Weighting in Ecobalances with the Ecoscarcity Method

Ecofactors 1997

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Contents

Abstracts

Die Methode der ökologischen Knappheit ermöglicht eine vergleichende Gewichtung verschiedener Umwelteinwirkungen mittels sogenannter Ökofaktoren. Der vorliegende Bericht aktualisiert und ergänzt die in der BUWAL-Schriftenreihe Umwelt Nr. 133 „Methodik für Ökobilanzen auf der Basis ökologischer Optimierung" (1990) erarbeiteten Ökofaktoren und stellt die Methode dar. Er enthält Gewichtungsfaktoren für die Emission verschiedener Substanzen in die Luft, in die Oberflächengewässer und in Boden/Grundwasser sowie für den Verbrauch von Energie-Ressourcen. Die Ökofaktoren werden aus den gegenwärtigen Umweltbelastungen (aktuelle Flüsse) und den als kritisch erachteten Belastungen (kritische Flüsse) berechnet. Der aktuelle Fluss wird aus den neusten verfügbaren Daten ermittelt. Der kritische Fluss wird aus wissenschaftlich begründeten Zielen der schweizerischen Umweltpolitik abgeleitet.

The method of environmental scarcity allows a comparative weighting and aggregation of various environmental interventions by use of so-called eco-factors. This report updates and complements the eco-factors first published in 1990 in the BUWAL series No. 133 "Methodik für Ökobilanzen auf der Basis ökologischer Optimierung", and presents the method. It contains weighting factors for different emissions into air, water and top-soil/groundwater as well as for the use of energy resources. The eco-factors are based on the actual pollution (current flows) and on the pollution considered as critical (critical flows). Current flows are taken from the newest available data. Critical flows are deduced from the scientifically supported goals of Swiss environment policy.

La méthode de la saturation écologique permet d'effectuer une pondération comparative de différentes nuisances pour l'environnement grâce aux écofacteurs. Ce rapport complète et met à jour les écofacteurs élaborés dans le Cahier de l'environnement n° 133 de l'OFEFP, « Méthodologie des écobilans sur la base de l'optimisation écologique » (1990), et présente la méthode utilisée. Il propose des facteurs de pondération pour déterminer l'émission de diverses substances dans l'air, les eaux superficielles et le sol/eaux souterraines, ainsi que la consommation des ressources énergétiques. Les écofacteurs sont calculés à partir des nuisances réelles pour l'environnement (flux actuels) et des nuisances considérées comme critiques (flux critiques). Le flux actuel est estimé sur la base des données les plus récentes, tandis que le flux critique découle d'objectifs visés par la politique suisse de l'environnement qui s'appuient sur des bases scientifiques.

Il metodo della scarsità ecologica permette una ponderazione comparativa di diversi effetti ambientali attraverso l'uso di cosiddetti ecofattori. Il presente rapporto attualizza e integra gli ecofattori elaborati nella „metodica per i bilanci ecologici basata sull'ottimizzazione ecologica" pubblicata nella serie di scritti sull'ambiente n. 133 dell'UFAFP (1990) e presenta il metodo in questione. Il rapporto contiene anche fattori di ponderazione per l'emissione di diverse sostanze nell'aria, nelle acque di superficie e nel suolo/acque sotterranee, nonché per il consumo delle risorse energetiche. Il calcolo degli ecofattori avviene partendo dagli attuali carichi ambientali (flussi attuali) e da quelli che sono considerati i carichi critici (flussi critici). Il flusso attuale è determinato partendo dai dati più aggiornati. Il flusso critico è estrapolato dagli obiettivi scientificamente motivati della politica svizzera in materia di ambiente.

Preface

In ecobalances, the evaluation (weighting) of environmental impacts is of central importance. This step is essential for integrating the numerous data of an ecoinventory into a contiguous whole. On this basis, an overall assessment of a product, a process or a company may be made.

The method of ecoscarcity represents one possible means of preparing a comprehensible and transparent assessment on a coherent basis. Following the Ecobalance for Packaging Materials, first published in 1984, S. Ahbe, A. Braunschweig and R. Müller-Wenk laid the basis for this method, which finally appeared in 1990 as No. 133 in the SAEFL Environment Series. This represented a significant step away from the separate assessment of environmentally relevant impacts towards an integrated assessment. The present report presents new and revised ecofactors.

Revision of the 1990 publication had become necessary for several reasons. For one, owing to the widespread introduction of environmental measures over the past few years, the reference values used have changed. Secondly, further parameters have meanwhile been included in the assessment by various users. Finally, the continuously increasing number of users asked for generally accepted data based on current figures.

It is clear that the result of an ecobalance of this kind by no means represents the 'ecological truth' as such, since many assumptions, simplifications and value-judgments are included within the method. The present report does, however, represent a broad consensus of a broad circle. Thereby, results may be compared with one-another and be effectively communicated to others.

The present report reflects the policy within SAEFL of encouraging the preparation and further development of promising assessment methods for ecobalances and LCA. This has enabled a contribution to be made to the discussion on social values in environmental policy, and an application oriented implementation of ecological objectives in everyday practice.

Summary

Ecobalances for products, processes and companies are performed in stages:

- Defining goal and scope of the study
- Inventory data collection
- Impact assessment and weighting
- Interpretation (evaluation) of all elements of the ecobalance
- Implementation of the ecobalance's results

The ecoscarcity method permits the data contained in the inventory to be weighted. The method was developed by Ahbe, Braunschweig and Müller-Wenk and first published by SAEFL in its Environment Series in 1990 [SRU 133]. The method is based on the "distance to target principle", i.e. on a comparison of the existing flow of a substance with the target value (critical flow). The ecofactor calculated from the current and critical flows of a substance is a measure of the ecological relevance of the emission concerned. The ecofactors thus permit weighting of inventories within an ecobalance.

In [SRU 133], ecofactors were presented for certain environmental interventions, and these have since been applied by a large number of users. However, new scientific results, new legal and political factors, as well as practical experience now make it necessary to carry out a revision. In the course of revision, the number of substances evaluated was greatly expanded. Furthermore, the data underlying the existing ecofactors were checked and brought up to date. The principal modifications are summarized as follows:

- New scientific insights and political assessments have led to a somewhat stronger weight of NOx, VOC and SO_2, and to a markedly higher weight of CO_2 as against [SRU 133]. For common combustion processes, the CO_2 rating becomes comparable to that of NOx and SO_2.
- The provision of ecofactors for heavy metal emission to the atmosphere, water and the soil, now available for the first time, makes improved assessment of many combustion, production and waste treatment processes possible.
- The immission of particles with a diameter of less than 10 micrometer (PM10) increases the risk of respiratory complaints. The provision of a suitable ecofactor allows this aspect to be taken into account.
- The calculation of ecofactors for emission of nitrate to groundwater and – for the first time – inclusion of the use of plant treatment products (pesticides), make possible an improved assessment of agricultural processes.
- The provision of an ecofactor for radioactive waste closes a further gap, especially in connection with electricity generation in nuclear power stations.

Ecofactors 1997 - Synopsis

	Current flow		Critical flow		Ecofactor 1997	Total-impact CH
	(t/a)	Q	(t/a)	Q		$(10^{12}$ UBP/a)
EMISSION TO THE ATMOSPHERE						
NO_x	136'000	A	45'000	a	**67** UBP/g NO_2	9.1
SO_2	34'300	A	25'400	a	**53** UBP/g SO_2	1.8
NMVOC	211'000	A	81'000	a	**32** UBP/g NMVOC	6.8
NH_3	70'700	A	33'400	b	**63** UBP/g NH_3	4.5
HCl	*2'360*	-	-	-	**47** UBP/g HCl	0.110
HF	*76*	-	-	-	**85** UBP/g HF	0.0065
PM10	36'000	C	18'000	a	**110** UBP/g PM10	4.0
CO_2 *	44'200'000	A	15'000'000	a	**0.20** UBP/g CO_2	9
CH_4 *	*237'000*	-		-	**4.2** UBP/g CH_4	1.0
N_2O *	*11'800*	-	-	-	**62** UBP/g N_2O	0.73
R11 equivalent *	1'470	C	850	a	**2'000** UBP/g R11 equiv.	3
Pb	226	B	280	a	**2'900** UBP/g Pb	0.66
Cd	2.5	B	4.5	a	**120'000** UBP/g Cd	0.300
Zn	630	B	1'100	a	**520** UBP/g Zn	0.33
Hg	*3.3*	B	-	-	**120'000** UBP/g Hg	0.400
EMISSION TO WATERS						
COD	115'000	B	140'000	b	**5.9** UBP/g COD	0.68
DOC	-	-	-	-	**18** UBP/g DOC	(cf. COD)
TOC	-	-	-	-	**18** UBP/g TOC	(cf. COD)
P	2'900	C	1'200	b	**2'000** UBP/g P	5.8
N total	40'000	C	24'000	a	**69** UBP/g N total	2.8
NH_4^+	-	-	-	-	**54** UBP/g NH_4^+	(cf. N total)
NO_3^-	-	-	-	-	**16** UBP/g NO_3^-	(cf. N total)
Cr	38	B	240	a	**660** UBP/g Cr	0.025
Zn	188	B	940	a	**210** UBP/g Zn	0.039
Cu	71	B	240	a	**1'200** UBP/g Cu	0.085
Cd	0.94	B	9.4	a	**11'000** UBP/g Cd	0.010
Hg	0.47	B	1.4	a	**240'000** UBP/g Hg	0.11
Pb	33	B	470	a	**150** UBP/g Pb	0.0050
Ni	42	B	470	a	**190** UBP/g Ni	0.0080
AOX	470	C	1'200	b	**330** UBP/g AOX	0.16

* further greenhouse gases and ozone depleting substances are shown in the table on page 12

	Current flow (t/a)	Q	Critical flow (t/a)	Q	Ecofactor 1997	Total-impact CH (10^{12} UBP/a)
EMISSION TO SOIL AND GROUNDWATER						
Nitrate to groundwater	150'000	B	75'000	b	**27** UBP/g NO_3^-	4.1
Pb	-	-	-	-	**2'900** UBP/g Pb	-
Cu	-	-	-	-	**1'900** UBP/g Cu	-
Cd	-	-	-	-	**120'000** UBP/g Cd	-
Zn	-	-	-	-	**520** UBP/g Zn	-
Ni	-	-	-	-	**1'900** UBP/g Ni	-
Cr	-	-	-	-	**1'300** UBP/g Cr	-
Co	-	-	-	-	**3'800** UBP/g Co	-
Hg	-	-	-	-	**120'000** UBP/g Hg	-
Th	-	-	-	-	**96'000** UBP/g Th	-
Mo	-	-	-	-	**19'000** UBP/g Mo	-
Plant treatment Products	1'800	A	1'500	b	**800** UBP/g active substance	1.4
Waste to landfill	3'030'000	C	2'430'000	a	**0.5** UBP/g waste	1.5
Waste in underground deposit	41'000	A	41'000	a	**24** UBP/g waste	1.0
	(m^3/a)		(m^3/a)			
Low to middle-active radioactive waste	1'190	C	600	a/c	**3'300** UBP/cm^3 waste	3.9
High-active radioactive waste	85	C	43	a/c	**46'000** UBP/cm^3 waste	3.9
RESOURCES						
	(TJ/a)		(TJ/a)			
Primary energy	1'027'000	A	1'012'000	a	**1.0** UBP/MJ Primary energy	1.0

Explanation of table:

The columns "current flow" and "critical flow" show the basic data used in calculating the ecofactors, together with an assessment of data quality (column Q). The quality shown for current flow reflects the accuracy of the available data and is designated by the letters A/B/C. Here, 'A' represents the highest quality. The quality shown for critical flow depends on the extent to which the underlying objectives are mandatory. It is quoted using the lower-case letters a/b/c, in which 'a' again represents the highest commitment. Where the data on current flow are set in italics – or are absent altogether – the ecofactor is derived by other means.

The "ecofactor 1997" column shows the ecofactor in environmental impact points (UBP) with respect to the relevant quantity units. The "total impact CH" column shows the product of the current flow and the ecofactor, and is a measure of the ecological relevance of the substance concerned within a Swiss context.

Ecofactors 1997 - Greenhouse gases and ozone depleting substances

The following table shows the ecofactors for further greenhouse gases and ozone depleting substances. The ecofactors are based either on global warming potential (GWP) or on ozone depletion potential (ODP), whereby in each case the dominant effect (in UBP) is used in the calculation.

Greenhouse gas or ozone depleting substance	Formula	Ecofactor 1997 in UBP/g	Basis
Chloroflourocarbons			
R 11	$CFCl_3$	**2'000**	ODP
R 12	CF_2Cl_2	**2'000**	ODP
R 13	CF_3Cl	**2'000**	ODP
R 111	C_2Cl_5F	**2'000**	ODP
R 112	$C_2Cl_4F_2$	**2'000**	ODP
R 113	$C_2Cl_3F_3$	**1'600**	ODP
R 114	$C_2Cl_2F_4$	**2'000**	ODP
R 115	C_2ClF_5	**1'200**	ODP
R 211	C_3Cl_7F	**2'000**	ODP
R 212	$C_3Cl_6F_2$	**2'000**	ODP
R 213	$C_3Cl_5F_3$	**2'000**	ODP
R 214	$C_3Cl_4F_4$	**2'000**	ODP
R 215	$C_3Cl_3F_5$	**2'000**	ODP
R 216	$C_3Cl_2F_6$	**2'000**	ODP
R 217	$C_3Cl_1F_7$	**2'000**	ODP
Fluorohydrocarbons			
R 23	CHF_3	**2'300**	GWP
R 32	CH_2F_2	**130**	GWP
R 41	CH_3F	**30**	GWP
R 43-10mee	$C_5H_2F_{10}$	**260**	GWP
R 125	C_2HF_5	**560**	GWP
R 134	$C_2H_2F_4$	**200**	GWP
R 134a	$C_2H_2F_4$	**260**	GWP
R 152a	$C_2H_4F_2$	**28**	GWP
R 143	$C_2H_3F_3$	**60**	GWP
R 143a	$C_2H_3F_3$	**760**	GWP
R 227ea	C_3HF_7	**580**	GWP
R 236fa	$C_3H_2F_6$	**1'300**	GWP
R 245ca	$C_3H_3F_5$	**110**	GWP

Greenhouse gas or ozone depleting substance	Formula	Ecofactor 1997 in UBP/g	Basis
Halogens			
Halogen 1211	CF_2BrCl	**6'000**	ODP
Halogen 1301	CF_3Br	**20'000**	ODP
Halogen 2402	$C_2F_4Br_2$	**12'000**	ODP
Perflourohydrocarbons			
Perfluoromethane	CF_4	**1'300**	GWP
Perfluoroethane	C_2F_6	**1'800**	GWP
Perfluoropropane	C_3F_8	**1'400**	GWP
Perfluorobutane	C_4F_{10}	**1'400**	GWP
Perfluorocyclobutan	$c\text{-}C_4F_8$	**1'700**	GWP
Perfluoropentane	C_5F_{12}	**1'500**	GWP
Perfluorohexane	C_6F_{14}	**1'500**	GWP
Partially halogenated chloroflourocarbons			
R 22	$CHClF_2$	**300**	GWP
R 123	$CHCl_2CF_3$	**40**	ODP
R 124	$CHFClCF_3$	**94**	GWP
R 141b	$C_2H_3Cl_2F$	**220**	ODP
R 142b	$C_2H_3ClF_2$	**360**	GWP
Further halogenated carbon compounds			
Carbon tetrachloride	CCl_4	**2'200**	ODP
Methyl bromide	CH_3Br	**1'400**	ODP
Methyl chloroform	$C_2H_3Cl_3$	**200**	ODP
Sulfur hexafluoride	SF_6	**4'800**	GWP

Total impact in Switzerland

By summing the amount of individual substances, the total load for all substances weighted here may be calculated for Switzerland. Using the 1997 ecofactors, the total load amounts to 68×10^{12} UBP '97/a. Using the ecofactors in [SRU 133], the total Swiss impact amounts to 49×10^{12} UBP '90/a. The increase is a result of including additional weighting factors and should not be interpreted as an increase in total environmental impact. In recalculating existing ecobalances based on the new ecofactors, higher UBP values can occur as a result of modified ecofactors and/or owing to inclusion of substances not previously weighted. Here too, an altered UBP value is not necessarily indicative of changed environmental impact.

There is a considerable shift with respect to the media affected. Whereas with the ecofactors in [SRU 133] the emissions to the atmosphere accounted for 85% of total Swiss impact, using those of 1997 the relative impact on soil and water is considerably increased at the expense of the atmospheric impact (cf. Table 1).

Environment sector	1990 [%]	1997 [%]
Atmosphere	85	61
Water	9	14
Soil	4	23
Energy	2	2
Total	**100**	**100**

Table 1:   Relative magnitude of total Swiss UBP-loads in the various environmental sectors weighted according to the 1990 and 1997 ecofactors.

1. Starting point

The evaluation method for ecofactors based on the principle of ecoscarcity developed by Ahbe, Braunschweig and Müller-Wenk was published by SAEFL in the Environment Series [SRU 133] in 1990. The method is based on the relative magnitude of the current and target (critical) flows of a substance. The target flows were determined whenever possible on the basis of legally or politically stipulated threshold values of Swiss environmental policy. The higher the current flow of a substance compared to the target value, the more significant its environmental impact. Correspondingly, the ecofactor increases.

New scientific knowledge gained over the past few years now allows more precise determination of the critical flows. As a result of environmental policy measures, current flows of various substances have diminished. Further, practical experience with the method has pointed to inadequacies in the selection of substances evaluated.

The Swiss Association for Ecologically Conscious Management ÖBU, in co-operation with interested member companies and SAEFL, has decided to revise the method and adapt it to the current situation. In revising the method, the ecofactors in [SRU 133] were brought up to date and new ecofactors for further substances were introduced.

2. Methodological basis

2.1. Terminology

The method applied in the present report is known under several terms, i.e. "ecoscarcity method ", "SAEFL method 133", "material flow method", "ecopoint method", "UBP method", and others. In the present publication, the term **"ecoscarcity method"** is used.

The applications of this method are in german called "Ökobilanz". This term encompasses both the Life Cycle Assessment of products LCA and the assessment of a company, a plant or a single process (company ecobalance etc.). In this publication, the term Ecobalance is used for all those application types.

Widely used Life Cycle Inventories have been published in Switzerland as "Ecoinventories" ("Ökoinventare"). The terms ecoinventory and inventory are therefore used as synonimous.

2.2. Positioning of the method in an ecobalance

In preparing an ecobalance of products, processes or complete organizations (factory, company, etc.), the ecoscarcity method allows for weighting of the environmental effects.

The input data required for the method are provided in an inventory. The result of weighting the inventory data is expressed in units of "environmental impact points (UBP)". As for all the stages in an ecobalance, the result obtained requires interpretation, after which it may be used as a basis for decision making.

According to current SETAC and ISO discussions, a product ecobalance (LCA) should consist of the following stages:

- Goal and scope definition

- Inventory analysis

- Impact assessment and possibly weighting

- Interpretation of all elements of the ecobalance

- followed by the application of the results

The present ecoscarcity method provides for weighting as part of the impact assessment. The phases shown above were developed for preparing product ecobalances. However, the same procedure may also be adopted in the ecological assessment of processes,

factories or whole companies. Thus the company ecobalance – also referred to as an "operational environmental balance" [BMU/UBA 1997] – represents a widely used instrument in environmental management.

2.3.   The ecoscarcity method

2.3.1. The basic principle

The ecoscarcity method is a "distance to target" method [SETAC 1996, p. 79]. The method provides standardized generic weights.

The assessment procedure is based on national or international environment protection objectives. Such objectives are:

- legally enacted or, at least, defined as an objective by the authorities concerned,

- formulated by a democratically elected or legitimated body, and

- directed as far as possible towards sustainability.

In the present method, weighting is applied in accordance with the objectives of Swiss environmental policy. Global or local impact categories are adapted to Swiss levels in determining the target values. However, the method is also applicable to other geographical regions, ecofactors existing in Holland, Norway, Sweden [Nordic 1995, Tab. A22/A23] and Belgium [SGP 1994].

The method is applicable to **optimization within the framework of environmental policy objectives.** Thereby, the assumption is made that emission limits are adhered to.

In common with all ecobalance assessment methods, the method weights **damage potential** – i.e. no actual damage is cited. In determining the ecofactors and applying weighting, not only the target values but also the current load is considered.

The purpose of the method is to express the various environmental impacts in terms of points, making the resulting scores comparable, and enabling them to be summed and compared. In a formal sense, the weighting is similar to a cost-benefit analysis in which the weights are determined both from the current environmental situation and from that envisaged by environmental policy, together with a computation algorithm.

2.3.2. Ecoscarcity and calculation of ecofactors

The ecoscarcity method weights the environmental impacts on the basis of their **"ecoscarcity".** For one, the method uses the total current flow of an environmental

impact, and secondly the maximum permissible flow of the same environmental impact, based on political objectives.

The evaluation is based on so called "ecofactors" for each environmental impact. The ecofactor is a measure of the potential ecological harmfulness of an impact, and is defined for each separate environmental impact as follows:

$$\text{Ecofactor} = 1 \text{ UBP} / F_k * F / F_k * c \qquad (1)$$

where: UBP = Environmental impact point

     F   =   Current annual flow of environmental impact (current flow over time; units frequently used: t/a)

     F_k =   Critical emission per year (critical flow over time; same units as F)

     c   = 10^{12}/a

The formula was taken from [SRU 133]. The first term weights the emission according to its critical flow (i.e. how important is the emission concerned relative to the critical flow?). The second term weights according to the relationship between current total flow and critical flow (i.e. how important are the total emissions relative to the critical emissions?). The factor c is identical for all ecofactors and is applied to provide better manageability of the figures. It represents a practical order of magnitude and is expressed as a function of time to neutralize the time unit resulting from the preceding terms.

To obtain the above formula, the time dimension was added to the formula given in [SRU 133]. Normally, the data for current and critical flows are quoted on a yearly basis. When other time periods are used for F and Fk, the loads are converted to yearly units. The unit for the ecofactor is "UBP per environmental impact unit", for example 2'000 UBP per gram CFC-11.

The **algorithm** first normalizes with respect to critical flow, and then weights according to the ratio of current and critical flow. In international practice, normalization is often performed based on current flow. The latter representation can be obtained by transforming the above formula for the ecofactor as follows:

$$\text{Ecofactor} = 1 / F_k * F / F_k * c \qquad (1; \text{ original formula})$$

$$= 1 / F * F / F_k * F / F_k * c \qquad (1a)$$

$$= 1 / F * (F / F_k)^2 * c \qquad (1b)$$

In (1b), normalization is performed using the current flow and then weighted as a function of the relationship between F and Fk. The exponent of the second term (1b) may be considered an independent variable, in this case having the value 2. In the case of the

Eco-indicator '95 [Goedkoop 1995], this exponent takes the value 1, so that in multiplying the two terms, the current flow disappears[1].

In the following chapters, values of F and Fk are given for each separate environmental impact.

2.3.3. What safeguard subjects are the ecofactors based on?

Explicit reference to protection objectives ("safeguard subjects") is a new development (cf. e.g. [Müller-Wenk 1997]). The present method is based on the safeguard subjects of the Federal Constitution, which states in Cl. 24 septies (Environmental Protection), that: "the Federation issues regulations on the protection of man and his natural environment against harmful and disruptive influences. (…)". Further safeguard subjects quoted in the Federal Constitution (Cl. 24, sexties Protection of the Natural and Cultural Heritage) are the animal and plant communities and moors, as well as (Cl. 24) water resources and waters. The following provisions tend in the same general direction: Cl. 22 quater of the Federal Constitution on appropriate use of the soil, and Cl. 24 octies concerning, among other things, environmentally compatible energy supply. [2]

Based on the environmental protection clause (Cl. 24 septies) in the Federal Constitution, the declaration of purpose of the Federal Environmental Protection Law requires that " …man, animals, plants, and their communities and habitats, [be] protected against harmful and disruptive influences, and the fertility of the soil preserved" (USG, Cl. 1). This formulation clearly illustrates the fact that human health and sustainability of ecosystems (ecosystem 'health' or quality) are central to Swiss environmental policy. Resource conservation is only briefly touched on. Relative weighting of the safeguard subjects is performed when quantifying the target values. The method of ecoscarcity presently contains no further weighting of safeguard subjects and objectives. Reasoning for the choice of safeguard subjects is to be found in the considerations underlying the respective laws and ordinances, and can be considered only briefly here.

2.3.4. Validity of ecofactors in space and time

The ecofactors given in the present publication are based on current flows and with regard to the objectives of Swiss environmental policy. The Swiss objectives are partly derived from global environmental policies (greenhouse gases, ozone depleting substances), and partly from specific Swiss situations (e.g. for phosphorus and heavy metals).

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[1]   A brief systematic discussion of possible methods may be found for example in [Tukker 1994] and [Müller-Wenk 1994].

[2]   During translation of this text into English, voters adopted the restructured Swiss Constitution, which still contains the same objectives.

Ecoinventories for product systems, however, mostly contain figures for globally distributed emissions and resource consumptions. In applying the ecofactors, it must be considered that each emission is weighted as if it had occurred in Switzerland. Stated in positive terms: in transferring the process to another country, the ecobalance remains unchanged if the emissions are held constant. This may be questioned, since the situation, e.g. at Lake Baikal, in the Australian Outback or in Brig are quite very different. As recommended in ISO 14043, this aspect should be given due attention in interpreting the results. Theoretically, a regionally adapted assessment of the various processes is possible. For this, however, a correspondingly large number of additional national weighting schemes would have to be defined.

In a product ecobalance, it is normally extremely time consuming to consider the **local conditions** applying in each particular case – i.e. excessive impacts or particularly unproblematic situations – owing to a lack of data on local environmental conditions. In interpreting the results of an ecobalance for a particular location, special attention must be paid to the local conditions pertaining. Thus with this weighting method, no account is taken of specific local impacts (for example, effluent discharge to a small stream). For this reason, **the present weighting method presupposes that the relevant emission limits are adhered to.**

Furthermore, attention must be paid to the validity of the ecofactors in time. Although the ecofactors do mirror current environmental objectives, a certain time delay is always incurred in "translating" an environmental problem into political targets. The ecofactors therefore seldom reflect the most recent scientific status regarding the target values. Moreover, the current flows represent at best no more than extrapolated 'historic' values. It is thus essential for the ecofactors to be updated at regular intervals in the future. However, there is no necessity for "on-line" updating, e.g. via internet; on the contrary, a daily "ecofactor exchange" would – far from providing greater precision – only lead to confusion.

The provision of ecofactors for anticipated future environmental situations could, however, be considered. In calculating ecofactors for **future** situations, consistently structured scenarios or trends showing the effective (and possibly critical) material flows over, e.g., the next ten years would have to be defined. Future-based ecofactors could be used to supplement a sensitivity analysis by providing ecological weighting of products or projects intended for later realization.

2.4. Principles for determination of 1997 ecofactors

Selection of interventions

Only environmental interventions with generally high relevance to ecology are weighted here. Measurement takes place at the point of transition between nature and the

antroposphere. Concerning selection of the interventions covered, see Figure 1.
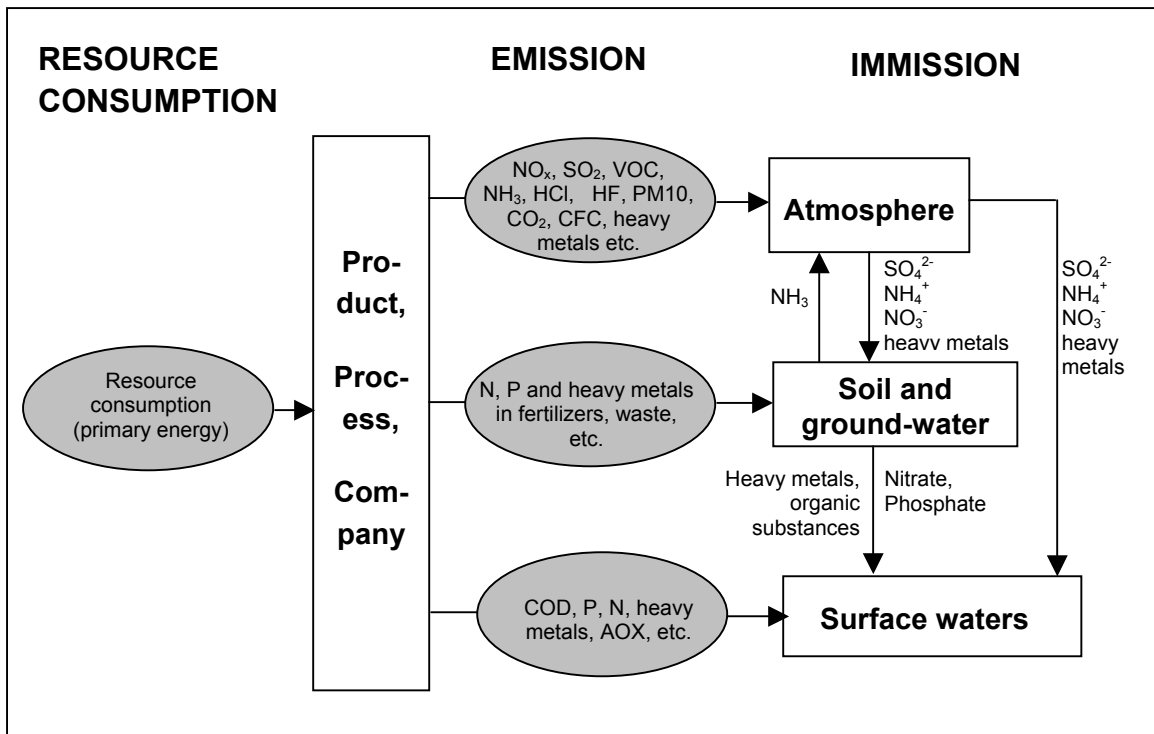
Figure 1:   System boundaries: The environmental impacts quantified by ecofactors are shaded gray.

Determination of critical flows

The critical flows are generally based on scientifically founded political objectives. Principally, these are legally specified protection objectives (immission limits). In cases where, despite the need for action, no legislative or political targets have been specified, or where existing targets are clearly based on short-term practicability and are not oriented towards long-term ecological objectives, scientifically founded targets prepared at expert level are adopted. The sources for determination of the critical flows are shown in Tab. 2.

The ecofactors, therefore, reflect the political and legal assessment concerning the ecological relevance of various pollutants. Thus, for example, the emission of a particular heavy metal to the atmosphere, to soil and to water, is assessed using three separate ecofactors calculated (ideally) from the respective current and critical flows. From this, different ecofactors may result for emission of a pollutant to the atmosphere, water or soil. These differences are the result of the methodology used and mirror the differing legal requirements and current flows. They are not always ecologically justifyable.

	Substance	Sources
Calculation or derivation based on immission targets and/or political declarations of intent	Heavy metals in waters	Water Protection Ordinance, draft revision
	Pb, Cd, Zn in the atmosphere	Clean Air Ordinance
	PM10	Clean Air Ordinance, revised 1.3.1998
	NO_x, NMVOC	Clean Air Ordinance (Immission limit for ozone)
	SO_2	UN/ECE Sulfur Protocol
	N in waters	Declaration of Intent of North-Sea Border States
	CO_2 and other greenhouse gases	Climate Convention 1992, Report of the Federal Council on CO_2 law
	Ozone depleting substances	Ordinance on Substances
	Deposition of waste	Technical Ordinance on Waste (TVA)
	Primary energy	Energy 2000 target
Expert recommendation / expert estimate of maximum tolerable flows	NH_3 in the atmosphere, nitrate in groundwater, phosphorus, COD	Strategy for reduction of nitrogen emission [SRU 273] and scientific reports of the project group
	AOX	Quality objective of IAWR
	Plant treatment products	Report on evaluation of the agricultural reform [BLW 1996]
Hypothetical model, advisory group	Radioactive waste	Moratorium / final storage capacity

Table 2:   Sources for determination of critical flows (cf. detailed discussion in Chaps. 3 to 5)

The calculation of ecofactors is based on national objectives. In preparing ecobalances for products, processes and companies, it is often necessary to include processes abroad. In the ecoscarcity method, these are evaluated using the same "Swiss" ecofactors as for Swiss processes.

As a consequence of adopting national goals, local aspects cannot always be adequately accounted for. For example, discharge of phosphorus to a lake in the Swiss Midlands (for example) would require a different assessment than a discharge to the Rhine at Basel. In practice, regional differentiation is not possible within the framework of the ecoscarcity method. The method does, however, assume that the local emission regulations are adhered to.

Classification and characterization

The method uses an impact assessment based on classification and characterization as a supporting measure where a "main effect" is used in the setting of the critical flow and where different interventions with the same effect occur. This is the case with the greenhouse effect, for ozone layer depletion, and for acidification due to certain substances. Adoption of the CML classification scheme [Hejungs et al. 1992] within this method involves the implicit assumption that in determining the critical flow F_k, not only the specific substance (e.g. CO_2) but also the totality of substances with the same effect was considered. It is therefore not permissible to reverse the procedure and determine a critical flow from an ecofactor derived via classification. Use of the classification approach represents a methodical extension of the ecoscarcity principle. It may be objected that the extension is only partial. Note, however, that the original objective was to use classification as a supplementary tool only in cases where a particular substance is dominant within the impact category and has no other significant effect, or where objectives are defined for the category as a whole.

Where a specific target has been defined for an intervention that leads to several different impacts, use of classification is excluded (e.g. for nitrogen emission to soil and water). In this case it is assumed that the maximum permissible emission covers the remaining effects, or is based on the most sensitive effect.

Sum parameters

Sum parameters containing groups of substances (e.g. NMVOC) are only employed when the ecological effect of the individual substances is similar, and when the effort required to monitor the entire range of substances would be exorbitant. By this means it is possible to approximately satisfy the principle of comprehensiveness.

Natural background immission level

Whenever possible, only the anthropogenic portion of total flow is adopted under exclusion of the natural background flow (example: total nitrogen in groundwater).

2.5. Data quality

The information given on data quality refers to basic data. For current flows, the precision of available data is assessed. The critical flows are assigned quality categories according to the extent to which the legislative or political objectives are mandatory.

The quality and mandatory nature of the data presented in the body of the report are characterized as follows:

Quality indicator	Imprecision of current flow
A	<20%
B	20 to 40%
C	>40%

Mandatory indicator	Determination of critical flow
a	Calculation or determination via immission objectives and/or political declarations of intent
b	Expert recommendation/ expert estimate
c	Model assumption of support group

Table 3:   Indicators of data quality and mandatory nature

2.6. Discussion of the method

2.6.1. Fundamentals

The present method largely satisfies the general requirements for assessment methods set out in [SETAC 1996, p. 87 and 88]. The subjectivity of the weighting results from the choice of environmental objectives. For weighting each impact category, the determination of the target values with which to compare the current flows is of major importance.

Fundamentally – and despite the fact that ecofactors currently are not available for all impacts – this method is applicable to **all** contemporary **environmental problems**. The method is also amenable to the inclusion of new environmental problems, by calculating an ecofactor for the new category. A drawback of this flexibility is the lack of a unique definition as to which substances and environmental problems should be assigned an ecofactor.

The method includes the **harmfulness** of environmental influences to the extent that these are covered by environmental policy decisions. It is relatively transparent in respect of the weighting criteria applied, although here the provisions contained in laws and ordinances, and in the explanatory notes concerned, must be consulted. The **non-reversibility** of harmful effects and the **uncertain nature** of the disruptive process will usually have been considered implicitly or explicitly in defining the target values (F_k). This is clearly illustrated by the case of CO_2 and the greenhouse gases. Here, the potential damages and low reversibility of the harmful processes, and not least the disruption anticipated (all of which are widely recognized internationally), have already led to strong reduction targets.

It is not always clear to what degree the legislature has consciously **harmonized** the various targets. However, from the standpoint of the economic players, this is of only subsidiary importance as long as the relevant regulations continue to exist. In setting future environmental targets, the commissions responsible might nevertheless wish to consider providing a comparative revue of this theme.

The method is not sensitive in respect of the chosen **units**. Thus, for example, it is of no consequence whether NO_2 is considered in terms of N or NO_2, provided the inventories and ecofactors are well matched.

The method permits only tentative handling of **uncertainties.** As an approximate guide, the current and critical flows are assigned a quality (precision) indicator.

In calculating ecofactors, a problem arises if the **critical flows** are, or may become, **very small**. Small values of F_k result in very large ecofactors. Uncertainties in determining F_k have an increasing effect on the ecofactor with decreasing F_k, and therefore a large potential effect on the ecobalance. The proposal has been voiced to exclude substances with small quantity flows from the weighting procedure. But although emission of CO_2 in Switzerland is measured in megatons, SO_2 in kilotons and CFC in tons, this can certainly not be taken to mean that – for example – cadmium (which is measured in kilograms) should be excluded from the weighting. Moreover, by no means all environmental impacts are quantified in terms of mass flows. Energy, for example, is measured in J (joule), radioactive waste in m^3, and in future land use may be again measured in m^2 and traffic noise in dB(A) or km. It is therefore not possible to define a cut-off criterion for "small flows" that would permit a valid comparison. In applying the method to substances with comparatively low critical flows, it should however be ascertained whether making a small change in F_k would decisively affect the result of the ecobalance. In practice, this is seldom the case.

The method assumes that the ecofactor increases in proportion to the relationship between the current flow and the target value. The relationship is assumed to be linear and continuous, i.e. inversion effects are not considered.

As in the first version of this method [SRU 133], the **list of weightable environmental interventions** in the present report **is restricted**. Generally speaking, the calculation of ecofactors is often no simple matter for those substances which have not been included (e.g. emission of silver to waters), as by no means all substances have been assigned target values under Swiss environmental policy. It has nevertheless been possible to add new areas, e.g. heavy metals, AOX, agricultural emission, and the various greenhouse gases and ozone depleting substances, in the course of the present revision.

2.6.2. The ecoscarcity method in the light of the international debate within ISO and SETAC

The requirements of ISO 14040 for product ecobalances and for impact assessment methods are specified in very general terms in [ISO 14040, §5.3], and are fulfilled not only by the ecoscarcity method, but also by any properly documented, coherent method. The detailed requirements and their implementation are later to be included in the standard dealing specifically with impact assessment [ISO 14042][3]. Importance will be attached in ISO 14040 ff to the interpretation of the individual results, and this will also be applicable to the present method.

The current status of the debate within SETAC allows more detailed consideration. In [SETAC 1996, p. 19], impact categories that must normally be included in an impact assessment are specified. The list has evolved gradually over the years (cf. e.g. [SETAC 1993a, p. 21] and [SETAC 1993b, p. 27]). The list is of course neither definitive nor complete, nor is there any methodical justification for inclusion of just these particular impact categories. It would, however, seem appropriate to consider which of the listed impact categories are presently covered by the ecoscarcity method in its present form (Switzerland 1997):

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[3] cf. draft version of ISO-CD 14042.1 in its present form

"Standard" impact category	Treatment of category in the present method:
Input category:	
1. Abiotic resources	contains energy aspects. Other resources not contained
2. Biotic resources	not currently contained (inclusion would be possible)
3. Land use and land consumption	not currently contained (inclusion possible – attempts in this direction described in the literature)
Output category:	
Greenhouse effect (GWP)	contained
Ozone depletion potential (ODP)	contained
Effects toxic to man	partly contained
Ecotoxic effects	partly contained
Photosmog (POCP)	largely contained (unified treatment of NMVOC)
Acidification	contained
Eutrophication	contained (excluding heat)
Odors	not contained
Noise	not currently contained (inclusion possible - attempts in this direction described in the literature)
Radiation	Emission of radiation not currently included – radioactive waste does, however, contain this aspect
Direct victims	not considered as being the subject of an ecobalance

Table 4:   Impact categories in [SETAC 1996, p. 19] and the extent to which they are treated in the present work

In the present revision, not all of the methodical proposals, e.g. contained in [Braunschweig/ Müller-Wenk 1993] for (transport) **noise** and **land utilization**, have been adopted. This omission should not be taken to mean that these categories are regarded as unimportant – on the contrary, their inclusion continues to be regarded as desirable. The methodical procedures were, however, judged to be insufficiently mature.

2.6.3. Application

The method represents a **generally applicable procedure.** It is suitable for the assessment, improvement and comparison of:

- industrial products (products of all current materials, including packagings) and processes

- services (e.g. logistics planning)

- companies/corporations (particularly in Switzerland)

The method can be applied without modification to systems in which the material flows are small in comparison to total Swiss flows. In preparing ecobalances for very large projects (e.g. the new trans-Alpine railway routes), the current flows are greatly modified as a result of the projects, so that the ecofactors may have to be recalculated in accordance with the project impacts.

The method is also applicable to most common functional units extending from packagings and logistics procedures, transport systems, food processing, textiles, furniture, and vehicles, right through to buildings.

The method should not be applied to processes and products having major effects that have not been considered, as for example land use, direct radiation and utilization of biotic resources. Examples of unsuitable cases are evaluation of a genetically modified agricultural system, comparison of fossil, atomic and hydroelectricity production, and comparison of fish "production" in breeding stations versus the sea. The method is also unsuitable for the evaluation of processes whose environmental effects are insufficiently discriminated by the method, e.g. for comparison of two chemical production processes emitting different quantities of aromatic VOC substances. The method is, however, suitable for evaluating a flue gas treatment process in which afterburning with its increased energy consumption (and pollutant emission) over a process without afterburning and concomitant VOC emission are to be compared.

The present method is applied subsequent to a completed **inventory.** The choice of ecofactors is well suited to the usual inventories (e.g. those for energy systems and packaging materials). Problems still exist in connection with suspended particles (i.e. PM10, which is usually not measurable, but included as an undefined part of "particles"), radioactive emission and waste, as well as with land use and noise not considered here. The most important environmental effects are mostly assessable, and those that are not are often of minor importance.

A particular problem to which, till now, scant attention has been paid is the correct coupling of inventory data to weighting factors. The new and very comprehensive inventories containing over 100 different entities present a particular problem of implementation.[4]

A result, i.e. a weighted inventory, is to be **interpreted** as follows:

- **Dominance analysis:** The key point for most users is to know from which processes and life cycle phases the major impacts arise. Further, they need to know what proportion of the total impact is attributable to each individual environmental influence.

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[4] Comment added to the english translation: A matching list between the three widely used Eco-inventories for energy, packaging and transport systems has been published as publication nbr. 16/1998 by ÖBU Switzerland, oebuinfo@oebu.ch, www.oebu.ch

- Note that in evaluating alternatives, and owing to the uncertainty in the inventory data, a marked difference in results (over 20% – or better, 50%) is required to clearly demonstrate **superiority.**

- The interpretation also includes a **sensitivity analysis** covering each step of the study. Therefore, also the ecofactors must be critically reviewed (despite the fact that, as experience shows, the assumptions made in defining the system boundaries of the study and in preparing the inventory usually have a much greater influence on a particular overall result).

3. Emissions into the atmosphere

3.1. Introduction

3.1.1. Choice of substances

In the SAEFL report entitled "Anthropogenic Emission of Atmospheric Pollutants in Switzerland from 1900 to 2100 " [SRU 256], the emission of 17 pollutants is quantified. The pollutants are assigned to the following four source groups: transport, industry and crafts, agriculture and forestry, and households. The choice of pollutants was made according to their ecological relevance in an overall Swiss context. High local loads cannot be assessed by the method. The following discussion of ecofactors for pollutants is based on this choice of substances. In addition, ecofactors are proposed for greenhouse gases and ozone depleting substances.

3.1.2. Data sources

The main source of data for the determination of current flows is the report on emission of atmospheric pollutants [SRU 256] mentioned above. This report was also used to modify slightly the quantitative targets of the Clean Air Concept, as the calculations for the years 1950 and 1960 resulted in somewhat different values than previously assumed. Data on current flows of greenhouse gases were taken from the "Swiss Greenhouse Gas Inventory 1995" [UN 1997].

3.2. Nitrogen oxide NO_x

3.2.1. Ecological impact

Emission of nitrogen oxides has a detrimental effect on plants and sensitive ecosystems, and may result in respiratory diseases. Nitrogen oxides also represent a principal intermediate substance in the formation of ozone. The formation of ozone is in Switzerland limited by nitrogen oxide alone. Further, following their deposition, nitrogen oxides lead to excessive nutrification of ecosystems and to acidification of the soil.

3.2.2. Current flow

NO_X emission in Switzerland rose between 1950 and 1985 from 31'300 t to 179'000 t per year. Since 1985, emission has declined. The value for 1995 was 136'000 t, and a further decline to 110'000 t is anticipated for the year 2005 [SRU 256, p. 72]. The uncertainty in this data amounts to approx. ±15-20% [SRU 256, p. 53].

3.2.3. Critical flow

In the Federal Clean Air Ordinance, limiting immission values are specified for nitrogen dioxide (NO_2) and for ozone (O_3). These were determined in such a way that, when adhered to, man, animals and plants, as well as their communities and habitats, are not endangered. At present, the limiting values for nitrogen dioxide are often exceeded by a considerable margin in city centers, whereas in country areas they are generally satisfied. The limiting immission values for ozone are exceeded mainly in country areas and frequently, too, in the conurbations [SRU 286, p. 20].

Compliance with the limiting immission values therefore requires significant emission reduction. The report of the Federal Commission on Air Hygiene [SRU 101, p. 247] states that a reduction in NO_x emission of at least 75% below the maximum in the 1980's would be necessary to reduce the maximum hourly average value of O_3 to the permissible level. To satisfy the limiting immission value for ozone, NO_X emission would have to be reduced to 45'000 t/a. This latter value has been taken as the critical flow for NO_x. The reduction would also enable the limiting immission value for NO_2 to be satisfied, and a contribution to be made to the reduction of nitrogen and acids immission to sensitive ecosystems.

As a first step, a minimum objective was specified in 1986 in the Federal Clean Air Concept to reduce NO_X emission to the 1960 level [Clean Air Concept 1986]. This amounts to a value of 64'000 t/a [SRU 256, p. 72]. The declaration adopted on 23 August 1993 in Graz by the German, Liechtenstein, Swiss and Austrian ministers responsible for environmental questions goes considerably beyond this and demands a diminuition of NO_x emission of 70% to 80% below the 1980 level [Graz 1993, p.2]. This results in an emission target of 45'000 t/a [SRU 272, p. 33], which corresponds to the critical value derived in the previous paragraph.

3.2.4. Ecofactor for NO$_X$

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t NO$_X$/a]	**136'000**	A	Source: SRU 256	191'000
Critical flow [t NO$_X$/a]	**45'000**	a	Adherence to limiting immission values for ozone [SRU 101, p. 247]	67'200
Ecofactor [UBP/g NO$_X$]	**67**		NO$_X$ measured in the form of NO$_2$	42.3

Table 5:   *Ecofactor for nitrogen oxide in UBP/g NO$_X$ (measured as NO$_2$, Q = data quality, see remarks in Chap. 2.5)*

Taken together, the reduction of the current flow and application of a reduced critical flow have resulted in a heavier weighting of nitrogen oxides compared to [SRU 133]. Had there been no emission reduction since 1990, the ecofactor for 1997 would have exceeded 90 UBP/g NO$_x$.

3.3.   Sulfur dioxide SO$_2$

3.3.1. Ecological impact

At elevated concentrations, sulfur dioxide causes disease to the respiratory tract, damage to plants and sensitive ecosystems, and damage to buildings. Sulfur dioxide is an important intermediate substance in the formation of acid rain and aerosols.

3.3.2. Current flow

SO$_2$ emission in Switzerland rose between 1950 and 1980 from 46'200 to 116'000 t per year. Since 1980, emission has declined. In 1995 it amounted to 34'300 t, and by the year 2005, a further reduction to 29'500 t is anticipated [SRU 256, p. 70]. The uncertainty in this data is approx. ±10% [SRU 256, p. 53], since the SO$_2$ emission can be calculated directly from the various motor and heating fuels.

3.3.3. Critical flow

The Clean Air Ordinance contains limiting immission values for sulfur dioxide. In general, these are satisfied both in urban and country areas. The reduction of SO$_2$ emission to the 1950 level [Clean Air Concept 1986], i.e. 46'200 t/a [SRU 256, p. 70], has been achieved.

The contribution of SO$_2$ to the acidification of ecosystems is defined in the UN/ECE Sulfur Protocol (United Nations / Economic Commission for Europe). The Swiss parliament

ratified the second Sulfur Protocol in autumn 1997. In Clause 2 of the latter, reduction below the critical loads, i.e. the critical emission for sulfur, is defined as a long-term objective [UN/ECE 1994].

Within the framework of negotiations on the Sulfur Protocols, the critical flows of SO_2 were defined for all European countries via critical deposition quantities. The critical deposition quantities (critical loads) for sulfur were calculated on the basis of the long-term tolerance of sensitive ecosystems to acid deposition.

The maximum critical emission quantities necessary to reduce impact below critical immission levels (critical loads) over the whole of Europe, calculated for each country on the basis of mathematical models, are documented in [IIASA 1991, p. 17]. For Switzerland, a critical flow of 25'400 t was computed, corresponding to a reduction of 78% below the 1980 level. Provided the reductions in all other countries proceed in an optimum fashion, this is sufficient to achieve comprehensive protection of all European ecosystems. This value can therefore be taken as the critical flow.

3.3.4. Ecofactor for SO_2

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t SO_2/a]	**34'300**	A	Source: SRU 256	68'000
Critical flow [t SO_2/a]	**25'400**	a	Long-term objective of second Sulfur Protocol (reduction below critical loads for acid immission)	54'400
Ecofactor [UBP/g SO_2]	**53**			23.0

Table 6:   Ecofactor for sulfur dioxide in UBP/g SO_2 (Q = data quality, see remarks in Chap.2.5).

The resulting ecofactor for SO_2 exceeds that in [SRU 133]. The calculation of the "old" ecofactor was based on the objective in the Clean Air Concept, which was primarily designed for human protection. In recent years, cross-boundary co-operation has led to political efforts to protect ecosystems from acidification. This can only be achieved by a marked additional reduction in the emission level. Had there been no reduction of emission since 1990, the ecofactor in 1997 would have exceeded 100 UBP/g SO_2.

3.4.   Volatile organic compounds

3.4.1. Ecological impact

Volatile organic compounds (NMVOC = non-methane volatile organic compounds) comprise a group of substances having different ecological effects. The spectrum extends

from non-toxic to highly toxic carcinogenic compounds[3]. Together with nitrogen oxides, NMVOC represent significant intermediate substances in the formation of photooxidants (tropospheric ozone/summer smog).

3.4.2. Current flow

The emission of volatile organic compounds (NMVOC emission) in Switzerland rose between 1950 and 1985 from 70'000 to 324'000 t per year. Since 1985, emission has declined, and amounted to 211'000 t in 1995. By the year 2005, a further decline to 170'000 t is anticipated [SRU 256, p. 74].

3.4.3. Critical flow

Limiting immission values for ozone (O_3) are stipulated in the Federal Clean Air Ordinance. At present, particularly in conurbations and in country areas, these are frequently exceeded [SRU 286, p. 20].

In order to satisfy limiting immission values, marked emission reductions are therefore essential. As shown in [SRU 101, p. 247], a reduction of the NMVOC emission by at least 75% below the maximum for the 1980's would be necessary to reduce the maximum permissible hourly average for O_3 to within the limiting value. The resulting critical flow for NMVOC is 81'000 t/a.

The minimum objective for NMVOC is contained in the Clean Air Concept, i.e. reduction to the level of 1960 (145'000 t/a [Clean Air Concept 1986], [SRU 256, p. 75]). Further, the German, Liechtenstein, Swiss and Austrian ministers responsible for environmental questions adopted a declaration on 23 August 1993 in Graz to reduce NMVOC emission by between 70% and 80% below the 1980 level [Graz 1993, p. 2]. This results in a maximum emission value of 64'800 to 97'200 t/a [SRU 272, p. 33]. The average of these two target values corresponds to the critical flow derived above.

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[3]   Owing to their physical and chemical properties, methane and chloroflorocarbons (CFC) belong to the group of volatile organic compounds, too. However, owing to their different ecological relevance, these substances are treated separately (cf. chapter on greenhouse gases and ozone depleting substances).

3.4.4. Ecofactor for NMVOC

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t NMVOC/a]	**211'000**	A	Source: SRU 256	308'000
Critical flow [t NMVOC/a]	**81'000**	a	Fulfillment of limiting immission value for ozone according to [SRU 101, p. 247]	146'900
Ecofactor [UBP/g NMVOC]	**32**			14.3

Table 7:   Ecofactor for volatile organic compounds (excluding methane and CFC) in UBP/g NMVOC (Q= data quality – see remarks in Chap.2.5)

NMVOC comprise numerous different organic substances of varying toxicity. The relevant effect for calculating the ecofactor is solely their propensity to form ozone proximate to the ground. The specific toxic effects of each compound are not considered.

The diminution in the current flow and the application of a lower critical flow have, taken together, led to a heavier weighting of NMVOC as against [SRU 133]. Had emission since 1990 not declined, the ecofactor for 1997 would have amounted to almost 50 UBP/g VOC.

3.5.   Ammonia

3.5.1. Ecological impact

Ammonia emission, partly by way of transformation, and following deposition, is a contributing factor in the acidification and excessive nitrogen nutrification of ecosystems, and is thus detrimental to species diversity. Additionally, ammonia facilitates the formation of sulfuric acid from sulfur dioxide in the air [SRU 273, p. 21]. Decisive for the deposition effect is the total nitrogen, i.e. the sum of N contained in nitrogen oxide, ammonia and their reaction products.

3.5.2. Current flow

Ammonia emission increased slowly from the beginning of the century to reach a maximum in 1980. From that point on, emission declined, and in 1995 amounted to 70'700 t NH_3/a [FAL/FAT 1996, p. 13][4]. Further reductions are expected up to the year 2005.

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4   The SAEFL report on antropogenic atmospheric pollutant emission in Switzerland quotes a value of 60'000 t for 1995 [SRU 256, p. 79]. In [SRU 273, p. 29], the emission in 1994 is estimated at 67'000 t. In the report of the agricultural research institutes cited, total Swiss ammonia emission from agricultural and non-agricultural sources is recalculated based on a detailed quantity matrix.

3.5.3. Critical flow

There are no specific targets for limitation of total Swiss ammonia flows. [SRU 273, p. 34] does, however, require that from an ecological standpoint the average total deposition of nitrogen compounds should be reduced in the long-term to 10 kg N/(ha*a).

Based on the deposition targets for total nitrogen and for nitrogen oxides, and in view of the import-export balances of the various N compounds, an ecologically justifiable objective for ammonia emission of between 25'000 and 30'000 t N (in NH_3) is derived [SRU 273, p. 34].

In calculating the ecofactor below, a critical flow of 27'500 t N (in NH_3) (corresponding to 33'400 t NH_3) is therefore assumed. In comparison to the present value, this amounts to a reduction of somewhat more than half.

3.5.4. Ecofactor for NH$_3$

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t NH$_3$]	**70'700**	A	Source: FAL/FAT 1996, p. 13	-
Critical flow [t NH$_3$]	**33'400**	b	Estimated from F_k for NO_X and from ecological objective based on total N deposition [SRU 273, p. 34]	-
Ecofactor [UBP/g NH$_3$]	**63**			-

Table 8:   Ecofactor for ammonia in UBP/g NH$_3$ (Q = data quality, see remarks in Chap. 2.5)

The ecofactor for ammonia is included in the list of ecofactors for the first time. No limiting emission values exist for ammonia. By deriving the critical flow from the deposition target for total nitrogen and from the critical flow for nitrogen oxides, a consistent weighting of the various sources of N emission to the atmosphere is achieved.

3.6. Hydrogen chloride and hydrogen fluoride (HCl and HF)

3.6.1. Ecological impact

Hydrogen chloride and hydrogen fluoride cause disease to plants and contribute to excessive acidity in the soil [SRU 256, p. 28].

It can be assumed that HCl and HF emission and the problems consequent thereon will continue to decline in the future. Note however that the expected relocation of aluminum production will result not in avoidance but only in diversion of HF emission. For this reason, and to permit comparison with previous ecobalances, the ecofactor for HCl has been retained, while a new factor has been introduced for HF.

3.6.2. Current flow

Prior to 1960, around 2'000 t **HCl** was emitted in Switzerland. This arose mainly from combustion of coal. Up to 1985, emission increased to almost 12'000 t/a, most of which emanated from waste incineration plant (primarily from PVC). Owing to the installation of flue gas filter equipment and the reduction in PVC consumption, emission fell to 2'360 t/a in 1995. Emission will decline in the coming years, and this will continue until all waste incineration plant has been fitted with flue gas filter equipment. In 2005, HCl emission is expected to amount to 560 t per year [SRU 256, p. 80].

HF emission arises mainly from aluminum production. For this reason, emission increased sharply shortly after the turn of the century (start-up of aluminum works in Chippis and Martigny in 1908). In 1980, emission reached a maximum of 800 t/a, but had fallen to 76 t/a in 1995. In the next 10 to 15 years, a further halving of flow is expected [SRU 256, p. 82].

3.6.3. Critical flow

For HCl and HF, neither limiting immission nor emission values exist. In the absence of political objectives, the ecofactors are calculated not from the current and critical flows, but via a comparison of the impact of HCl and HF with that of SO_2.

3.6.4. Ecofactors for HCl and HF

If the simplifying assumption is made that the ecological impacts of HCl and HF emission are mainly attributable to acidification of the soil, the ecofactors can be calculated from a comparison of the acidification potentials with SO_2. According to [Hejungs et al.1992, p. 86], the acidification potential of HCl is 12% smaller than for SO_2 and of HF 60% higher than for SO_2. This results in ecofactors 12% lower or 60% higher, respectively, than the ecofactor for SO_2.

	Acidification potential relative to SO_2 (in %)	Ecofactor 1997 [UBP/g HCl or HF]	Ecofactor 1990 [SRU 133] [UBP/g HCl]
HCl	88	47	42.3
HF	160	85	-

Table 9:   Ecofactors for HCl and HF in UBP/g HCl and HF

The coupling of HCl and HF with SO_2 means that the ecofactors for HCl and HF are independent of the current flows (and thus of any need for ecological action). They characterize HCl and HF compared to SO_2. Further, plant toxicological effects of HCl and HF are not included in this method. The overall ecological effect of these two substances thus tends to be underestimated in using the ecofactors proposed here. This must be especially considered for processes with very high HCl or HF emission.

3.7. Particles PM10

3.7.1. Ecological impact

Recent epidemiological studies have shown that particles with a diameter of less than 10 micrometer (PM10) correlate strongly with the observed detrimental effects of air pollution on human health. PM10 particles may enter the lungs via the larynx. PM10 is a mixture arising from primary emission (particles from combustion processes, scattered road dust and particles from surface and tire abrasion) and secondary aerosols [SRU 270, p. 9]. In the National Research Program No. 26 on Human Health and the Environment it was shown, for example, that for an increase in the long-term immission of 10 microgram PM10 per m^3, the risk of various respiratory diseases increases by 30 to 60%.

3.7.2. Current flow

In [SRU 256, p.85], a revue on emission of total particles is given. This shows that up to 1960, emission steadily increased, and thereafter declined. In 1995, total particle emission was lower than in 1900. Note however that the measures taken to treat exhaust gases have mainly led to a reduction of larger particles, so that current emission largely consists of fine particles with significant health risk.

The PM10 emission from road transport is estimated at just under 18'000 t/a for 1995 (see Appendix 4). Immission studies ("receptor studies") show that the contribution of road transport to PM10 immission (excluding background level due to imports) lies between 40 and 60%, or an average of 50% [Wanner 1997, p. 42]. If, as a first approximation, it is assumed that the contribution of road transport to PM10 immission corresponds to PM10 emission, a total emission of PM10 of approx. 36'000 t/a results.

3.7.3. Critical flow

In the revised Clean Air Ordinance, which came into effect on 1 March 1998, limiting immission values for PM10 were included for the first time (yearly average value 20 $\mu g/m^3$; 24-h average value 50 $\mu g/m^3$). The values cited were included on the recommendation of the Federal Commission on Air Hygiene on the basis of the dangers to health of fine particles [SRU 270]. Compliance with these limiting values requires the current flow to be reduced by about half.

3.7.4. Ecofactor for PM10

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t PM10/a]	**36'000**	C	Estimate - for details see Appendix	-
Critical flow [t PM10/a]	**18'000**	a	Estimate based on revision of Clean Air Ordinance	-
Ecofactor [UBP/g PM10]	**110**			-

Table 10:   Ecofactor for PM10 in UBP/g PM10 (Q = data quality - see remarks in Chap. 2.5)

The provision of an ecofactor reflects the growing significance of PM10 in environmental policy. Owing to uncertainties in the data, the factor is at present suitable only for consultative purposes. The PM10 ecofactor may not be applied to the so-called "total particle" emission used in many inventories (cf. Chapter 3.7.5).

3.7.5. PM10 in inventories

The inventories presently available in Switzerland contain, as yet, no data on PM10. Till now, the so-called "total particle" emission has mostly been quoted. Data available from abroad on the PM10 contribution to "total particles" are not necessarily valid for Switzerland. Note that "total particles" contain direct emission from combustion and production processes, but neither scattered dust from road transport nor particles from tire and surface abrasion nor aerosols formed subsequently in the atmosphere.
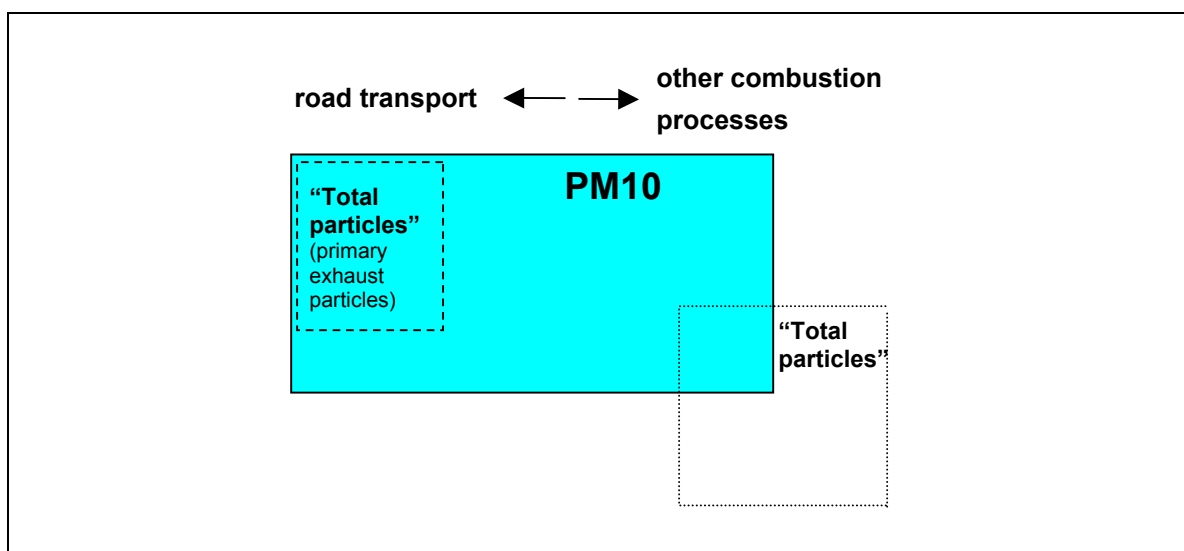
Fig. 2:   *"Total particles" emission contained in current inventories and relationship of "total particles" to PM10 emission from road transport and combustion processes*

In Figure 2, the relationship between "total particles" and PM10 emission from road transport and other combustion processes is shown. It can be assumed that the primary exhaust particles (designated as "total particle" emission in earlier inventories) arising from combustion processes in road vehicles, consist entirely of PM10 [SRU 270, p. 32]. In addition, PM10 contains secondary particles and abrasion particles not included in "total particles". Taken overall, the PM10 emission from road transport is some six times higher than the "total particle" emission [SRU 256, p. 85]. For the remaining combustion processes, only part of the "total particle" emission is attributable to PM10 [SRU 270, p. 32], and – vice versa – only part of the PM10 emission to "total particles". Taken overall, "total particle" emission and PM10 emission from the remaining combustion processes are of the same order [SRU 256, p. 85].

To enable PM10 to be included in the weighting, detailed measurements of PM10 emission should be included in the inventories at the earliest possible date. A rough "rule of thumb" for applying the PM10 factor to existing inventories may be found in Appendix 5.

3.8. Greenhouse gases

3.8.1. Ecological impact

The emission of greenhouse gases leads to an anthropogenic amplification of the greenhouse effect. It is widely assumed that the rise in global average temperature of 0.3 to 0.6°C observed over the past 100 years, and the rise in the sea level observed over the same period, are partly the result of anthropogenic amplification of the natural greenhouse effect [Explanatory Note 1997, p. 10], [IPCC 1996, p. 4]. Calculations based on mathematical models indicate that doubling the CO_2 concentration compared to the pre-industrial era would lead to an increase in global average temperature of between 1 and 3.5°C and to a rise in the sea level by 15 to 95 cm by the year 2100. On a continental scale, significant deviations from the global average values must be expected. It must be assumed that at no time over the last 10'000 years has the global temperature changed at a comparable rate [Explanatory Note 1997, p. 10], [IPCC 1996, p. 5].

The principal greenhouse gases are CO_2, CH_4 (methane) and N_2O (laughing gas). Further, the various categories of chlorinated and fluoridated hydrocarbons (CFC, HCFC, FHC, PFHC) and SF_6 contribute directly to the greenhouse effect. The greenhouse effect of the various gases relative to CO_2 is expressed by the GWP (global warming potential). The emission of 1 kg N_2O is equivalent to the emission of 310 kg CO_2 measured in terms of the accumulated greenhouse effect over a period of 100 years. Thus N_2O has a GWP_{100} of 310 equivalent CO_2 units.

In the scientific assessment contained in the Second Assessment Report [IPCC 1996] of the Intergovernmental Panel on Climate Change, the relative greenhouse effect was assessed quite differently compared to the first report [IPCC 1990]. In particular, the report now distinguishes between the direct and indirect contributions. In Tab. 11, only direct contributions (except for methane) are shown under GWP_{100}, as, scientifically, these are better founded.

3.8.2. Current flow

Current flows of the primary greenhouse gases and their greenhouse effect (global warming potential GWP_{100}, basis 100 years) are shown in the following table. CFC/HCFC, FHC and PFHC represent classes of substances with different greenhouse effect (also see Chapter 3.8.5).

Greenhouse gas	GWP_{100}	Emission 1995 [1'000 t]	Contribution to total Swiss greenhouse effect (weighted with GWP_{100})
CO_2	1	44'200	ca. 78%
CH_4	21	237	ca. 9%
N_2O	310	11,8	ca. 6%
FCKW/HFCKW	90 - 8'100	2	ca. 5%
FKW	140 - 11'700	0.2	ca. 0.7%
PFKW	6'500 - 9'200	0.005	ca. 0.7%
SF_6	23'900	0.03	ca. 1%

Table 11:   Emission of greenhouse gases in Switzerland, 1995 [UN 1997, p. 35-37], direct greenhouse effect[5] according to [IPCC 1996, p. 119, 121].

3.8.3. Critical flow for CO_2

The United Nations Framework Convention on Climate Change was signed by Switzerland on 12 June, 1992, and ratified on 10 December, 1993 [UN 1994, p. 31]. The objective of the convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level sufficient to avoid the risk of anthropogenic disruption of the climatic system.

Immediate stabilization of CO_2 concentration at the present level is hardly feasible, as this would require a worldwide reduction of CO_2 emission by at least 50 to 70% in the short term [IPCC 1995, p. 9]. A reduction of worldwide CO_2 emission from the present approx. 7 Gt C/a to approx. 5.5 Gt C/a would lead to a CO_2 concentration in the atmosphere lying below *twice* the level of the pre-industrial era [IPCC 1996, p. 23]. This value was roughly estimated as the level at which populated areas and ecosystems may adjust to a changed climate without significant risk to man and the biosphere. On the assumption that every human being is entitled to emit the same quantity of CO_2, and that the world population will augment to 8 billion by 2050, a maximum per capita emission of approx. 2 t CO_2/a results.

This also corresponds to the assessment of the Swiss Federal Council contained in the Explanatory Note concerning the law on reduction of CO_2 emission: "The per capita carbon dioxide emission of 6.5 t CO_2 lies below the average for the OECD countries. … Worldwide, Switzerland lies significantly above the average, and is thus far from maintaining a climatically sound emission volume, which scientific studies have shown to

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5   With the exception of CH4. GWP for methane also includes indirect effects (formation of tropospheric ozone and stratospheric water vapor).

be below 2 t" [Explanatory Note 1997, p.17]. Based on the value of approx. 2 t CO_2/a per capita, an annual critical flow for Switzerland of some 15'000'000 t CO_2[6] results.

Concurrently to ratification of the climate convention, Switzerland has undertaken to stabilize CO_2 emission to the level of 1990 by the year 2000, and then to reduce it. In the above-mentioned Explanatory Note on the CO_2 law, the stated objective is a reduction of 10% below the 1990 status by the year 2010. The connotation of this reduction objective is formulated as follows: "The reduction target of 10% following stabilization is to be understood as a further stage in Swiss climate policy. In order to achieve the objectives of the climate convention, further-reaching steps, both nationally and internationally, will be needed for the period after 2010." [Explanatory Note 1997, p. 6].

The critical flow calculated according to the objective of the climate convention is thus significantly lower than the 10% reduction planned over the respective 10-year period in the CO_2 law. This is equivalent to the procedure for the atmospheric pollutants, NO_x, SO_2 and VOC, in which the immission protection objective (limiting immission values or critical loads) is assigned greater importance than the emission targets in the Clean Air Concept. This approach permits a unified weighting procedure for atmospheric pollutants.

3.8.4. Ecofactor for CO_2

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [1'000 t CO_2/a]	**44'200**	A	[UN 1997, p. 35-37]	43'400
Critical flow [1'000 t CO_2/a]	**15'000**	a	Derivation from the protection target of the climate convention [Explanatory Note 1997, p. 17], [IPCC 1995, p. 9]	34'700
Ecofactor [UBP/g CO_2]	**0.20**			0.036

Table 12: Ecofactor for CO_2 in UBP/g CO_2 (Q = Data quality - see remarks in Chap. 2.5).

Use of the lower critical flow for CO_2 emission directed towards the objectives of the climate convention leads to a significantly higher assessment of CO_2 than in [SRU 133]. The new ecofactor results in a stricter valuation of all combustion processes (including road transport) and underlines the ecological necessity of reducing emission.

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[6] Strictly speaking, the reduction to 2 tonnes per person and year includes not only CO2 emission but also the combined effect of all greenhouse emission determinable on the basis of GWP. On this basis, the resulting critical flow for CO2 would be about one-fifth lower.

3.8.5. Critical flows for other greenhouse gases

By considering GWP_{100}, the contribution of other greenhouse gases to the anthropogenic amplification of the greenhouse effect is equivalent to that of CO_2. The determination of the ecofactors for the remaining greenhouse gases is therefore performed on the basis of their greenhouse potential [IPCC 1996] in relation to that of CO_2. Possible additional ecological effects of the remaining greenhouse gases (e.g. the effects of decomposition metabolites of fluoridated hydrocarbons used as herbicide) are ignored. Greenhouse potential and the ecofactors calculated therefrom are given in Table 13.

For substances that contribute both to the greenhouse effect and to ozone depletion, ecofactors were in an initial step calculated and compared both on the basis of their greenhouse potential and their ozone depletion effect. The objective here was to determine for each substance the dominating environmental effect on which to base the calculation of the ecofactor. For R 22, R 124 and R 142b, greenhouse potential outweighs that of ozone depletion. The corresponding ecofactors are therefore calculated on the basis of greenhouse potential. The values are given in Table 13.

The determination of ecofactors for CFC and other HCFC is discussed in Chapter 3.9.

3.8.6. Ecofactors for CH$_4$, N$_2$O and other greenhouse gases

Greenhouse gas	Chemical formula	Greenhouse potential (basis: 100 years) [IPCC 1996]	Ecofactor in UBP/g
CO$_2$		1	**0.20**
CH$_4$		21	**4.2**
N$_2$O		310	**62**
Fluorohydrocarbons			
R 23	CHF$_3$	11'700	**2300**
R 32	CH$_2$F$_2$	650	**130**
R 41	CH$_3$F	150	**30**
R 43-10mee	C$_5$H$_2$F$_{10}$	1'300	**260**
R 125	C$_2$HF$_5$	2'800	**560**
R 134	C$_2$H$_2$F$_4$	1'000	**200**
R 134a	C$_2$H$_2$F$_4$	1'300	**260**
R 152a	C$_2$H$_4$F$_2$	140	**28**
R 143	C$_2$H$_3$F$_3$	300	**60**
R 143a	C$_2$H$_3$F$_3$	3'800	**760**
R 227ea	C$_3$HF$_7$	2'900	**580**
R 236fa	C$_3$H$_2$F$_6$	6'300	**1'300**
R 245ca	C$_3$H$_3$F$_5$	560	**110**
Perfluorohydrocarbons			
Perfluoromethane	CF$_4$	6'500	**1'300**
Perfluoroethane	C$_2$F$_6$	9'200	**1'800**
Perfluoropropane	C$_3$F$_8$	7'000	**1'400**
Perfluorobutane	C$_4$F$_{10}$	7'000	**1'400**
Perfluorocyclobutane	c-C$_4$F$_8$	8'700	**1'700**
Perfluoropentane	C$_5$F$_{12}$	7'500	**1'500**
Perfluorohexane	C$_6$F$_{14}$	7'400	**1'500**
Partially halogenated chloroflourocarbons*			
R 22	CHClF$_2$	1'500	**300**
R 124	CHFClCF$_3$	470	**94**
R 142b	C$_2$H$_3$ClF$_2$	1'800	**360**
Sulfur hexafluoride	SF$_6$	23'900	**4'800**

*   other partially halogenated hydrocarbons are assessed on the basis of their ozone depletion effect (cf. Chapter 3.9).

Table 13:   Ecofactors for other greenhouse gases, calculated on the basis of the ecofactor for CO$_2$

Determination of ecofactors for the remaining greenhouse gases via the greenhouse potential of CO_2 results in the ecofactors reflecting the ecological effect but not the current flows. However, by coupling these to CO_2, consistent weighting is achieved for all greenhouse gases.

3.9. Ozone depleting substances

3.9.1. Ecological impact

Several groups of halogenated hydrocarbons contribute to the depletion of the strato-spheric ozone layer. The ozone layer protects the biosphere from the sun's ultraviolet rays. Depletion of the ozone layer leads, among other things, to an increase in the incidence of skin cancer in man and to augmentation of the mutation rate for all species.

The CFC (chlorofluorocarbons) and the halogens are the principal ozone depleting sub-stances, and these are at the same time contributing to the anthropogenic amplification of the greenhouse effect. The HCFC (partially halogenated hydrochloroflourocarbons) have the same basic effect but at a level 10 to 100 times lower. The magnitude of the ozone depletion effect is designated by the dimensionless ozone depletion potential (ODP), whereby ODP for R 11 is set to 1.

In the following, an ecofactor is derived covering all ozone depleting substances (measured in R11 equivalent). From this, the ecofactors for the individual substances are calculated via the ODP.

3.9.2. Current flow

Between 1950 and 1975, CFC, halogens and HCFC were used in increasing quantities. The **import** of ozone depleting substances is monitored by SAEFL, and thus is known fairly precisely. No ozone depleting substances are produced in Switzerland. In 1986, the consumption of CFC amounted to over 6'000 t, but this had diminished to 500 t in 1995. HCFC are partly used as a substitute for CFC in refrigeration plant and as foaming agents (consumption in 1995: approx. 900 t). The use of halogens in Switzerland has become negligible.

The **emission** of ozone depleting substances stems from various sources:

(A) Losses of CFC and HCFC used as foaming agents and as refrigerants in cooling and air conditioning plants, in heat pumps, and as insulation material (new and for repair).

(B) Diffuse emission from existing foam insulation containing CFC and HCFC in buildings and refrigeration plant.

(C) Losses during disposal processes of equipment containing CFC and HCFC (e.g. refrigerators).

There is considerable uncertainty concerning the quantities emitted from the various sources.

CFC can also arise as a by-product of chemical processes. Owing to lack of an adequate data basis, these are not included in the estimates made by SAEFL. The very roughly estimated emission from the various groups of substances is shown in the following table for 1995.

	Group A Consumption Emission			Group B Storage Emission			Group C Disposal** Emission			Total emission	
	t/a	%	t/a	t	%	t/a	t/a	%	t/a	t/a	t R11eq/a
CFC (ODP =1)											
Solvent	150	50%	75							75	75
Refrigerant*	350	100%	350				10	10%	1	351	351
Foam (insulation)				50'000	2%	1'000	50	10%	5	1'005	1'005
Total (t CFC)	500		425	50'000		1'000	60		6	1'431	1'431
HCFC (ODP = 0.08 *)**											
Refrigerant	400	50%	200				20	20%	4	204	16
Foam (insulation)	360	10%	36	6'000	5%	300	6	20%	1	337	27
Total (t HCFC)	760		236	6'000		300	26		5.2	541	43
Grand total (t)	**1'260**		**661**	**56'000**		**1'300**	**86**		**11**	**1'972**	**1'474**

    *   Average 1993/94/95. Consumption in older plant needing repair (leakage) plus reserve storage
    **   Disposal procedures in progress
    *** Assumption: emitted HCFC mainly comprises R 22 (ODP = 0.055) and R 141b (ODP = 0.11)

Table 14:   Derivation of CFC and HCFC emission in Switzerland in 1995 (rough estimates by SAEFL / INFRAS).

As a result of agreements reached in the wake of the Montreal Protocol, the total emission of ozone depleting substances has declined continuously since 1985, and amounted to approx. 2'000 t/a in 1995 (Table 14. Also see [SRU 256, p. 97]). This is equivalent to an ozone depletion potential of approx. 1'470 t R 11. More than two-thirds of total emission now stem from insulation containing CFC and HCFC in existing buildings (group B). The emission of this group of substances is expected to diminish only slowly in the coming years.

3.9.3. Critical flow

The production and import of ozone depleting substances is regulated in the Ordinance relating to Environmentally Hazardous Substances. The regulations concerned are based on the global reduction objectives for the various ozone depleting substances as stipulated in the Montreal Protocol on protection of the ozone layer, and in subsequent agreements.

The ordinance prohibits the production and import of **CFC.** Exceptions are made at present for the import, among others for medical purposes (asthma sprays and manufacture of micro capsules), as well as for servicing refrigeration plant.

The use of **HCFC** in open-cycle plant has been prohibited since 1995. The use of HCFC in foaming agents is permitted until 1999, and as refrigerant in new plant till the end of 2001. After this date, HFCKW will be permitted only for servicing existing refrigeration plant. Mainly, the refrigerant R 22 will be used for this purpose.

The provisions of the Ordinance relating to Environmentally Hazardous Substances will result in further reduction in emission of ozone depleting substances. Substantial emission from existing building insulation will continue, albeit in gradually reduced quantities, until the buildings concerned will reach their end of life.

The ordinance, therefore, regulates the application of ozone depleting substances, but not their emission. Prohibition of the use of ozone depleting substances is alone insufficient to define a critical flow. The starting point for the determination of critical flow must therefore be the value of emission tolerated in the ordinance when all intermediate provisions have terminated. This value falls steadily from 2001 onwards, and is therefore dependent on the chosen reference year. For this reason, the critical flow was based on the average permissible emission over the first 10 years (2001 to 2011) following termination of the intermediate provisions in the Ordinance relating to Environmentally Hazardous Substances. This is equivalent to approx. 850 t R 11 (Table 15).

	Group A Consumption Emission			Group B Storage Emission			Group C Disposal* Emission			Total emission	
	t/a	%	t/a	t	%	t/a	t/a	%	t/a	t/a	t R11eq/a
CFC (ODP =1) Solvent	0	50%	0							0	0
Refrigerant	0	100%	0				50	10%	5	5	5
Foam (insulation)				40'000	2%	800	250	10%	25	825	825
Total (t FCKW)	0		0	40'000		800	300		30	830	830
HCFC (ODP = 0.08 **) Refrigerant	200	50%	100				40	20%	8	108	9
Foam (insulation)	0	10%	0	3'500	5%	175	10	20%	2	177	14
Total (t HFCKW)	200		100	3'500		175	50		10	285	23
Grand total (t)	**200**		**100**	**43'500**		**975**	**350**		**40**	**1'115**	**853**

* Disposal procedures in progress
** Assumption: HFCKW emission mainly comprizes R 22 (ODP = 0.055) and R 141b (ODP = 0.11)

Table 15:   Annual emission of CFC and HCFC in Switzerland averaged over the period 2001 to 2011 (corresponding to average emission for the first 10 years after termination of the intermediate provisions in the Ordinance relating to Environmentally Hazardous Substances (rough estimates SAEFL / INFRAS)).

Thus over the next 10 years, emission of ozone depleting substances is expected to decline to about 1'000 t/a, equivalent to an ozone depletion potential of approx. 850 t R11.

3.9.4. Ecofactor for ozone depleting substances

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t R 11equ/a]	**1'470**	C	Rough estimate: INFRAS/SAEFL	(5'200)
Critical flow [t R 11equ/a]	**850**	a	Permissible emission in the Ordinance relating to Environmentally Hazardous Substances, following termination of intermediate provisions. Rough estimate INFRAS/SAEFL	(1'075)
Ecofactor [UBP/g R 11 equ/a]	**2'000**			(4'500)

Table 16:   Ecofactor for R 11 equivalent in UBP/g R 11 equ (Q = data quality - see remarks in Chap. 2.5). In [SRU 133], only CFC was weighted.

Based on the ecofactor derived for ozone depleting substances (measured in t R 11 equivalent), the ecofactors for the individual substances may be calculated from their ozone depletion potential (see Table 17).

Most ozone depleting substances also contribute to the greenhouse effect. As a first step, ecofactors for these substances were calculated and compared both on the basis of the greenhouse effect and of ozone depletion. The object of this is to determine the dominating environmental effect in calculating the ecofactor. For R 22, R 124 and R 142b, the greenhouse effect gives a higher weighting than the ozone depletion potential. The ecofactors were thus calculated based on the greenhouse potential. The values are shown in Table 13.

Refrigerant compounds are weighted with the ecofactors for the constituent substances according to their proportion by weight.

The **problem** in calculating ecofactors for ozone depleting substances lies in the time lag between the time the substances are deployed and the corresponding emission. Present-day emission is to a large extent the result of previous actions, and today's legislation (i.e. prohibition) will not become fully effective in reducing emission until 50 years' time.

In determining the ecofactor for the ozone depleting substances, the provisions concerning production processes in the Ordinance relating to Environmentally Hazardous Substances were applied in calculating the emission. Although the ecofactor reacts very sensitively to the assumptions made, it does of course reflect the political and scientific demand for more far-reaching emission reduction for ozone depleting substances.

The result is a lower ecofactor for CFC than in [SRU 133]. This is mainly due to the marked reduction in emission which has already occurred, i.e. in the current flow.

Ozone depleting substances	Chemical formula	Ozone depletion potential (R 11=1)	Ecofactor in UBP pro g
Chlorofluorocarbons			
R 11	$CFCl_3$	1	**2'000**
R 12	CF_2Cl_2	1	**2'000**
R 13	CF_3Cl	1	**2'000**
R 111	C_2Cl_5F	1	**2'000**
R 112	$C_2Cl_4F_2$	1	**2'000**
R 113	$C_2Cl_3F_3$	0.8	**1'600**
R 114	$C_2Cl_2F_4$	1	**2'000**
R 115	C_2ClF_5	0.6	**1'200**
R 211	C_3Cl_7F	1	**2'000**
R 212	$C_3Cl_6F_2$	1	**2'000**
R 213	$C_3Cl_5F_3$	1	**2'000**
R 214	$C_3Cl_4F_4$	1	**2'000**
R 215	$C_3Cl_3F_5$	1	**2'000**
R 216	$C_3Cl_2F_6$	1	**2'000**
R 217	$C_3Cl_1F_7$	1	**2'000**
Halogens			
Halogen 1211	CF_2BrCl	3	**6'000**
Halogen 1301	CF_3Br	10	**20'000**
Halogen 2402	$C_2F_4Br_2$	6	**12'000**
Partially halogenated chlorofluorocarbons*			
R 22	$CHClF_2$	0.055	cf. Table 13
R 123	$CHCl_2CF_3$	0.02	**40**
R 124	$CHFClCF_3$	0.022	cf. Table 13
R 141b	$C_2H_3Cl_2F$	0.11	**220**
R 142b	$C_2H_3ClF_2$	0.065	cf. Table 13
Other halogenated carbon compounds			
Carbon tetrachloride	CCl_4	1.1	**2'200**
Methyl bromide	CH_3Br	0.7	**1'400**
Methyl chloroform	$C_2H_3Cl_3$	0.1	**200**

*   The partially halogenated hydrocarbons R 22, R 124 and R 142b, are assessed on the basis of their
     greenhouse effect (cf. Chapter 3.8, Table 13).

*Table 17:   Ecofactors for ozone depleting substances in UBP/g of the corresponding
              substance, calculated on the basis of ozone depletion potential (ODP;
              [Montreal 1993])*

3.10. Heavy metals

3.10.1. Ecological impact

Lead pollution results in animal and plant disease and affects soil fertility. Lead accumulates in the food chain and can affect the formation of blood cells and inhibit child development [SRU 256, p. 29]. Long-term pollution by **cadmium,** even at very small dosage, is toxic to man and animals (bioaccumulation) and carcinogenic. It is toxic to plants and microorganisms, and affects soil fertility [SRU 256, p. 30]. Pollution by **zinc** affects plant growth [SRU 256, p. 29]. **Mercury** is highly toxic to man and animals (aspiration, accumulation in various organs). It is toxic to plants and microorganisms, and affects soil fertility [SRU 256, p. 30].

3.10.2. Current flow

Lead emission rose sharply from the 1950's onwards due to addition of lead to gasoline. The maximum of 2'160 t/a occurred in 1970. Emission has since declined. In 1995, it amounted to 226 t/a and is expected to fall below 100 t/a by 2005 [SRU 256, p. 86].

Maximum **cadmium** emission of 7 t/a occurred around 1970. From 1980 onwards, a marked reduction was observed. In 1995, emission amounted to approx. 2.5 t/a. A further reduction is anticipated over the next 10 years [SRU 256, p. 90].

Up to the 1970's, **zinc** emission resulted mainly from steelworks and open waste incineration. Maximum total emission (1'750 t/a) occurred in 1970. Emission declined to some 630 t in 1995, and by 2005 a further reduction to 560 t/a is expected [SRU 256, p. 88].

Mercury emission increased between 1970 and 1980 owing to emission from waste incineration plants to approx. 8 t/a. Since then, improved effluent filtration methods have led to a marked reduction to 3.3 t/a (1995). A further reduction of some 30% can be expected by 2005 [SRU 256, p. 92].

3.10.3. Critical flow

In the Clean Air Ordinance, limiting immission values (annual average values) are contained for lead, zinc and cadmium in precipitated particles. In addition, the Ordinance on Pollution of the Soil contains standard values permitting assessment of soil impact for all heavy metals considered here. These arise on the one hand from atmospheric deposition, and on the other from pollutant immission in agriculture. The legal values are shown in Table 18 along with the measured values.

	Source	Pb	Cd	Zn	Hg	Remarks
Heavy metals in precipitated particles						
Limiting value [µg/(m2*d)]	LRV	100	2	400	-	Annual average
Measured values 1996 [µg/(m2*d)] (15 measurement stations)	[SRU 286]	<80	<1.1	<234		Annual average
Concentration of soil pollutants						
Standard value [mg/kg]	VSBo	50	0.8	200*	0.8*	Total content
Measurement topsoil (median) [mg/kg]	[SRU 200]	24	0.23	53	0.1	Total content
Measurement subsoil (median) [mg/kg]	[SRU 200]	10	0.13	38	0.03	Total content

* In the draft Ordinance on Pollution of the Soil ([VBBo 1997] under consultation as from autumn 1997), lower values are
   proposed: Zn 150 mg/kg; Hg 0.5 mg/kg.

*Table 18:   Legally specified values and measured values for heavy metals in
                  precipitated particles and for soil pollutant content*

An analysis of the measured values shows that the highest average annual values
measured for heavy metals in precipitated particles all lie below the limiting values (for
lead by 20%, for Cd by 45%, and for Zn by 42%). On the heavily simplified assumption of
a linear relationship between total Swiss emission and maximum measured concentration,
it may be concluded that the current flow lies below the critical flow by a corresponding
margin. On this basis, there are resulting (rounded) critical flows of 280 t/a for lead, 4.5 t/a
for cadmium and 1'100 t/a for zinc (see Table 19).

The Clean Air Ordinance does not contain a limiting value for mercury in precipitated
particles. This is due not so much to lower potential risk as to problems in measurement.

The Ordinance on Soil Pollutants (VSBo) does, however, contain standard values for
pollutant content of the soil. For mercury, this is 0.8 mg/kg, i.e. the same as for cadmium,
and considerably lower than for lead (50 mg/kg) and zinc (150 mg/kg). Further, as current
atmospheric emission of the two heavy metals is of the same order, the ecofactor for
mercury is set to the same value as for cadmium.

3.10.4. Ecofactors for heavy metals in the atmosphere

	Current flow [t/a]	Q	Critical flow [t/a]	Q	Ecofactor [UBP/g]
Pb	226	B	280	a	**2'900**
Cd	2.5	B	4.5	a	**120'000**
Zn	630	B	1'100	a	**520**
Hg	3.3	B	-		**120'000**

Table 19:   Ecofactors for heavy metals in UBP/g (Q = data quality, see remarks in Chap. 2.5).

The considerable variability in the ecofactors for emission of various heavy metals to the atmosphere reflects the weighting of their ecological relevance in the legislation. It is, however, probable that the chosen procedure for determining the critical flow on the whole underestimates the ecological relevance of the heavy metals, since it does not account for accumulation of heavy metals in the soil. This contradicts the precautionary principle in the Environment Law.

3.11. Dioxins and furans

Among the dioxins and furans (PCDD and PCDF), some are highly toxic to man and animals. They accumulate in the food chain and are also embryotoxic [SRU 256]. Emission until 1955 amounted to less than 40 g/a. In the period between 1955 and 1980, emission increased to 484 g/a, and has since declined owing to improved flue gas filtration in waste incineration plants. The value in 1995 amounted to 181 g/a. The significance of illegal waste incineration is expected to increase in future due to higher disposal costs (e.g. household waste disposal).

Limiting emission values for dioxins and furans have not been set, so that the basis for determining a critical flow, and thus an ecofactor, is not given[7].

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[7]   In the new Ordinance on Pollution of the Soil ([VBBo, 1997] under consultation since August 1997), which is to replace the present VSBo, standard, test and rehabilitation values for soil content of dioxins and furans are specified. However, these do not permit direct conclusions to be drawn as to limiting emission quantities.

4. Emission to surface waters

4.1. Introduction

4.1.1. Preliminary remarks

The ecofactors for weighting emission to surface waters are based on total Swiss emission and thus reflect the "average" Swiss situation. Regional factors are not considered. Thus, for example, substances that would have considerable negative consequences in a small stream may well be degraded without difficulty in the Rhine. Ideally therefore, separate ecofactors would be needed for each water emission situation. As detailed weighting of this kind would lead to implementation problems (all inventory data would have to be correspondingly detailed), and would demand very extensive effort, it was decided against this procedure.

The derivation of the ecofactors for emission to water is therefore performed on a simplified basis, and for this reason does not fully reflect the ecological situations. Here, too, the objective of the ecofactors is not an ecological assessment of each emission, but to provide a comparative weighting over the totality of ecological factors within an ecobalance.

4.1.2. Choice of substances

The measures already taken in effluent treatment have enabled emission of numerous substances to water to be heavily reduced over the past years. The remaining emission sources are partly of minor ecological significance for Swiss waters. The question therefore arises as to whether it is necessary to provide ecofactors for such substances. Note that here, the ecofactors apply not only to Swiss processes, but also to prior processes occurring abroad. For substances which are largely unproblematic in Switzerland, but may be ecologically relevant abroad, the ecofactor has been retained.

In the modified general Water Protection Ordinance (consultation procedure commenced autumn 1997 [GSchV 1997]), **quality targets** are specified for substances which, in general, are ecologically relevant to water quality. The list is shorter than in the present Ordinance on Effluent Discharge, since the quality of rivers has improved over the last few years. This list is the basis for the discussion on choice of ecofactors for water polluting substances. Phosphorus represents an additional pollutant playing an important role in the quality of water in lakes, as well as the AOX sum parameter (halogenated organic substances in water).

In specific circumstances, additional substances should be included in the weighting.

4.1.3. Data sources

Calculation of immission (for heavy metals and AOX)

Measurements of the concentration of various heavy metals are being carried out under the NADUF program for the chemical and physical monitoring of key rivers in Switzerland. The AOX immission level is being assessed at several points in the Rhine, Aare, Reuss and Limmat rivers.

For the current revision of the ecofactors, current immission values are derived from measurements of concentration of the respective pollutants and the flow rates of the Rhine, Rhone and Ticino rivers at exit from Switzerland (for details, see Appendix 1). The pollutant load measured in this way contains both the natural and the anthropogenic constituents. Since heavy metal is deposited in the sediment of rivers, and AOX is degraded to a varying degree, the computation method tends to underestimate the current flow.

The critical flows of the principal pollutants are determined on the basis of the quality objectives for rivers in the Water Protection Ordinance (draft revision [GSchV 1997]). The critical flow of AOX is derived from the quality objective of the International Working Group of the Waterworks in the Rhine Area (IAWR).

Calculation of emission (for COD, phosphorus and total nitrogen)

For certain substances, it is not possible to calculate the quantities emitted to rivers from their concentrations on leaving Switzerland owing to their degradation properties. For these, figures are based on calculations and estimates of emission at source.

4.2. Organic substances (COD, DOC, TOC)

4.2.1. Ecological impact

COD (chemical oxygen demand), DOC (dissolved organic carbon) and TOC (total organic carbon) are a measure of the concentration of organic substances in waters. These organic substances stem partly from natural sources and partly from effluent. Basically, all organic substances affect water quality via removal of oxygen and cause detriment to the habitat of fauna. Many substances also have specific toxic effects (e.g. organic chlorine compounds, endocrinologic substances) which would have to be considered separately [Kummert 1989], [Sigg 1989].

Owing to measures taken toward effluent treatment, the concentration level of organic substances in Swiss waters has declined in the past decades. Legislation also requires that the content of organic substances in effluent be reduced to such a level that they are no longer detrimental to waters. Residual pollution after effluent treatment is generally

uncritical compared to the total quantity of oxygen present. Of ecological relevance are thus mainly the persistent, bioaccumulative and toxic organic substances. The specific effects of substances contained in the "organic substances" summation parameter are, however, not considered here.

The concentration of organic substances in waters can be determined by means of the COD, DOC and (if necessary) TOC parameters mentioned.

COD (chemical oxygen demand)
The COD parameter specifies the quantity of oxygen necessary to oxidize the organic compounds. In Switzerland, COD is mainly applied in determining the quality at outlet from effluent treatment plant ("effluent parameter"). Abroad, water pollution by organic substances is mostly assessed via COD. Numerous ecoinventories contain data on COD.

DOC (dissolved organic carbon)
DOC specifies the content of organic carbon in dissolved organic compounds. At the low concentration levels pertaining in Swiss rivers, this value provides more precise results than COD ("pure water parameter").

TOC (total organic carbon)
TOC specifies the total carbon content of organic molecules. It contains both dissolved organic carbon and carbon in particles.

Owing to the fact that numerous inventories specify COD, an ecofactor for COD is determined. Should a transformation from DOC to COD be necessary, this can be performed with the following rule-of-thumb: COD (in g) $\approx$ 3 DOC (in g). In cases where TOC only was measured, this can be weighted (as a rough approximation) with the ecofactor for DOC.

4.2.2. Current flows

The current flow cannot be calculated from the concentration at the point where the large rivers leave Switzerland, since on the one hand, part of the organic substances is of natural origin, and on the other certain substances are fairly rapidly degraded in rivers and are no longer present at those measurement stations. The current flow is estimated from the pollution load per equivalent resident at outlet from the sewage plant (25 g / (EW*d)) and from the number of equivalent residents (12 million) served. The proportion of residents served by effluent treatment plants in Switzerland is 95%. The current flow from anthropogenic sources amounts to 115'000 t/a [N Household Sources 1996, p.16-17].

4.2.3. Critical flow

The critical flow cannot be calculated from the target values of the Water Protection Ordinance since the organic substances are degraded, and part of these is of natural origin. In [N Household Sources 1996, p. 16-17], the critical flow is therefore estimated from ecological criteria. From an ecological standpoint, a maximum of 30% (on average) of the oxygen dissolved in the water must be consumed downstream of the outlet. The average concentration of oxygen in river water is estimated at 10 g/m^3. From this, a maximum permissible consumption of 3 g O_2/m^3 and thus a maximum permissible flow of 3 g COD/m^3 [N Household Sources 1996, p. 16-17] results.

The maximum permissible (critical) COD flow from anthropogenic sources may be calculated on the basis of the flow quantity leaving Switzerland, and amounts to some 140'000 t/a.

4.2.4. Ecofactors for COD, DOC and TOC

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t COD/a]	**115'000**	B	Estimate of emission from sewage works [N Household Sources 1996, p. 16-17]	267'000
Critical flow [t COD/a]	**140'000**	b	Derived from [N Household Sources 1996, p. 16-17]	264'000
Ecofactor [UBP/g COD]	**5.9**			3.83
Ecofactor [UBP/g DOC]	*18*		*Derived from ecofactor for COD with COD ≈ 3 DOC*	*11.5*
Ecofactor [UBP/g TOC]	*18*		*Rough estimate: TOC = DOC*	

Table 20: Ecofactor for COD (chemical oxygen demand) in UBP/g COD (Q = data quality – see remarks in Chap. 2.5). The ecofactors for DOC and TOC can be calculated using the rough approximations that COD ≈ 3 DOC and DOC = TOC.

The method of calculation is different from that in [SRU 133], permitting the ecofactor to be calculated on the basis of the anthropogenic part of the current and critical flows. The new ecofactor allows a better representation of the problems caused by organic substances arising from the antroposphere. Compared to [SRU 133] the emission of organic substances takes on greater significance. The ecofactor for COD may be converted to that for DOC assuming that COD ≈ 3 DOC. As a first approximation, the factor for TOC is set equal to that for DOC.

Weighting of specific effects of bioaccumulative, persistent, substances is not possible with the ecofactor for COD. If targets are specified for emission of particular substances, ecofactors should be introduced for these.

4.3. Phosphorus

4.3.1. Ecological impact

Pollution by phosphorus is more critical for lakes than for rivers, as in lakes, the growth of algae is limited by the quantity of phosphorus assimilable by algae, whereas in rivers, other factors may limit growth. The critical flow for phosphorus is thus determined from the permissible value for lakes. Note that:

- The limiting value for lakes is strongly dependent on hydrological (retention time), morphological (bed form and depth) and meteorological (wind, stratification) parameters, and therefore varies from one lake to another. Extrapolation to the whole of Switzerland is only possible with reservations.

- A considerable proportion of the phosphorus emission in agriculture does not make its appearance in waters until after a considerable delay. According to [FAC 1994], a mere 10% of excess phosphorus from agriculture accrues to waters. The remaining 90% is retained in "intermediate storage" in the soil. A reduction of phosphorus input is therefore not carried over to waters until after a considerable delay. In determining the current and critical flows, phosphorus immission to waters alone is considered.

- Phosphorus flow downstream of Swiss lakes is mainly of importance to the coastal regions of the oceans.

4.3.2. Current flow

The current phosphorus flow in Swiss waters was derived in [N Household Sources 1996, p. 14-16] based on phosphorus emission in agriculture and from sewage works. On this estimate, a current anthropogenic phosphorus flow of 2'900 t/a may be expected, whereby more than half originates from sewage plant.

4.3.3. Critical flow

The critical phosphorus flow for lakes depends on numerous factors. It can, however, be assumed that concentrations due to anthropogenic causes of between 20 and 30 mg P/m^3 at inflow to lakes are in most cases ecologically unproblematic [N Household Sources 1996, p.14-16]. No final statement can be made on critical ecological flows of phosphorus

for coastal regions of the oceans. It may roughly be assumed that adequate protection of the coastal regions of the oceans is assured with a "limiting value" of 25 mg/m^3 (average between 20 and 30 mg/m^3).

Based on the critical concentration (25 mg/m^3), and the total outflow of rivers from Switzerland, a critical phosphorus flow of some 1'200 t/a results. (The discrepancy between this critical flow and that given in [N Household Sources 1996] is a result of a revised calculation of total outflow).

4.3.4. Ecofactor for phosphorus

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t P/a]	**2'900**	C	Rough estimate in [N Household Sources 1996, p. 14-16]	4'000
Critical flow [t P/a]	**1'200**	b	Rough estimate in [N Household Sources 1996, p. 14-16]	2'300
Ecofactor [UBP/g P]	**2'000**			756

Table 21: *Ecofactor for phosphorus in UBP/g P (Q = data quality – see remarks in Chap. 2.5)*

The basis for calculating current flow takes into account anthropogenic sources only. Further, in determining the critical flow, more stringent criteria were applied than in [SRU 133]. From this, phosphorus emission takes on greater significance that in [SRU 133].

4.4. Chloride

Chloride is a non-toxic substance. Provided the natural content is not significantly exceeded, no risk to the environment is given. Chloride arises naturally from erosion of rock. Artificial sources of chloride are household, industry, effluent from landfill sites, and road surface water in winter. In rarer cases, chloride may be significant in small waters used for drinking water. No ecofactor for chloride is therefore calculated.

4.5. Total nitrogen

4.5.1. Ecological impact

95% of total nitrogen from anthropogenic sources in surface waters is composed of nitrate and ammonium (or ammonia).

Nitrate is assimilated by humans via drinking water (among other sources) and converted to toxic nitrosamines. Nitrates are a particular problem in groundwater. For this, an ecofactor is calculated in Chapter 5.2.

Ammonium represents a hazard to water resources. At certain temperatures and pH values of the water, ammonium is converted to ammonia, which is toxic to fish. The ammonium concentration in large rivers is very low. High concentrations occur only locally. Local problems of this nature cannot reasonably be covered by ecofactors. Thus no ecofactor is calculated for ammonium.

To account for the nutrient effect of ammonium and nitrate, an ecofactor is applied for **total nitrogen**. Present knowledge indicates that current total nitrogen flow does not represent an ecological problem in Switzerland. On the other hand, nitrogen levels in the North Sea and other shallow seas are of major significance in connection with eutrophication. In the ecofactor for total nitrogen, direct nitrogen input to waters alone is considered. Input to waters via groundwater is included in the ecofactor for nitrate in groundwater (see Chapter 5.2).

Sources of nitrogen in waters are agricultural fertilizers and effluent from industry and households.

4.5.2. Current flow

The current flow is calculated based on estimates of emission in [SRU 273, p. 29]. The anthropogenic contribution amounts to approx. 40'000 t/a. An additional 18'000 t/a arises from natural sources.

4.5.3. Critical flow

As early as 1987, the North Sea states issued a declaration of intent as a result of the alarming overnitrification in the 1980's. The objective was to reduce phosphorus and nitrogen inputs by 50% below the 1985 level. Although the Swiss contribution to total flow is small, it is Switzerland's intention to contribute to the achievement of these objectives by a reduction of this order for the Rhine region downstream of lakes [SRU 273, p. 36].

This objective is taken as a basis for establishing the critical flow for the whole of Switzerland.

Taking into account the reduction of approx. 15% already achieved between 1985 and 1995 (derived from [SRU 273, p. 36/37]), a critical flow of 24'000 t results.

4.5.4. Ecofactor for N in surface waters

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t N/a]	**40'000**	C	Rough estimate in [SRU 273, p. 29]	-
Critical flow [t N/a]	**24'000**	a	50% flow reduction over 1985 [SRU 273, p. 36]	-
Ecofactor [UBP/g N]	**69**			-
Ecofactor [UBP/g NH$_4^+$]	*54*		*Based on ecofactor for total N*	*8*
Ecofactor [UBP/g NO$_3^-$]	*16*		*Based on ecofactor for total N*	*0.2*

Table 22:   *Ecofactor for total nitrogen in UBP/g N (Q = Data quality – see remarks in Chap. 2.5.). For the calculation for nitrate and ammonium, see Appendix 6*

The newly introduced factor for total nitrogen may be used to account for the nutrification of the North Sea and other shallow seas caused by ammonium and nitrate via direct input of nitrogen to surface waters. The impact of nitrate on groundwater is discussed in Chapter 5. With ammonium, problems are only likely at local level, so no ecofactor has been provided.

4.6. Sulfate

Sulfate gets to surface waters via erosion of rock and, in heavily populated areas, mainly from domestic and industrial effluent. In the proposed revision of the Water Protection Ordinance [GSchV 1997], no limiting value for sulfate is specified anymore. Sulfate no longer represents an ecological problem as far as water quality is concerned. An ecofactor is not, therefore, provided for sulfate.

4.7. Heavy metals

4.7.1. Ecological impact

In the draft revision of the Water Protection Ordinance, seven heavy metals relevant to the environment are listed [GSchG 1997]. These are: mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn) and nickel (Ni), which are all toxic at higher concentrations. The heavy metals listed have a detrimental effect on aquatic ecosystems, since they build up in organisms and cause growth retardation and metabolic disturbances. Heavy metals are widely distributed via the food chain.

Sources are industry and, to a lesser extent, erosion of rock.

4.7.2. Current flow

The current flow is calculated from concentration data for the Rhine near Basel, measurements being available only at this point. Under the simplified assumption that the remaining rivers, namely Rhone, Ticino and Inn, are polluted to the same degree, the following current flows result:

Heavy metal	Concentration in μg/l in the Rhine near Basel	Current flow in t/a
Chromium	0.8	38
Zinc	4	188
Copper	1.5	71
Cadmium	0.02	0.94
Mercury	0.01	0.47
Lead	0.7	33
Nickel	0.9	42

Table 23:   Current heavy metal flows in Switzerland calculated from concentration of heavy metals in the Rhine [NADUF 1996] and total flow of water leaving Switzerland (cf. Appendix 1; assumption: all rivers equally polluted)

The total concentration of heavy metals rises with the concentration of suspended particles, since heavy metals tend to concentrate in these. In the Rhone, with its comparatively high particle concentration, the heavy metal concentration is probably higher than in the Rhine. On the other hand, owing to the type of industry in the region, the mercury concentration in the Rhine is likely to be above average. Further, heavy metals are being deposited in the sediments between the outflow and the measurement

point in Basel. The measured flows are therefore likely to be lower than the actual quantities of heavy metals released to the rivers.

4.7.3. Critical flow

The critical flow is derived on the basis of the quality objectives contained in the proposed revision of the Water Protection Ordinance [GSchV 1997]. The concentrations cited there are multiplied by the total water flow leaving Switzerland (4.7×10^{10} m³/a). The draft revision provides for a marked tightening of the quality objectives for effluent discharge over the ordinance presently in force. This results in correspondingly lower critical flows (see Table 24). The (anticipated) more stringent assessment of the heavy metal content of water has therefore been included in advance. Should changes be made to the limiting values in the course of the consultation procedure, the ecofactors must be modified to suit.

Heavy metal	Quality objectives in mg/l in present Ordinance on Effluent Discharge	Quality objectives in mg/l in [GSchV 1997]	Critical flow in t/a in [GSchV 1997]
Chromium	0.06	0.005	240
Zinc	0.2	0.02	940
Copper	0.01	0.005	240
Cadmium	0.005	0.0002	9.4
Mercury	0.001	0.00003	1.4
Lead	0.05	0.01	470
Nickel	0.05	0.01	470

Table 24:   Specification of critical flow for heavy metals in water.

4.7.4. Ecofactors for heavy metals in surface waters

Heavy metal	Current flow in t/a	Q	Critical flow in t/a in [GSchV 1997]	Q	Ecofactor [UBP/g]
Chromium	38	B	240	a	**660**
Zinc	188	B	940	a	**210**
Copper	71	B	240	a	**1'200**
Cadmium	0.94	B	9.4	a	**11'000**
Mercury	0.47	B	1.4	a	**240'000**
Lead	33	B	470	a	**150**
Nickel	42	B	470	a	**190**

Table 25:   Ecofactors for heavy metals in waters in UBP/g (Q = Data quality – see remarks in Chap. 2.5)

The ecofactors reflect the stringent assessment of especially mercury and cadmium emission to surface waters according to the draft Water Protection Ordinance.

4.8.   AOX

4.8.1. Ecological impact

The abbreviation AOX (absorbable organic halogenated compounds) is a summation parameter comprising organic halogenated (mostly chlorinated) substances. It contains substances of anthropogenic and natural origin, such as chlorinated non-aromatic hydrocarbons (e.g. chloroform), chlorinated aromatic hydrocarbons, and polychlorinated biphenyls (PCB).

Toxicity and ecological impacts of the substances subsumed under AOX vary greatly. An important criterion for toxicity is the propensity of the substance to build up in the organism. Liposoluble substances have this characteristic, and are thus readily bioavailable. The higher the degree of chlorination, the more toxic liposoluble substances become.

Tab 26 shows a rough classification of AOX in order of increasing environmental toxicity.
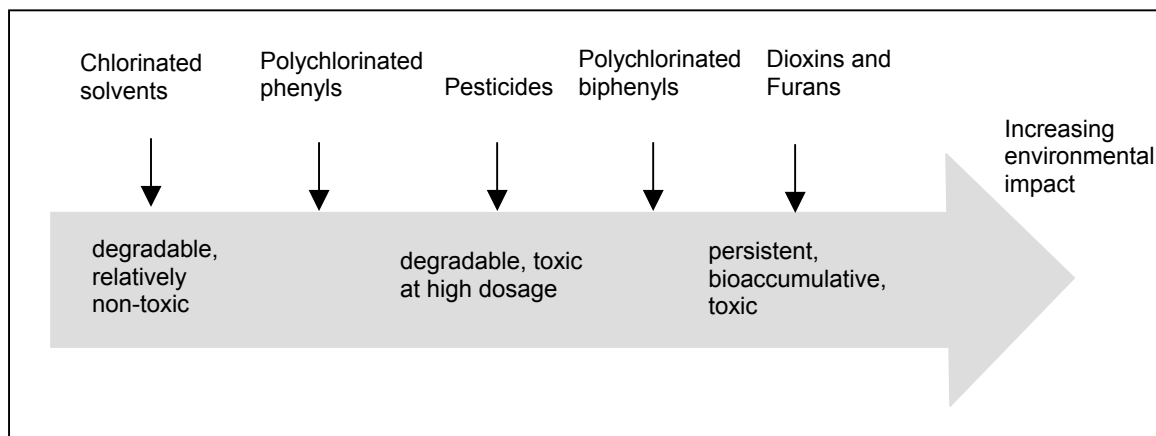
Chlorinated solvents Polychlorinated phenyls Pesticides Polychlorinated biphenyls Dioxins and Furans Increasing environmental impact

degradable, relatively non-toxic degradable, toxic at high dosage persistent, bioaccumulative, toxic

Table 26:   Rough classification of AOX according to ecological impact

Provision of an ecofactor for AOX represents a compromise. The weighting of very different toxic substances and their inclusion in a single ecofactor can lead to false conclusions with respect to ecological impact. On the other hand, separation of the AOX into different, themselves homogeneous, classes of substances (or into individual substances), would be impracticable. However, if the AOX factor were to be left out altogether, an important group of pollutants in the paper/packaging and galvanising industries would be lacking in the analysis.

4.8.2. Current flow

The AOX content of surface waters in Switzerland is minimal. Measurements made in the Canton of Aargau showed average AOX concentrations in the Rhine, Aare, Reuss and Limmat rivers of between 4 and 19 µg/l and maximum values of 4 to 44 µg/l [Building Department, Canton of Aargau, 1993, p. 22]. The substances subsumed under the AOX summation parameter are degraded in greatly differing measure. An extrapolation of measured concentrations (on average approx. 10 µg/l) to total Swiss emission gives a value of 470 t/a, representing a lower limit for total Swiss emission. The actual emission flow is probably considerably higher, but insufficient data are available for more precise determination.

4.8.3. Critical flow

The draft revision of the Water Protection Ordinance contains various provisions on AOX. Thus it is stipulated that, should the concentration at the outlet from sewage works exceed 40 µg/l AOX, the cause shall be sought. In addition, regulations for production processes in various branches of industry are specified. In the manufacture of cellulose, which is a

principal source of AOX, not more than 1 kg AOX per ton of cellulose is permitted. However, no quality objective exists in Switzerland for the AOX concentration in rivers.

A quality objective along these lines has been specified by the International Working Group of the Waterworks in the Rhine Area (IAWR) as 25 µg/l. This objective was derived from requirements for drinking water. The value in question is, however, a recommendation, and is not legally binding. If this objective is taken as the basis for roughly estimating for the critical flow of AOX in Switzerland, a critical flow of approx. 1200 t/a results. Owing to the degradation process, this is again a lower limit.

4.8.4. Ecofactor for AOX

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t AOX/a]	**470**	C	Rough approximation (lower limit) based on measurement	-
Critical flow [t AOX/a]	**1'200**	b	Rough estimate (lower limit), derived from quality objective of IAWR	-
Ecofactor [UBP/g AOX]	**330**			-

Table 27:   Ecofactor for AOX in UBP/g AOX (Q = Data quality – see remarks in Chap. 2.5)

AOX comprises various individual substances having very different environmental impacts. The ecofactor is valid for an average composition. The objective in question is thus based on a very approximate estimate that will require further refinement in the course of time. The purpose of the estimate is to close a gap whose presence was recognized as unsatisfactory in carrying out ecological assessments of paper production.

4.9. PAH

The abbreviation PAH is a summation parameter and stands for polycyclic aromatic hydrocarbons. PAH can have carcinogenic effects on mammals. They occur only in substances in suspension. The concentration of PAH is therefore dependent on the concentration of suspended substances in water. Sources are combustion processes and surface water from roads. The data on current and critical flows is at present insufficient to permit the establishment of an ecofactor.

5. Emission to soil and groundwater

5.1. Introduction

5.1.1. Fundamentals

Soil quality in Switzerland is affected by various material impacts (acidification, excessive nutrification, pollution by heavy metals and harmful organic substances). The present chapter describes how the major impacts due to substances may be weighted.

On an equal plain with impacts due to substances are the disruption or destruction of the soil due to impermeable coverings, erosion and mechanical soil compaction. As no proven methodical system is available yet for weighting land use types, it is not presently possible to adequately analyze these effects by the ecoscarcity method. Use of landfill space, which is covered by the Environmental Protection and Area Planning Laws, was however already assigned an ecofactor [SRU 133]. In Chapter 5.5, this concept is applied to other types of waste disposal site.

5.1.2. Definition of the "soil/groundwater" compartment

The ecoscarcity method assesses the flow of substances at the point of entry to the environment, i.e. where they leave the antroposphere. While the interface between the antroposphere and the environment is relatively simple to define for emission to the atmosphere and to water ("end of pipe" concept, e.g. outlet from chimney, outflow from sewage works), difficulties in system delineation arise with soil and groundwater. For example, the nutrients in agricultural fertilizers are initially available to crops, and are partly taken up by these as long as they remain within reach of the roots. The nutrients taken up by plants remain within the agricultural production system. Nutrients are only detrimental to the environment when they leave the soil region accessible to the roots.

Contrary to this, when heavy metals are introduced to the topmost soil layers and accumulate there, they are effectively not part of the intended agricultural cycle and are beyond anthropogenic influence. The standard values for the pollutant content of the soil contained in the Ordinance on Soil Pollutants (VSBo) are applicable to the topmost 20 cm of the soil. In the sense intended by the VSBo, this soil region is part of the "environment" as far as heavy metals are concerned.

The interface between the antroposphere and the soil/groundwater compartment is therefore defined as follows: substances leave the antroposphere at the point where they are no longer available for agricultural purposes, i.e. when they leave the productive system. Current and critical flows for nutrients are therefore considered at the point where they leave the productive system of agriculture and are carried over to groundwater

(nitrate), on erosion or washout to surface waters (phosphate), or on emission to the atmosphere (ammonia and laughing gas). Heavy metals leave the productive system on entering the soil and must be considered at this point. In preparing ecobalances for agricultural products, the necessary inventories and transfer functions must be provided with appropriate interfaces.

5.1.3. Choice of substances

(a) Soil pollution by substances

In soil pollution via substances, several input paths must be considered:

- Diffuse input of nutrients, acidifiers and heavy metals via the atmosphere

- Input via fertilizers

- Input via plant treatment products

Diffuse input

Pollutants are input either in liquid form (wet deposition) or attached to particles (dry deposition).

With diffuse input, the principal pollutants are:

- Heavy metals, i.e. lead, zinc, cadmium and mercury

- Acidifiers, i.e. SO_4^{2-}, NO_3^-, NH_4^+. These also contribute to excessive nutrification of ecosystems (with the exception of SO_4^{2-}).

Diffuse inputs from the atmosphere to the soil are measured and evaluated at the point of emission to the atmosphere (cf. Chapter 3). Thus special ecofactors for diffuse inputs to the soil are not necessary.

Input via fertilizer (farm manure, waste fertilizers, mineral fertilizers)

The object of fertilizers is to provide the soil with the nutrients necessary for plant growth. Even with optimum application of fertilizers, nutrients are not entirely taken up by plants, and a remainder is carried over to waters (i.e. groundwater and surface waters) and the atmosphere (ammonia, laughing gas, molecular nitrogen). Nutrients are measured and evaluated at the point where they leave the productive system, i.e. at input to surface waters (phosphate: Chapter 4.3), at emission to the atmosphere (ammonia, laughing gas: Chapters 3.5 and 3.8), and at input to groundwater (nitrate). For input of nitrate to

groundwater, an ecofactor is established below (Chapter 5.2). The environmental effects of N in fertilizers may thus be assessed using the ecofactors for emission of ammonia and laughing gas to the atmosphere, and for nitrate to groundwater (see Appendix 6).

In using waste fertilizers, heavy metals and organic substances are released to the soil. Also, the use of farm manure (particularly from intensive pig farms) can lead to the accumulation of heavy metals (Cu, Zn) [Mosimann 1996, p. 9]. For this reason, ecofactors for the principal heavy metals are discussed in Chapter 5.3. The choice of heavy metals is based on the Ordinance on Soil Pollutants.

Plant treatment products

Plant treatment products ("Pflanzenbehandlungsmittel", PTP) comprise plant protection agents (protection of plants from insects, other animal pests and from plant diseases caused by fungi and bacteriae), weedkillers, plant growth regulators, and the so-called additives [SAEFL 1991, p. 34]. Plant treatment products comprise a combination of various agents having different ecological effects. Residues from plant treatment products can accumulate in the soil and be carried over to groundwater.

Owing to lack of a scientific basis, it is not as present possible to provide an ecofactor for each active agent in plant treatment products. An ecofactor is therefore provided for an aggregate of plant treatment products (Chapter 5.4).

(b) Use of space in waste deposits

In the present chapter, the impact of solid waste on soil and the landscape is discussed. The establishment and updating of ecofactors for the following types of waste deposit are considered:

- Deposit (landfill) for inert materials

- Landfill for combustible waste and slag from waste incineration plants (bioactive landfill)

- Landfill for stabilized residues

- Underground deposit for special waste

Ecofactors are considered in Chapter 5.5. Terminal storage for radioactive waste represents a special case (Chapter 5.6).

The quantities of material deposited are specified for bioactive landfill and underground deposits in t, and for radioactive waste in m^3. This corresponds to the procedure in the Ecoinventory for Energy Systems [Energy Systems 1996].

5.2. Nitrate in groundwater

5.2.1. Ecological impact

Nitrate assimilated with food may be converted in the human body into nitrosamines, having a carcinogenic effect [SRU 273, p. 10]. Additionally, nitrate can filter into surface waters via groundwater, thus contributing to nitrogen pollution of the oceans (see Chapter 4.5).

5.2.2. Current flow

In 1994, some 5'000 t N from sewage sludge and compost and 66'000 t N from mineral fertilizers were applied in agriculture [SRU 273, p. 30]. Additionally, 130'000 t N/a accrue to the soil from farm manure (value for 1990 [FAC 18, p.34]). In total, 34'000 t N (representing 150'000 t nitrate) were washed into groundwater [SRU 273, p. 29].

5.2.3. Critical flow

In [SRU 273, p. 37], halving the current nitrate flow of 150'000 t nitrate/a is postulated on the basis of the permissible nitrate concentration in groundwater, and thus also in drinking water. The resulting critical flow of nitrate to groundwater is 75'000 t nitrate/a.

5.2.4. Ecofactor for nitrate in groundwater

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t Nitrate/a]	**150'000**	B	[SRU 273, p. 29]	-
Critical flow [t Nitrate/a]	**75'000**	b	Reduction of current flow by 50% [SRU 273, p. 36]	-
Ecofactor [UBP/g Nitrate]	**27**			-

Table 28:   Ecofactor for Nitrate in groundwater in UBP/g nitrate (Q = Data quality – see remarks in Chap. 2.5)

The provision of an ecofactor for weighting nitrate filtration into groundwater permits improved evaluation of agricultural processes. The ecofactor for UBP/g N calculated from UBP/g nitrate is higher than for N to surface waters. This corresponds to the differing ecological relevance of these two effects.

5.3. Heavy metals

5.3.1. Ecological impact

Heavy metals hamper plant growth, reduce soil fertility, and can accumulate in the food chain. Long-term assimilation of heavy metals in food can lead to chronic poisoning [Mühlbauer 1996, p. 14]. Further, rehabilitation of soils polluted by heavy metals is hardly practicable.

5.3.2. Current flow

The current flow of heavy metals to the soil includes diffuse input via the atmosphere, and direct input via fertilizers (particularly compost and sewage sludge) and plant treatment products.

Continuous measurement of 8 heavy metals and fluorine is being undertaken at 102 sites by the National Observation Network (NABO). Among the heavy metals treated in the VSBo, molybdenum and thallium are not monitored by NABO. The measurements permit establishment and assessment of current heavy metal concentrations in soil. As heavy metals accumulate in the soil, the measured values reflect total emission from the beginning of the industrial era. Values for *current* annual flows could only be derived from an analysis of annual pollution increase. However, data representative of the whole of Switzerland are not available.

5.3.3. Critical flow

Standard values for pollutant concentrations in soils are specified in the Ordinance on Soil Pollutants (VSBo). These provide an indication of the extent of ecological problems caused by accumulation of heavy metals in the soil. In principle, these values enable the maximum permissible total inputs (i.e. from the beginning of the industrial era to the distant future) to be calculated. Derivation of annual inputs is, however, not possible on this basis.

5.3.4. Ecofactors for heavy metals in the soil

Ecofactors for emission of Pb, Zn, Cd and Hg to the atmosphere are defined indirectly on the basis of the maximum permissible input flows from the atmosphere to the soil. The direct input of these substances to the soil is set equal to that to the atmosphere. Ecofactors for the remaining substances are derived from a simple classification scheme.

For this, cadmium is taken as basis. As classification parameter, the standard value in the VSBo is used.

	Standard values VSBo [mg/kg]	Measured values		Ecofactor [UBP/g]	Remarks
		Topsoil* [mg/kg]	Subsoil* [mg/kg]		
Pb	50	28	10	2'900	Equal to EF to atmosphere
Cu	50	18	13	1'900	Calculated from EF (Cd)
Cd	0.8	0.23	0.13	120'000	Equal to EF to atmosphere
Zn	200	53	38	520	Equal to EF to atmosphere
Ni	50	22	25	1'900	Calculated from EF(Cd)
Cr	75	25	21	1'300	Calculated from EF (Cd)
Co	25	5.7	6.1	3'800	Calculated from EF (Cd)
Hg	0.8	0.1	0.03	120'000	Equal to EF to atmosphere
Th	1	-	-	96'000	Calculated from EF (Cd)
Mo	5	-	-	19'000	Calculated from EF (Cd)

* Median value according to [SRU 200, p.71]

Table 29:   Calculation of ecofactors for heavy metal input to the soil in UBP/g of the
              respective heavy metal

The above ecofactors are intended for application in weighting direct heavy metal input to the soil, for example in applying waste fertilizers (sewage sludge and compost).

The marked difference in the magnitude of the ecofactors for the various heavy metals reflects their differing potential risks expressed by the standard values in the VSBo. However, the current flow is not considered in calculating the ecofactor (except for Pb, Zn and Cd).

In comparing the ecofactors for emission of individual heavy metals to the soil and to surface waters, it is apparent that emission of Cu, Zn, Cr and Hg to the soil is assessed as less serious than to water, while for Cd, Ni and Pb, emission to the soil is more serious. This result mirrors the differing ecological impacts of heavy metals on the various environmental media as expressed by the more-or-less restrictive standard values in the ordinances. For example, the standard value for Cd concentration in the soil contained in VSBo is of the same order as that for mercury, while the quality objective for rivers contained in the Ordinance on Effluent Discharge is some 7 times higher for Hg than for Cd.

5.4. Plant treatment products

5.4.1. Ecological impact

According to the Ordinance on Substances, plant treatment products comprise plant protection agents, weedkillers and plant growth regulators. They contain a mixture of agents having different effects. In the following, synthetic chemical plant treatment products only are considered. The environmental problems connected with their application arise both from their primary effect, from degradation of the chemical agents, and from the type and behavior of the residues. For example, owing to the low degradability of atrazine, groundwater and drinking water now almost always contain traces of atrazine. This has been the case since the beginning of the 1990's.

5.4.2. Current flow

In 1995, 1'800 t of synthetic chemical plant treatment products were sold in Switzerland (quantity of active agent [SGCI 1996, p. 2]). Principal areas of application were in grain, fruit and wine production.

Although the absolute quantities of plant treatment products applied have little meaning in terms of ecological impact, it may be assumed that the products are now applied more specifically and in smaller doses.

The extension of the area under integrated production and biological farming anticipated in the coming years will certainly lead to a further diminution of the quantities applied: One of the principles of integrated production is to emphasize exploitation of the natural regulatory mechanisms in plant production. In biological farming, the use of synthetic chemical plant treatment products is largely prohibited.

5.4.3. Critical flow

In the course of the current agricultural reform, the intention is to "ecologize" Swiss agriculture. This also involves a reduction in the emission of plant treatment products. As a specific objective, the Federal Office of Agriculture has specified a reduction in the application of plant treatment products by 30 % below the value for 1990/92 (average value 2'100 t/a) by the year 2005 [BLW 1996, p. 1]. This represents a critical flow of 1'500 t PTP/a [SGCI 1996, p. 2].

5.4.4. Ecofactor

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [t PTP/a]	**1'800**	A	[SGCI 1996, p. 2]	-
Critical flow [t PTP/a]	**1'500**	b	Reduction of 30% over 1990/92 [BLW 1996, p.1]	-
Ecofactor [UBP/g PTP]	**800**			-

Table 30:   Ecofactor for emission of plant treatment products (PTP) to groundwater in UBP/g active agent PTP (Q = Data quality – see remarks Chap. 2.5).

The establishment of an ecofactor for plant treatment products represents a compromise. Grouping a wide range of individual substances into a single summation parameter is essential for their inclusion in the weighting. However, the ecological impact of particularly harmful substances is not adequately modeled this way.

5.5. Use of space for solid waste deposits

5.5.1. Fundamentals

The objective of the Federal Technical Ordinance on Waste (TVA) is to protect man, animals and plants, and their communities, from hazardous and disruptive influences caused by waste, and as a precautionary measure to limit the detriment to the environment caused by waste. TVA envisages three different types of waste deposit for Switzerland:

- Landfill for inert materials

- Landfill for stabilized residues

- Bioactive landfill

In addition, solid waste originating from Switzerland is stored in underground deposits abroad.

In TVA, it is specified that in **landfills for inert materials,** only materials akin to stone having low pollutant content, and for which leaching is negligible, may be deposited. These include building waste such as concrete, tiles and road demolition waste free of special waste, whereby re-usable materials (metals, plastics, paper, wood and textiles) have as far as possible been removed in advance. Landfills for inert materials require no special sealing provided a suitable site is chosen.

In **landfills for stabilized residues,** inorganic materials with known composition and elevated pollutant content that emit neither gases nor substances readily soluble in water, are deposited. These include e.g. consolidated filter ash from waste incineration plants (approximately one-third of the electrofilter waste in Switzerland is deposited in landfills for stabilized residues), and consolidated galvanic sludge from metals processing. Landfills for stabilized residues require a watertight lining at the base and flanks. Additionally, the seepage water must be collected and if necessary treated.

All remaining waste authorized for deposition in Switzerland must be deposited in a **bioactive landfill.** At present, domestic waste, combustible building waste and sewage sludge are the main components in this type of deposit. Further, slag may be deposited in special compartments within bioactive landfills. From the year 2000 onwards, direct deposition of combustible waste (domestic waste, combustible building waste and sewage sludge) will be prohibited. Controlled drainage of bioactive landfills is stipulated. The gases emitted must be treated.

Part of the waste arising in Switzerland is deposited in **underground deposits** in Germany. This consists primarily of untreated special waste that according to TVA may no longer be deposited inland since 1 February, 1996. In 1995, for example, approximately two-thirds of the electrofilter waste arising in Switzerland was deposited in German salt

mines legally authorized for this purpose. Parliament had originally intended to prohibit export of filter waste, but it was finally decided otherwise owing to opposition from the Cantons. Owing to the fact that electrofilter waste requires negligible treatment prior to deposition in underground deposits, costs for this method of disposal are low compared to those for solidification and subsequent deposition in landfills for stabilized residues. The danger here is that low-cost export could hinder the further development of processes for treatment and utilization of filter ash [SAEFL 1996a, p. 30].

5.5.2. Ecological impact

The ecological impact of waste deposits arises on the one hand from their emission, and on the other from their negative effects on the landscape and on the biological quality of the habitat. The type of emission depends strongly on the particular waste deposit. This must be addressed specifically in preparing inventory data and, if necessary, via transfer functions [ESU 1996].

In addition, an ecofactor for "scarcity of waste deposit sites" is introduced to take account of the negative effect on the landscape. Waste deposits influence the landscape physically over an extended period of time, whereby both its aesthetic quality and its biological quality as habitat are affected. Further, particularly for bioactive landfills and improperly managed deposits, there is a potential danger of toxic emissions due to the unknown composition of the waste. Also, not all geological conditions are suitable for waste deposits. It was decided for this reason to introduce an ecofactor for scarcity of deposit sites.

Although the type of emission varies heavily according to deposit, bioactive, inert material and stabilized residue landfills have comparable impact on landscape and habitats. The scarcity of deposit sites may therefore be accounted for by a single ecofactor for all Swiss deposits. A separate ecofactor is introduced for foreign underground deposits.

5.5.3. Current flow

Table 31 shows the quantities of waste deposited in Swiss deposits. Deposits of household waste, slag and sewage sludge in bioactive landfills are monitored by the Cantons. Additionally, owners of deposits are under obligation to keep records of all materials deposited. Special waste deposited in foreign underground deposits must be reported to the authorities (Ordinance on Handling Special Waste), so they are relatively well documented.

Deposit type	Quantity in 1000 t	Reference Year	Source
Total Swiss deposits	**3'030**		
comprising:			
Landfill for inert materials	**1'500**	1996	Estimate SAEFL
Landfill for stabilized residues	**30**	1996	Estimate SAEFL
Bioactive landfill:			
Household waste	640	1996	Data SAEFL
Combustible building waste	100	1994	SAEFL 1996b, p. 18
Sewage sludge (dry matter)	40	1994	SAEFL 1996b, p. 18
Other industrial waste	30	1994	SAEFL 1996b, p. 18
Slag from waste incineration plants*	690	1996	Data SAEFL
Total bioactive landfill	**1'500**		
Underground deposits**	**41**	1995	SAEFL 1996a, p. 30
comprising:			
Untreated electrofilter waste from flue gas filtration from waste incineration plants	33	1995	SAEFL 1996a, p. 30

*   Arising from incineration of 2.3 million tons of household waste

**   In addition, some 6.600 t of electrofilter waste from German waste incineration plants were pretreated in Switzerland and subsequently re-exported. These are not included in the current flow.

Table 31:   Current flow of waste in different types of waste deposit

5.5.4. Critical flow

The revised Technical Ordinance on Waste (TVA), which has been approved by parliament, will result in a reduction in the quantity of waste deposited in bioactive landfills. From 1 January, 2000, dumping of untreated domestic waste, sewage sludge, combustible building waste and other combustible waste will be prohibited. As a result of the revision, the quantity of waste incinerated in waste incineration plants and the quantity of residues to be deposited from these plants will increase.

No laws or declarations of intent exist that limit waste deposition in the other types of deposit. Of greater significance than specifying quantity limits would be to ensure that illegal waste disposal is turned into official channels. Even so, the deposition of waste in deposits will affect the environment over an extended period. In accordance with the statement of objectives in TVA (precautionary limitation of environmental impact due to waste), a reduction of the annual quantities of waste deposited is desirable in the long term.

As already noted in [SRU 133], in the absence of more detailed provisions the first step would be to stabilize the quantity of waste.

The critical flow for deposition of waste in deposits is therefore determined as follows:

Quantities in 1000 t/a		**Swiss deposits**	**Underground deposits**	Remarks
Basis	Current flow 1994/96	3'030	41	cf. Table 31
Minus	Combustible materials whose deposition will in future be prohibited[8]	810	-	cf. Table 31
Plus	Increase in quantity of slag arising from increased incineration in waste incineration plants	210	-	1996: 690'000 t (cf. Table 31). 2000: 900'000 t [SRU 228, p. 24]
Critical flow (target flow after 2000)		2'430	41	

Table 32:   Determination of critical flow for deposition of waste in deposits

For waste deposition in Swiss bioactive, inert material and stabilized residue landfills, a critical flow of 2'430'000 t/a results. The critical flow for deposition of waste in foreign underground deposits is 41'000 t.

5.5.5. Ecofactors for waste deposition

Deposition in ...	Current flow in t/a	Q	Critical flow in t/a	Q	Ecofactor [UBP/g waste]
Bioactive, inert material and stabilized residue landfills	3'030'000	C	2'430'000	a	**0.5**
Underground deposits	41'000	A	41'000	a	**24**

Table 33:   Ecofactors for deposition of waste in various types of deposit in UBP/g of the respective waste (Q = Data quality – see remarks in Chap. 2.5)

The ecofactor for deposition of materials in Swiss deposits is applicable to the deposition of all materials (inert materials, household waste, combustible waste, sewage sludge, residues) in authorized Swiss deposits.

The proposed ecofactor for deposition of waste in Swiss bioactive, inert material and stabilized residue landfills permits consistent weighting of the effects of waste deposition on the aesthetic and biological quality of the landscape. For deposition of special waste in

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8   i.e. sum of household waste, combustible building waste, sewage sludge and remaining industrial waste

underground deposits, a markedly lower ecofactor results than in [Braunschweig/ Müller-Wenk 1993] due to the revised quantity flows. Furthermore, incorporation of the prohibition of combustible waste deposition from the year 2000 results in a higher ecofactor than in [SRU 133] and [Braunschweig/Müller-Wenk 1993].

5.6. Final storage of radioactive waste

5.6.1. Preliminary remarks

A drawback of the ecofactors in [SRU 133] was that they did not permit consistent weighting of the various forms of electricity production. While the electricity produced from combustion of fossil fuels was comparatively highly rated due to the associated pollutant emission to the atmosphere, it was not possible to account for the detrimental effects of nuclear electricity production via environmental impact points. This corresponds neither to the scientific nor to the political assessment. It also has the effect that ecobalances depend heavily on the choice of electricity mix.

In the following, the attempt is made to close this gap by including for the first time one particular aspect of nuclear electricity production, namely that of disposal of radioactive waste. Notwithstanding this and in common with all ecobalances, other aspects such as those of radiation and accident risk, remain ignored.

5.6.2. Fundamentals

The strategy applied in Switzerland for the disposal of radioactive waste is first to reduce the quantities and harmfulness of residues, and secondly to permanently isolate these in terminal storage. Legislation requires radioactive waste to be disposed of inland [HSK 1997]. The high-active spent fuel elements from atomic power stations are partly transported abroad for reprocessing, while others remain in intermediate storage awaiting final (terminal) storage.

It is the intention to deposit low and middle-active waste in a so-called terminal storage category B, and high-active waste in a terminal storage category C. No terminal storage facilities are presently available in Switzerland.

The required terminal storage capacity is determined on the basis of the estimated quantity of radioactive waste including "packaging". Owing to improvements in waste processing, the estimated quantities are subject to frequent correction, and the tendency is for the required volume to diminish. The flows specified below are only approximate.

5.6.3. Current flow

A number of different data sources based on alternate boundary conditions (inclusion of reprocessing, account taken of packaging (waste matrix)) exists concerning current quantities of radioactive waste. The following estimate is based on [Energy Systems 1996], and includes all radioactive waste including packaging (waste matrix) assigned for deposition in Switzerland. Excluded from this is demolition waste that will arise following decommissioning of Swiss atomic power stations.

Based on an installed capacity of 6'000 MW and an average life cycle of 40 years, [Energy Systems 1996] cites the quantities of low and middle-active waste (terminal storage B: 95'070 m^3) and of high-active waste (terminal storage C: 6'740 m^3)[9]. It has meanwhile become apparent that the assumptions as to installed capacity are too high, as existing Swiss atomic stations have an average capacity of only 3'000 MW. Thus the waste quantities cited in [Energy Systems 1996] are too high by a factor of two. Referring the corrected quantities to a period of one-year, a current flow of 1'190 m^3 low and middle-active waste results for terminal storage B and 85 m^3 high-active waste for terminal storage C.

The quantity of low and middle-active waste from [Energy Systems 1996] corresponds well with the data in [NAGRA 1997]. NAGRA anticipates a volume of some 100'000 m^3 low and middle-active waste. Of this, 56'000 m^3 represents demolition waste. Based on a life cycle of 40 years, 1'100 m^3 low and middle-active waste per year result from the total of 44'000 m^3 operative waste. No comparable figures are available from NAGRA for high-active waste.

5.6.4. Critical flow

In determining the critical flow, the following points have to be considered:

- In approving the plebiscite calling for introduction of a nuclear moratorium, Swiss voters expressed their desire that production of nuclear electricity in the country should not be increased. Existing production and, implicitly, production of the corresponding radioactive waste, was sanctioned in the plebiscite. Viewed from this perspective, the critical flow would have to be set equal to the current flow.

- At present, terminal storage capacity is available neither for low, middle, nor for high-active waste in Switzerland. Thus at the moment radioactive waste cannot be disposed of in an environmentally acceptable way as intended by parliament. From this standpoint, the critical flow would have to be set equal to zero.

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9   The quantity of low and middle-active waste is shown in Tab.VII.12.3., and of high-active waste in Tab. VII.12.5. [Energy Systems 1996, p. 225-226]

The critical flow on which the determination of the ecofactor must be based thus lies somewhere between zero and the current flow. As a first tentative approximation, the critical flow is set to one-half the current flow. This amounts to 600 m^3 low and middle-active waste and 43 m^3 high-active waste.

The critical flow determined in this way is not based on any political consensus. Whereas those taking a confident technological standpoint regard the entire present-day waste quantity as unproblematic, those taking a critical view regard even a minimum of radioactive waste as unacceptable. Specification of a critical flow makes it possible to include radioactive waste in ecobalances for the first time. In cases where radioactive waste dominates the ecobalance, prudent interpretation of the results is called for.

5.6.5. Ecofactor for radioactive waste

	Current flow in m^3/a	Q	Critical flow in m^3/a	Q	Ecofactor [UBP/cm^3 radioactive waste]
Low and middle-active waste in terminal storage B	1.190	C	600	a/c	**3.300**
High-active waste in terminal storage C	85	C	43	a/c	**46.000**

Table 34: Ecofactor for radioactive waste in terminal storage B and C in UBP/cm^3 radioactive waste (Q = data quality – see remarks in Chap. 2.5).

The ecofactors for disposal of low and middle-active waste in terminal storage B and of high-active waste in terminal storage C are based on the Ecoinventory for Energy Systems [Energy Systems 1996]. This enables simple application of the ecofactors to the inventory data. The ecofactor is applied to the volume of radioactive waste in terminal storage, including packaging.

The ecofactor represents a novelty as against [SRU 133]. By this means, a sensitive gap in weighting electricity production may partly be closed. It should, however, be emphasized that this provides only a provisional and incomplete weighting of nuclear electricity. Further environmentally relevant aspects of nuclear energy, such as radiation and accident risk, are not covered. The assessment of nuclear electricity will need to be considered in more detail in future.

The ecofactor for terminal storage of radioactive waste results in additional impact points for electricity produced in nuclear power stations. In producing 1 MJ of nuclear electricity, approx. 0.018 cm^3 low and middle-active and 0.0014 cm^3 high-active waste accrue over the life cycle of the power station [Energy Systems 1996, Part 2, p. 249]. As a result, nuclear electricity gets assigned 124 UBP/MJ for nuclear waste.

6. Resources

6.1. Introduction

The ecoscarcity method permits weighting of emission, e.g. **release** of substances to the environment. These were discussed in Chapters 3, 4 and 5. Using the same method, the **extraction** of resources from the environment can be assessed as well.

Energy is the only resource whose scarcity is evaluated with an ecofactor. This is justified as, for thermodynamic reasons, energy is not recyclable. Other resources remain materially unchanged after use by civilization, albeit partly in altered form. They may be reclaimed by technical processes, but always involving expenditure of energy.

The ecofactor for energy consumption takes into account only the scarcity of energy. The environmental effects of energy use are accounted for via emission, i.e. via their impacts to atmosphere, water and soil.

Consumption of primary energy, i.e. of energy resources, is assessed at the point where it is available for industrial exploitation. The decentralized use of renewable energy resources (sun, wind, biomass) is excluded from the weighting as these are not "used up", and since their use is still negligible in comparison to existing potential. Hydro power is, however, included in the weighting, since the available potential has already been exploited to a significant extent, and an extension would exceed the limits dictated by environmental policy concerning land use and residual flow.

Consequently, the following primary energy resources are considered:

- coal

- crude oil and oil derivatives

- natural gas

- nuclear fuels

- hydro power

- household and industrial waste: 50% of the energy quantity produced from domestic and industrial waste is considered to be non-renewable[10], and is therefore included in the weighting.

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[10] Defined by the Swiss Federal Office of Energy (SFOE) as follows: renewable constituents: paper, cardboard, compostable waste, etc.; non-renewable constituents: glass, metals, plastics, etc.

6.2. Current flow

The figure for current consumption of primary energy (current flow) in Switzerland is based on the energy statistics. In these, the primary energy balance is categorized according to type of energy resource. The statistics include inland exploitation of primary energy resources as well as import and export of primary and secondary energy [VSE 1996, p. 6]. The relevant data are shown in the following table.

TJ	**1990**	**1995**
Fossil energy resources		
Coal	14'890	7'960
Domestic & industrial waste [(*)]	11'600	16'410
Crude oil and oil derivates	511'750	510'260
Gas	75'900	102'140
Total fossil	**614'140**	**636'770**
Electricity		
Hydro power	138'040	160'190
Nuclear fuels	243'240	256'210
Surplus production of electricity	-7'590	-26'180
Total electricity	**373'690**	**390'220**
Total primary energy	**987'830**	**1'026'990**

(*) = 50 % of total quantity

Table 35:   Primary energy balance in Switzerland [VSE 1996, S. 6]

The primary energy balance for Switzerland shows gross energy consumption of fossil energy resources, nuclear fuels and hydro power of somewhat more than 1 million TJ (1'027'000 TJ) in 1995[11] .

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11   This figure does not include conversion losses for imported electricity and imported petroleum products arising abroad. However, conversion losses for exported electricity are included. Actual primary energy consumption in Switzerland is probably somewhat higher owing to the fact that imported electricity (with the exception of the UCPTE mix) involves higher transformation losses than exported electricity, the latter being produced via nuclear and hydro power.

6.3. Critical flow

Concerning emission, extensive regulations and ambitious objectives are a central part of Swiss environmental policy. The objective of resource conservation has, however, been little considered. The critical flow derived in the following is based on the objectives of Swiss energy policy.

In the Federal Resolution on Energy Use (1990), the fundamental principle of using as little energy as efficiently as possible, and of increased exploitation of renewable energy, was laid down.

Swiss energy policy was stated in terms of measurable objectives within the Energy 2000 Action Program:

1. The total consumption of fossil energy resources (oil, gasoline, gas, coal) and CO_2 emission arising from their combustion to be stabilized at the 1990 level, and then reduced.

2. The rate of increase in electricity consumption to be progressively throttled during the 1990's, and demand stabilized from 2000 onwards.

Based on these objectives, a politically sanctioned critical flow for primary energy consumption from fossil, nuclear and hydro power sources may be derived (in the following, all figures have been rounded to 1000 TJ):

•   Fossil energy resources: set equal to the current flow in 1990 (614'000 TJ).

•   Consumption of primary hydro and nuclear power resources: The stipulated throttling of the rate of increase of energy consumption and stabilization of consumption from 2000 onwards, are accounted for by halving the rate of increase over the period 1990 to 1995 and applying this to the period 1995 to 2000. From this, a critical flow of primary hydro and nuclear energy of 398'000 TJ results.

The critical flow for utilization of primary energy from fossil and nuclear energy resources and primary energy from hydro power thus amounts to 1'012'000 TJ.

6.4. Ecofactor for primary energy

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [TJ/a]	**1'027'000**	A	[VSE 1996]	1'004'000
Critical flow [TJ/a]	**1'012'000**	a	Energy 2000 objectives	1'004'000
Ecofactor [UBP/MJ]	**1.0**			1

Table 36:   *Ecofactor for consumption of primary energy resources in UBP/MJ primary energy (Q = Data quality – see remarks in Chap. 2.5). Appendix 7 gives the specific heat for several important primary energy resources*

The primary energy ecofactor is applicable to utilization of fossil energy resources (coal, petroleum products, gas) and of electricity (excepting locally produced solar electricity). Values quoted in terms of energy supplied must be converted to an equivalent quantity of primary energy. Additionally, the non-renewable part of primary energy produced from household and industrial waste is assigned an ecofactor of 1 UBP/MJ.

The energy content of energy resources used for purposes other than energy production (so-called feedstock energy, e.g. use of hydrocarbons as refrigerants) is weighted with the factor for primary energy provided the system concerned does not pass on the energy resource to other systems.

The revised ecofactor for consumption of primary energy is practically the same as that in [SRU 133] owing to the small difference between critical and current flow. The direct environmental impact of fossil energy resources (mainly emission to the atmosphere) retain their markedly higher weighting in comparison to the scarcity of energy resources.

This reflects the political assessment of the situation. Although environmental legislation contains extensive regulations on emission reduction, no regulations exist on reduction of energy consumption. Current efforts to reduce energy consumption were motivated not so much by scarcity of resources as by negative effects on the environment. As a result, the consumption of fossil fuels (for example) continues to be weighted far more heavily by virtue of direct emission (principally to the atmosphere) than by resource scarcity.

Notwithstanding this, an important postulate of sustainable development is that the remaining reserves should never be entirely exhausted [IDARio 1995, p.37]. This makes necessary an increasing reduction of the consumption of non-renewable resources. From a long-term viewpoint that respects the principle of (strong) sustainability, the use of energy resources would have to be assigned a markedly higher ecofactor. Furthermore, the consumption of non-energetic resources would have to be included in the weighting.

Swiss policy requires application of the sustainability principle. To this end, the Federal Council approved an Action Plan for sustainable development [National Council 1997], and prepared a Strategy Paper [Federal Council 1997], in which concrete objectives were

formulated and implementation procedures proposed. In the energy sector, emission reduction remains, as in the past, a primary objective. The resource conservation postulate mentioned above was neither mentioned explicitly in the Strategy Paper nor in the Action Plan.

Glossary and list of abbreviations

a	Year
AOX	Adsorbable organic halogen compounds (summation parameter containing the quantity of halogenated substances in waters and in sewage sludge)
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (german for: SAEFL)
CFC	Chloroflourocarbons
COD	Chemical oxygen demand (measure of the quantity of oxygen required to oxidize the organic compounds in water)
DOC	Dissolved organic carbon (measure of the organic carbon content in dissolved organic compounds)
Ecoscarcity	Computed as a function of the limited environmental tolerance to anthropogenic impact (critical flow) and the actual extent of this impact (current flow) on the environment. The higher the current flow in comparison to the critical flow, the higher the ecoscarcity
EF	Ecofactor
ESU	"Energie – Stoffe – Umwelt" (= Energy – Substances – Environment), the section of the Swiss Federal Institute of Technology which published inventory data.
F	Current flow (annual emission to a particular region)
Feedstock	Energy resource used other than for energy production
FHC	Fluorohydrocarbon
FIT	Federal Institute of Technology
F_k	Critical flow (annual critical emission to a particular region)
GWP_{100}	Global warming potential (greenhouse effect of a substance relative to CO_2. In the present report, all data is based on a time interval of 100 years)
HCFC	Partially halogenated hydrochloroflourocarbon
IAWR	Internationale Arbeitsgemeinschaft der Wasserwerke im Rheineinzugsgebiet (International Working Group of Waterworks in the Rhine Area)

Inventory	Element of an Ecobalance, containing the material and energy balance, or result of a material and energy flow analysis
ISO	International Organization for Standardization (Geneva/CH)
NMVOC	Non-methane volatile organic compounds (volatile organic compounds excluding methane and CFC). See also VOC
ODP	Ozone depletion potential; measure of the ozone depleting effect of a substance relative to R11
PAH	Polycyclic aromatic hydrocarbons
PFHC	Perfluorohydrocarbon
PM10	Particles with a diameter of less than 10 micrometer. These may pass into the lungs
PTP	Plant treatment products
SAEFL	Swiss Federal Agency for the Environment, Forests and Landscape (german: BUWAL)
SETAC	Society for Environmental Toxicology and Chemistry (Brussels/B)
TOC	Total organic carbon (comprises total carbon contained in organic molecules)
UBP	Environmental impact point (in german: 'Umweltbelastungspunkt')
VOC	Volatile organic compounds. Examples of VOC are to be found in the Clean Air Ordinance of 16 December, 1985, in Cl. 72 (table for organic gas, vapor and particulate substances)

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Appendix

Appendix 1: Calculation of current effluent flows from concentration measurements

The current flows of a number of pollutants in surface waters are calculated from measured values in the Rhine, Rhone, Ticino and Inn rivers on the Swiss border (cf. Chapter 4.3.1). The latest available data for the river Inn dates from 1987. Measured data for 1991 are used for the Ticino, and for 1995 for the Rhine and the Rhone.

The Swiss portion of the rivers is determined according to the size of the population (i.e. for the Rhine near Basel, 80% of the flow leaving Switzerland; Rhone downstream of Geneva 76%, Ticino 100%, Inn 95%). A current flow of 4.7 x 10^{10} m^3/a results [NADUF data contained in the Swiss Hydraulic Yearbooks for 1995, 1991, 1978], [GWA 3/94].

Appendix 2: Principal sources of inventory data

In preparing ecobalances, inventory documentation and/or transfer functions are available for upstream and downstream processes. The following inventories are of central importance:

- Ecoinventories for Energy Systems:
  Frischknecht, R., Knoepfel, I., Dones, R., Zollinger, E.: Ökoinventar Energiesysteme, Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz [Ecoinventory for Energy Systems, Basic Data for the Ecological Comparison of Energy Systems and Incorporation of Energy Systems in Ecobalances in Switzerland], 3rd ed. Zurich/Villigen 1996.
  (Available from: ENET, PO Box 130, CH-3000 Bern 16, Fax: 031 352 77 56)

- Ecoinventory of Transport:
  Maibach, M., Peter, D., Seiler, B.: Ökoinventar Transporte, Grundlagen für den ökologischen Vergleich von Transportsystemen und für den Einbezug von Transportsystemen in Ökobilanzen [Ecoinventory for Transport, Basic Data for the Ecological Comparison of Transport Systems and Incorporation of Transport Systems in Ecobalances], Zurich 1995.
  (Available from: INFRAS, Gerechtigkeitsgasse 20, CH-8002 Zürich, Fax: 01 205 95 99)

- Ecoinventories of Waste Disposal Processes:
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- Ecoinventories and Impact Assessment of Building Materials:
  Weibel, T., Stritz, A.: Ökoinventare und Wirkungsbilanzen von Baumaterialien, Grundlagen für den ökologischen Vergleich von Hochbaukonstruktionen [Ecoinventories and Impact Assessment of Building Materials, Basic Data for the Ecological Comparison of Over-Ground Buildings], ETH Zurich. Zurich 1995. (Available from: ENET, PO Box 142, CH-3000 Bern 16, Fax: 031 352 77 56)

- Ecoinventories for Packagings:
  Habersatter, K., Fecker, I. Swiss Federal Agency for the Environment, Forests and Landscape (SAEFL): Ökoinventare für Verpackungen [Ecoinventories for Packagings], Environment Series No. 250 I/II, Bern 1996. (Available from: SAEFL Documentation Service, CH-3003 Bern / Schweizerisches Verpackungsinstitut, Brückefeldstr. 18, CH-3012 Bern)

Appendix 3: Environmental impact of fertilizers (approximate transfer functions)

Phosphorus

As an average for the whole of Switzerland, approximately one-quarter of the phosphorus applied to agricultural land via the various fertilizers is assimilated by plants, 65% accumulates in the soil and 7% is eroded or washed out to waters (Table 37). These data represent average values for the whole of Switzerland. Local values are subject to considerable variation depending on type of fertilizer and farming method. The phosphorus compounds that have accumulated in the soil remain available to plants for a certain period, and are then mineralized. The main problem arises from erosion and washout of P compounds to waters (see Chap. 4.3).

Phosphorus in fertilizers:	T [%]
Assimilation by plants	28
Erosion and washout	7
Accumulation in the soil	65

Table 37:   Transfer coefficients T for phosphorus in fertilizers [FAC 1994, p.34]

In 1990, some 3'000 t P from sewage sludge and compost, 17'000 t from mineral fertilizers and 25'000 t from farm manure were applied to agricultural land [FAC 1994, p. 34].

Of ecological relevance are primarily the P flows to surface waters. Applying the ecofactor in Chapter 4.3 to these flows, and assuming that some 7% of the phosphorus applied in the various fertilizers filters into waters, the average emission of phosphorus contained in fertilizers may be calculated. The resulting value is 140 UBP/g P in fertilizers. As the

transfer coefficient for transfer of phosphorus contained in fertilizers to waters depends strongly on type of fertilizer and farming method, this represents a very approximate estimate reflecting average Swiss conditions. A more detailed assessment (for example in order to compare conventional with biological products) would require a more detailed determination of the P transfer coefficients to waters, better answering to the particular problem posed.

Nitrogen

Approximately one-quarter of the nitrogen contained in the various fertilizers applied to agricultural land is taken up by plants, whereas three-quarters are emitted to the atmosphere and water. The figures quoted represent average values for the whole of Switzerland. Locally, values may vary greatly depending on farming method and type of fertilizer.

Nitrogen in fertilizers	T [%]
Assimilation by plants	23
Leaching to groundwater	22
Emission as ammonia to the atmosphere	26
Emission as laughing gas to the atmosphere	4
Emission as N_2 to the atmosphere	25

Table 38:   Transfer coefficients T for nitrogen in fertilizers [SRU 273, p. 30], [FAC 1994, p.34]

In 1994, approx. 5'000 t N in sewage sludge and compost and 66'000 t in mineral fertilizers were applied to agricultural land [SRU 273, p. 30]. Further, 130'000 t P/a were applied to the land via farm manure (value for 1990 [FAC 18, p.34]).

The environmental impact for N in fertilizers may be derived from the ecofactors for ammonia and laughing gas emission to the atmosphere and nitrate to groundwater. The resulting value is 48 UBP/g N in fertilizers. As the transfer coefficient for release of nitrogen to the atmosphere and water depends strongly on type of fertilizer and farming method, this represents a rough estimate reflecting average Swiss conditions. A more detailed assessment (for example in order to compare conventional with biological products) would require a more detailed determination of the N transfer coefficients to the atmosphere and water, better answering to the particular problem posed.

Appendix 4: PM10 emission from transport vehicles

		Emission in t/a 1995	Source
Primary exhaust particles	Road transport	2'290	[SRU 255]
	Off-road vehicles	2'783	[SAEFL 1996c]
	Total	**5'073**	
Abrasion particles	Total	**8'310**	Calculated from [IHA 1996]
Secondary particles *	Total	**4'487**	Calculated from [IHA 1996]
Total emission		**17'870**	

*   Formation in the atmosphere, expressed in terms of emission

Table 39:   Derivation of PM 10 emission from transport based on data in [SAEFL 1996c], [IHA 1996] and [SRU 255]

Appendix 5: PM10 / Total particles in inventories

PM10 emission is not presently quoted in the inventories. In the interim, the following "rule of thumb" can be applied.

FIT ecoinventories (ESU 1996):

- Particles (p) process specific: contain no PM10
  (emission consists to almost 100% of large particles)

- Particles (s) stationary: 100% PM10
  (the entire particle emission is weighted with the PM10 ecofactor)

- Particles (m) transport: 100% PM10
  (the particle emission and dust emission quoted comprise only exhaust particles that are microscopic in size, so that the entire emission is weighted with the PM10 ecofactor)

Other inventories:

- Particles (mixed sources): 55% PM10 [Hofstetter], [Dockery et al. 1994]
  (55% of particle emission is weighted with the PM10 ecofactor)

Appendix 6: Emission conversion factors

	Molecular weight	
NO_X as NO_2	46	1 g NO_2 is equivalent to 0.3 g NO_X-N
NH_3	17	1 g NH_3 is equivalent to 0.82 g NH_3-N
NH_4^+	18	1 g NH_4^+ is equivalent to 0.78 g NH_4^+-N
NO_3^-	62	1 g NO_3^- is equivalent to 0.23 g NO_3^--N
N_2O	44	1 g N_2O is equivalent to 0.64 g N_2O -N
PO_4^{3-}	95	1 g PO_4^{3-} is equivalent to 0.33 g PO_4^{3-}-P
COD	-	1 g COD is equivalent to 0.3 g DOC (rough estimate)

Table 40:   Conversion factors for emission of nitrogen and phosphorus compounds, and for COD/DOC

Appendix 7: Specific heat of primary energy resources

Energy	Specific heat	Source
Liquid combustion and motor fuels (heating oil, diesel, kerosene)	42 MJ/kg	[VSE 1996]
Electricity	3.6 MJ/kWh	[VSE 1996]
Gas	46 MJ/kg	[SRU 132]
	37 MJ/m^3	[SRU 132]
Coal (excl. lignite)	28 MJ/kg	[VSE 1996]
Lignite	10 MJ/kg	[SRU 132]
Charcoal	28 MJ/kg	[VSE 1996]
Wood	15 MJ/kg	[SRU 132]

Table 41:   Specific heat of primary energy resources ([VSE 1996], [SRU 132, p. A18])