.5–10/a)	22 000	B	Applying target for PM10	
Current flow (t PM2.5–10/a)	9 255	B	Difference between PM2.5 and PM10, emissions incl. diesel soot	-
Critical flow (t PM2.5–10/a)	5 048	a		-
Weighting (-)	3.36			
Eco-factor (EP/g PM2.5–10)	150			110

Q = Data quality; for explanation see Section 2.4

Although PM10 emissions have dropped since 1997, the eco-factor is higher as a stricter reduction target is now applied. The eco-factors for PM2.5 and PM2.5–10 are identical to those for PM10, as the same reduction target is applied in each case.

3.8.5 Instruction for implementation

If the eco-factor for diesel soot is also used, care must be taken that no double weighting of particles is performed (see Section 3.9.4), as the particle groups overlap (Fig. 3).

3.9 Particulate matter (II): Diesel soot

3.9.1 Introduction

The sources and impacts of diesel soot are described in Section 3.8.1.

There is considerable debate on diesel soot at present. This has to do on the one hand with the precise definition (as “elemental carbon” in the present report), and on the other hand with its toxic effects. There are indications that the toxic effect of elemental carbon particles correlates more closely with particle number than with mass. If that is the case, the eco-factor would need to relate to the particle number. The requisite measurement technology, however, is not yet mature and derivation based on particle number is therefore not (yet) possible.

3.9.2 Normalization

The normalization flow is identical to the current flow, as no characterization is applied and the target directly concerns diesel soot.

3.9.3 Weighting

Current flow

The calculation of the current flow for **diesel soot** is based primarily on the data given in the BUWAL report UM-136 (BUWAL 2001b), whereby certain updates were performed for road transport, construction machines and aviation. The Swiss Air Pollution Control Ordinance LRV uses the term “diesel soot”. In addition to diesel engines, further sources are taken into account in the calculations whose soot emissions scarcely differ from diesel soot. Following the rules established by SUVA for diesel engines in underground mining, diesel soot is measured as elemental carbon. The emissions of the following processes are taken into account:

> Diesel and internal combustion engines in vehicles (automobiles, buses, utility vehicles, aircraft, ships, locomotives, agricultural vehicles, military vehicles and construction machines)
> Oil and gas firings
> Diesel aggregates
> Gas turbines

Soot emissions from the combustion of wood, coal and wastes are not taken into account. A total current flow of 3400 t/a results.

Critical flow

There is no threshold value for the carcinogenic effect of **diesel soot.** Therefore, applying the minimization rule for the emissions of carcinogenic substances (LRV, Annex 1 (82) para 1), the standard to be applied is that as much is done to reduce emissions as technology and operating conditions will allow, providing this is economically viable, i.e. the precautionary principle is to be applied (Section 2.2.3).

It follows from earlier publications and more recent findings that it should be possible to reduce diesel soot emissions in Switzerland, while applying the precautionary principle, to less than 500 t/a; this can be achieved above all by fitting particle filters to diesel engines.[10] The precautionary principle is considered to be observed under the following assumptions:

1. EURO5/6 for road vehicle (truck, automobile, bus) emissions in accordance with the "Future Diesel" proposal by UBA, or elimination of diesel soot emissions from road transport by means of particle filters
2. Equipment of 40 %[11] of construction machines with particle filters in accordance with the requirements established by the FOEN construction directive
3. Reduction of diesel soot emissions from construction machines, agriculture, forestry and industrial machinery in accordance with EU Directive 2004/26/EC (EU3B)
4. Particle filters are only used in specific cases in agriculture, forestry and industrial machinery, as the emissions standard for particles can also be achieved without using such filters.

As the EU directive makes strict stipulations with its EU3B standard, diesel soot emissions from agriculture and forestry are dropping rapidly even without particle filters being mandatory. For larger machines in particular (>56 kW), a reduction of particle emissions by a factor of 50 from present levels is prescribed. In the other emission sectors, particle filters eliminate 99 % and more of diesel soot emissions. This results in the achievable critical flow of 450 t/a.

3.9.4 Eco-factor for diesel soot (elemental carbon, EC)

Tab. 24 > Eco-factor for diesel soot in EP/g diesel soot

To be applied when the life cycle inventory contains correspondingly adjusted PM10 and PM2.5 data.

	Situation 2006	Q	Notes	Situation 1997
Normalization (t diesel soot/a)	3400	B		
Current flow (t diesel soot/a)	3400	B	Derived from BUWAL (2001b) and updated t	-
Critical flow (t diesel soot/a)	450	a	Precautionary principle	-
Weighting (-)	57.1			
Eco-factor (EP/g diesel soot)	17000			-

Q = Data quality; for explanation see Section 2.4

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[10] Personal communication, H. Jenk, FOEN, 22 February 2005

[11] Proportion of construction sites in Switzerland for which particle filters are mandatory

This newly introduced eco-factor for diesel soot (elemental carbon, EC) is higher by a factor of 100 than that for PM10 or PM2.5. This reflects the fact that diesel soot particles have a far more harmful impact upon human health than other particles. Particle filters effectively eliminate soot particles. A considerable reduction of other air pollutants has already been achieved by deploying catalytic converters. Current assessments of transport and combustion processes therefore depend greatly upon diesel soot emissions.

Diesel soot also has a global warming impact (see Section 3.2.7). The eco-factor calculated for that impact, however, is much lower than the eco-factor derived here for the human health impact.

3.10 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 mircoorganisms (e.g. oxidation of methane). Motor vehicle traffic generates around a half of all anthropogenic emissions (BUWAL 1995, p. 77).

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. The carbon monoxide eco-factor is therefore derived on the basis of its global warming potential (Section 3.2.7).

3.11 Benzene

3.11.1 Sources and environmental impact

Small quantities of benzene are already present in crude oil. Further quantities are formed when mineral oil is refined and when organic matter is burnt incompletely (e.g. in forest fires). Emissions of benzene to the atmosphere result primarily from combustion processes. In Switzerland, motorized transport is the source of three-quarters of all benzene emissions. The remainder is attributable to wood- and oil-fired heating systems, and to losses in fuel handling and storage (BUWAL 2003b).

Inhalation is the main exposure route for benzene. Benzene is soluble in fat and is therefore stored in the fatty tissue of the body. As women have a higher body fat ratio than men, the impacts of this pollutant are greater for women. Individuals living or working near to highly frequented roads or petrol stations are also more greatly exposed. Uptake via the skin is only relevant where 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 presents no hazard to human health (BUWAL 2003b).

3.11.2 Normalization

As the reduction target relates solely to benzene and no characterization is performed, the normalization flow is identical to the current flow.

3.11.3 Weighting

Current flow

Emissions in 2000 figured approx. 1370–1430 t/a. A reduction to half this level (680–740 t/a) by 2010 is expected, primarily in the transport sector due to tightened exhaust standards (BUWAL 2003b). The mean value of the years 2000 and 2010 is used here as the current flow for 2005, i.e. 1055 t/a.

Critical flow

There is no threshold value for the carcinogenic effect of benzene. In accordance with the principle that emissions of carcinogenic substances must be minimized (LRV, Annex 1 (82), para 1) the precautionary principle should be applied (Section 2.2.3). This means that all measures must be taken that technology and operating conditions will allow and that are economically viable.

Engines in line with the EURO4 standard are the state of the art in road transport. No further tightening of hydrocarbon limit values is currently under debate. It is assumed for boat motors and small equipment that benzene emissions are halved by 2010 (more 4-stroke engines, more alkylated petrol). For the handling and storage of fuels and for firings, the figures anticipated by BUWAL (2003b) in 2010 are used here. Benzene emissions are assumed to drop by 2030 to a level of 316 t/a in road transport, 77.5 t/a in the fields of boat motors and small equipment, and 130 t/a in the field of handling / storage / firings, which results in a total critical flow of 525 t/a.

According to the report on "Benzene in Switzerland" (BUWAL 2003b) benzene emissions would need to be reduced to 100 t per year if an acceptable risk is not to be exceeded. Such a target, however, would go substantially beyond what technology and operating conditions and economic viability would allow today.

3.11.4 Eco-factor for benzene

Tab. 25 > Eco-factor for benzene in EP/g benzene

	Situation 2006	Q	Notes	Situation 1997
Normalization (t benzene/a)	1 055	A		
Current flow (t benzene/a)	1 055	A	(BUWAL 2003b)	-
Critical flow (t benzene/a)	525	a	Precautionary principle	-
Weighting (-)	4.04			
Eco-factor (EP/g benzene)	3 800			32*

Q = Data quality; for explanation see Section 2.4
* NMVOC eco-factor based on situation in 1997

Benzene was not previously assessed as an individual substance, but as a part of the NMVOC group. The new form of assessment, based on carcinogenicity, leads to an eco-factor that is approximately 100 times greater; this is appropriate considering the severity of the problems presented by this substance compared to average NMVOCs.

3.12 Dioxins and furans (PCDD/PCDF)

3.12.1 Environmental impact

Dioxins and furans (PCDD and PCDF) are chlorinated aromatic hydrocarbons, some of which are highly toxic to humans and animals. There are in total 76 dioxins and 135 furans. They are formed in technological but also in 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-TEQ).[12] 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 (genital) organs, and intellectual deficits (BUWAL 1995; Lippmann 2000).

Dioxins and furans are scarcely volatile; their dispersal is mainly through attachment to particles. The main exposure route is via the ingestion of foods containing fat. In 1990, the WHO set the limit value for the acceptable daily intake (ADI) by humans at 10 pg 2,3,7,8-TCDD-eq per kg body weight. Based on more recent findings, the Dutch health ministry has proposed reducing the ADI limit value to 1 pg I-TEQ/kg body weight. The daily dioxin and furan intake of individuals in Western Europe is between 0.3 and 2 pg I-TEQ per kg body weight. Thanks to the drop in emissions, a reduction of the daily dioxin and furan intake can be expected (BUWAL 1997a).

The guideline value for dioxins and furans in soil, which is 5 ng I-TEQ/kg, is not exceeded in Switzerland, except in soils subject to major anthropogenic impact.

3.12.2 Normalization

Dioxins and furans are practically always stated in life cycle inventories as characterized quantities in I-TEQ. The reduction target therefore also applies to this characterized quantity, and thus the normalization flow is identical to the (already characterized) current flow.

3.12.3 Weighting

Current flow

Before 1955, dioxin and furan emissions were below 40 g I-TEQ/a. They rose between 1955 and 1980 to a level of 485 g I-TEQ/a. Since then they have been dropping thanks to improved exhaust purification technology, as today all municipal waste incineration plants are fitted with a flue gas purification system (BUWAL 2003a). In 2000 they amounted to 70 g I-TEQ/a, whereby now almost half of the emissions (30 g I-TEQ/a) are generated by households (BUWAL 1997a).

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[12] I-TEQ: International toxicity equivalent is a weighting factor that aggregates the various dioxins and furans in accordance with their respective toxicities. The factor 1 is assigned to the Seveso dioxin 2,3,7,8-TCDD.

For the period to 2010, it is anticipated on the one hand that overall emissions will drop slightly to 65 g I-TEQ/a due to improvements in municipal waste incineration plants and in industrial processes. On the other hand, it must be expected that the introduction or increase of waste collection charges will cause more household wastes and treated wood to be burnt in open fires (including cheminées). Private households will then be responsible for more than half of total emissions (37 g I-TEQ/a out of a total of 65 g I-TEQ/a) (BUWAL 1997a). The current flow is taken as the mean of the emissions in 2000 and those in 2010, i.e. 67.5 g I-TEQ/a.

Critical flow

As dioxins and furans accumulate in the food chain, their formation needs to be prevented wherever possible. In line with the precautionary principle (Section 2.2.3), the calculation of the critical flow is based on the state of the art in dioxin and furan emissions reduction. Flue gas purification systems such as those installed in municipal waste incineration plants achieve 99 % reduction of dioxins and furans in the exhaust.[13] The provisions of the Swiss Air Pollution Control Ordinance on nitrogen oxide emissions also have an indirect limiting effect on dioxin and furan emissions. As a result, it can be assumed that there is a minor potential for further reductions in combustion facilities in industry and commerce. There is significant potential in private households, whose emissions could be reduced by 99 % if only untreated wood and no wastes at all were burnt. This means that household emissions could be reduced from 33.5 g I-TEQ to 0.33 g I-TEQ, which translates into roughly halving the current flow to 34.5 g I-TEQ/a. This quantity is taken as the critical flow.

3.12.4 Eco-factor for dioxins and furans

Tab. 26 > Eco-factors for dioxins and furans in EP/g I-TEQ

	Situation 2006	Q	Notes	Situation 1997
Normalization (g I-TEQ/a)	67.5	B		
Current flow (g I-TEQ/a)	67.5	B	(BUWAL 1997a)	-
Critical flow (g I-TEQ/a)	34.5	b	Precautionary principle	-
Weighting (-)	3.83			
Eco-factor (EP/g I-TEQ)	$5.7 * 10^{10}$			-

Q = Data quality; for explanation see Section 2.4

The eco-factor for dioxins and furans is very high. This is an expression of the low emission quantities in the order of several grams per year, and further reflects the great harmfulness of these substances and the available reduction options.

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[13] According to the personal communication by Beat Müller, FOEN, of 17.2.2005 a reduction by a factor of 100 to 1000 is to be expected, and a reduction by 99 % is thus a reasonable assumption.

3.13 Lead (Pb)

Lead exposure damages animals and plants, and impairs soil fertility. Lead accumulates in food chains. It can impair blood formation and can cause developmental disorders in children (BUWAL 1991, p. 29).

3.13.1 Normalization

As the various lead compounds are not characterized, the normalization flow is the quantity emitted to air across the whole of Switzerland.

3.13.2 Weighting

Current flow

Because lead was blended into petrol, lead emissions rose sharply from the 1950s onwards. They peaked at 2160 t/a in 1970. Thanks to the introduction of unleaded petrol, emissions have dropped again since then. Further uses of lead include batteries, paints and lead for bullets. Total emissions figured 226 t/a in 1995 and were estimated at 91 t/a for 2005 (BUWAL 1995, p. 86). These 91 tonnes are generated mainly by waste incineration plants and the steel industry.

Critical flow

The Swiss Air Pollution Control Ordinance (Luftreinhalteverordnung, LRV) stipulates ambient limit values (annual mean values) for lead in dust deposition. However, no critical flow can be derived from this. A theoretical critical flow can, however, be derived from the weighting factor for soil, as set out in the following.

Weighting factor

The purpose o the LRV is to *"[…] protect humans, animals, plants, their biotic communities and habitats as well as soil from air pollution that is harmful or noxious"* (LRV, Art. 1). Soil protection is thus a stated goal of the LRV. It is therefore possible to apply targets established for soils to air emissions, 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 finally enter the soil via deposition must be the same as that for direct emissions to soil. The weighting factor for lead to soil, as determined in Section 6.2, is therefore used.

3.13.3 Eco-factor for lead

Tab. 27 > Eco-factor for lead emissions to air in EP/g lead

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Pb/a)	91	B		
Current flow (t Pb/a)	91	B	Value for 2005 in accordance with BUWAL (1995, p. 86)	226
Critical flow (t Pb/a)	(58)		Theoretical value calculated from weighting	280
Weighting (-)	2.44		Corresponds to weighting factor for lead loading of soil	
Eco-factor (EP/g Pb)	27 000			2 900

Q = Data quality; for explanation see Section 2.4

Due to the new derivation methodology, the new eco-factor is substantially higher than the previous one, although emissions have already dropped significantly. The increase by almost a factor of 10 is possibly due to the circumstance that the ambient limit value (the previous basis) tends to be set more generously than is the case for other heavy metals, because of the emissions from the transport sector. This has led until now to a relatively less strict assessment.

3.14 Cadmium (Cd)

3.14.1 Environmental impact

Even small quantities of cadmium are toxic to humans and animals if exposure is chronic. 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).

3.14.2 Normalization

As the various cadmium compounds are not characterized, the normalization flow is the quantity emitted to air across the whole of Switzerland.

3.14.3 Weighting

Current flow

Cadmium emissions peaked at 7 t/a around 1970. As a result of measures taken in waste incineration and in the metal industry, they 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 approx. 2.5 t/a. Emissions are estimated at 2 t/a for 2005 (BUWAL 1995, p. 90).

Critical flow

The Swiss Air Pollution Control Ordinance (Luftreinhalteverordnung, LRV) stipulates ambient limit values (annual mean values) for cadmium in dust deposition. However, no critical flow can be derived from this. A theoretical critical flow can, however, be derived from the weighting factor for soil, as set out in the following.

Weighting factor

The purpose o the LRV is to *"[…] protect humans, animals, plants, their biotic communities and habitats as well as soil from air pollution that is harmful or noxious"* (LRV, Art. 1). Soil protection is thus a stated goal of the LRV. It is therefore possible to apply targets established for soils to air emissions, 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 finally enter the soil via deposition must be the same as that for direct emissions to soil. The weighting factor for cadmium to soil, as determined in Section 6.2, is therefore used.

3.14.4 Eco-factor for cadmium

Tab. 28 > Eco-factor for cadmium emissions to air in EP/g cadmium

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Cd/a)	2.00	B		
Current flow (t Cd/a)	2.00	B	Value for 2005 in accordance with BUWAL (1995, p. 90)	2.5
Critical flow (t Cd/a)	(2.08)		Theoretical value calculated from weighting	4.5
Weighting (-)	0.925		Corresponds to weighting factor for cadmium loading of soil	
Eco-factor (EP/g Cd)	460 000			120 000

Q = Data quality; for explanation see Section 2.4

The current flow of cadmium has dropped in recent years and is now slightly below the critical flow. Due to the ban on accumulators containing cadmium and their resulting replacement by more modern, cadmium-free products, a further drop can be expected in future.

3.15 Mercury (Hg)

3.15.1 Environmental impact

Mercury is highly toxic to humans and animals. It is taken in via the respiratory tract and accumulates in various organs. It is also toxic to plants and microorganisms and impairs soil fertility (BUWAL 1995).

3.15.2 Normalization

The normalization flow is identical to the current flow.

3.15.3 Weighting

Current flow

Industry and commerce are the principal generators of mercury emissions. In the past, municipal waste incineration plants were a further important source, but their emissions have been reduced substantially through improved flue gas purification. Switzerland reported annual emissions of 1020 kg Hg to the United Nations for 2004.[14].

Critical flow

As mercury is not addressed by the study on heavy metal inventories (Keller et al. 2005b), no eco-factor can be derived for mercury from the rate of accumulation in soil. Mercury is, however, addressed by the NABO standard measurement programme. This has found major dynamics with regard to mercury concentration changes. The guideline value of 0.5 mg/kg was, however, only exceeded at 3 of 102 sites (BUWAL 2000b).

The strictest target of the Swiss air pollution control strategy is to reduce emissions to the level of 1950 (Schweizerischer Bundesrat 1999). In the case of mercury, emissions in 1950 amounted to 2220 kg Hg. This value is taken as the critical flow.

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[14] Personal communication by N. Egli, FOEN, 3 November 2006

3.15.4 Eco-factor for mercury

Tab. 29 > Eco-factor for mercury emissions to air in EP/g mercury

	Situation 2006	Q	Notes	Situation 1997
Normalization (kg Hg/a)	1 020	B		
Current flow (kg Hg/a)	1 020	B		3.3
Critical flow (kg Hg/a)	2 220	b		
Weighting (-)	0.21			
Eco-factor (EP/g Hg)	210 000			120 000*

Q = Data quality; for explanation see Section 2.4
* In the absence of a defined critical flow, the eco-factor for cadmium was also applied for mercury in Brand et al. (1998)

The current flow of mercury has dropped steadily in recent years. No further reduction is expected.

3.16 Zinc (Zn)

3.16.1 Environmental impact

Zinc loads impair plant growth (BUWAL 1991, p. 29).

3.16.2 Normalization

As the various zinc compounds are not characterized, the normalization flow is the quantity emitted to air across the whole of Switzerland.

3.16.3 Weighting

Current flow

Until the 1970s, zinc emissions came mainly from steelworks and from the unfiltered burning of wastes. Total emissions peaked in 1970 at 1750 t/a. In 1995, approx. 630 t were still emitted, whereby dropping emissions in industry and commerce were partly compensated by rising zinc emissions from road traffic (tyre and road abrasion). A further drop to 560 t/a is taken as the figure for 2005, whereby the transport sector is now the main source, accounting for two-thirds (BUWAL 1995, p. 88). If the trend towards increasing zinc emissions from transport persists, it must be expected that overall zinc emissions rise again, as no further significant reductions are to be expected in industry.

Critical flow

The Swiss Air Pollution Control Ordinance (Luftreinhalteverordnung, LRV) stipulates ambient limit values (annual mean values) for zinc in dust deposition. However, no critical flow can be derived from this. A theoretical critical flow can, however, be derived from the weighting factor for soil, as set out in the following.

Weighting factor

The purpose o the LRV is to *"[…] protect humans, animals, plants, their biotic communities and habitats as well as soil from air pollution that is harmful or noxious"* (LRV, Art. 1). Soil protection is thus a stated goal of the LRV. It is therefore possible to apply targets established for soils to air emissions, 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 finally enter the soil via deposition must be the same as that for direct emissions to soil. The weighting factor for zinc to soil, as determined in Section 6.2, is therefore used.

3.16.4 Eco-factor for zinc

Tab. 30 > Eco-factor for zinc emissions to air in EP/g zinc

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Zn/a)	560	B		
Current flow (t Zn/a)	560	B	Value for 2005 in accordance with BUWAL (1995, p. 88)	630
Critical flow (t Zn/a)	(359)		Theoretical value calculated from weighting	1 100
Weighting (-)	2.44		Corresponds to weighting factor for zinc loading of soil	
Eco-factor (EP/g Zn)	4 400			520

Q = Data quality; for explanation see Section 2.4

The current flow of zinc has dropped slightly compared to 1997. However, due to the new derivation methodology, the critical flow has dropped much more strongly, leading to an eco-factor that is now higher.

4 > Emissions to surface waters

4.1 Introduction

4.1.1 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. Thus, for example, substances which pose a problem in individual small water bodies nevertheless present levels in the Rhine below the required concentration limit for waters, owing to dilution. Ideally graded eco-factors should be made available to reflect the situation in different water bodies. 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 (Chapter 2).

The derivation of eco-factors for emissions into waters is based on simplifications which do not entirely take the ecological conditions into account. The aim of determining eco-factors is not to be able to make an ecological assessment of individual pollutant emissions but to produce a comparative weighting across all environmental media as part of life cycle assessments.

As explained in the chapter on groundwater (see Section 5.1) , the eco-factors for surface waters should *not* be applied to pollutants emitted into groundwater.

4.1.2 Selection of substances

Owing to effluent purification measures taken, it has been possible to reduce significantly the emission of a number of substances into surface waters, with any emissions remaining being of subordinate importance for the ecology of Swiss waters. The question arises as to what extent eco-factors should be assigned to such substances. On the other hand, it should be borne in mind that eco-factors are applied not only to emissions within Switzerland, but also outside the country. Where possible an eco-factor is assigned to substances that may well pose no problem within Switzerland but may be environmentally significant elsewhere.

Since the entry into force of the Swiss Water Protection Ordinance (WPO; Gewässerschutzverordnung, GSchV*)* in the autumn of 1997 water quality requirements are only specified for substances which are still relevant to the quality of watercourses today. The list in the WPO represents a starting point for the selection of eco-factors for substances polluting waters. Additions to the list include phosphorus on account of its significant impact on water quality in lakes, the aggregate parameter AOX (adsorbable organic halogens in waters), endocrine disruptors and radioactive emissions (from reprocessing spent fuel elements).

The water pollutants weighted with an eco-factor are listed in Tab. 31. The impacts of the pollutants are also outlined, showing which of them is critical in determining the eco-factor. In many instances the quality target set by the ICPR (International Commission for the Protection of the Rhine), which does not relate to one single impact, has been used.

4.1.3 Guidelines for application

Switzerland is not responsible for any emissions directly into the sea. However, emissions can be released indirectly through the manufacture of products imported, so the eco-factors derived in this chapter are also to be applied to emissions into the sea. The eco-factors for nitrogen and radioactive emissions are in any case based to some extent on marine protection targets.

Tab. 31 > Impact mechanisms of the water pollutants assessed

	Environmental				Human						Notes
	Eutrophication	Oxygen consumption	Toxicity in fish	Bioaccumulation	Metabolic disturbances	Carcinogenicity	Mutagenesis	Embryonal damage	Other/further types of damage	Characterization	
Nitrogen	#		(x)							-	
Phosphorus	#									-	
Organic matter (BOD, COD, DOC, TOC)		#								-	
Arsenic				x	x	x		(x)		-	As per ICPR Rhine quality target
Lead (Pb)				x	x					-	As per ICPR Rhine quality target
Cadmium (Cd)				x	x	x		(x)		-	As per ICPR Rhine quality target
Chromium (Cr)				x	x					-	As per ICPR Rhine quality target
Copper (Cu)				x	x					-	As per ICPR Rhine quality target
Nickel (Ni)				x	x					-	As per ICPR Rhine quality target
Mercury (Hg)				x	x					-	As per ICPR Rhine quality target
Zinc (Zn)				x	x					-	As per ICPR Rhine quality target
Radioactive emissions to the sea							x		x	C14-eq.	Reduction to natural background levels
AOXs				x	x				x	-	As per ICPR Rhine quality target
Chloroform						(x)			x	-	As per ICPR Rhine quality target
PAHs						x				-	As per ICPR Rhine quality target
Benzo(a)pyrene (BaP)						(x)				-	As per ICPR Rhine quality target
Endocrine disruptors					#			x	x	E2-eq.	

x Impact or link proven
(x) Impact or link presumed
Principal impact for determining the eco-factor

4.2 Nitrogen

4.2.1 Environmental impact

Over 90 % of anthropogenic total nitrogen in surface waters consists of nitrate and ammonium or ammonia. Sources of nitrogen in waters are agricultural fertilizers and industrial, commercial and household effluents. The eco-factors in this chapter only evaluate the the nitrogen loads in surface waters. Nitrogen compounds (notably nitrate) which are first released into groundwater and enter surface waters from there are assessed separately in the chapter on groundwater (see Section 5.2).

In present quantities nitrate no longer represents a general problem for the ecology of surface waters in Switzerland, although a few local problems may persist. However, the nitrogen load in the North Sea and other shallow seas is of great importance with regard to eutrophification. The aim, therefore, is to achieve a marked reduction in the nitrogen discharged into the North Sea, including by reducing loads in the Rhine (BUWAL 1996c).

4.2.2 Normalization

The assessment of the normalization flow is based on the nitrogen discharge into the Rhine catchment according the model developed by Prashun et al. (2005) extrapolated to the whole of Switzerland using the ratio of Rhine catchment runoff to total Swiss runoff.

The nitrogen load for the Rhine catchment amounts to 30 556 t N/a. Runoff via the Rhine amounts to a long-term average of around 38 bn. m^3/a, and the total for Switzerland to 48 bn. m^3/a. This produces an extrapolated load of 38 597 t N/a for the whole of Switzerland.

4.2.3 Weighting

Current flow

Since the reduction target refers only to emissions in the Rhine catchment within Switzerland (see next paragraph on critical flows), the current flow must cover the same area. According to the OSPAR Commission (2006) the current flow amounts to 24 827 t N/a.

Critical flow

In 1987, as a result of the over-use of fertilizers which became evident in the course of the 1980s, the countries bordering the North Sea issued a declaration of intent.[15] The aim of this 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 1996c, p. 36). In the case of nitrogen the target has still not been reached, with the reduction amounting to 29 % by 2003 (OSPAR Commission 2006).

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

This target is used as a basis for establishing the critical flow for total nitrogen emissions (N_{tot}). In 1985 the nitrogen load in the Rhine catchment was 35 020 t N/a (OSPAR Commission 2006), producing a critical flow of 17 510 t N/a. The derivation of the critical flow from the Swiss Water Protection Ordinance would result in a significantly higher critical flow[16], so for that reason it is not used.

4.2.4 Eco-factor for nitrogen in surface waters

Tab. 32 > Eco-factor for nitrogen and nitrogen compounds in surface waters in EP/g N

	Situation 2006	Q	Remarks	Situation 1997
Normalization flow (t N/a)	31 360	B	Extrapolated to the whole of Switzerland using NADUF runoff data	
Current flow (t N/a)	24 827	A	Rhine catchment only (OSPAR Commission 2006)	40 000
Critical flow (t N/a)	17 510	a	50 % reduction target in Rhine catchment (OSPAR Commission 2006)	24 000
Weighting factor (-)	2.01			
Eco-factor (EP/g N)	64			69

Q = Data quality; for explanation see Section 2.4

The eco-factor for nitrogen has fallen slightly compared with the previous situation, as the nitrogen load has been significantly reduced from the 1997 level.

4.3 Phosphorus

4.3.1 Environmental impact

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

The phosphorus load in lakes varies enormously according to location. Alpine lakes (e.g. Lake Lucerne, Lake Thun) exhibit very low concentrations, whereas lakes in areas of intensive farming can still be severely polluted by the phosphorus that is applied to the fields in manure and synthetic fertilizers. The connection of households and businesses to sewage treatment works and the ban on phosphates in textile detergents has led to a marked drop in the phosphorus load over the last two decades (BLW & BUWAL 1998; BUWAL 2004a).

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[16] Assuming a mean runoff via the Rhine of 1000 m^3/s and taking the required value of 5.6 mg NO_3-N/l, a critical flow of 176,600 t NO_3-N/a would result for the Rhine catchment.

Phosphorus is released into waters as particle-bound phosphate, mainly through erosion and leaching from cropland. The still substantial contribution of agriculture to the loads is also a consequence of liberal use of fertilizers in the past. Thus agricultural land in Switzerland registers a phosphorus content far in excess of the plants' annual requirements. In integrated production systems it is now only permitted to use as much phosphorus as the crops can take up, which has improved the situation somewhat (BUWAL 2004a). The ChemRRV (Chemical Risk Reduction Ordinance) also contains regulations on permitted applications of compost, fermented material and silage effluent, which should result in further improvement.

4.3.2 Normalization

The amount of phosphorus discharged into surface waters in the whole of Switzerland can only be estimated, as the runoff from agricultural land, which accounts for a significant proportion, is impossible to measure. Phosphorus entering the waters is absorbed by aquatic plants and eventually deposited through sedimentation of the biomass.

Assessment of the normalization flow is based on the phosphorus entering the Rhine catchment according to the model developed by Prashun et al. (2005) and extrapolated to the whole of Switzerland using the ratio of Rhine catchment runoff to total Swiss runoff. The most recent figures (2003) are published in OSPAR Commission (2006).

The phosphorus load for the Rhine catchment amounts to 1341 t P/a. Runoff via the Rhine itself amounts to a long-term average of around 38 bn. m^3/a and that from the whole of Switzerland to 48 bn. m^3/a. This produces a phosphorus load of 1694 t P/a for the country as a whole.

4.3.3 Weighting: Protecting the North Sea

Current flow

The current flow differs from the normalization flow, as the reduction target only applies to the Rhine catchment. According to the OSPAR Commission (2006) the phosphorus load amounts to 1341 t P/a.

Critical flow

The states bordering the North Sea have issued a ministerial declaration, which Switzerland has also signed, agreeing to reduce phosphorus and nitrogen loads to 50 % of the 1985 level. The phosphorus target has already been achieved. At 1434 t P/a the critical flow is slightly higher than the current flow (OSPAR Commission 2006).

4.3.4 Weighting: Phosphorus content of Swiss lakes

Alternatively, the weighting factor (and consequently the eco-factor) for phosphorus can also be calculated separately for every lake in Switzerland by using the target value for the phosphorus concentration in lake water (Tab. 33). The target value is set at

20 mg P/m³ of well-mixed open water (BLW & BUWAL 1998, p. 6). Some lakes have a measured value well below this target (Walensee), 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 Extremeely varied.

To determine an average ecological scarcity for Switzerland both the current individual phosphorus concentrations and the volume of water in the lakes are relevant. The capacity of the lakes to absorb phosphorus is dependent on 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. 33).

Tab. 33 > Calculation of the weighting factor for Swiss lakes based on the current and target concentrations

Only lakes with reliable values for 2004, or if necessary 2005, have been included

	Volume of lake m³ (millions)	Total concentration of phosphorus mg/m³	Year recorded	Target value mg/m³	Weighting factor (-)
Lake Geneva	89 900	29.5	2004	20	2.18
Lake Constance	48 000	9	2004	20	0.20
Lake Neuchâtel	14 170	7	2004	20	0.12
Lake Maggiore	37 100	10	2004	20	0.25
Lake Lucerne	11 800	5	2004	20	0.06
Lake Zurich	3 900	24.6	2004	20	1.51
Lake Lugano, north basin	4 690	110	2005	20	30.25
Lake Lugano, south basin	1 140	45	2005	20	5.06
Lake Thun	6 500	4	2004	20	0.04
Lake Biel	1 240	18	2004	20	0.81
Lake Zug	3 210	108	2005	20	29.16
Lake Brienz	5 170	4	2004	20	0.04
Walensee	2 490	3	2004	20	0.02
Lake Murten	600	11	2004	20	0.30
Lake Sempach	660	29	2004	20	2.10
Lake Hallwil	215	49	2004	20	6.00
Greifensee	161	67	2004	20	11.22
Lake Baldegg	178	43	2004	20	4.62
Pfäffikersee	58	22	2004	20	1.21
Weighting factor for Switzerland					2.04

Source: phosphor_dans_les_lacs.xls[17]

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[17] Data on phosphorus in lakes, transmitted by Dr. P. Liechti (FOEN/BAFU) on 5 April 2006. The data were collected by international commissions (CIPEL, CIPAIS, IGKB), cantonal authorities, Eawag and Wasserversorgung Zürich (WVZ, the Zurich water utility; for Lake Zurich and the Walensee).

4.3.5 Eco-factor for phosphorus

In Sections 4.3.3 and 4.3.4, the weighting has been derived by two different methods: in one instance from the 50 % reduction target for emissions into the North Sea and in the second from the protection target for Swiss lakes. The latter produces a larger eco-factor, so the one derived from the 50 % reduction target will not be included in Tab. 34.

Tab. 34 > Eco-factor for phosphorus in EP/g P

	Situation 2006	Q	Remarks	Situation 1997
Normalization flow (t P/a)	1 694	B	Extrapolated using NADUF runoff data from the loads for the Rhine catchment according to the OSPAR Commission (2006)	
Current flow (t P/a)	-			2 900
Critical flow (t P/a)	-			1 200
Weighting factor (-)	2.04		Calculated from the lake protection target	
Eco-factor (EP/g P)	1 200			2 000

Q = Data quality; for explanation see Section 2.4

The smaller eco-factor reflects the easing of the phosphorus problem and the effect of the measures undertaken. As shown in Tab. 33, some lakes are still subject to severe pollution, although concentrations have fallen compared with previous years.

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

4.4.1 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 waste water. 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 to this, many substances (such as chlorinated organic compounds or endocrine substances) can have specific toxic impacts which should be recorded separately (Kummert & Stumm 1989; Sigg & Stumm 1989).

The pollution of Swiss waters has fallen in recent decades, owing to measures to improve effluent treatment. Moreover, the legislation (WPO) requires implementation of measures to reduce organic endocrine substances in effluent to a level at which there is no ecological detriment to waters. In most cases the residual load from effluent treatment works is non-critical in terms of the total oxygen available. Of foremost environmental importance, therefore, are persistent, bioaccumulative and toxic organic substances. However, the specific impacts of the substances encompassed by the aggregate parameter “organic matter” cannot be considered here.

The concentration of organic matter in waters 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 5 days (BOD_5). The proportion of hydrocarbons which break down readily, particularly through microbial degradation, is determined from this. The BOD value is always lower than that for COD. Usually BOD_5 is determined.

COD (chemical oxygen demand)
COD expresses the amount of oxygen required to oxidize organic compounds. In Switzerland COD is used principally to determine the quality of the discharge from water treatment works (effluent parameter). In most other countries pollution of waters with organic substances 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 of 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 derived for it. If necessary DOC can be converted into COD using the estimation factor COD (in g) ≈ 3 DOC (in g). A lower estimate for COD can also be derived from BOD, with COD (in g) = BOD (in g). If only the TOC value has been measured, this can be regarded as equivalent to DOC for the purpose of a rough approximation, hence COD can be estimated with COD (in g) ≈ 3 TOC (in g) (Brand et al. 1998).

4.4.2 Normalization

The total load cannot be extrapolated from the COD concentrations at the places where the large rivers flow out of Switzerland, as firstly some of the organic substances are of natural origin and secondly organic substances degrade to some extent relatively quickly in watercourses and do not reach the measuring stations at these runoff points.

The loads from sewage treatment works and agriculture have been determined for the canton of Berne. Dinkel et al. (2004) have extrapolated the total Swiss flow of 47 700 t COD/a from this data.

4.4.3 Weighting

Current flow

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

Critical flow

In the project group Nitrogen Balance Switzerland (Stickstoffhaushalt Schweiz, 1996, p. 16–17) the critical flow is assessed on the basis of ecological criteria: from an environmental perspective a maximum of 30 % of the oxygen dissolved in water should be consumed downstream from the discharge points. The average oxygen content of river water is estimated at 10 g/m³, which produces a maximum permissible consumption of 3 g O_2/m³ together with a maximum permissible load of 3 g COD/m³ (Projektgruppe Stickstoffhaushalt Schweiz 1996, p. 16–17).

The maximum anthropogenically generated COD load can be extrapolated from the quantity of runoff from Switzerland (48 bn. m³) and is put at 144 000 tonnes per year.

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

As all these factors measure the same thing – organic carbon – care must be taken not to count them twice. It is preferably 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 Section 4.4.1.

Tab. 35 > co-factor for COD (chemical oxygen demand) in EP/g COD

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

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (t COD/a)	47 700	B		
Current flow (t COD/a)	47 700	B	(Dinkel & Stettler 2004)	115 000
Critical flow (t COD/a)	144 000	b	Derived from the project group Nitrogen Balance Switzerland (1996, p. 16–17)	140 000
Weighting factor (-)	0.11			
Eco-factor (EP/g COD)	2.30			5.9
Eco-factor (EP/g BOD)	2.30		Rough approximation: BOD ≈ COD	5.9
Eco-factor (EP/g DOC)	6.90		Derived from the eco-factor for COD with COD ≈ 3 DOC	18
Eco-factor (EP/g TOC)	6.90		Rough approximation: COD ≈ 3 DOC ≈ 3 TOC	18

Q = Data quality; for explanation see Section 2.4

The eco-factor is smaller than in 1997 as a result of the reduction in emissions. Waste water purification throughout Switzerland and the regulations governing the discharge of effluent into waters have led to a drop in organic matter there.

The weighting of specific impacts of persistent bioaccumulative substances is not possible with the eco-factor for COD.

4.5 Heavy metals and arsenic

4.5.1 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 through the food chain. However, these substances do not represent a major problem in Switzerland.

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 fertilizers and pesticides, meaning that agriculture is another source of heavy metals. Chromium arises mainly from the corrosion of chromium steel products. Since the use of leaded petrol has declined and industrial effluent discharges have been cleaned up these have now become the predominant sources of heavy metals (BUWAL et al. 2000).

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

4.5.2 Normalization

The total load of heavy metals entering surface waters in Switzerland can be extrapolated from the concentration values measured in the Rhine.

In Weil am Rhein heavy metal concentrations in the water are determined in accordance with NADUF (Swiss National River Monitoring and Survey Programme) regulations (BUWAL et al. 2000), and the heavy metal content of suspended matter is measured according to the International Commission for the Protection of the Rhine (IKSR 2004). To determine the normalization the NADUF values have been used, as these include dissolved heavy metals. In order to compensate for the occasional wide variations in concentration from one year to another and obtain more representative values, the average for the years 2001 to 2004 has been used in each case (Tab. 36).

The following factors could account for any 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.
- the Rhine may exhibit above average mercury loads on account of the structure of industry in the catchment.
- 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.

Tab. 36 > Calculation of the normalization flow for heavy metals based on NADUF concentration figures (mean value for the years 2001 to 2004) at Weil am Rhein monitoring station.

	Average concentration in the Rhine g/s	Normalization t/a
Arsenic (As)	0.188*	8.6*
Lead (Pb)	0.704	32
Cadmium (Cd)	0.0134	0.61
Chromium (Cr)	0.555	25
Copper (Cu)	1.61	74
Nickel (Ni)	1.84	84
Mercury (Hg)	0.0044	0.20
Zinc (Zn)	3.65	167

* Arsenic values calculated from ICPR (2004) concentration figures and the assumption of 17.9 kg of suspended solids/s (mean value for the years 2001 to 2004 based on NADUF)

4.5.3 Weighting

Weighting factor

Seven heavy metals with implications for the environment are listed in the Swiss Water Protection Ordinance (WPO). They are mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn) and nickel (Ni). The WPO sets out quality requirements both for watercourses in the form of required and guideline values and for the discharge of effluent into sewers and waters. The limits for the latter are more rigorously defined (BUWAL et al. 2000).

In addition, in 2003 the Convention on the Protection of the Rhine (IKSR 1999), which was renewed in 1999 and to which Switzerland is also a signatory, entered into force. The ICPR (International Commission for the Protection of the Rhine), like the WPO, sets water quality targets in the form of concentration limits – including for heavy metals. The ICPR targets for heavy metals bound in the suspended solids phase are roughly similar to the WPO concentration limits for effluent discharges (working on the basis of an average suspended matter content of 16 mg/l).

The ratio of the heavy metal content of suspended solids to their ICPR (2004) target levels is significantly higher than the ratio of the total concentration of heavy metals in water to the limits set by the WPO. Therefore for weighting purposes the more stringent targets, and thus higher eco-factors based on ICPR data, are used. To produce the weighting factor the concentrations in the suspended solids (rather than the rivers) are compared directly with each other (Tab. 37). The data on current concentrations is taken from the annual report from the Rhine monitoring station at Weil am Rhein (AUE 2005), which gives the most recent figures.

Tab. 37 > Weighting factors for heavy metals calculated from current and critical concentrations

	Current concentration (measured value) mg/kg suspended matter	Critical concentration (target value) mg/kg suspended matter	Weighting (-)
Arsenic (As)	10.5	40	0.07
Lead (Pb)	38	100	0.14
Cadmium (Cd)	0.42	1.00	0.18
Chromium (Cr)	44	100	0.19
Copper (Cu)	51	50	1.04
Nickel (Ni)	38	50	0.57
Mercury (Hg)	0.21	0.50	0.18
Zinc (Zn)	182	200	0.83
Quelle:	(AUE 2005)	(IKSR 2004)	

4.5.4 Eco-factors for heavy metals and arsenic in surface waters

Tab. 38 > Eco-factors for heavy metals in surface waters in EP/g of each heavy metal

	Normalization t/a	Q	Current concentration mg/kg	Q	Critical concentration mg/kg	Q	Weighting (-)	Eco-factor 2006 EP/g	Eco-factor 1997 EP/g
Arsenic (As)	8.6	B	10.5	A	40	a	0.069	8 000	-
Lead (Pb)	32	B	38	A	100	a	0.14	4 400	190
Cadmium (Cd)	0.61	B	0.42	A	1.00	a	0.18	290 000	11 000
Chromium (Cr)	25	B	44	A	100	a	0.19	7 600	660
Copper (Cu)	74	B	51	A	50	a	1.04	14 000	1 200
Nickel (Ni)	84	B	38	A	50	a	0.57	6 800	190
Mercury (Hg)	0.20	B	0.21	A	0.50	a	0.18	880 000	240 000
Zinc (Zn)	167	B	182	A	200	a	0.83	5 000	210

Q = Data quality; for explanation see Section 2.4

The values required by the WPO have not altered since being used in Brand et al. (1998), which would have resulted in the eco-factors staying more or less the same. By using the more stringent targets from the ICPR account has been taken of political developments which have not yet found expression in the Water Protection Ordinance. The resulting eco-factors are significantly higher than those from 1997.

4.6 Radioactive emissions to seas

4.6.1 Introduction

Until now radioactive emissions have been excluded from assessments using the ecological scarcity method. The quantity of emissions from nuclear power plants in Switzerland is well below statutory limits. No other substantial sources of emissions have been identified in the country.

The reason why radioactive emissions to seas are now being assessed lies in the OSPAR Conventions for the protection of the North Sea. The OSPAR member states have agreed to reduce substantially the loads of radioactive substances from reprocessing plants into the Irish and North Seas.

Because of that an eco-factor is derived on the basis of emissions occurring outside Switzerland. The reduction targets are based on international agreements which Switzerland supports. (A similar procedure is applied in relation to fresh water use in arid countries, see Section 7.5)

The moratorium on reprocessing spent fuel elements, which came into effect on July 1 2006, has no influence on the scarcity formula produced here. It is an exceptional situation, and of limited duration. The cessation of reprocessing and its associated emissions of radioactive elements to the seas will nonetheless have an impact on future inventory analyses of electricity generation at Swiss nuclear power plants, although those of, for example, French nuclear energy and France’s strategy for disposing of spent fuel elements remain unaffected. Emissions generated by French nuclear energy are still relevant to Switzerland because of the electricity imported from there.

4.6.2 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 characterization factors take both 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.

4.6.3 Characterization

The environmental impact of the emission of radioactive elements is characterized according to its carcinogenic impact on humans. Impacts on ecosystems are not considered. As reduction targets for discharges to the Irish and North Seas were stipulated under OSPAR agreements, the characterization values of pollutant discharges to seas are of interest here. Carbon-14 has been chosen as the reference substance. The characterization factors are assessed on the basis of Frischknecht et al. (2000) and are listed in Tab. 39.

Tab. 39 > Characterization factors for the cancer-inducing potential of radioactive discharges to seas, according to Frischknecht et al. (2000), reference element C-14

		Carcinogenic potential of radioactive elements (kBq C-14-eq. /kBq)
Americum-241	Am-241	25.8
Carbon-14	C-14	1.00
Curium-alpha	Cm alpha	47.5
Cobalt-60	Co-60	0.325
Cesium-134	Cs-134	0.066
Cesium-137	Cs-137	0.066
Tritium	H-3	5.75E-05
Iodine-129	I-129	83.3
Plutonium-alpha	Pu alpha	6.17
Ruthenium-106	Ru-106	0.117
Antimony-125	Sb-125	0.0125
Strontium-90	Sr-90	0.0033
Uranium-234	U-234	0.0192
Uranium-235	U-235	0.0208
Uranium-238	U-238	0.0192

4.6.4 Normalization

Around 2500 tonnes of spent fuel rods are reprocessed annually at the two reprocessing plants at La Hague and Sellafield (Select Committee on Science and Technology 1999).

The annual emissions classified by isotope are documented in (British Nuclear Group 2005; OSPAR Commission 2003; OSPAR Commission 2004; OSPAR Commission 2005). The radionuclides listed there are assigned characterization factors in accordance with Section 4.6.3. The volume of emissions characterized amounts to an average of 190 TBq C-14-eq./a, for the years 2001 to 2004.

Switzerland's electricity production from nuclear power plants represents around 1.05 % of that of Europe as a whole (based on figures for the same period). This percentage is used for the normalization, resulting in a normalization value of 2.0 TBq C-14-eq./a.

4.6.5 Weighting

Current flow

OSPAR targets are defined separately for alpha and beta emitters (see next paragraph). These two separate targets have been amalgamated here to a single goal by means of characterization. As the French reprocessing plant at La Hague does not set any quantitative targets it is assumed that the Sellafield target is also applicable there. Having made this assumption, it is sufficient to look at the emissions from the Sellafield reprocessing plant to determine the weighting factor.

The emissions from the Sellafield plant fluctuate from year to year with no obvious trend (see British Nuclear Group 2005; OSPAR Commission 2003; OSPAR Commission 2004; OSPAR Commission 2005). For this reason a sliding average over four years (2001–2004)is used. This four-year average value of the current emissions from Sellafield amounts to 96.0 TBq C14-eq (3.2 TBq C14-eq alpha and 92.8 TBq C14-eq beta emitters).

Critical flow

The OSPAR Decision 2000 aims to prevent pollution of the North Sea by ionising radiation through substantial reductions in 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 of synthetic isotopes to practically zero (OSPAR Convention 2000).

This general demand was put in more concrete terms in the 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 are to fall to 0.2 TBq per year, and those from beta emitters to 65 TBq per year. This corresponds to a characterized volume of emissions totalling 64.1 TBq C14-eq (2.0 TBq C14-eq alpha and 62.1 TBq C14-eq beta emitters).

4.6.6 Eco-factor for radioactive emissions to seas

Current and critical flows are based on characterized values. The ratio of current to critical flow is 2.24. The normalization flow is based on Switzerland's contribution to the characterized volume of all alpha and beta emitters discharged annually into the North Sea from La Hague and Sellafield.

Tab. 40 > Eco-factor for radioactive emissions to seas in EP/kBq C14-eq

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (TBq C14-eq/a)	2.00	C		
Current flow (TBq C14-eq/a)	96.0	B	Characterized four-year average (2001–04) of emissions from the Sellafield plant	
Critical flow (TBq C14-eq/a)	64.1	b	Characterized emissions target for the Sellafield plant 2020	
Weighting factor (-)	2.24			
Eco-factor (EP/kBq C14-eq)	1100			

Q = Data quality; for explanation see Section 2.4

The eco-factor is assigned for the first time here, as the reduction targets for the protection of the North Sea, which Switzerland supports, have only been stipulated in recent years.

4.6.7 Eco-factors for individual isotopes

Using the characterization described in Section 4.6.3 it is possible to calculate eco-factors for selected isotopes. These are listed in Tab. 41. They apply to the discharge of these substances to seas. Because of the way these eco-factors have been derived they should not be used for discharges to other waters.

Tab. 41 > Eco-factors for the discharge of radioactive isotopes to seas, deduced from their impact potential according to Frischknecht et al. (2000)

		Carcinogenic potential of radioactive elements (kBq C-14-eq./kBq)	Eco-factor 2006 (UBP/kBq)
Americum-241	Am-241	25.8	29 000
Carbon-14	C-14	1	1 100
Curium-alpha	Cm alpha	47.5	53 000
Cobalt-60	Co-60	0.325	360
Cesium-134	Cs-134	0.066	74
Cesium-137	Cs-137	0.066	74
Tritium	H-3	5.75E-05	0.064
Iodine-129	I-129	83.3	93 000
Plutonium-alpha	Pu alpha	6.17	6 900
Ruthenium-106	Ru-106	0.117	130
Antimony-125	Sb-125	0.0125	14
Strontium-90	Sr-90	0.0033	3.7
Uranium-234	U-234	0.0192	21
Uranium-235	U-235	0.0208	23
Uranium-238	U-238	0.0192	21
Actinides, radioactive, unspecified	*	10.3	11 000
Radioactive species, nuclides, unspecified	*	4.06	4 500

* For explanation see Section 4.6.8

4.6.8 Guidelines for using the appropriate ecoinvent v2.01 dataset

With the exception of tritium, caesium-134 und 137 und strontium-90 the emissions of radioactive isotopes are given only in summary form in the current ecoinvent v2.01 dataset. The alpha emitters (Am-241, Cm-alpha, Pu-alpha) are listed under “Actinides, radioactive, unspecified”, and all other isotopes under “Radioactive species, nuclides, unspecified”.

Collected within these two groups are isotopes with very different impacts. The eco-factors for these two aggregate parameters were derived on the basis of the eco-factors of the isotopes emitted, weighting each individual eco-factor 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 size of the average eco-factor.

4.7 AOX

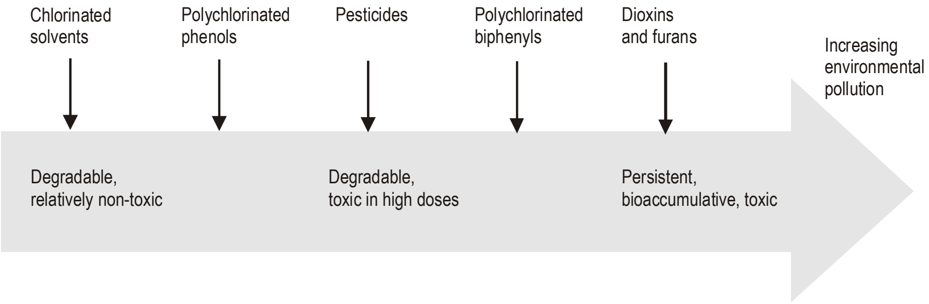
4.7.1 Environmental impact

AOX (adsorbable organic halogenated compounds) is an aggregate parameter including halogenated (mostly chlorinated) organic substances. 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 fall into this group.

The toxicity and environmental impact of the compounds in the AOX group varies widely. An important criterion for toxicity is the ability of the substance to accumulate in an organism. This is possible for fat-soluble substances. The greater the chlorination, the more toxic the substance, as they are fat-soluble and thus bioavailable. Because of this the eco-factor in the following is determined in relation to the chlorine, so that the eco-factor of a substance rises in proportion to the number of chlorine atoms.

Tab. 42 shows the rough classification of the AOXs according to their environmental impacts.

Tab. 42 > Rough classification of various AOXs according to their environmental impacts



AOX pollution of surface waters in Switzerland has fallen significantly in recent years and has lost much of its importance regarding water protection. Furthermore, the creation of an eco-factor for AOXs is a compromise. The weighting of very different toxic substances with a common eco-factor can lead to inaccurate statements in respect of environmental pollution. Nevertheless an eco-factor is derived for AOXs, partly because life cycle inventories often still state this value and partly because subdividing AOXs into distinct, homogeneous substance classes or even individual substances is only practicable to a limited extent. A separate eco-factor is derived below for chloroform alone (Section 4.8). In this case too there has been a marked fall in pollution in the intervening period, owing to a ban on its use.

4.7.2 Normalization

Measurements taken at the Rhine monitoring station at Weil am Rhein (AUE 2005) show AOX concentrations of between 3.2 and 8.5 µg Cl^-/l with a mean value of 6.0 µg Cl^-/l. The substances included in the AOX aggregate parameter degrade by very varying degrees. Extrapolating the concentrations measured to total Swiss loads[18] produces a lower limit of 288 t Cl^-/a for the loads measured.

4.7.3 Weighting

Current flow

The current flow corresponds to the normalization flow, as the reduction target also applies to the whole of Switzerland.

Critical flow

The Swiss Water Protection Ordinance (WPO) contains various regulations concerning AOXs. One of these stipulates that a limit of 10 µg/l applies in groundwater used for drinking water. In addition there are requirements regarding industry-specific production processes: no more than 0.5 kg of AOXs may be produced in the manufacture of 1 tonne of pulp, which is an important source of AOX pollution. Yet no quality target exists in Switzerland for the AOX concentration in surface waters.

However, the international association of waterworks in the Rhine catchment area (IAWR) has established just such a quality target at 25 µg/l (IAWR 2003), in line with the requirements for the drinking water supply, although this is a recommendation and is in no way legally binding. If this quality target is taken as the basis for a rough estimate of the critical flow for AOXs for Switzerland, it produces a resulting flow of around 1200 t Cl^-/a; on account of degradability this is also a lower limit.

4.7.4 Eco-factor for AOXs

Tab. 43 > Eco-factor for AOXs in EP/g Cl

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (t AOX as Cl-/a)	288	B		
Current flow (t AOX as Cl^-/a)	288	B	Calculated using concentration readings (AUE 2005)	470
Critical flow (t AOX as Cl^-/a)	1 200	a	Quality target for surface waters (IAWR 2003)	1 200
Weighting factor (-)	0.058			
Eco-factor (EP/g AOX as Cl^-)	200			330

Q = Data quality; for explanation see Section 2.4

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[18] Assuming a runoff of 48 bn. m^3/a for the whole of Switzerland

The AOX group is made up of various individual substances with widely differing environmental impacts. The eco-factor represents an average composition, and is therefore a rough estimate. Since AOXs are now only of minor importance in water protection, a more accurate determination of this aggregate parameter is not of prime concern. Where possible a specific eco-factor should be derived for environmentally significant substances which would fall into the AOX category.

4.8 Chloroform

4.8.1 Environmental impact

Chloroform is a substance in the AOX group (see Section 4.7), which was formerly in widespread use in dry cleaning, as a solvent, and as a disinfectant, amongst other things. ChemRRO[19] prohibits both the distribution and use of chloroform. Exceptions to this include the use in closed industrial processes, such as in the manufacture of CFC-22. Chloroform is produced as a by-product of chlorination of, for example, drinking water (EPA 2000; IARC 1999; Lippmann 2000).

In animal experiments chloroform emerged as a carcinogen, although to date there is insufficient evidence of this effect in humans. The IARC classifies chloroform as Group 2B (possibly carcinogenic in humans) (IARC 1999).

4.8.2 Normalization

The total load for Switzerland is estimated from the total Swiss runoff (48 bn. m³) and the concentration readings at Weil am Rhein (0.04 µg/l) according to AUE (Amt für Umwelt und Energie, the Basel department for energy and the environment) (2005). Based on these values the load amounts to around 1.9 t chloroform/a.

4.8.3 Weighting

Weighting factor

The weighting factor is derived from the measured (current) concentration and the ICPR target value (critical concentration) (2004). The former comes out at 0.04 µg/l, the latter at 0.6 µg/l.

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[19] Swiss Chemical Risk Reduction Ordinance (Chemikalien-Risikoreduktions-Verordnung, ChemRRV)

4.8.4 Eco-factor für Chloroform

Tab. 44 > Eco-factor for chloroform ($CHCl_3$) in EP/g $CHCl_3$

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (t $CHCl_3$/a)	1.5	B		
Current concentration (µg $CHCl_3$/l)	0.04	B	Concentration readings as per AUE (2005)	
Critical concentration (µg $CHCl_3$/l)	0.60	b	ICPR quality target for surface waters (IKSR 2004)	
Weighting factor (-)	0.0028			
Eco-factor (EP/g $CHCl_3$)	1500			

Q = Data quality; for explanation see Section 2.4

The eco-factor for chloroform is several times higher than for AOXs. However, the situation with regard to pollution is similar and in general terms chloroform no longer presents a problem.

4.9 PAHs (polycyclic aromatic hydrocarbons)

4.9.1 Environmental impact

PAH is an aggregate parameter and stands for polycyclic aromatic hydrocarbons. PAHs have some carcinogenic effect in mammals. They occur exclusively in suspended matter, so the PAH concentration is dependent on the concentration of suspended solids in waters. They arise from combustion processes and runoff from roads. The most common PAHs (including CAS numbers and synonyms) are listed in A3.

4.9.2 Normalization

The calculation of Switzerland's total discharge to waters is extrapolated from the concentration in the Rhine at Weil am Rhein monitoring station. The concentration for four PAHs[20] measured gives a reading of <0.003 µg/l (this is excluding benzo(a)pyrene, as this is assessed separately in Section 4.10). The estimate is based on 0.003 µg/l, which, with the runoff of 48 bn. m^3/a from Switzerland results in a load of 144 kg/a.

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[20] Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene

4.9.3 Weighting

Weighting factor

The weighting factor is derived from the measured concentrations and the target values, in exactly the same way as for heavy metals. The measured concentration for PAHs is <0.004 µg/l (0.001 µg/l benzo(a)pyrene content), so it is calculated on the basis of a concentration of 0.004 µg/l. The ICPR target (IKSR 2004) is set at 0.1 µg/l and therefore substantially higher.

4.9.4 Eco-factor for PAHs

Tab. 45 > Eco-factor for PAHs in EP/g PAH

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (t PAH/a)	0.144	B		
Current concentration (µg PAH/l)	0.004	B	Calculated from concentration readings, AUE 2005	
Critical concentration (µg PAH/l)	0.1	a	Target for surface waters (IKSR 2004)	
Weighting factor (-)	0.0016			
Eco-factor (EP/g PAH)	11 000			

Q = Data quality; for explanation see Section 2.4

There was previously no eco-factor for PAHs, as the available data did not suffice. The eco-factor now derived appears rather high, but compared with other substances certain PAHs are highly toxic and even carcinogenic. Furthermore, they are only emitted to waters in small quantities, so the eco-factor is appropriate to the situation.

The available data is insufficient for a characterization of individual PAHs, so they are assigned the same eco-factor. Only benzo(a)pyrene is allocated its own eco-factor in the section below. In A3 there is a list of some of the other PAH substances.

4.10 Benzo(a)pyrene

4.10.1 Environmental impact

Benzo(a)pyrene (BaP) belongs to the PAH group (see Section 4.9). 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, but also in cigarettes. The carcenogenicity of BaP has long been proven in experiments on animals, and is probable in humans (IARC Group 2A) (EPA 2006; IARC 1983; UGZ 2003).

Sources relevant to water bodies are wood preservatives containing creosote, used for instance on railway sleepers. Creosote contains benzo(a)pyrene, which over time is washed out and enters waters. ChemRRO[21] now prohibits the use of creosote in wood preservatives for domestic purposes, although it is permitted for commercial applications, provided that the benzo(a)pyrene content is less than 50 mg/kg.

4.10.2 Normalization

The load in waters is estimated from concentration readings at Weil am Rhein. The average concentration measured is 0.001 µg/l (IKSR 2004), which with a runoff of 48 bn. m^3 produces an estimated load of 48 kg/a.

4.10.3 Weighting

Weighting factor

The weighting factor is derived from the concentrations in exactly the same way as for the PAHs. The measured concentration is 0.001 µg/l, with the target concentration slightly higher at 0.01 µg/l (IKSR 2004).

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[21] Ordinance on the reduction of risks in dealing with specific particularly hazardous substances, preparations and objects (Verordnung zur Reduktion von Risiken beim Umgang mit bestimmten besonders gefährlichen Stoffen, Zubereitungen und Gegenständen)

4.10.4 Eco-factor for benzo(a)pyrene

Tab. 46 > Eco-factor for benzo(a)pyrene (BaP) in EP/g BaP

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (kg BaP/a)	48	B		
Current concentration (µg BaP/l)	0.001	B	ICPR concentration readings (2004)	
Critical concentration (µg BaP/l)	0.01	b	ICPR quality target for surface waters (IKSR 2004)	
Weighting factor (-)	0.010			
Eco-factor (EP/g BaP)	210 000			

Q = Data quality; for explanation see Section 2.4

The separate eco-factor for benzo(a)pyrene is around twice as high as that of the PAH aggregate parameter. This takes account of the above-average toxicity and carcinogenicity of this substance within the PAH group.

4.11 Endocrine disruptors

4.11.1 Environmental impact

Hormones are chemical messengers between tissues and cells that regulate processes in the body. Sex hormones play an important role in reproduction and the development of an organism. Hormones are already effective in very small concentrations (BUWAL 1999b; SNF 2002).

Endocrine disruptors are hormonally active exogenous substances which attack and disrupt one of the various hormone systems. In humans especially, substances which 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 – aquatic and terrestrial (BUWAL 1999b; SNF 2002). There are also indications that elevated amounts of endocrine disruptors (notably PCBs) in otters' prey have led to reproductive problems which have made the long-term survival of this species in Switzerland impossible (BUWAL 1999b).

Endocrine disruptors 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.

Substances which attack the reproductive endocrine system have the potential to cause oestrogenous effects (the same effect as the female sex hormone oestrogen) and androgenous effects (the same effect as the male sex hormone androgen), as well as anti-oestrogenous and anti-androgenous effects (BUWAL 1999b).

In humans intake of endocrine disruptors is principally via the digestive tract, the skin or the lungs, while aquatic organisms absorb them mainly from the water. As certain types of hormone receptor occur throughout the animal kingdom, a very large number of species can be affected by a single endocrine disruptor (SNF 2002).

Concentrations of endocrine disruptors have been found which are sufficiently high to trigger oestrogenous (feminizing) effects in male fish (BUWAL 1999b), in particular close to the water discharge points of sewage treatment plants.

Hormonal effects have been proven in the case of the following substances and substance groups (BUWAL 1999b; SNF 2002):

> natural (e.g. 17β-oestradiol, oestrone) and synthetic oestrogens (e.g. 17α-ethinylo-estradiol)
> phyto- und myco-oestrogens (e.g. isoflavones)
> alkylphenol polyethoxylates (APEOs) and byproducts (e.g. nonylphenol, octylphenol)
> various organochlorate pesticides (e.g. DDT, methoxychlor, lindane und kepone)
> certain industrial chemicals used in plastics (e.g. bisphenol A, PCBs and possibly phthalate)
> various polychlorinated dibenzo-p-dioxins and furans (PCDDs/PCDFs)
> organotin compounds used among other things in antifouling ship paints (e.g. tributyltin (TBT) und triphenyltin (TPT))
> certain UV filter substances contained in sun lotions (presumed in the case of 4-methylbenzylidene camphor)

It should be noted here that there are as yet no standardized and validated tests to identify a chemical as an endocrine disruptor. Many of the chemicals presently on the market have not been tested for effects of this type.

4.11.2 Characterization

Rutishauser et al. (2004) lists the oestrogenic potential (kg E2-eq./kg) of a number of endocrine disruptors. This figure describes the strength of the impact of an endocrine disruptor in relation to 17β-oestradiol (abbreviation E2). The equivalence factors were determined by using YES (yeast estrogen screening), as other methods can easily produce inaccurate factors. The YES procedure is well accepted in scientific circles.

The figures for oestrogenic potential in Tab. 47 can be used as characterizations for calculating the eco-factors of individual substances. To determine eco-factors for other endocrine substances their oestrogenic potential must be known. It should also be noted that, for reasons of comparability, the characterization factors should in each case be based on results from similar testing systems.

Tab. 47 > Characterization factors for some endocrine disruptors, based on their oestrogenic potential according to Rutishauser et al. (2004)

Name of substance	Abbreviation	Oestrogenic potential (kg E2-eq./kg)
Oestrone	E1	0.38
17β-oestradiol	E2	1
Oestriol	E3	$2.40 * 10^{-3}$
17α-ethinyloestradiol	EE2	1.19
Bisphenol A	BPA	$1.10 * 10^{-4}$
Nonylphenol	NP	$2.50 * 10^{-5}$
4-tert-octylphenol	OP	$7.80 * 10^{-6}$
Mestranol	MES	0.013
β-oestradiol-17-valerate	E2-Val	0.21

4.11.3 Normalization

The discharge of endocrine disruptors from anthropogenic sources to surface waters can be extrapolated from concentration measurements in the outfall from sewage treatment plants. Based on the estimated average concentration of endocrine disruptors in the runoff from treatment plants in Tab. 48 and the total runoff from all Swiss treatment plants of 1511 million m³/a (BUWAL 2000a) the load for Switzerland is calculated at 5.0 kg E2-eq./a.

Tab. 48 > Concentration data for the oestrogenic potential of three treatment plants and the weighted average from two of these

Treatment plants	Discharge from plants (m³/d)	Oestrogenic potential		
		Minimum (ng E2-eq./l)	Maximum (ng E2-eq/l)	Mean* (ng E2-eq./l)
Rontal **	8200	0.4	(53)	
Glatt	45000	2.4	5.5	3.95
Surental	15000	0.5	2.2	1.35
Glatt & Surental	60000	1.93	4.68	3.30

Source: Aerni et al. 2004

* own calculation from minimum and maximum values

** not used for the calculation, as the maximum value shown is an anomaly and would have skewed the result.

4.11.4 Weighting

Current flow

As the critical flow target refers to the whole of Switzerland, the current flow is identical to the normalization, i.e. 5.0 kg E2-eq./a.

Critical flow

Statutory limits or required values for an endocrine disruptor aggregate parameter do not yet exist. Experts assume that at a concentration below 0.5 ng E2-eq./l (predicted no effect concentration – PNEC) no further chronic effects should arise and that this value can therefore be used as the quality target (Chèvre 2003, personal communication[22]).

Based on the runoff for the whole of Switzerland of 48 bn. m³/a, an upper estimate for this target delivers a critical flow of 24.0 kg/a.

4.11.5 Eco-factor for endocrine disruptors

Tab. 49 > Eco-factor for endocrine disruptors in EP/g E2-eq.

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (kg E2-eq./a)	5.0	B		
Current flow (kg E2-eq./a)	5.0	B	Estimated from effluent measurements at sewage treatment plants (Rutishauser et al. 2004)	
Critical flow (kg E2-eq./a)	24.0	b	Quality target for surface waters (PNEC in Chèvre (2003)	
Weighting factor (-)	0.043			
Eco-factor (EP/g E2-eq.)	$8.7 * 10^6$		E2 = 17β- oestradiol	

Q = Data quality; for explanation see Section 2.4

The eco-factor should be regarded as a lower estimate, as the estimate of the critical flow is rather high. By using characterization (see Section 4.11.2) eco-factors can be established for further substances for which the oestrogenic potential is known.

4.11.6 Eco-factor for individual endocrine disruptors

The method of characterization by means of oestrogenic potential described in Section 4.11.2 is used below to calculate further eco-factors for individual endocrine disruptors. The eco-factor in Tab. 49 serves as a starting point.

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[22] Personal communication by Beate Escher (EAWAG, Swiss Federal Institute of Aquatic Science and Technology), 6 April 2006

Tab. 50 > Eco-factors of some endocrine disruptors in EP/g of the substance, calculated using oestrogenic potential as the characterization factor

Name	Abbreviation	Oestrogenic potential [kg E2-eq./kg]	Eco-factor 2006 [EP/g]	Eco-factor 1997
Oestrone	E1	0.38	$3.3 * 10^{6}$	-
17β- oestradiol	E2	1	$8.7 * 10^{6}$	-
Oestriol	E3	$2.40 * 10^{-3}$	$2.1 * 10^{4}$	-
17α- ethinyloestradiol	EE2	1.19	$1.0 * 10^{7}$	-
Bisphenol A	BPA	$1.10 * 10^{-4}$	$9.6 * 10^{2}$	-
Nonylphenol	NP	$2.50 * 10^{-5}$	$2.2 * 10^{2}$	-
4-tert-octylphenol	OP	$7.80 * 10^{-6}$	$6.8 * 10^{1}$	-
Mestranol	MES	0.013	$1.1 * 10^{5}$	-
β-oestradiol-17-valerate	E2-Val	0.21	$1.8 * 10^{6}$	-

Source: Rutishauser et al. 2004

5 > Emissions to groundwater

5.1 Introduction

More than 80 % (1 bn. m³/a) of Switzerland's drinking water supply comes from groundwater (BUWAL 2003c). Groundwater is therefore particularly important and justifies quality requirements relating specifically to its use which are stricter than for surface water.

The boundaries between groundwater and surface water are very porous. Water which initially enters groundwater via precipitation and drainage will sooner or later reach surface waters, either through natural processes or via groundwater use.

Only nitrate is assessed, as this is the only substance for which relevant data is presently available.

5.2 Nitrate in groundwater

5.2.1 Environmental impact

Especially in areas where farming practices are intensive nitrate concentrations in groundwater often exceed the required limits for groundwater that is used or reserved for use, and in some cases even exceed the tolerance value for drinking water. Nitrogen fertilizer applied to fields is readily washed from the soil into groundwater.

5.2.2 Normalization

According to BUWAL (1996c) the nitrate discharged into groundwater amounts to 34 000 t N/a (1994 figure). As other nitrogen compounds are only present in small quantities, this normalization flow can be used not only for nitrate, but also for nitrogen loads in general.

According to FOEN experts the total load has scarcely altered, so the normalization flow remains at 34 000 t N/a.

5.2.3 Nitrate weighting

Current flow

The current flow is identical to the normalization flow: 34 000 t N/a, as the reduction target for nitrate applies to the whole of Switzerland as well.

Critical flow

On the basis of the targets and limits for groundwater and thus also for drinking water, BUWAL (1996c, p. 37) calls for a target of halving the 1990 nitrate flow. This delivers a critical flow of 17 000 t NO_3-N/a for nitrate discharges into groundwater.

5.2.4 Eco-factor for nitrate in groundwater

The eco-factor for nitrate in groundwater is practically unchanged from 1997, but it is higher than that for the load in surface waters. This is in line with the fact that nitrate continues to be problematic in groundwater – in contrast to surface waters – notably with regard to its use as drinking water.

Tab. 51 > Eco-factor for nitrate-N in groundwater in EP/g NO_3^--N and for nitrate in groundwater in EP/g NO_3^-

	Situation 2006	Q	Notes	Situation 1997
Normalization flow (t N/a)	34 000	B		
Current flow (t N/a)	34 000	B	Assuming that the nitrogen load has remained constant since 1996	34 000
Critical flow (t N/a)	17 000	a	(BUWAL 1996c, S. 37)	17 000
Weighting factor (-)	4.0			
Eco-factor (EP/g NO_3-N)	120		Eco-factor for nitrate-N into groundwater	(118)
Eco-factor (EP/g NO_3)	27.1		Eco-factor for nitrate into groundwater	27

Q = Data quality; for explanation see Section 2.4

6 > Emissions to soil

6.1 Introduction

6.1.1 Background

The quality of soils in Switzerland is impaired by various substance-related impacts (acidification, overfertilization, contamination by heavy metals and organic pollutants). The contamination stems on one hand from the direct input of substances into the soil (plant protection products, fertilizer, waste landfilling), but also indirectly through the deposition of pollutants emitted to air.

The Swiss Ordinance on Soil Pollution (Verordnung über die Belastungen des Bodens, VBBo) is not applicable to all surfaces. Thus soils that are permanently paved over, sediment in waters 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). As a result soil protection is addressed not only in the Ordinance on Soil Protection, but also in other ordinances with indirect relevance to soils, such as the Swiss Federal Ordinance on Air Pollution Control or the Chemical Risk Reduction Ordinance (EPA, Art. 33, para. 1). In each of these the long-term maintenance of soil fertility must be taken into account (BUWAL 2001a).

Equally important for the long-term maintenance of soil fertility is the partial or total destruction of soils by paving over them, by erosion and by mechanical damage (soil compaction). These impacts can be assessed partly via land use and are treated separately in Section 7.3.

Assessment of the most important substance-related contaminations is discussed below.

6.1.2 Separating the soil and groundwater compartments

The ecological scarcity method assesses substance flows at their point of entry into the environment, i.e. when they leave the anthroposphere. Whereas with emissions to air and waters the boundary between anthroposphere and environment is relatively easy to define (“end of pipe” concept: the top of the chimney, the outfall from the sewage treatment plant), separating the systems is more difficult in the case of soil and groundwater. Thus the nutrients from fertilizers are available to agricultural crops and are taken up by them to some extent as long as they remain in the root zone of the soil. Hence nutrients taken up by plants do not leave the agricultural production system.

Heavy metals, on the other hand, which enter the topmost layers of soil and accumulate there, do not form part of the desired agricultural cycle. The guidelines for pollutant content of soil in the Ordinance on Soil Pollution refer to the top 20 cm of the soil. Therefore the Ordinance intends that, with regard to heavy metals, this soil layer belongs to the "environment".

The boundary between the anthroposphere and the soil/groundwater compartment is therefore drawn at the point where substances no longer form part of agricultural use. Current and critical flows for nutrients are thus assessed when they leave the productive agricultural system, therefore when 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 assessed at this point.

6.1.3 Selection of substances

In the case of substance-related soil contamination we should distinguish between different paths of entry:

- non-point inputs of nutrients, acidifiers, and heavy metals from the atmosphere
- entry via fertilizers (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 deposition) 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 overfertilization of ecosystems.

Non-point airborne inputs to soils (atmospheric deposition) are inventoried and assessed at the point of their emission to air (cf. Section 2.1). Separate eco-factors for non-point inputs to soils are therefore unnecessary. Therefore only the direct inputs to soils listed in Tab. 52 are assessed.

Tab. 52 > Impact mechanisms of the water pollutants assessed

	Environment			Human						Notes
	Damage to flora	mpairment of soil fertility	Bioaccumulation	Metabolic disturbances	Carcinogenicity	Mutagenesis	Embryonal damage	Other/further types of damage	Characterization	
Lead (Pb)	x	#	x	x					-	
Cadmium (Cd)	x	#	x	x	x		(x)		-	
Copper (Cu)	x	#	x	x					-	
Zinc (Zn)	x	#	x	x					-	
Plant protection products (PPPs)	x	x	x	x	x	x	x	x	PSM	A single PPP normally only exhibits some of the impacts listed. Moreover, plant damage is an intentional effect of herbicides.

x Impact or link proven
(x) Impact or link presumed
Principal impact for determining the eco-factor

6.2 Heavy metals in soils

6.2.1 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.

6.2.2 Normalization

The normalization flow is the current flow extrapolated to the surface area according to the Ordinance on Soil Pollution (Keller et al. 2005a). The surface area in the Ordinance has been determined from the categories wooded areas, agriculturally utilized areas and unproductive vegetation in the Swiss Land Use Statistics (BfS 2001) and covers 3.06 million hectares (around three quarters of Switzerland). It has also been taken into account that heavy metal inputs via pesticides, fertilizers and sewage sludge occur primarily on land used for agriculture (around 1.5 million hectares, over which loads may be subject to wide regional variations), whereas deposition from the atmosphere affects all types of land (Tab. 53).

Tab. 53 > Calculation of the normalization value for heavy metal input into soils based on the values for atmospheric deposition and on direct loading via pesticides, manure, mineral fertilizers and sewage sludge

	Deposition (g/(ha*a))	Direct input (g/(ha*a))	Normalization value (t/a)
Lead (Pb)	22	8.25	79.9
Cadmium (Cd)	0.7	0.55	2.98
Copper (Cu)	5.05	68.4	120
Zinc (Zn)	96.8	376	870

6.2.3 Weighting

Current flow

The current flow of heavy metals to soils is made up of non-point input via the atmosphere and direct input through fertilizers (especially compost) and plant protection products.

Eight heavy metals together with fluoride have been recorded at 105 different sites by the Swiss Soil Monitoring Network NABO. Of the heavy metals regulated by the Ordinance on Soil Protection (VBBo), 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 2000b).

In connection with the NABO monitoring programme Keller et al. (2005a) have established detailed substance inventories for lead, cadmium, copper and zinc on 48 selected representative areas of land. The median[23] of these values has been used as the current flow for heavy metals. The values are listed in the corresponding tables of eco-factors (Tab. 54 to Tab. 57).

Critical flow

It is not possible to derive critical flows from the guideline values in the Ordinance on Soil Protection. However, the long-term maintenance of soil fertility is stated in Art. 1 as the purpose of this Ordinance (this applies only to soil types included in the Ordinance – see Section 6.1.1). To achieve this there should be no accumulation of heavy metals in the soil, i.e. the maximum input must be only as great as the output. Keller et al. (2005a) assess only the output via plants, and this is used as a first approximation for the critical flow. Transfer of heavy metals into groundwater or transport through erosion were not investigated. However, except for antimony and chromium (VI) this effect is of little relevance.

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[23] Using the median reduces the influence of individual extreme values (e.g. owing to the application of copper as a pesticide in vineyards) on the calculation of the current flow, compared with the mean value.

6.2.4 Eco-factor for lead

Tab. 54 > Eco-factor for lead in soils in EP/g lead

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Pb/a)	79.9	B	Extrapolation to surface area based on VBBo definition	
Current flow (g Pb/(ha*a))	30.3	B	Calculated from data in Keller et al. (2005b)	
Critical flow (g Pb/(ha*a))	19.4	b	Calculated from data in Keller et al. (2005b)	
Weighting (-)	2.44			
Eco-factor (EP/g Pb)	31 000			2 900

Q = Data quality; for explanation see Section 2.4

The new derivation method for heavy metal eco-factors produces an eco-factor for lead around 10 times higher than that derived by Brand et al. (1998). This is because 1) the eco-factor now only applies to areas without settlements, 2) the ambient limit value for lead was probably set at a rather generous level previously (owing to the substantial volume of emissions from transport) and 3) the existing ambient limit values are clearly inadequate for sustainable protection of the soil.

6.2.5 Eco-factor for cadmium

Tab. 55 > Eco-factor for cadmium in soils in EP/g cadmium

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Cd/a)	2.98	B	Extrapolation to surface area based on VBBo definition	
Current flow (g Cd/(ha*a))	1.25	B	Calculated from data in Keller et al. (2005b)	
Critical flow (g Cd/(ha*a))	1.30	b	Calculated from data in Keller et al. (2005b)	
Weighting (-)	0.925			
Eco-factor (EP/g Cd)	310 000			120 000

Q = Data quality; for explanation see Section 2.4

The eco-factor for cadmium is also somewhat higher than before, although less markedly so than for lead. It can be assumed that in future, as a result of the ban on cadmium in accumulators and plastics, the problem and therefore the eco-factor, too, will reduce.

Cadmium is the only heavy metal for which the current flow is lower than the critical flow. Hence the rise in the eco-factor as against the former method is relatively small compared with the other eco-factors.

6.2.6 Eco-factor for copper

Tab. 56 > Eco-factor for copper in soils in EP/g copper

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Cu/a)	120	B	Extrapolation to surface area based on VBBo definition	
Current flow (g Cu/(ha*a))	73.4	B	Calculated from data in Keller et al. (2005b)	
Critical flow (g Cu/(ha*a))	58.0	b	Calculated from data in Keller et al. (2005b)	
Weighting (-)	1.60			
Eco-factor (EP/g Cu)	13 000			1 900

Q = Data quality; for explanation see Section 2.4

The previous eco-factor is substantially lower than the new one, which is derived from the ordinance on safeguarding soil fertility. This corresponds to the higher eco-factors for the remaining heavy metals.

Copper is also used for plant protection, notably in organic farming. However, the derivation of the eco-factor in accordance with Section 6.3 (Plant protection products (PPPs)) results in a substantially lower eco-factor, which is why the eco-factor shown in Tab. 56 is used.

6.2.7 Eco-factor for zinc

Tab. 57 > Eco-factor for zinc in soils in EP/g zinc

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Zn/a)	870	B	Extrapolation to surface area based on VBBo definition	
Current flow (g Zn/(ha*a))	473	B	Calculated from data in Keller et al. (2005b)	
Critical flow (g Zn/(ha*a))	303	b	Calculated from data in Keller et al. (2005b)	
Weighting (-)	2.44			
Eco-factor (EP/g Zn)	2 800			520

Q = Data quality; for explanation see Section 2.4

The increase from the previous eco-factor is practically identical to copper and lies between those for lead and cadmium, which indicates the robustness of the new method of derivation.

6.3 Plant protection products (PPPs)

6.3.1 Environmental impact

According to the Ordinance on plant protection products (Pflanzenschutzmittelverordnung, PSMV)[24], such products include crop protectants, plant development regulators and post-harvest protection products. These can be substances, preparations, organisms or other agents. One of their purposes can be to destroy undesired plants or parts of plants. The eco-factor assessment mainly addresses chemical-synthetic 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, and in specialist fruit growing and viticulture. Their use on grassland is minimal (BLW 2000).

In a field trial in Denmark Esbjerg et al. (2002) demonstrated not only that the pesticide dose correlates with plant diversity (which is the desired effect, particularly in the case of herbicides), but also that it reduces the diversity of creatures outside the target group, such as spiders, myriapoda and birds.

The movement of soil particles in the wind and atmospheric transport of plant protection products has also led meanwhile to the detection of active agents in mountain lakes and in rain. Human health impacts of these products arise notably from the use of groundwater as drinking water. Furthermore, two thirds of the active agents of plant protection products licensed in Switzerland cannot be routinely analysed (Angehrn 2001).

6.3.2 Characterization

The recommended dose for plant protection products (PPPs) – in terms of the quantity of the active agent – varies by approximately a factor of 1000 between traditional PPPs which are applied at the rate of several kilograms per hectare (e.g. atrazine, copper, sulphur) and modern PPPs, where in some cases a few grams per hectare suffice (e.g. triflusulfuron) (BUWAL 2003e).

It is assumed that the standard weighed dose (expressed in kg/ha) of a plant protection product represents as first approximation a measure of its effectiveness – the higher the permitted dose, the smaller the effect per unit measured. In the absence of better information about the environmental side effects of PPPs it is assumed that the specific effectiveness in relation to the intended effect and the side effects runs parallel. The

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[24] In older ordinances Pflanzenbehandlungsmittel (PBM) [plant treatment product] was used as the umbrella term, with Pflanzenschutzmittel (PSM) [plant protection product] as a sub-category. PBM is now no longer in use and PSM has become the umbrella term.

characterization factor is therefore set in inverse proportion to the standard weighed dose.

The standard dose of a plant protection product depends on the crop to be treated and sometimes also on the pest to be controlled. In order to obtain an average standard dose these values are weighted with the area of Switzerland under cultivation.

The data on the standard dose comes from the Swiss directory of plant protection products (FAW et al. 1999). For the small number of pesticides not listed in the directory, e.g. because they are not licensed in Switzerland, data sheets from the products' manufacturers have been used.

The standard dose of an average plant protection product used in Switzerland is 2.24 kg/ha. This amount is used as a reference unit to perform the characterization. The 20 active agents most sold in Switzerland and the approximately 80 pesticides listed in the ecoinvent v1.2 life cycle inventory dataset are characterized. Tab. 59 shows the standard doses and characterization factors for selected PPPs. The full list can be found in A4.

6.3.3 Normalization

As a characterization is performed, the normalization flow corresponds to the characterized quantities. The quantity of plant protection products used is not available classified by substance: detailed application rates are only available for 20 PPPs (von Arx 2005). However, these make up two thirds of the total quantity, so the characterized normalization flow is estimated from these 20 substances and a linear extrapolation of the missing third. This delivers an annual flow of 1507 t PPP-eq.

6.3.4 Weighting

Current flow

The increasing use of newer PPPs, some of which are effective with a dose of only a few grams per hectare, growing financial pressure, and direct payments for extensive farming programmes (without fungicide or insecticide) and organic farming have led to a substantial drop in the consumption of plant protection products from 2455 tonnes in 1988 to 1577 tonnes in 2000 (weight based on quantity of active agent). In 2000 this included 700 tonnes each of herbicide and fungicide (BUWAL 2002; BUWAL 2003e).

Critical flow

The Swiss Federal Office for Agriculture envisaged as a target a reduction of 30 % in the use of plant protection products from the1990/1992 level (mean value, 2100 t/a) by 2005 (BLW 2000). This corresponds to a critical flow of 1500 t PPP/a (rounded) (BLW 2000; BUWAL 2003e). A longer-term goal has not yet been stipulated. There is no information about the reduction of individual substances envisaged (for example, the current top 20 PPPs). Therefore the weighting factor is determined on the basis of the quantities of active agents which have not been characterized.

6.3.5 Eco-factor für durchschnittliches Pflanzenschutzmittel

Tab. 58 > Eco-factor for the emission of plant protection products into soils in EP/g PPP active agents

	Situation 2006	Q	Notes	Situation 1997
Normalization (t PPP-eq/a)	1 507	A		
Current flow (t PPP/a)	1 577	A	Quantity in 2000 according to BUWAL 2002	1 800
Critical flow (t PPP/a)	1 500	b	Reduction of 30 % from 1990/92 BLW 2000	1 500
Weighting (-)	1.11			
Eco-factor (EP/g PPP-eq.)	730			800

Q = Data quality; for explanation see Section 2.4

The eco-factor is slightly lower than in 1997,as a consequence of the characterization, which delivers a lower normalization value. However, this does not outweigh the reduction in the current flow. It can be assumed that the current flow will fall further in future as a result of the use of plant protection products which are effective in lower doses and the growing proportion of organic farming.

6.3.6 Eco-factor of other plant protection products

It is possible to calculate eco-factors for individual PPPs using the characterization based on the standard dose of PPPs described in Section 6.3.2. Tab. 59 provides an overview of selected characterization and eco-factors. The comprehensive list can be found in A4.

Tab. 59 > Eco-factors for selected pesticides

Active agent	Standard dose (g/ha)	Characterization factor (kg PSM-eq/kg)	Eco-factor 2006 (EP/g)	Eco-factor 1997 (EP/g)
Herbicides				
Atrazine	1 000	2.2	1 600	800
Dinitro cresol (DNOC)	18 300	0.12	88	800
Glyphosate	2 490	0.90	660	800
Metsulfuron-methyl	6.5	340	250 000	800
Insecticides				
Bifenthrin	19	120	88 000	800
Chlorpyrifos-ethyl	662	3.4	2 500	800
Mineral oil	37 900	0.059	43	800
Fungicides				
Folpet	1 860	1.2	880	800
Copper	4 380	0.51	370	800
Metconazole	90	25	18 000	800
Average PPP	2 240	1.0	730	800

Eco-factors for selected pesticides. The complete table can be found in A4

7 > Resources

7.1 Overview

The extraction of certain resources from nature is also weighted with an eco-factor. Until now, only the consumption of energy resources has been weighted within the scope of the ecological scarcity method. The present review now integrates further types of resource consumption for the first time.

A new distinction in relation to energy resources (Section 7.2) is now made between an eco-factor for renewable (limited rate of replenishment) and non-renewable energies (limited stock). This takes account of the different sustainability aspects of these types of energy. Furthermore, new eco-factors are defined for land use (Section 7.3), for the extraction of natural gravel (Section 7.4) and for freshwater (Section 7.5), as these are increasingly considered to be ecologically scarce.

7.2 Energy resources

7.2.1 Environmental relevance

The Federal Constitution (Art. 89) states the goal of efficient and environmentally sound energy supply in the same sentence in which it calls for reliable and economical supply: *"Within their powers, the Confederation and the Cantons shall strive to ensure a sufficient, diversified, reliable, and economical energy supply compatible with the protection of the environment, and the economical and efficient use of energy."*

Not only the available quantities of non-renewable energy carriers – such as oil, gas and uranium – are limited. The renewable resources are also limited. The sun, the driving force behind most renewable energies, only supplies a limited quantity of energy to the Earth per unit time. Moreover, a part of this energy is required to keep Ecosystem Earth running, e.g. for the biogenic production of oxygen, pollination and pollen dispersal by wind, maintenance of the hydrological cycle, provision of daylight, etc. Furthermore, when solar energy is converted into renewable energy carriers, the efficiency is often only a few percent. It is therefore not known which proportion of renewable energy can be utilized sustainably. It can at least be concluded that an upper utilization limit also applies to renewables. It is therefore purposeful 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 utilized technically does not in fact dissipate uselessly. This is why renewables are assessed not on the basis of primary energy content, but on the basis of final energy.

In contrast, where non-renewable energy carriers deliver no further ecological benefit, the entire energy contained in the resource should be utilized 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 energy yield – the energy content of the biomass harvested, 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.

The eco-factor for energy consumption assesses the scarcity of the energy resource; account is taken of the environmental impacts of energy uses caused by emissions through the corresponding eco-factors for air, water and soil pollution.

7.2.2 Characterization

Beside reducing energy consumption, a further goal of the 2000 watt society (cf. also 7.2.4) is to increase the proportion of renewable energies: of the 2000 watts per person, 1500 are to be produced from renewable sources (Schweizerischer Bundesrat 2002b). Conventional energy supply with non-renewable energy carriers is the reference (i.e. a characterization factor of 1 MJ-eq./MJ non-renewable energy). The goal is that renewable sources are to supply three times more energy than non-renewable sources, which results in a politically established characterization factor of ⅓ MJ-eq./MJ (Tab. 60). In other words, 3 MJ energy from renewable sources is rated as being equivalent to 1 MJ from non-renewable sources.

Tab. 60 > Characterization factors for renewable and non-renewable energy carriers, based on Schweizerischer Bundesrat (2002a)

	Characterization factor (MJ-eq./MJ)
Non-renewable energy	1
Renewable energy	⅓

7.2.3 Normalization

Aggregate energy statistics (BFE 2004) present the energy balance of Switzerland according to energy carriers (Tab. 61). This encompasses domestic production as well as imports and exports. The normalization flow comprises the characterized flow. For this, renewable and non-renewable energy consumption is multiplied by the corresponding characterization factors (⅓ and 1). This results in a normalization flow of 1030 PJ-eq./a (Tab. 61).

7.2.4 Weighting

Current flow

The current flow corresponds to the primary energy consumption of Switzerland and figures 1169 PJ/a (Tab. 61).

Tab. 61 > Primary energy consumption in Switzerland according to 2003 energy statistics (BFE 2004), and its conversion into characterized primary energy consumption

	Non-renewable energy (PJ)		Renewable energy (PJ)		Primary energy consumption (PJ)	Primary energy consumption (PJ-eq.)
Mineral oil	537	100 %	-	0 %	537	537
Nuclear fuels	283	100 %	-	0 %	283	283
Hydropower	-	0 %	164	100 %	164	55
Gas	110	100 %	-	0 %	110	110
Coal	6	100 %	-	0 %	6	5.9
Wood and charcoal	0	0 %	23	100 %	23	7.5
Municipal and industrial wastes	23	50 %	22	50 %	45	30
Solar, wind, biogas, ambient heat	-	0 %	13	100 %	13	4.2
Electricity exports	-148	91 %	-16	9 %	-164	-153
Electricity imports	150	98 %	3	2 %	152	150
Total	960	82 %	209	18 %	1169	1030

Critical flow

The goal of the 2000 watt society (Schweizerischer Bundesrat 2002b) is used to determine the weighting factor. The 2000 watt society is a long-term goal without any specific target year for goal attainment: The various studies state 2050, 2100 or 2150 (Koschenz & Pfeiffer 2005; Spreng & Semadeni 2001; Würsten 2003). The goal is, however, definitely a long-term one. In order to define a medium-term goal, the same procedure is adopted as for greenhouse gas emissions. The long-term goal is taken to apply to 2050, and is then interpolated to the year 2030. 2030 can be interpreted as the most distant tangible time horizon of Swiss energy policy, as it is for the year 2030 that the draft of the Swiss Electricity Supply Act (as per 3 December 2004) sets a specific target for the proportion of renewable energies in Swiss electricity generation.

The critical flow is taken to be equal to the current flow for the short term, as no specific short-term statutory or political reduction targets have been established at present.

The long-term reduction target is 2000 watts per person by the year 2050. The population figure is taken from the intermediate scenario of the BFS (2006), which anticipates a resident population of 8.06 million for the year 2050.

7.2.5 Eco-factors for energy

Tab. 62 > Eco-factors for primary energy consumption in accordance with the 2005 and 2050 endpoints, in EP/MJ-eq.

Eco-factor of endpoints

	2006 target	Q	2006 target	Q	Notes
Normalization (PJ-eq./a)	1 030	A	1 030	A	Characterized energy quantity
Current flow (PJ/a)	1 169	A	1 169	A	
Critical flow (PJ/a)	1 169	b	508	b	
Weighting (-)	1.00		5.29		
Eco-factor (EP/MJ-eq.)	0.97		5.14		Basis for interpolation

Q = Data quality; for explanation see Section 2.4

The eco-factor varies by a factor of five depending upon whether the short-term or long-term target is selected (Tab. 62). The former would underestimate the situation, while the latter exaggerates the issue, as the target only needs to be achieved in a good 40 years. In the following, the eco-factor is interpolated to 2030, as explained above.

Tab. 63 > Eco-factor for the consumption of energy equivalents in EP/MJ-eq., calculated from the targets for 2005 and 2050 and interpolated to 2030

Interpolated eco-factor

	Situation 2006	Q	Notes	Situation 1997
Normalization (PJ-eq./a)	1 030	A	Characterized energy quantity	-
Current flow (PJ/a)	-			1 027
Critical flow (PJ/a)	-			1 012
Weighting (-)	3.38	b	Interpolated and calculated from eco-factor and normalization	-
Eco-factor (EP/MJ-eq.)	3.3		Energy eco-factor interpolated to 2030	1.0

Q = Data quality; for explanation see Section 2.4

7.2.6 Eco-factors for renewable and non-renewable energy carriers

Tab. 64 > co-factors for renewable final energy and non-renewable primary energy in EP/MJ renewable and non-renewable energy

	Characterization (PJ-eq./PJ)	Normalization (PJ-eq./a)	Weighting (-)	Eco-factor 2006 (UBP/MJ-eq)	Eco-factor 1997 (UBP/MJ-eq)
Non-renewable primary energy	1	1030	3.38	3.3	1.0
Renewable final energy	0.33	1030	3.38	1.1	1.0*

for the eco-factors for renewable primary energy see Tab. 65.
* Hydropower was assessed with an eco-factor in EP97, but the other forms of renewable energy carriers were not.

As a result of characterizing forms of energy in accordance with the 2000 watt society goal, the eco-factor for non-renewable energy is appreciably higher than in the past, while the eco-factor for renewable energy retains practically the same value. This eco-factor for renewable energy, however, was previously only applied to hydropower, while now it applies to all forms of renewable energy.

The energy content of energy resources not used for energy production (feedstock energy content, for instance when hydrocarbons are used as refrigerants or wood is used in a building) is also assessed with a primary energy factor.

7.2.7 Guideline for application in relation to the ecoinvent v2.01 dataset

Tab. 65 presents the application of the two energy eco-factors to the energy resources listed in the ecoinvent dataset.

Eco-factors of common energy carriers

If a life cycle inventory is based on other assumptions concerning energy content and transformation ratio, the eco-factors can be adjusted to that specific situation following the same method.

Tab. 65 > Eco-factors for the consumption of primary energy resources. Calculated using the eco-factors from Tab. 64 and the energy values in Frischknecht et al. (2007)

	Energy content		Eco-factor, primary energy	
Fossil energy				
Crude oil (before refining)	45.8	MJ/kg	151	UBP/kg
Natural gas (before refining)	40.3	MJ/Nm³	133	UBP/Nm³
Mine gas	39.8	MJ/Nm³	131	UBP/Nm³
Hard coal (in mine)	19.1	MJ/kg	63	UBP/kg
Lignite (in mine)	9.9	MJ/kg	33	UBP/kg
Nuclear energy				
Uranium (in ore)	560 000	MJ/kg	1 850 000	UBP/kg
Biomass				
Energy in biomass	1	MJ/MJ	1.10	UBP/MJ
Energy in biomass, primary forest clearcut	1	MJ/MJ	3.30	UBP/MJ
Hardwood, standing a)	19.6	MJ/kg	21.57	UBP/kg
Softwood, standing a)	20.4	MJ/kg	22.44	UBP/kg
Hydro				
Potential energy of water in impoundment b)	0.95	MJ_e/MJ	1.05	UBP/MJ
Further renewables				
Kinetic energy in wind b)	0.93	MJ_e/MJ	1.02	UBP/MJ
Solar energy in solar radiation b)	0.91	$MJ_{e\ u.\ t}/MJ$	1.00	UBP/MJ
Geothermal energy b)	1.00	MJ_t/MJ	1.10	UBP/MJ

a) Wood may only be assessed here if it is not already taken account of as energy in biomass, as otherwise double counting would occur.

b) According to the ecoinvent v2.01 dataset, the transformation ratio (ratio of final to primary energy) is: hydro = 0.95; wind = 0.93; solar = 0.91 (average of photovoltaics (0.935) and solar thermal (0.885)); geothermal = 1.00.

7.3 Land use

7.3.1 Introduction

The land-use statistics of 1992/97 (BfS 2001) break down the area of Switzerland, which totals 41 286 km², into four broad types of use:

1. 6.8 % settlement and urban areas (buildings, transportation areas, recreational and green urban areas, landfills, building sites)
2. 36.9 % agriculturally utilized areas (grassland, arable land, orchards)
3. 30.8 % wooded areas (forest, shrub forest, woods)
4. 25.5 % unproductive areas (rock, ice, lakes, rivers, glaciers)

The Swiss Spatial Planning Act (Raumplanungsgesetz) prescribes that soil resources should be used prudently and urban sprawl should be countered. Settlement area is expanding nonetheless. According to the Swiss land-use statistics of 92/97, the overall settlement area is growing at a rate of around one square metre per second, mostly at the expense of agricultural land in the Swiss plateau (the “Mittelland” region of Switzerland). In remote areas, agricultural land that is no longer managed is transformed again into wooded areas. While the unproductive areas are subject to constant change, their overall area remains roughly constant (BfS 2001).

According to the BfS (2001), the settlement area of Switzerland, which totals 2791 km², is composed as follows:

- 49.3 % building areas
- 32.0 % transportation areas
- 7.2 % industrial areas
- 5.8 % special urban areas (utility facilities, quarries/mines and dumps, construction sites)
- 5.7 % recreational and green urban areas

Growth in settlement area is driven by a growing population, in combination with growing levels of land take per person. The target of the Swiss Federal Council set out in the 2002 strategy for a sustainable Switzerland is to meet further demand wherever possible by means of inward development, i.e. improved utilization of existing settlement areas (Schweizerischer Bundesrat 2002a).

7.3.2 Characterization

The characterization of land use applies the method developed by Köllner (2001), which assesses the various types of land cover in accordance with their respective plant biodiversity. Building upon the Swiss biodiversity monitoring programme and other publications, Köllner (2001) derives EDP (Ecosystem Damage Potential) factors for various land-use types, which reflect the anticipated number of species and the actually encountered number of species for the specific type of land use. Positive EDP factors of a land use mean that plant biodiversity is below average, while negative EDP factors indicate a plant diversity that is above the average.

The non-linear EDP factors ($EDP_{total\text{-}nonl\text{-}pla}$) were used to derive the characterization factors. “Settlement area” is taken as the reference type of land cover (see the full list in A5).

In order to reach a degree of detail that is suitable for life cycle assessments, the extended CORINE nomenclature set out in Köllner (2007) was adopted. The EDP factors, however, are not available in similar detail. Where items of data were absent, average values were used, or an estimate performed by means of equation with similar land-use types. The use of water surfaces and bare land (e.g. rock) can not be characterized at present. These types, however, are usually of minor importance for life cycle assessments, and hence neglecting them is unlikely to have any significant effect on the outcome.

For *unknown uses,* a category encountered occasionally in life cycle inventories, a suitable EDP factor was derived. In Switzerland, most land-use changes involve a transformation from agricultural area to settlement area. The weighted mean was taken from the EDP factors for these two area types – the resultant EDP factor for unknown use captures an average settlement/agriculture area in Switzerland.

7.3.3 Normalization

On the basis of the characterization, the normalization flow is also calculated as a characterized quantity. The surface areas of the land-use types, with their respective characterization factors, result in a normalization flow of 3378 km^2-eq*a.

7.3.4 Weighting

Current flow

Both the critical flow (cf. below) and the current flow relate to the Swiss settlement area of 2791 km² (BfS 2001).

Critical flow

The declared goal is to stabilize settlement area at 400 m² per inhabitant (Schweizerischer Bundesrat 2002a; Schweizerischer Bundesrat 2002b). As this is a longer-term goal, a future population of 8.06 million is assumed, in accordance with the intermediate scenario of the BfS (2006). This results in a critical flow of 3224 km².

7.3.5 Eco-factor for settlement area

Tab. 66 > Eco-factor for land use in EP/m²a-eq. settlement area

	Situation 2006	Q	Notes	Situation 1997
Normalization (km²*a-eq.)	3378	A	Characterized area	
Current flow (km²)	2791	A	In accordance with 92/97 land-use statistics in (BfS 2001)	-
Critical flow (km²)	3224	a	Sustainability goal: 400 m² per inhabitant (Schweizerischer Bundesrat 2002a)	-
Weighting (-)	0.749			
Eco-factor (EP/(m²*a SA-eq.))	220		Eco-factor for average settlement area (with EDP = 0.55)	-

Q = data quality; SA-eq. = settlement area equivalent; EDP = Environmental Damage Potential

The "settlement area" land-use type used here as reference is a mixture of highly disparate types, ranging from green urban areas to industrial estates. The differentiated eco-factors should therefore be used wherever possible (see Section 7.3.6).

7.3.6 Eco-factors (and characterization) for specific types of land use

Tab. 67 compiles the eco-factors and the characterization values of several frequent categories of land cover; A5 provides the full list.

Tab. 67 > Overview of the eco-factors for selected land-use types in EP/(m²a) of land covered

CORINE+	Land use	EDP	Charact. factor (m² SF-eq./m²)	Eco-factor 2006 (UBP/m²a)
Settlement area				
REF	Settlement area (reference)	0.548	1.0	220
111	Urban fabric, continuous, >80 % sealed	0.68	1.2	260
112	Urban fabric, discontinuous, <80 % sealed	0.54	0.99	220
121	Industrial or commercial units	0.573	1.0	220
122	Road and rail networks and associated land	0.56	1.0	220
Agricultural areas				
211b	Arable land, non-irrigated, IP	0.32	0.58	130
211c	Arable land, non-irrigated, organic	0.15	0.27	59
245	Agricultural fallow with hedgerows	-0.12	-0.22	-48
Forests				
311	Forest, broad-leaved	0.0378	0.069	15
313	Forest, mixed	-0.020	-0.037	-8.1
314	Forest, forest edge	-0.11	-0.20	-44
Other use				
-	Unknown use	0.403	0.74	160

A5 provides the complete list
REF: Reference area (average of several CORINE land-cover types); SA-eq.: settlement area equivalents

A5 contains the full list of land-cover types. Section 7.3.7 gives recommendations on how to classify land-use types not contained in this list, such as FSC forest or green roofs.

7.3.7 Guidelines for application: Assessing special land-use types

There are two possible ways to handle land uses not covered by the extended CORINE nomenclature (cf. also Tab. 68):

1. **Increasing the degree of detail:** A land use can be broken down into defined types of use. The assessment problem can thus be transferred to the life cycle inventory level at which is it is more readily resolved (for instance, forests managed to FSC standards can be inventoried by assigning a part to managed forest and a part to natural forest).
2. **Forming analogies:** A land use is similar to a type of use for which there is an eco-factor (for instance, the eco-factor for green urban areas can be applied to green roofs).

Tab. 68 > Recommendation for the characterization of "FSC forest" and "green roof"

Land-use type	Recommendation for classification	Notes
Forest, managed to FSC standards	a) Depending upon the type of forest and management: 1) 311: Forest, broad-leaved 2) 312: Forest, coniferous 3) 313: Forest, mixed In the case of plantations, the subcategories 311a, 312a and 313c are to be used b) and, in accordance with the circumstances on the ground, proportions classified as semi-natural 1) 311b: Forest, broad-leaved, semi-natural 2) 312b: Forest, coniferous, semi-natural 3) 313: Forest, mixed	The Swiss FSC rules prescribe ecological management and designation of at least 5 % of the area as strict reserve (Naturwaldreservat) (BUWAL 1999a). The rules are specified at national level, and can therefore differ in other countries. The inventorization of FSC forest should be performed at the level of the life cycle inventory.
Green roof	1) 113: Urban fallow	Where plantings are ecologically valuable, e.g. oligotrophic grassland on a large flat roof
	2) 141: Green urban areas	Where roof planting is simple Note: Areas are only counted once, either as normal settlement area or as green roof

7.3.8 Implementation in the ecoinvent v2.0 dataset

In the ecoinvent dataset, managed forests are classified as "forest, high-intensity", being the average form of managed forest in Europe. This would correspond to plantation forests in the present categorization (cf. categories 311a, 312a and 313c in A5). This leads to an assessment that does not fully reflect circumstances in European forest management, especially not in Switzerland. For the assessment of products and fuels from Swiss timber, we therefore recommend using the (identical) eco-factors for "forest, broad-leaved" or "forest, coniferous" (see A5) in place of the ecoinvent category "forest, high-intensity".

7.4 Gravel extraction

7.4.1 Introduction

Gravel is a *sui generis* resource: On the one hand a construction material, and on the other hand a material important to the protection and formation of groundwater. Not all physical gravel occurrences are extractable – permissible land uses set limits. An eco-factor is therefore defined for gravel here for the first time.

Gravel is used mainly in the construction sector, notably as a concrete aggregate and in road and railway subgrades. 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).

Gravel resources replenish very slowly. Only around 1 % of Switzerland's annual gravel consumption is formed anew in rivers in the same period. Moreover, the geological gravel deposits are reduced by competing demands such as housing construction, groundwater protection and, in some cases, forest protection. 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 utilizable gravel reserves suffice for only 18 years (Raumplanungsamt Kt. Zug 2005).

7.4.2 Normalization

The normalization flow is identical to the current flow, as the latter relates to the whole of Switzerland.

7.4.3 Weighting

Current flow

The gravel production of Swiss gravel works depends to some degree upon construction sector activity, and has ranged between 30 and 40 million t over the past 20 years, with a maximum around 1990. In the year 2000, 34 million t were extracted (Rubli & Jungbluth 2004); this is taken as current flow.

Critical 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 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). Across the whole of Switzerland, the volume of gravel reserves designated for extraction has always been sufficient for the next 15 to 20 years. It follows that, although the resource is essentially finite, the present extraction situation is tolerated. The critical flow is therefore taken to be equal to the current flow.

7.4.4 Eco-factor for gravel extraction

Tab. 69 > Eco-factor for gravel extraction in EP/g gravel

	Situation 2006	Q	Notes	Situation 1997
Normalization (million t gravel/a)	34	A		
Current flow ((million t gravel/a)	34	A	Rubli et al. 2005	
Critical flow ((million t gravel/a)	34	c		
Weighting (-)	1.00			
Eco-factor (EP/g gravel)	0.029			

Q = Data quality; for explanation see Section 2.4

The eco-factor for gravel is defined for the first time here. It reflects the presently tolerated extraction volume.

7.5 Freshwater consumption

7.5.1 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. Nonetheless, the Federal Council (Schweizerischer Bundesrat 2002a, p. 9) demands that *"[…] natural resources be utilized 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.

With this in mind, and because an eco-factor for freshwater is purposeful when considering water-poor locations, three types of eco-factors are derived for freshwater:

1. Country-specific (for Switzerland and for further OECD states)
2. Average of OECD countries (as first approximation for cases in which a life cycle inventory does not list water consumption levels in a differentiated manner)
3. For six different scarcity situations (low, Moderatee, medium, high, very high and Extremee)

This now makes it possible for the first time to differentiate – for instance in life cycle assessments of foods or of other products requiring large amounts of water for their production – between origin from arid regions where water scarcity prevails and from regions with ample water resources, and to take account of the aspect of water scarcity in arid regions that can be relevant in some cases. Users of the method can also derive regional or local eco-factors themselves to address specific issues.

According to the OECD (2004, p. 24) the scarcity of freshwater resources can be expressed as the share of gross consumption in the available renewable water resource (precipitation, plus inflows from neighbouring states, minus evaporation).

If the share of gross consumption in the available resource is 10–20 %, water stress is classed as Moderatee according to the OECD (2004), if the ratio is 20–40 % it is medium to high, and if it is above 40 %, it is high. The OECD considers a Moderatee to medium pressure on water resources to be tolerable. The critical flow is therefore set at 20 % of the available resource.

In accordance with the OECD (2004) and FAO (2005) we understand water consumption to mean all extractions of freshwater for production or consumption processes. Water consumption does not include water used by hydroelectric facilities to generate electricity (cf. also Section 2.1.4).

7.5.2 Normalization

The Swiss level of water consumption, which is 2.57 km³/a (around 350 m³ per capita and year or 1000 litres per capita and day) is used as normalization flow (FAO 2005). This value corresponds to the current flow when assessing the eco-factor for Switzerland. When calculating country-specific eco-factors or assessing water scarcity categories, their weighting factors must be converted to the Swiss situation, i.e. normalized. This normalization also applies to any other, regionalized freshwater eco-factors (cf. also Section 2.1.4).

7.5.3 Weighting

Current and critical flow for Switzerland

According to the FAO (2005), the **current flow,** i.e. the quantity of freshwater consumed annually in Switzerland, is 2.57 km³/a. This includes not only consumption for potable water, but also water extractions to irrigate agricultural areas and for use in industrial processes. According to the FAO (2005) the available annual resource in Switzerland is 53.5 km³.

According to the OECD (OECD 2004) a tolerable water stress is 20 % of the available resource. It follows that the **critical quantity** of freshwater use for Switzerland is 10.7 km³/a.

Current and critical flow for the OECD states (average value)

The water consumption of all OECD states (excluding the Slovak Republic, for lack of data) is 1020 km³/a (calculated from data in FAO (2005), A6 lists the data for the individual OECD states). The water consumption figure includes mine water and water extracted by irrigation measures. The extraction of water that was already used once and was returned to a body of surface water is also contained in the gross consumption figure. Water used in hydropower facilities is considered in-situ consumption and is therefore not included in the statistics. The **current flow** of all OECD states is 1020 km³/a (see A3 for detailed country data).

As noted above, a Moderatee to medium pressure on water resources is considered tolerable, and the critical flow is therefore set at 20 % of the available water resource. This means for the OECD states a **critical flow** of 2050 km³/a (the entire available renewable resource is 10 300 km³/a, see A6 for detailed country data).

It is assumed that water scarcity in the OECD states provides an expedient average value for weighting. This pragmatic assumption is supported by the broad range of countries represented – from very water-rich countries such is Ireland and Iceland, to those where there are greater levels of water scarcity, such as Spain. Moreover, reliable data are available for these countries.

Weighting according to scarcity situation

The OECD defines four categories of water scarcity, whereby if the share of water consumption in the available resource exceeds 0.4 it is assumed that water scarcity is high (OECD 2004). For the purposes of a life cycle assessment, however, cases may also arise in which very high (up to a ratio of 1) and Extremeely high scarcity (water consumption exceeds the available resource) are relevant. The OECD categories are therefore complemented by two further categories: very high (0.6 to <1.0) and Extremee (≥1.0).

The weighting factor is given by the ratio of water consumption to available resource (without needing to know the absolute values) and the assumption that the critical flow is 20 % of the available resource as:

$$\text{Weighting} = \left(\frac{\text{Current flow}}{\text{Critical flow}}\right)^2 \qquad (10)$$

$$= \left(\frac{\text{Water consumption}}{(\text{Available resource} \cdot 20\,\%)}\right)^2 \qquad (11)$$

$$= \left(\underbrace{\left(\frac{\text{Water consumption}}{\text{Available resource}}\right)}_{\text{Scarcity ratio}}\right)^2 \cdot \left(\frac{1}{20\%}\right)^2 \qquad (12)$$

Tab. 70 > Calculation of weighting factors from the ratios of water consumption to available resource, for the different water scarcity categories

Category		Weighting		
	Water scarcity ratio $\left(\frac{\text{Water consuption}}{\text{Available resource}}\right)$	Ratio used for calculation	Critical flow at x% of available resource	Weighting factor (-)
Low	<0.1	0.05	20 %	0.0625
Moderate	0.1 to <0.2	0.15	20 %	0.563
Medium	0.2 to <0.4	0.3	20 %	2.25
High	0.4 to <0.6	0.5	20 %	6.25
Very high	0.6 to <1.0	0.8	20 %	16.0
Extreme	≥1	1.5	20 %	56.3

7.5.4 Eco-factor for Swiss freshwater

Tab. 71 > Eco-factor for the consumption of Swiss freshwater, in EP/m^3 freshwater

	Situation 2006	Q	Notes	Situation 1997
Normalization (km^3/a)	2.57	A		
Current flow (km^3/a)	2.57	A	FAO 2005	
Critical flow (km^3/a)	10.7	b	20 % of available resource according to FAO 2005	
Weighting (-)	0.0577		Ratio of water consumption to available resource: 0.048	
Eco-factor (EP/m^3)	22			

Q = Data quality; for explanation see Section 2.4

This eco-factor applies to freshwater consumption in Switzerland. No water scarcity prevails in Switzerland. Nonetheless, local water shortages can arise in summer months. The eco-factor stated here does not capture such temporarily and spatially limited situations. Where such situations need to be assessed, users of the method can derive eco-factors themselves in accordance with the methodology set out in Sections 2.1.4 and 2.1.5.

7.5.5 Eco-factors for freshwater according to scarcity categories

Tab. 72 > Eco-factors for freshwater use in regions with different levels of water scarcity, in EP/m^3 freshwater

	Water scarcity ratio $\left(\frac{\text{Water consumption}}{\text{Available resource}}\right)$	Normalization (km^3/a)	Weighting (-)	Eco-factor 2006 (EP/m^3)	Eco-factor 1997 (EP/m^3)
Low	<0.1	2.57	0.0625	24	-
Moderate	0.1 to <0.2	2.57	0.563	220	-
Medium	0.2 to <0.4	2.57	2.25	880	-
High	0.4 to <0.6	2.57	6.25	2 400	-
Very high	0.6 to <1.0	2.57	16	6 200	-
Extreme	≥1	2.57	56.3	22 000	-

The weighting factors come from Tab. 70

Numerous countries have “low” to “medium” water scarcity, corresponding to eco-factors spanning a factor of around 40. In contrast, there is almost a factor of 1000 between the eco-factors in the “low” and “extreme” categories. This reflects the severe over-exploitation in arid regions such as Saudi Arabia, where, despite seawater desalination, more freshwater (especially groundwater) is utilized than can regenerate.

7.5.6 Eco-factors for freshwater in OECD states (average value)

Tab. 73 > Eco-factor for freshwater of unknown or undifferentiated origin, in EP/m³ freshwater – derived from the water scarcity in OECD countries

	Situation 2006	Q	Notes	Situation 1997
Normalization (km³/a)	2.57	A	Water consumption in Switzerland (i.e. current flow in Switzerland)	
Current flow (km³/a)	1 020	A	FAO 2005	
Critical flow (km³/a)	2 040	b	20 % of available resource according to FAO 2005	
Weighting (-)	0.250		Corresponds to a ratio of water consumption to available resource of 0.10	
Eco-factor (EP/m³)	97			

Q = Data quality; for explanation see Section 2.4

This average value should be applied when the water consumed is of unknown or undifferentiated origin. The eco-factor is positioned between the categories for low and moderate water scarcity (Tab. 72), which is considered plausible. Water scarcity is a particular problem in arid regions, where it can be further exacerbated by intensive agriculture. Water scarcities that are limited in space or time are not taken into account by this eco-factor.

Wherever possible, classification into one of the six water scarcity categories (Section 7.5.5) is preferable over use of this average eco-factor. A6 lists eco-factors for the individual OECD states.

7.5.7 Guidelines for application

The eco-factors can be applied to all types of renewable water resources. Applications of water that neither pollute it chemically nor change its temperature or physical state, and do not remove it from the hydrological cycle for longer periods, are exempted from the assessment using the freshwater eco-factor. This exemption also applies to hydropower facilities, as the water becomes available again after the turbine and its quality or physical parameters are not appreciably changed. Cases in which the freshwater eco-factor is to be applied include – the list is not conclusive:

- Drinking water use (incl. distribution losses)
- Irrigation in agriculture (incl. losses)
- Use for and in industrial processes, including use as cooling water (because of the change in the physical state or temperature)

If the life cycle inventory contains no regional or scarcity-based differentiation, the average eco-factor as set out in Section 7.5.6 is to be used. When fossil (non-renewable) water is used, the eco-factor of the most severe scarcity category is to be applied.

These country eco-factors have already been calculated for the OECD countries, and are listed in A6. If corresponding data are available, eco-factors can be calculated for further countries or certain eco-regions. The procedure is analogous to that for calculating the Swiss eco-factor. In all cases, the data sources, all assumptions made, and the calculation of any eco-factors derived by users must be stated in a reproducible manner.

Tab. 74 classes several typical countries in the six scarcity categories. This list provides orientation in order to be able to appraise, by analogy, the water scarcity category of other countries or regions without detailed data. These eco-factors do not, however, capture any regional scarcities within these countries.

Tab. 74 > Classification of several countries in the water scarcity categories

	Water scarcity ratio $\left(\frac{\text{Water consumption}}{\text{Available resource}}\right)$	Typical countries
Low	<0.1	Argentina, Austria, Estonia, Iceland, Ireland, Madagascar, Russia, Switzerland, Venezuela, Zambia
Moderate	0.1 to <0.2	Czech Republic, Greece, France, Mexico, Turkey, USA
Medium	0.2 to <0.4	China, Cyprus, Germany, Italy, Japan, Spain, Thailand
High	0.4 to <0.6	Algeria, Bulgaria, Morocco, Sudan, Tunisia
Very high	0.6 to <1.0	Pakistan, Syria, Tadzhikistan, Turkmenistan
Extreme	≥1	Israel, Kuwait, Oman, Qatar, Saudi Arabia, Yemen

8 > Wastes

8.1 Introduction

The following sections determine eco-factors for different types of wastes. Wastes in aboveground landfills are assessed on the basis of their carbon content. Certain hazardous wastes (Section 8.3) and radioactive wastes (Section 8.4) are stored underground.

8.2 Carbon in material consigned to bioreactive landfills

8.2.1 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 minimize the C flow to landfills. The experts at FOEN therefore consider this to be the key critical aspect when consigning material to bioreactive landfills.

8.2.2 Normalization

The normalization flow is identical to the current flow, as the current flow represents the C flow in landfills for the whole of Switzerland.

8.2.3 Weighting

Current flow

The current flow comprises the quantity of carbon stored through the waste in bioreactive landfills and slag compartments. According to FOEN estimates, slags contain an estimated 4 % C, while the average for other wastes consigned to bioreactive landfills (excluding slags) is 15 %.[25] Wastes consigned to landfills for inert materials or to landfills for stabilized residues contain practically no reactive organic material. 661 500 t slags are consigned annually to bioreactive landfills, plus 473 000 t other wastes (figures for 2002: BUWAL 2003a). This yields the current flow of 97 410 t C/a.

Critical flow

The target for the C content in bioreactive landfill wastes is 7 %.[26] With the quantity currently landfilled, this translates into a critical C flow of 79 420 t C/a.

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[25] Personal communication by M. Tellenbach, FOEN, 15 July 2006.

[26] Personal communication by M. Tellenbach, FOEN, 15 July 2006.

8.2.4 Eco-factors for carbon in bioreactive landfill wastes

Tab. 75 > Eco-factor for carbon in bioreactive landfill wastes, in EP/g C. The table also lists eco-factors for average slags and for other bioreactive landfill wastes

	Situation 2006	Q	Notes	Situation 1997
Normalization (t C/a)	97 410	B		
Current flow (t C/a)	97 410	B		
Critical flow (t C/a)	79 420	b		
Weighting (-)	1.50			
Eco-factor (EP/g C)	15			
Eco-factor (EP/g slags)	0.61		C content: 4 %	
Eco-factor (EP/g other bioreactive landfill wastes)	2.3		C content: 15 %	

Q = Data quality; for explanation see Section 2.4

The eco-factors for carbon in wastes consigned to landfill is presented here for the first time.

8.2.5 Guideline for application in relation to ecoinvent v2.01 dataset

It is not possible to apply this eco-factor directly in the ecoinvent database, as the C content of wastes consigned to landfill is not listed. Long-term TOC emissions are used instead as a proxy. In the ecoinvent database, these come exclusively from bioreactive landfills and landfills for stabilized residues. The transfer coefficient of bioreactive landfills for carbon in waste to carbon as long-term TOC is 0.244. The eco-factor to be applied in the ecoinvent database can thus be calculated. This figures 63 EP/g TOC.

8.3 Hazardous wastes in underground repositories

8.3.1 Background

The greater part of the hazardous wastes arising in Switzerland (around 1.1 million t per year) is treated within the country. Around one third can be incinerated, while the rest is, wherever possible, recycled, consigned to physical-chemical treatment or otherwise stored in a landfill for stabilized residues. Soil removed when cleaning up contaminated sites is the principal source of hazardous waste, accounting for around one quarter of the quantity (BUWAL 2003a, pp. 42–43).

Hazardous wastes are only exported in exceptional cases; this accounts for around 10 % of the total hazardous waste quantity. One third of the exported quantity is made up of the filter dusts of municipal waste incineration plants, which are stored in underground repositories. Their storage in underground repositories has been declining slightly since 1996, as the acid scrubbing process is increasingly being deployed. When this process is used, it is no longer necessary to store filter dust in underground repositories (BUWAL 2003a, p. 44).

8.3.2 Normalization

No characterization is performed, and both the current and the critical flow comprise the entire quantity of hazardous wastes consigned to underground repositories. The normalization flow is therefore identical to the current flow.

8.3.3 Weighting

Current flow

The Swiss waste statistics give the quantity of wastes stored in underground repositories. This figures 36 900 t/a in 2002, and is exported in its entirety (BUWAL 2003a, p. 44). There are no underground repositories in Switzerland.

Critical flow

The Swiss Environmental Protection Act (Umweltschutzgesetz, USG, Art. 30 para 3) stipulates the principle that wastes *“must be disposed of…, insofar as this possible and reasonable, within Switzerland.”* It is assumed that the exported quantity cannot be consigned purposefully to final storage in Switzerland, and therefore the critical flow is equated with the current flow.[27]

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[27] According to personal communication by H.-P. Fahrni, FOEN, of 28 February 2005, this determination is expedient.

8.3.4 Eco-factors for the consignment of hazardous wastes to repositories

Tab. 76 > Eco-factor for consigning hazardous wastes to underground repositories, in EP/g and EP/cm³ waste

	Situation 2006	Q	Notes	Situation 1997
Normalization (t Abfall/a)	36 900	A		
Current flow (t Abfall/a)	36 900	A		41 000
Critical flow (t Abfall/a)	36 900	c		41 000
Weighting (-)	1.00			
Eco-factor (EP/g Abfall)	27			24
Eco-factor (EP/cm³ Abfall)	43		Density 1,600 kg/m³ in accordance with Doka 2003b, Part III, p. 41	

Q = Data quality; for explanation see Section 2.4

This eco-factor relates exclusively to hazardous wastes stored in underground repositories. The final storage of wastes – including hazardous wastes – on normal above-ground landfills is assessed via the eco-factors for land use and for emissions to air, water and groundwater.

8.4 Radioactive wastes in final repositories

8.4.1 Preliminary note

The generation of electricity in nuclear power plants produces radioactive wastes that must eventually be consigned to final storage. No final repository could yet be constructed in Switzerland. The Wellenberg site in the canton of Nidwalden was envisaged for low-level and medium-level wastes. In 2002 the construction of an exploratory shaft was rejected in a referendum, so that now a new site must be sought. Similarly, no decision has yet been taken on a final repository site for high-level and long-lived wastes, nor is this in prospect in the near future. As the unresolved issues have remained largely unchanged, the approach towards defining an eco-factor established by Brand et al. (1998) is adopted here for the assessment of radioactive wastes.

8.4.2 Background

The Swiss strategy for the disposal of radioactive wastes is to aim for the interim to reduce the quantities and harmfulness of residues and then to isolate these permanently through final storage. The Swiss Nuclear Energy Act (Kernenergiegesetz, Art. 30 para 2) requires for the radioactive wastes that arise that *“The radioactive wastes arising in Switzerland must be disposed of within the country as a matter of principle”*. In addition, the Act stipulates a moratorium on reprocessing spent fuel elements from July 2006 to 2016.[28]

Originally two final repositories were envisaged – one for spent fuel elements, high-level wastes (HLW) and long-lived medium-level wastes (LMLW), and a second for low-level and medium-level wastes. Following rejection of the Wellenberg as a site for low-level and medium-level wastes, the option of building one single deep repository is now also under review.

The planned capacities required for the repository are determined on the basis of the estimated quantities of radioactive wastes including their encasements. Improved reprocessing processes will tend to reduce the volumes. On the other hand, extending the service life of nuclear power plants from the original term of 40 to 60 years increases repository capacity requirements. NAGRA[29] now also bases its calculations of required volumes on plant service lives of 60 years (192 GW scenario).

Based on this scenario, some 8300 m³ spent (and conditioned) fuel elements, some 1000 m³ HLW from reprocessing and 4360 m³ (cement waste option; 3460 m³ in the case of the vitrification option) LMLW arise. One option calculated assumes an additional 2900 m³ LMLW. Overall, the deep repository thus needs to accept around 16 000 m³ long-lived high-level and medium-level wastes (volume incl. encasements) (NAGRA 2002).

According to the plans drawn up in 1996, the repository for short-lived low-level and medium level wastes is to have a capacity of 100 000 m³. Of this, 42 000 m³ are wastes from nuclear power plant decommissioning, 11 000 m³ from plant operation, 24 000 m³ from reprocessing and the remaining 23 000 m³ from research and medicine (of which 14 000 m³ from the decommissioning of the PSI proton accelerator). This volume was estimated on the basis of a 40-year service life of nuclear power plants and a 70-year collection period for wastes from medicine and research (Prêtre 1996). Extrapolation to a service life of 60 years implies a required storage volume of around 115 000 m³ (volume incl. encasements).

The hazardousness of radioactive wastes depends upon 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
2. Long-lived medium-level wastes (LMLW), high-level wastes (HLW) and spent fuel elements

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[28] 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."*

[29] NAGRA is the national cooperative for radioactive waste storage (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle) in Switzerland

The former are relatively short-lived, and already present a minor hazard after a shorter period. A requisite shut-in time of around 500 years is assumed (KFW 2002; PSI 1996).

The shut-in time of long-lived wastes is much longer. It is assumed that these need to be stored safely for at least 100 000 years (EKRA 2000; PSI 1996).

8.4.3 Normalization

No characterization is performed. The normalization flow is thus identical to the current flow.

8.4.4 Weighting

Current flow

The quantity of radioactive wastes (incl. encasements) currently arising is taken from the ecoinvent report on nuclear power (Dones 2003). The net capacity of Swiss nuclear power plants figured 2.96 GW in 2002 (Dones 2003, Table 9.1), which results in a current flow of 1230 m^3/a for low-level and medium-level wastes, and 218 m^3/a for high-level wastes (HLW).

Critical flow

When setting the critical flow, the following aspects need to be taken into account:

- In Switzerland there is presently no repository capacity – neither for low-level and medium-level nor for high-level and long-lived wastes. The repository envisaged in the Wellenberg has been rejected. At the present time, radioactive wastes therefore cannot be disposed of (as envisaged by the legislator) in an environmentally sound manner. It would follow from this consideration that the critical flow would need to be set at zero.
- Possible repositories that could accept the wastes arising in existing nuclear power plants are in a tangible planning stage. Although no statement can be made as to the point in time at which such a facility may commence operations nor at which site, it is possible that sufficient repository capacity will exist in future. This consideration would suggest that the current flow should be equated with the critical flow.

The Swiss strategic report on sustainability (Schweizerischer Bundesrat 2002a, p.9) postulates as a guideline that "Accident risks are only to be accepted to the extent that, even in the case of occurrence of the most severe event, no permanent damage that extends beyond one generation is caused." The present interim storage of radioactive wastes in surface storage sites is a transitional solution.

The critical flow used to determine the eco-factor is therefore positioned between the current flow and zero. In a first, rough approximation, the critical flow is set at half of the current flow. This reflects the present situation, in which there are efforts to find a final repository, but no specific construction project is under way.

This determination of the critical flow is not based on a political consensus: Those who have confidence in technology view the overall present waste quantity as unproblematic, while those who hold a critical position consider even a minimum quantity of radioactive wastes to be unacceptable.

8.4.5 Eco-factor for radioactive wastes

Tab. 77 > Eco-factor for consignment of short-lived low-level and medium-level radioactive wastes to repository, in EP/cm³ waste

	Situation 2006	Q	Notes	Situation 1997
Normalization (m³/a)	1 230	A		
Current flow (m³/a)	1 230	A	Calculated from figures in (Dones 2003)	1 190
Critical flow (m³/a)	615	c	Set at half of the current flow (see text)	600
Weighting (-)	4.00			
Eco-factor (EP/cm³)	3 300		Low-level and medium-level wastes	3 300

Q = Data quality; for explanation see Section 2.4

Tab. 78 > Eco-factor for consignment of long-lived or/and high-level radioactive wastes to repository, in EP/cm³ wastes

	Situation 2006	Q	Notes	Situation 1997
Normalization (m³/a)	218	A		
Current flow (m³/a)	218	A	Calculated from figures in Dones 2003	85
Critical flow (m³/a)	109	c	Set at half of the current flow (see text)	43
Weighting (-)	4.00			
Eco-factor (EP/cm³)	18 000		Spent fuel elements, LMLW and HLW	46 000

Q = Data quality; for explanation see Section 2.4

The eco-factor is applied to repository volume for radioactive wastes, including their encasements. Through the development and application of new processes in radioactive waste management (e.g. cement waste option) it is possible that the current flow drops in future. On the other hand, the volume of long-lived and high-level wastes in particular has risen since 1997 due to the moratorium on reprocessing.

9 > Not assessed: Noise

ARE (2004, p.14) defines noise as a parameter determined by subjective factors: “Noise is a sound perceived to be unpleasant and disturbing. The actual level of impairment depends largely upon the subjective perception of the person affected.””

Noise pollution is an ubiquitous problem, especially in cities. The main sources are road and rail vehicles on the one hand, and the building sites on the other hand that are needed to maintain and extend settlement infrastructure. In rural areas agricultural and silvicultural machines cause noise, but also jingling cow bells can be perceived as noise by some. In the vicinity of airports, arriving and departing aircraft are a relevant source of noise. Persons living next to bodies of water can be affected by ambient noise caused by motorboats. Shooting ranges and sports facilities or similar installations are locally defined, stationary sources of noise.

The Swiss Noise Abatement Ordinance (Lärmschutzverordnung, LSV) defines the noise target that is to be achieved – in analogy to the precautionary principle (Section 2.2.3) – as what technology and operating conditions will allow providing this is economically acceptable. A further goal is that there should be no severe nuisance to the affected public. These goals apply to both mobile and stationary sources of sound.

The basic problem in assessing noise is that, in contrast to substance emissions, sound quickly dissipates and is therefore always locally contained. A further problem is that assessment can only be performed on the basis of the ambient situation, as it is only through the human perception of a sound that this can be considered to be noise. It is therefore essential when conducting an assessment to consider the emission situation in combination with the ambient situation. Sound emissions are locally bound, which makes it difficult to derive eco-factors. No generally recognized method for assessing noise in life cycle assessments is yet available.

Doka (2003a) has developed an option for integrating road traffic noise in the ecological scarcity method. The derivation is relatively complex and not immediately transferable to noise from other sources. In the present report, these factors, which only apply to road traffic, have not been adopted, as this would result in a one-sided attribution of impacts to road vehicles alone. These factors can continue to be highly useful when addressing specific issues in the road transport sector, but when studies address other issues they would produce an unfair assessment bias.

> Annex

A1 Conversion factors for emissions

Tab. 79 > Conversion factors for emissions of nitrogen and phosphorous compounds and for COD/DOC

	Mass, rounded (g/mol)	
NO_x as 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 grey shading of values in the table indicates whether the GWP or the ODP was used for the calculation. The GWP values are in accordance with IPCC (2001), the ODP values are in accordance with UNEP (2000).

Tab. 80 > Eco-factors for greenhouse gases and ozone-depleting substances

	Formula	CAS No.	GWP (CO_2-eq.)	ODP (R11-eq.)	Eco-factor 2006 (EP/g)	Eco-factor 1997 (EP/g)	Basis in 1997
Carbon dioxide	CO_2	124–38–9	1	-	0.31	0.2	GWP
Carbon monoxide	CO	630–08–0	1.57	-	0.49	0.2	GWP
Methane	CH_4	74–82–8	23	-	7.1	4.2	GWP
Nitrous oxide	N_2O	10024–97–2	296	-	92	62	GWP
Chlorofluorocarbons (CFCs)							
CFC-11	CCl_3F	75–69–4	4 600	1	11 000	2 000	ODP
CFC-12	CCl_2F_2	75–71–8	10 600	1	11 000	2 000	ODP
CFC-13	$CClF_3$	75–72–9	14 000	1	11 000	2 000	ODP
CFC-111	C_2Cl_5F	354–56–3	-	1	11 000	2 000	ODP
CFC-112	$C_2Cl_4F_2$	76–12–0	-	1	11 000	2 000	ODP
CFC-113	CCl_2FCClF_2	76–13–1	6 000	0.8	8 800	1 600	ODP
CFC-114	$CClF_2CClF_2$	76–14–2	9 800	1	11 000	2 000	ODP
CFC-115	CF_3CClF_2	76–15–3	7 200	0.6	6 600	1 200	ODP
CFC-211	C_3Cl_7F	422–78–6	-	1	11 000	2 000	ODP
CFC-212	$C_3Cl_6F_2$	3182–26–1	-	1	11 000	2 000	ODP
CFC-213	$C_3Cl_5F_3$	2354–06–5	-	1	11 000	2 000	ODP
CFC-214	$C_3Cl_4F_4$	29255–31–0	-	1	11 000	2 000	ODP
CFC-215	$C_3Cl_3F_5$	4259–43–2	-	1	11 000	2 000	ODP
CFC-216	$C_3Cl_2F_6$	661–97–2	-	1	11 000	2 000	ODP
CFC-217	C_3ClF_7	422–86–6	-	1	11 000	2 000	ODP
Hydrofluorocarbons (HFCs)							
HFC-23	CHF_3	75–46–7	12 000	-	3 700	2 300	GWP
HFC-32	CH_2F_2	75–10–5	550	-	170	130	GWP
HFC-41	CH_3F	593–53–3	97	-	30	30	GWP
HFC-125	CHF_2CF_3	354–33–6	3 400	-	1 100	560	GWP
HFC-134	CHF_2CHF_2	359–35–3	1 100	-	340	200	GWP
HFC-134a	CH_2FCF_3	811–97–2	1 300	-	400	260	GWP
HFC-143	CHF_2CH_2F	430–66–0	330	-	100	60	GWP
HFC-143a	CF_3CH_3	420–46–2	4 300	-	1 300	760	GWP
HFC-152	CH_2FCH_2F	624–72–6	43	-	13	-	
HFC-152a	CH_3CHF_2	75–37–6	120	-	37	28	GWP
HFC-161	CH_3CH_2F	353–36–6	12	-	3.7	-	

	Formula	CAS No.	GWP (CO_2-eq.)	ODP (R11-eq.)	Eco-factor 2006 (EP/g)	Eco-factor 1997 (EP/g)	Basis in 1997
HFC-227ea	CF_3CHFCF_3	431–89–0	3 500	-	1 100	580	GWP
HFC-236cb	$CH_2FCF_2CF_3$	677–56–5	1 300	-	400	-	
HFC-236ea	CHF_2CHFCF_3	431–63–0	1 200	-	370	-	
HFC-236fa	$CF_3CH_2CF_3$	690–39–1	9 400	-	2 900	1 300	GWP
HFC-245ca	$CH_2FCF_2CHF_2$	679–86–7	640	-	200	110	GWP
HFC-245fa	$CHF_2CH_2CF_3$	460–73–1	950	-	290	-	
HFC-365mfc	$CF_3CH_2CF_2CH_3$	406–58–6	890	-	280	-	
HFC-43–10mee	$CF_3CHFCHFCF_2CF_3$	138495–42–8	1 500	-	470	260	GWP
Partially halogenated chlorofluorocarbons (HCFCs)							
HCFC-21	$CHCl_2F$	75–43–4	210	0.04	440	-	
HCFC-22	$CHClF_2$	75–45–6	1 700	0.055	610	300	GWP
HCFC-31	CH_2FCl	593–70–4	-	0.02	220	-	
HCFC-121	$CHCl_2CCl_2F$	354–14–3	-	0.04	440	-	
HCFC-122	$CHCl_2CClF_2$	354–21–2	-	0.08	880	-	
HCFC-123	$CHCl_2CF_3$	306–83–2	120	0.02	220	40	ODP
HCFC-124	$CHFClCF_3$	2837–89–0	620	0.022	240	94	GWP
HCFC-131	CH_2ClCCl_2F	359–28–4	-	0.05	550	-	
HCFC-133a	CH_2ClCF_3	75–88–7	-	0.06	660	-	
HCFC-141	$CH_2ClCHClF$	430–57–9	-	0.07	770	-	
HCFC-141b	CH_3CFCl_2	1717–00–6	700	0.11	1 200	220	ODP
HCFC-142b	CH_3CF_2Cl	75–68–3	2 400	0.065	740	360	GWP
HCFC-225ca	$CF_3CF_2CHCl_2$	422–56–0	180	0.025	280	-	
HCFC-225cb	$CClF_2CF_2CHClF$	507–55–1	620	0.033	360	-	
HCFC-253	$C_3H_4F_3Cl$	460–35–5	-	0.03	330	-	
HCFC-261	$CH_3CClFCH_2Cl$	420–97–3	-	0.02	220	-	
HCFC-271	C_3H_6FCl	430–55–7	-	0.03	330	-	
Perfluorocarbons (PFCs)							
Methane, perfluoro- (HFC-14)	CF_4	75–73–0	5 700	-	1 800	1 300	GWP
Ethane, perfluoro- (HFC-116)	C_2F_6	76–16–4	11 900	-	3 700	1 800	GWP
Propane, octafluoro- (HFC-218)	C_3F_8	76–19–7	8 600	-	2 700	1 400	GWP
Propane, hexafluorocyclo-	c-C_3F_6	931–91–9	16 800	-	5 200	-	
Butane, decafluoro-	C_4F_{10}	355–25–9	8 600	-	2 700	1 400	GWP
Butane, octafluorocyclo-	c-C_4F_8	115–25–3	10 000	-	3 100	1 700	GWP
Pentane, dodecafluoro-	C_5F_{12}	678–26–2	8 900	-	2 800	1 500	GWP
Hexane, tetradecafluoro-	C_6F_{14}	355–42–0	9 000	-	2 800	1 500	GWP

	Formula	CAS No.	GWP (CO_2-eq.)	ODP (R11-eq.)	Eco-factor 2006 (EP/g)	Eco-factor 1997 (EP/g)	Basis in 1997
Brominated hydrocarbons							
Methane, bromo-	CH_3Br	74–83–9	5	0.6	6 600	1 400	ODP
Methane, dibromo-	CH_2Br_2	74–95–3	1	-	0.31	-	
Methane, bromochloro-	CH_2BrCl	74–97–5	-	0.12	1 300	-	
Methane, bromofluoro-	CH_2FBr	373–52–4	-	0.73	8 000	-	
Methane, bromodifluoro-	$CHBrF_2$	1511–62–2	470	0.74	8 100	-	
Methane, dibromofluoro-	$CHFBr_2$	1868–53–7	-	1	11 000	-	
Halon 1211 (Methane, bromochlorodifluoro-)	$CBrClF_2$	353–59–3	1 300	3	33 000	20 000	ODP
Halon 1301 (Methane, bromotrifluoro-)	$CBrF_3$	75–63–8	6 900	10	110 000	20 000	ODP
Halon 2402 (Ethane, 1,2-dibromo-1,1,2,2-tetrafluoro-)	$C_2Br_2F_4$	124–73–2	-	6	66 000	12 000	ODP
Chlorinated hydrocarbons							
Methane, tetrachloro-, (R-10)	CCl_4	56–23–5	1 800	1.1	12 000	2 200	ODP
Chloroform, (R-20)	$CHCl_3$	67–66–3	30	-	- *	-	
Methane, monochloro-, (R-40)	CH_3Cl	74–87–3	16	-	- *	-	
Methane, dichloro-, (R-30)	CH_2Cl_2	75–09–2	10	-	- *	-	
Ethane, 1,1,1-trichloro-, (R-140)	CH_3CCl_3	71–55–6	140	0.1	1 100	200	ODP
Further halogenated hydrocarbon compounds							
Methane, trifluoroiodo-	CF_3I	2314–97–8	1	-	0.31	-	
Ethanol, 2,2,2-trifluoro-	CF_3CH_2OH	75–89–8	57	-	18	-	
1-propanol, 2,2,3,3,3-pentafluoro-	$CF_3CF_2CH_2OH$	422–05–9	40	-	12	-	
2-propanol, 1,1,1,3,3,3-hexafluoro-	$(CF_3)_2CHOH$	920–66–1	190	-	59	-	
Nitrogen trifluoride	NF_3	7783–54–2	10 800	-	3 300	-	
Sulphur, pentafluoro(trifluoromethyl)-	SF_5CF_3	373–80–8	17 500	-	5 400	-	
Sulphur hexafluoride	SF_6	2551–62–4	22 200	-	6 900	-	
Ethers and halogenated ether compounds							
Ether, dimethyl-	CH_3OCH_3	115–10–6	1	-	- *	-	
Ether, methyl perfluoroisopropyl-	$(CF_3)_2CFOCH_3$	22052–84–2	330	-	100	-	
HCFE-235da2	$CF_3CHClOCHF_2$	26675–46–7	340	-	110	-	
HFE-125	CF_3OCHF_2	3822–68–2	14 900	-	4 600	-	
HFE-134	CHF_2OCHF_2	1691–17–4	6 100	-	1 900	-	
HFE-227ea	$CF_3CHFOCF_3$	2356–61–8	1 500	-	470	-	

* s assessed with the eco-factor for photochemical ozone creation potential (POCP), as that value is higher

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 use can be found in Section 4.9.

Tab. 81 > PAHs (polycyclic aromatic hydrocarbons)

PAH No.	Name	CAS No.	Molecular weight	Synonyms
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)fluoranthene	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)fluoranthene	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	Fluoranthene	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 Plant protection products

Tab. 82 > Plant protection products

	Standard dose (g/ha)	Characterization factor (kg PPP-eq/kg)	Eco-factor (EP/g)
Herbicides			
2,4-D	951	2.4	1 800
Aclonifen	2 580	0.87	640
Alachlor	3 360	0.67	490
Amidosulfuron	36.2	62	45 000
Asulam	2 150	1	730
Atrazine	1 000	2.2	1 600
Benazolin	301	7.4	5 400
Bentazone	1 180	1.9	1 400
Bifenox	1 630	1.4	1 000
Bromoxynil	378	5.9	4 300
Carbetamide	2 780	0.81	590
Chloridazon	2 060	1.1	800
Chlorothalonil	1 500	1.5	1 100
Chlorotoluron	2 000	1.1	800
Cinidon-ethyl	50	45	33 000
Clethodim	173	13	9 500
Clodinafop-propargyl	86.1	26	19 000
Clomazone	99.3	23	17 000
Cloquintocet-mexyl	18	120	88 000
Desmedipham	98.7	23	17 000
Dicamba	234	9.6	7 000
Dichlobenil	294	7.6	5 500
Dichlorprop-P	630	3.6	2 600
Diflufenican	86.8	26	19 000
Diflufenzopyr-sodium	66.7	34	25 000
Dimefuron	545	4.1	3 000
Dimethachlor	656	3.4	2 500
Dimethenamid	1 260	1.8	1 300
Dinoseb	5 160	0.43	310
Diquat	1 580	1.4	1 000
DNOC	18 300	0.12	88
Ethofumesate	750	3	2 200
Fluazifop-p-butyl	276	8.1	5 900
Flumioxazin	450	5	3 700
Fluorochloridone	735	3	2 200
Fluoroglycofen-ethyl	30	75	55 000

	Standard dose (g/ha)	Characterization factor (kg PPP-eq/kg)	Eco-factor (EP/g)
Fluroxypyr	233	9.6	7 000
Foramsulfuron	90	25	18 000
Glufosinate	838	2.7	2 000
Glyphosate	2 490	0.9	660
Imazethapyr	89	25	18 000
Ioxynil	660	3.4	2 500
Isoproturon	1 250	1.8	1 300
Linuron	648	3.5	2 600
MCPA	1 070	2.1	1 500
MCPB	1 710	1.3	950
Mecoprop	770	2.9	2 100
Mecoprop-P	1 010	2.2	1 600
Metamitron	3 390	0.66	480
Metazachlor	1 000	2.2	1 600
Methabenzthiazuron	2 730	0.82	600
Methiocarb	119	19	14 000
Metolachlor	1 670	1.3	950
Metribuzin	546	4.1	3 000
Metsulfuron-methyl	6.5	340	250 000
Monolinuron	1 080	2.1	1 500
Nicosulfuron	50	45	33 000
Napropamide	1 310	1.7	1 200
Orbencarb	3 150	0.71	520
Oxadixyl	215	10	7 300
Oxydemeton-methyl	545	4.1	3 000
Paraquat	723	3.1	2 300
Pendimethalin	1 590	1.4	1 000
Phenmedipham	864	2.6	1 900
Propaquizafop	163	14	10 000
Prosulfocarb	3 540	0.63	460
Prosulfuron	13.5	170	120 000
Pyridate	735	3	2 200
Rimsulfuron	8.98	250	180 000
Simazine	992	2.3	1 700
Starane	208	11	8 000
Sulfosate	3 270	0.68	500
Tebutam	3 300	0.68	500
Teflubenzuron	55.4	40	29 000
Terbufos	206	11	8 000
Terbuthylazine	767	2.9	2 100
Thifensulfuron-methyl	17.5	130	95 000
Triasulfuron	7.5	300	220 000

	Standard dose (g/ha)	Characterization factor (kg PPP-eq/kg)	Eco-factor (EP/g)
Tribenuron	30	75	55 000
Trifluralin	1 240	1.8	1 300
Triflusulfuron-methyl	12.5	180	130 000
Plant growth regulators			
Chlormequat	690	3.2	2 300
Chlormequat Chloride	690	3.2	2 300
Ethephon	269	8.3	6 100
Mepiquat chloride	980	2.3	1 700
Trinexapac-ethyl	125	18	13 000
Seed dressings			
Fenpiclonil	50.2	45	33 000
Fipronil	90	25	18 000
Metalaxyl	8	280	200 000
Insecticides			
Bifenthrin	19	120	88 000
Carbofuran	2 500	0.9	660
Chlorpyrifos	662	3.4	2 500
Cyfluthrin	44.5	50	37 000
Cypermethrin	50	45	33 000
Deltamethrin	12.5	180	130 000
Diflubenzuron	120	19	14 000
Dimethoate	400	5.6	4 100
Endosulfan	945	2.4	1 800
Esfenvalerate	15.6	140	100 000
Lambda-cyhalothrin	7.58	300	220 000
Mineral oil	37 900	0.059	43
Parathion	1 000	2.2	1 600
Permethrin	2 000	1.1	800
Pirimicarb	76.1	29	21 000
Rapeseed oil	2 580	0.87	640
Tau-fluvalinate	50.3	44	32 000
Molluscicides			
Metaldehyde	7 500	0.3	220
Fungicides			
Captan	1 600	1.4	1 000
Carbendazim	274	8.2	6 000
Cymoxanil	120	19	14 000
Cyproconazole	70	32	23 000

	Standard dose (g/ha)	Characterization factor (kg PPP-eq/kg)	Eco-factor (EP/g)
Cyprodinil	600	3.7	2 700
Difenoconazole	125	18	13 000
Dimethomorph	150	15	11 000
Dithianon	600	3.7	2 700
Epoxiconazole	93.8	24	18 000
Fenbuconazole	100	22	16 000
Fenpropidin	300	7.5	5 500
Fenpropimorph	750	3	2 200
Fentin acetate	364	6.1	4 500
Fentin hydroxide	339	6.6	4 800
Fluazinam	250	9	6 600
Flusilazole	225	9.9	7 200
Folpet	1 860	1.2	880
Fosetyl-Al	2 400	0.93	680
Fluquinconazole	79.7	28	20 000
Hexaconazole	185	12	8 800
Imazamox	40	56	41 000
Iodosulfuron	4	560	410 000
Iprodione	550	4.1	3 000
Kresoxim-methyl	127	18	13 000
Copper	4 380	0.51	370
Lindane	1 500	1.5	1 100
Mancozeb	2 110	1.1	800
Maneb	2 250	1	730
Mesotrione	125	18	13 000
Metconazole	90	25	18 000
Prochloraz	450	5	3 700
Propamocarb HCl	758	3	2 200
Propiconazole	125	18	13 000
Sulphur	32 500	0.069	50
Spiroxamine	752	3	2 200
Tebuconazole	206	11	8 000
Thiophanate-methyl	934	2.4	1 800
Thiram	1 510	1.5	1 100
Triadimenol	40	56	41 000
Tridemorph	280	8	5 800
Vinclozolin	375	6	4 400

A5 Eco-factors for land use

The EDP (Ecosystem Damage Potential) values are adopted or derived from Köllner (2001) (see notes at the end of the table). The characterization factors are calculated using the EDP of 0.55 for the reference land-cover type (settlement area – SA).

Tab. 83 > Eco-factors for land use

CORINE+	Land use	EDP		Charact. factor (m^2 SA-eq./m^2)	Eco-factor 2006 (EP/m^2)
Settlement areas					
REF	Settlement area (reference)	0.55		1	220
111	Urban fabric, continuous, >80 % sealed	0.68	a)	1.24	260
112	Urban fabric, discontinuous, <80 % sealed	0.54	a)	0.986	220
113	Urban fallow	-0.08	a)	-0.146	-33
114	Rural settlement	0.48	a)	0.876	190
121	Industrial or commercial units	0.573	b)	1.05	220
121a	Industrial area, built up part, >80 % sealed	0.68	c)	1.24	260
121b	Industrial area, part with vegetation, <80 % sealed	0.52	a)	0.949	210
122	Road and rail networks and associated land	0.56	d)	1.02	220
122a	Road networks	0.56	d)	1.02	220
122b	Road embankments and associated land (min. 100 m width)	0.46	e)	0.84	180
122c	Rail networks	0.56	d)	1.02	220
122d	Rail embankments and associated land (min. 100 m width)	0.45	a)	0.821	180
122e	Rail fallow	-0.01	a)	-0.0183	-4
125	Industrial fallow	-0.09	a)	-0.164	-35
131	Mineral extraction sites	0.56	d)	1.02	220
132	Dump sites	0.56	d)	1.02	220
133	Construction sites	0.56	d)	1.02	220
134	Mining fallow	-0.08	a)	-0.146	-33
14	Artificial, non-agricultural areas with vegetation	0.56	b)	1.02	220
141	Green urban areas	0.46	a)	0.84	180
142	Sport and leisure facilities	0.66	a)	1.2	260
Agricultural areas					
211	Arable land, non-irrigated	0.258	b)	0.472	100
211a	Arable land, non-irrigated, conventional	0.27	a)	0.493	110
211b	Arable land, non-irrigated, IP	0.32	a)	0.584	130
211c	Arable land, non-irrigated, organic	0.15	a)	0.274	59
211d	Arable land, non-irrigated, fibre/energy crops	0.28	a)	0.511	110
211e	Arable land, non-irrigated, fallow	-0.1	a)	-0.183	-40
211f	Arable land, non-irrigated, artificial meadow	0.24	f)	0.438	97
22	Permanent crops	0.071	b)	0.13	29
221	Permanent crops, vineyards	0.071	j)	0.13	29

CORINE+	Land use	EDP		Charact. factor (m² SA-eq./m²)	Eco-factor 2006 (EP/m²)
221a	Permanent crops, vineyards, intensive	0.071	j)	0.13	29
221b	Permanent crops, vineyards, non-intensive	0.071	j)	0.13	29
222	Permanent crops, fruit trees and berry plantations	0.032	b)	0.059	13
222a	Permanent crops, orchards, conventional	0.24	f)	0.438	97
222b	Permanent crops, orchards, organic	-0.03	a)	-0.0548	-12
231	Pastures and meadows	0.145	b)	0.265	57
231a	Pastures and meadows, intensive	0.21	a)	0.383	84
231b	Pastures and meadows, less intensive	0	a)	0	0.0
231c	Pastures and meadows, organic	-0.12	a)	-0.219	-48
245	Agricultural fallow with hedgerows	-0.12	a)	-0.219	-48

Forests and shrub

311	Forest, broad-leaved	0.038	b)	0.069	15
311a	Forest, broad-leaved, plantations	0.26	g)	0.475	100
311b	Forest, broad-leaved, semi-natural	-0.02	a)	-0.0365	-8.1
312	Forest, coniferous	0.038	b)	0.069	15
312a	Forest, coniferous, plantations	0.26	g)	0.475	100
312b	Forest, coniferous, semi-natural	-0.02	h)	-0.0365	-8.1
313	Forest, mixed	-0.02	h)	-0.0365	-8.1
313a	Forest, mixed broad-leaved	-0.02	h)	-0.0365	-8.1
313b	Forest, mixed coniferous	-0.02	h)	-0.0365	-8.1
313c	Forest, mixed, plantations	0.26	g)	0.475	100
314	Forest, forest edge	-0.11	a)	-0.201	-44
321	Shrub and/or herbaceous vegetation, grassland, semi-natural	-0.09	a)	-0.164	-35
322	Shrub and/or herbaceous vegetation, moors and heathland	0.03	a)	0.0548	12
323	Shrub and/or herbaceous vegetation, sclerophyllous vegetation	-0.03	i)	-0.0548	-12
324	Shrub and/or herbaceous vegetation, transitional woodland/shrub	-0.03	i)	-0.0548	-12
325	Shrub and/or herbaceous vegetation, hedgerows	-0.1	a)	-0.183	-40

Other uses

-	Unknown use	0.403	b)	0.736	160

SA: Settlement area

a) Derived from the values in Tab. App. 6a-1 in Köllner (2001)

b) Derived via weighted average of subcategories

c) Equated with factor for Corine 111

d) Derived using the “Artificial high-intensity” average factor in accordance with Köllner (2001)

e) Derived using the “Artificial low-intensity” average factor in accordance with Köllner (2001)

f) Derived using the “Agriculture high-intensity” average factor in accordance with Köllner (2001)

g) Derived using the “Forest high-intensity” average factor in accordance with Köllner (2001)

h) Derived using the “Forest low-intensity” average factor in accordance with Köllner (2001)

i) Derived using the “non use” average factor in accordance with Köllner (2001)

j) Equated with the factor for Corine 22

A6 Eco-factors for freshwater consumption in the OECD states

The eco-factors listed in the following table are only to be used for specific or sufficiently detailed life cycle inventories. Normally the classification in scarcity categories as set out in Section 7.5.5 should be applied.

Tab. 84 > Eco-factors for freshwater consumption in the OECD states

	Scarcity ratio	Normalization (km³/a)	Current flow (km³/a)	Critical flow (km³/a)	Weighting (-)	Eco-factor 2006 (EP/m³)
Australia	0.049	2.57	23.9	98.4	0.0591	23
Austria	0.027	2.57	2.11	15.5	0.0184	7.2
Belgium-Luxembourg	0.42	2.57	8.98	4.28	4.4	1700
Canada	0.016	2.57	46	580	0.00627	2.4
Czech Republic	0.2	2.57	2.58	2.63	0.962	370
Denmark	0.21	2.57	1.27	1.2	1.12	440
Finland	0.023	2.57	2.48	22	0.0127	4.9
France	0.2	2.57	40	40.7	0.962	370
Germany	0.31	2.57	47.1	30.8	2.33	910
Greece	0.1	2.57	7.77	14.9	0.274	110
Hungary	0.073	2.57	7.64	20.8	0.135	53
Iceland	0.00088	2.57	0.15	34	0.0000195	0.0076
Ireland	0.022	2.57	1.13	10.4	0.0118	4.6
Italy	0.23	2.57	44.4	38.3	1.34	520
Japan	0.21	2.57	88.4	86	1.06	410
Korea	0.12	2.57	9.02	15.4	0.342	130
Luxembourg	a)	2.57	a)	a)	a)	a)
Mexico	0.17	2.57	78.2	91.4	0.732	280
Netherlands	0.087	2.57	7.94	18.2	0.19	74
New Zealand	0.0065	2.57	2.11	65.4	0.00104	0.40
Norway	0.0057	2.57	2.19	76.4	0.000822	0.32
Poland	0.26	2.57	16.2	12.3	1.73	670
Portugal	0.16	2.57	11.3	13.7	0.672	260
Slovak Republic	b)	2.57	b)	b)	-	-
Spain	0.32	2.57	35.6	22.3	2.55	990
Sweden	0.017	2.57	2.96	34.8	0.00723	2.8
Switzerland	0.048	2.57	2.57	10.7	0.0577	22
Turkey	0.18	2.57	37.5	42.7	0.772	300
UK (Great Britain & Northern Ireland)	0.065	2.57	9.54	29.4	0.105	41
USA	0.16	2.57	479	610	0.617	240
OECD	0.1	2.57	1018	2043	0.248	97

a) See Belgium (contained there)
b) No data available
Source: (FAO 2005)

>Index

Abbreviations

a
Annum, year

AOXs
Adsorbable organic halogen compounds (aggregate parameter expressing the quantity of halogenated substances in waters and in sewage sludge)

CFCs
Chlorofluorocarbons

COD
Chemical oxygen demand (measure of the quantity of oxygen needed to oxidate organic compounds in waters)

DOC
Dissolved organic carbon (measure of the content of organically bound carbon from dissolved organic compounds)

Ecological scarcity
Is determined as a function of the limited carrying capacity of the environment in relation to anthropogenic impacts (critical flow) and of the effective extent of these impacts (current flow) upon the environment. The greater the ratio of the current flow to the critical flow, the greater the ecological scarcity.

EP
Eco-point (unit for the ecological scarcity assessment method)

eq.
equivalent

F
Current flow (emission load in an area over a year)

Feedstock
Energy resource not used to produce energy

F_k
Critical flow (critical emission load in an area over a year)

F_n
Normalization flow (emission load of Switzerland, as characterized quantity where required)

GWP_{100}
Global warming potential (of a substance relative to CO_2; in the present report, all data relate to a time horizon of 100 years and are based on the latest IPCC figures (IPCC 2001))

HCFCs
Partially halogenated CFCs

IAWR
Internationale Arbeitsgemeinschaft der Wasserwerke im Rheineinzugsgebiet (international association of waterworks in the Rhine catchment area)

Inventory
Analysis of material and energy flows, or outcome of such an analysis

ISO
International Organisation for Standardization (Geneva/CH)

MJ
Megajoule (10^6 joules)

MJ_e
Megajoule electric (in the form of electric energy)

MJ_t
Megajoule thermal (in the form of thermal energy)

NMVOCs
Non-methane volatile organic compounds (excl. methane, excl. CFCs), see also VOCs

ODP
Ozone depletion potential (measure of the ozone-depleting effect of a substance relative to R11)

PAHs
Polycyclic aromatic hydrocarbon compounds

PFCs
Perfluorocarbons

PJ
Petajoule (10^{15} joules)

PM10
Particle with a diameter of less than 10 micrometres

PM2.5
Particle with a diameter of less than 2.5 micrometres

PPP
Plant protection product; comprises herbicides, plant growth regulators and products and items which protect plants and their propagative material against diseases and pests

SETAC
Society for Environmental Toxicology and Chemistry (Brussels/B)

TJ
Terajoule (10^{12} joules)

TOC
Total Organic Carbon (carbon bound in organic molecules)

VOCs
Volatile organic compounds (examples of VOCs are listed in the Swiss Air Pollution Control Ordinance of 16 December 1985 in Art. 72 (table of organic substances in gaseous, vapour or particle form))

Figures

Tables

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