Centre for
Environmental Assessment
of Products and Material Systems

A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – Models and data of the default method

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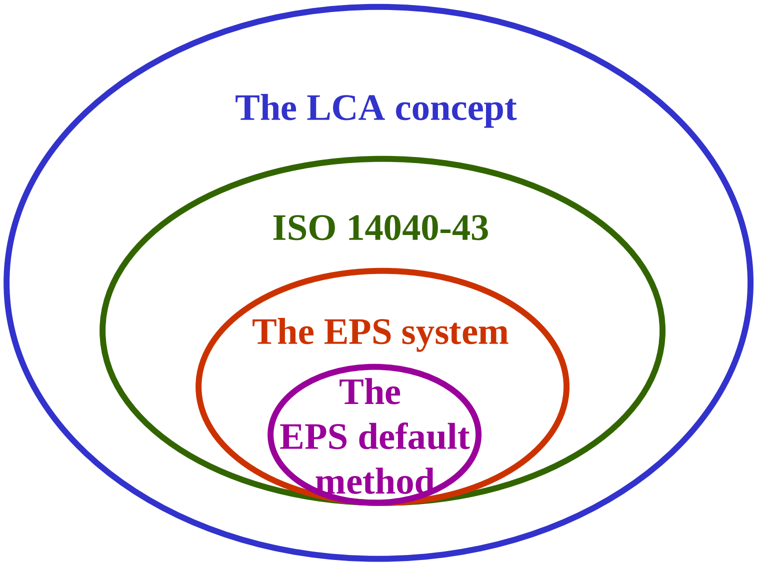
CPM report 1999:5



Chalmers University of Technology, Environmental Systems Analysis

Foreword

The present version of the EPS system has been developed within CPM (Centre for the environmental assessment of Products and Material systems). CPM is a joint research environment at Chalmers University of Technology with participation from industry. CPM is supported by The Swedish National Board for Technical and Industrial Development. Bengt Steen from the department of Environmental System Analysis at Chalmers University of Technology has been project leader.

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The report is describing models and data used in the default methodology of the EPS system. The system principles and methodology is described in a separate report (1999:4). The present version has been given the number 2000. In comparison with the 1996 version, some models and data have been updated, the description is more detailed and the ISO standard language is adopted.

Acknowledgement

The EPS system, as it is presented in this report, has taken its form through contributions from many individuals and organisations. It has been a privilege to further the achievements from the Swedish Product Ecology project and much valuable input have come from the co-authors of the EPS system report of that project (Ryding et.al. 1995).

Financial support from the Swedish Waste Research Board and from The Swedish National Board for Technical and Industrial Development is greatly acknowledged.

A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – Models and data of the default method

Contents

Summary

Models and data for the weighting and characterisation phases of the EPS default method, version 2000 have been selected and defined. Some support models for the inventory phase are also presented. The weighting factors obtained are summarised in table 1 below.

Table 1 Weighting factors and category indicators of the EPS default method v.2000.

Safe guard subject	Impact category	Category indicator	Indicator unit	Weighting factor (ELU/indicator unit)	Uncertainty factor
Human health	Life expectancy	YOLL	Person-years	85000	3
Human health	Severe morbidity	Severe morbidity	Person-years	100000	3
Human health	Morbidity	Morbidity	Person-years	10000	3
Human health	Severe nuisance	Severe nuisance	Person-years	10000	3
Human health	Nuisance	Nuisance	Person-years	100	3
Ecosystem production capacity	Crop growth capacity	Crop	kg	0.15	2
Ecosystem production capacity	Wood growth capacity	Wood	kg	0.04	1.4
Ecosystem production capacity	Fish and meat production capacity	Fish and meat	kg	1	2
Ecosystem production capacity	Soil acidification	Base cat-ion capacity of soil	mole H+ -equivalents	0.01	2
Ecosystem production capacity	Production capacity for irrigation water	Irrigation water	kg	0.003	4
Ecosystem production capacity	Production capacity for drinking water	Drinking water	kg	0.03	6
Abiotic stock resources	Depletion of oil reserves	Fossil oil	kg	0.506	1.4
Abiotic stock resources	Depletion of coal reserves	Fossil coal	kg	0.0498	2
Abiotic stock resources	Depletion of natural gas reserves	Natural gas	kg	1.1	2
Abiotic stock resources	Depletion of Ag reserves	Ag reserves	kg of element	54000	2.2
Abiotic stock resources	Depletion of Al reserves	Al reserves	kg of element	0.439	2
Abiotic stock resources	Depletion of Ar reserves	Ar reserves	kg of element	0	1
Abiotic stock resources	Depletion of As reserves	As reserves	kg of element	1490	2.2
Abiotic stock resources	Depletion of Au reserves	Au reserves	kg of element	1190000	3
Abiotic stock resources	Depletion of B reserves	B reserves	kg of element	0.05	10
Abiotic stock resources	Depletion of Ba reserves	Ba reserves	kg of element	4.45	3
Abiotic stock resources	Depletion of Bi reserves	Bi reserves	kg of element	24100	2.2
Abiotic stock resources	Depletion of Be reserves	Be reserves	kg of element	958	3
Abiotic stock resources	Depletion of Br reserves	Br reserves	kg of element	0	1
Abiotic stock resources	Depletion of Cd reserves	Cd reserves	kg of element	29100	2.2
Abiotic stock resources	Depletion of Ce reserves	Ce reserves	kg of element	45.2	3
Abiotic stock resources	Depletion of Cl reserves	Cl reserves	kg of element	0	1
Abiotic stock resources	Depletion of Co reserves	Co reserves	kg of element	256	3
Abiotic stock resources	Depletion of Cr reserves	Cr reserves	kg of element	84.9	3
Abiotic stock resources	Depletion of Cs reserves	Cs reserves	kg of element	512	3
Abiotic stock resources	Depletion of Cu reserves	Cu reserves	kg of element	208	3
Abiotic stock resources	Depletion of Dy reserves	Dy reserves	kg of element	1020	3

Table 1 Weighting factors and category indicators of the EPS default method v.2000.

Safe guard subject	Impact category	Category indicator	Indicator unit	Weighting factor (ELU/indicator unit)	Uncertainty factor
Abiotic stock resources	Depletion of Er reserves	Er reserves	kg of element	1410	3
Abiotic stock resources	Depletion of Eu reserves	Eu reserves	kg of element	3130	3
Abiotic stock resources	Depletion of F reserves	F reserves	kg of element	4.86	3
Abiotic stock resources	Depletion of Fe reserves	Fe reserves	kg of element	0.961	2.2
Abiotic stock resources	Depletion of Ga reserves	Ga reserves	kg of element	212	3
Abiotic stock resources	Depletion of Gd reserves	Gd reserves	kg of element	1060	3
Abiotic stock resources	Depletion of Ge reserves	Ge reserves	kg of element	2120	3
Abiotic stock resources	Depletion of H reserves	H reserves	kg of element	0	1
Abiotic stock resources	Depletion of He reserves	He reserves	kg of element	0	1
Abiotic stock resources	Depletion of Hf reserves	Hf reserves	kg of element	512	3
Abiotic stock resources	Depletion of Hg reserves	Hg reserves	kg of element	53000	2.2
Abiotic stock resources	Depletion of Ho reserves	Ho reserves	kg of element	4790	3
Abiotic stock resources	Depletion of I reserves	I reserves	kg of element	0	1
Abiotic stock resources	Depletion of In reserves	In reserves	kg of element	48700	3
Abiotic stock resources	Depletion of Ir reserves	Ir reserves	kg of element	59400000	3
Abiotic stock resources	Depletion of K reserves	K reserves	kg of element	0.01	10
Abiotic stock resources	Depletion of La reserves	La reserves	kg of element	92.0	3
Abiotic stock resources	Depletion of Li reserves	Li reserves	kg of element	0.1	10
Abiotic stock resources	Depletion of Lu reserves	Lu reserves	kg of element	11000	3
Abiotic stock resources	Depletion of Mg reserves	Mg reserves	kg of element	0	1
Abiotic stock resources	Depletion of Mn reserves	Mn reserves	kg of element	5.64	3
Abiotic stock resources	Depletion of Mo reserves	Mo reserves	kg of element	2120	3
Abiotic stock resources	Depletion of N reserves	N reserves	kg of element	0	1
Abiotic stock resources	Depletion of Na reserves	Na reserves	kg of element	0	1
Abiotic stock resources	Depletion of Nb reserves	Nb reserves	kg of element	114	3
Abiotic stock resources	Depletion of Nd reserves	Nd reserves	kg of element	115	3
Abiotic stock resources	Depletion of Ne reserves	Ne reserves	kg of element	0	1
Abiotic stock resources	Depletion of Ni reserves	Ni reserves	kg of element	160	2.2
Abiotic stock resources	Depletion of O reserves	O reserves	kg of element	0	1
Abiotic stock resources	Depletion of Os reserves	Os reserves	kg of element	59400000	3
Abiotic stock resources	Depletion of P reserves	P reserves	kg of element	4.47	3
Abiotic stock resources	Depletion of Pb reserves	Pb reserves	kg of element	175	2.2
Abiotic stock resources	Depletion of Pd reserves	Pd reserves	kg of element	7430000	3
Abiotic stock resources	Depletion of Pr reserves	Pr reserves	kg of element	471	3
Abiotic stock resources	Depletion of Pt reserves	Pt reserves	kg of element	7430000	3
Abiotic stock resources	Depletion of Rb reserves	Rb reserves	kg of element	27	3
Abiotic stock resources	Depletion of Re reserves	Re reserves	kg of element	7430000	3
Abiotic stock resources	Depletion of Rh reserves	Rh reserves	kg of element	49500000	3
Abiotic stock resources	Depletion of Ru reserves	Ru reserves	kg of element	29700000	3
Abiotic stock resources	Depletion of S reserves	S reserves	kg of element	0.1	5
Abiotic stock resources	Depletion of Sb reserves	Sb reserves	kg of element	9580	3
Abiotic stock resources	Depletion of Sc reserves	Sc reserves	kg of element	424	3
Abiotic stock resources	Depletion of Se reserves	Se reserves	kg of element	35800	3
Abiotic stock resources	Depletion of Sm reserves	Sm reserves	kg of element	632	3

Table 1 Weighting factors and category indicators of the EPS default method v.2000.

Safe guard subject	Impact category	Category indicator	Indicator unit	Weighting factor (ELU/indicator unit)	Uncertainty factor
Abiotic stock resources	Depletion of Sn reserves	Sn reserves	kg of element	1190	2.2
Abiotic stock resources	Depletion of Sr reserves	Sr reserves	kg of element	9.40	3
Abiotic stock resources	Depletion of Ta reserves	Ta reserves	kg of element	1980	3
Abiotic stock resources	Depletion of Tb reserves	Tb reserves	kg of element	5940	3
Abiotic stock resources	Depletion of Te reserves	Te reserves	kg of element	594000	3
Abiotic stock resources	Depletion of Th reserves	Th reserves	kg of element	288	3
Abiotic stock resources	Depletion of Ti reserves	Ti reserves	kg of element	0.953	3
Abiotic stock resources	Depletion of Tl reserves	Tl reserves	kg of element	3960	3
Abiotic stock resources	Depletion of Tm reserves	Tm reserves	kg of element	9900	3
Abiotic stock resources	Depletion of U reserves	U reserves	kg of element	1190	3
Abiotic stock resources	Depletion of V reserves	V reserves	kg of element	56.0	3
Abiotic stock resources	Depletion of W reserves	W reserves	kg of element	2120	
Abiotic stock resources	Depletion of Y reserves	Y reserves	kg of element	143	3
Abiotic stock resources	Depletion of Yb reserves	Yb reserves	kg of element	1980	3
Abiotic stock resources	Depletion of Zn reserves	Zn reserves	kg of element	57.1	2.2
Abiotic stock resources	Depletion of Zr reserves	Zr reserves	kg of element	12.5	3
Biodiversity	Species extinction	NEX	dimensionless	1.10E+11	3

The combined characterisation and weighting factors (impact indices) obtained for the most common emissions are summarised in table 2 below.

Table 2 Default impact indices for some common emissions to air

Substance flow group	Impact index, (ELU/kg)	Substance flow group	Impact index, (ELU/kg)
As	95.3	HCl	2.13
Benzene	3.65	HF	2.07
Butadiene	10.7	Hg	61.4
Cd	10.2	N_2O	38.3
CH_2O	6.47	NH_3	2.90
CH_4	2.72	Ni	0
CO	0.331	NOx	2.13
CO_2	0.108	PAC (PAH)	64300
Cr	20.0	Pb	2910
Cu	0	PM_{10}	36.0
Ethylene	3.45	Propylene	2.64
H_2S	6.89	SO_2	3.27
		Zn	0

The combined characterisation and weighting factors (impact indices) obtained for emissions of freons and similar substances to air are summarised in table 3 below.

Table 3 Default impact indices for emissions of freons and similar substances to air

Substance flow group	Impact index (ELU/kg)	Substance flow group	Impact index (ELU/kg)
CFC:s		**Others**	
CFC-11	5.41E+02	HFC-23	1.34E+03
CFC-12	1.04E+03	HFC-32	6.42E+01
CFC-13	1.39E+03	HFC-43-10mee	1.77E+02
CFC-113	6.59E+02	HFC-125	3.54E+02
CFC-114	1.11E+03	HFC-134	1.33E+02
CFC-115	1.08E+03	HFC-134a	1.44E+02
		HFC-152a	1.55E+01
HCFC:s		HFC-143	3.21E+01
HCFC-22	1.94E+02	HFC-143a	4.87E+02
HCFC-123	1.23E+01	HFC-227ea	3.65E+02
HCFC-124	5.53E+01	HFC-236fa	8.85E+02
HCFC-141b	8.06E+01	HFC-245ca	6.75E+01
HCFC-142b	2.28E+02	SF6	2.76E+03
HCFC-225ca	2.13E+01	CF4	6.97E+02
HCFC-225cb	6.19E+01	C2F6	1.38E+03
		c-C4F8	1.01E+03
Bromocarbons		C6F14	7.52E+02
H-1301	2.20E+03		

The combined characterisation and weighting factors (impact indices) obtained for some VOC emissions to air are summarised in table 4 below.

Table 4. Default impact indices for VOC emissions to air

Substance flow group	Impact index (ELU/kg)	Substance flow group	Impact index (ELU/kg)
Ethan	1.46E+00	1,2,3-Trimetylbenzene	2.41E+00
Propane	2.24E+00	1,2,4-Trimetylbenzene	2.38E+00
N-butane	2.15E+00	1,3,5-Trimetylbenzene	2.40E+00
I-butane	1.74E+00	O-ethyltoluene	2.23E+00
N-pentane	2.25E+00	M-ethyltoluene	2.28E+00
I-pentane	1.80E+00	P-ethyltoluene	2.28E+00
Hexane	2.57E+00	N-propylbenzene	2.07E+00
2-metylpentane	2.43E+00	I-propylbenzene	2.07E+00
3-metylpentane	2.32E+00	Methanol	1.44E+00
N-heptane	2.58E+00	Ethanol	1.95E+00
N-oktane	2.41E+00	I-propanol	1.46E+00
2-metylheptane	2.40E+00	Butanol	2.33E+00
N-nonane	2.29E+00	I-butanol	1.85E+00
2-metyloktane	2.36E+00	But-2-iol	1.66E+00
N-decane	2.45E+00	Acetone	1.46E+00
2-methylnonane	2.45E+00	Methyl ethyl ketone	1.85E+00
N-undecane	2.34E+00	Methyl i-butyl ketone	2.37E+00
N-dodecane	2.19E+00	Acetaldehyde	2.11E+00
Metyl-cyclohexane	1.87E+00	Propionaldehyde	2.33E+00
1-butene	2.59E+00	Butyraldehyde	2.30E+00
2-butene	2.57E+00	I-butyraldehyde	2.20E+00
1-pentene	2.46E+00	Valeraldehyde	2.26E+00
2-pentene	2.54E+00	Acrolein	3.32E+00
2-m-1-butene	2.40E+00	Methyl chloroform	1.15E+00
2-m-2-butene	2.84E+00	Allyl chloride	2.16E+00
Butylene	2.58E+00	Dimethylester	1.25E+00
Isoprene	2.11E+00	Dimethylether	1.66E+00
Acetylene	1.64E+00	Propylene glycol methyl ether	2.54E+00
Toluene	1.95E+00	Propylene glycol methyl ether acetate	1.70E+00
O-xylene	1.91E+00	ethylacetate	1.68E+00
M-xylene	2.20E+00	n-butylacetate	1.94E+00
P-xylene	2.25E+00	i-butylacetate	1.66E+00
Etylbenzene	2.11E+00	Average NMVOC	2.14E+00

The combined characterisation and weighting factors (impact indices) obtained for some emissions to water are summarised in table 5 below.

Table 5 Default impact indices for some common emissions to water.

Substance flow group	Impact index, (ELU/kg)
BOD	2.01E-03
COD	1.01E-03
N-tot	-3.81E-01
P-tot	5.50E-02

The combined characterisation and weighting factors (impact indices) obtained for the use of some pesticides are summarised in table 6 below.

Table 6 Default impact indices for application of some of pesticides

Substance name	Impact index (ELU)/kg	Substance name	Impact index (ELU/kg)
Alachlor	3.57E-01	Fenamiphos	1.43E+01
Aldicarb	3.57E+00	Glyphosate	3.57E-02
Aldrin	1.19E+02	Heptachlor	7.13E+00
Atrazine	1.02E-01	Hexachlorbenzene	4.46E+00
Benomyl	7.13E-02	Lindane	1.19E+01
Captan	2.74E-02	Malathion	1.78E-01
Carbaryl	3.57E-02	Methomyl	1.43E-01
Carbofuran	7.13E-01	Methoxychlor	7.13E-01
Chlordane	7.13E+00	Naled	1.78E+00
Chlorpyrifos	1.19E+00	Oxamyl	1.43E-01
Cypermethrin	3.57E-01	Paraquat	7.93E-01
2,4-Dichlorophenoxyacetic acid (2,4-D)	3.57E-01	Permethrin	7.13E-02
Demeton	8.92E+01	Phosphine	1.19E+01
Dichlorvos (DDVP)	7.13E+00	Pirimifos-methyl	3.57E-01
Dieldrin	7.13E+01	Propachlor	2.74E-01
Diflubenzuron	1.78E-01	Resmethrin	1.19E-01
Dimethoate	8.92E+00	Sodium fluoracetate	1.78E+02
Diquat	1.62E+00	Thallium sulfate	4.46E+01
Disulfoton	8.92E+01	Thiram	7.13E-01
Endosulfan	5.94E-01	2,4,5, Trichlorophenoxyacetic acid (2,4,5-T)	3.57E-01
Endrin	1.19E+01	Warfarin	1.19E+01
		Zinc phosphide	1.19E+01

The combined characterisation and weighting factors (impact indices) obtained for land use are summarised in table 7 below

Table 7 Default impact indices for some land use activities

Activity	Unit	Index,(ELU/unit)
Arable land use	m^2year	0.001562
Forestry	m^2year	0.00055
Forestry	m^3	6.25
Hardmaking of forest land	m^2year	0.0455
Littering	m^2	13.9

Often, there is a lack of inventory data for the waste management phases. Models are therefore presented in the report for use in the inventory phase as an aid in estimating such data for waste management processes. For open loop material recycling, default allocation rules of thumb are given based on type of material

Disclaimer

The models and data given in this report are intended to improve the likely environmental performance of products. The choice and design of the models and data are made from an anticipated utility perspective of a product developer. They are, for instance not intended to be used as a basis for environmental protection strategies for single substances, or as a sole basis for environmental product declarations. In most of those cases additional site-specific information and modelling is necessary.

It is up to the user to ensure that the models and data as presented in this report fulfil her or his needs.

Abbreviations

Abbreviation	Meaning
CVM	Contingent Valuation Method. A method to estimate WTP.
DALY	Disability Adjusted Life Years
DS	Dry Substance
EPS	Environmental Priority Strategies in product design
GWP	Global Warming Potential
IPCC	International Panel of Climate Change
ISO	International Standardisation Organisation
NEX	Normalised EXtinction of species. Normalisation is made with respect to the species extinct during one year on a global basis.
NMVOC	Non Methane Volatile Organic Compounds
ODP	Ozone Depletion Potential
OECD	Organisation for Economic Co-operation and Development
PAC	PolyAromatic Compounds.
PAH	PolyAromatic Hydrocarbons
PM_{10}	Particulate Matter with aerodynamic diameters less than 10 micron
$PM_{2.5}$	Particulate Matter with aerodynamic diameters less than 2.5 micron
POCP	Photo Oxidant Creation Potential
POCP-1	Photo Oxidant Creation Potential as measured by peak ozone concentration
SETAC	Society for Ecotoxicology and Chemistry
UN	United Nations
UNEP	United Nations Environmental Program
USGS	United States Geological Survey
VOC	Volatile Organic Compounds
VSL	Value of a Statistical Life
WHO	World Health Organisation
WTA	Willingness to Accept
WTP	Willingness To Pay
YOLL	Years Of Lost Life

1. Introduction

The EPS system is developed to assist designers and product developers in finding which one of two product concepts, which has the least impact on the environment. The EPS system is based on Life Cycle Assessment methodology. The general principles and features of the EPS system has been described in an earlier report (Steen, 1999:4).

One of these principles is the default principle. This means that as far as possible, there are recommended choices of how to proceed in the Life Cycle Assessment.

This report describes default data and models used in the EPS default method, mainly characterisation and weighting factors, but also some methods for the estimation of inventory data from waste management processes.

In figure 1.1 below, the relation between LCA concept, ISO standard framework, EPS system and EPS default method is indicated.

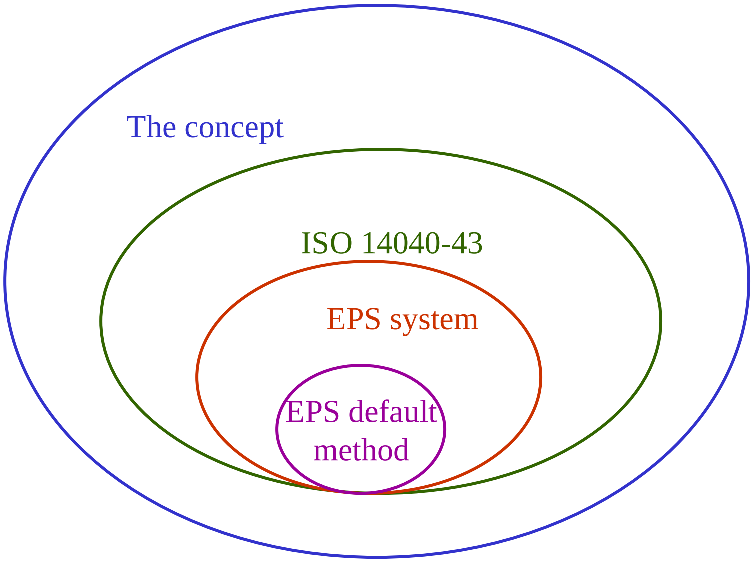

Figure 1.1 Relation between LCA concept, ISO standard framework, EPS system and EPS default method

The LCA concept often referred to as “life cycle thinking” requires that impacts are considered in the whole product system, from “cradle to grave”. Within this concept ISO has standardised a framework methodology, with demands on terminology and transparency. The ISO 14040-series of standards are meant to be useful in a number of applications. When specifying the goal and scope, a stricter methodology can be designed than what is done by ISO. This is done in the EPS system, which still is a framework methodology. The EPS default method is a traditional method, and given certain inventory results the default method will give the same result when two different persons use it.

2. Weighting factors

2.1. Human health

2.1.1. Life expectancy

To set a monetary value of human life is controversial, but nevertheless it is done indirectly in many of the decisions made by individuals and authorities. When building a road, the cost increases with increasing the safety. Somewhere the investment in safety has a limit. This may be described by the willingness to pay (WTP) for preserving lives. The same is valid for building hospitals. The more expensive and modern equipment and the more skilful personnel that is available the more lives may be saved.

The WTP for preserving lives in this way is normally referred to as VSL, the 'value of a statistical life'. It expresses the WTP for preserving lives given the prevailing circumstances in today’s society. Strand and Wenstöp (1991) and Bergman (1992) have reviewed measurements of the WTP in various sectors of the society to decrease excess mortality. They found figures between a few hundred thousand dollars and several million dollars. The first versions of the EPS system (Steen and Ryding 1992) used 10^6 EUR as a best estimate of to represent the value of a statistical life. However, there is a relatively large uncertainty involved in determining and describing the VSL. The EPS system use distribution functions to describe the uncertainty and actual variability. Assuming a log normal distribution for the VSL the estimated uncertainty was described by a standard deviation corresponding to a factor of 5.

In the last few years a more extensive study on environmental damage costs have been done in the ExternE project (1995). In the ExternE report various methods and studies for determining the value of a statistical life is reviewed (table 2.1). ExternE conclude that the figure 2.6 million EUR (1990 years values) is a best estimate. In their conclusion they argue that the ‘wage-risk’ method are likely to give too low results while the ‘CVM’ method are likely to give too high results. The ‘wage risk’ method studies the relation of increased mortality and wages. The ‘CVM’ method is based on interviews, and the ‘market’ method(s) studies how prices on goods and services varies with safety.

Method	European studies (Million EUR)	Studies in USA (Million EUR)
Wage-risk	2.8 - 3.5	3.5 - 5.5
CVM	4.1 - 6.3	1.4-2.5
Market	0.7 - 3.4	1.0 - 1.1
Average	2.5 - 4.4	2.0 - 3.0

Table 2.1 Results from various studies for the determination of the value of a statistical life (VSL). From ExternE (1995).

In 1998 monetary values 2.6 million EUR corresponds to $3.2 \cdot 10^6$ EUR. The variation in the study material is less than a factor of two, but there is en epistemological[1] uncertainty indicated in the ExternE report (1995) which at least is of the same magnitude. Thus we assume a factor of three as being a reasonable estimate of the uncertainty range.

In the last years it has become more and more common to express mortality impacts in terms of life expectancy. One reason is that in early studies, where the correlation between environmental pollution and mortality was discovered, daily mortality figures were correlated to daily environmental quality figures in a particular area. In these studies it was not possible to say if a decreased environmental quality would shorten the life one day or much longer. In the last decade several studies has been made where different cities were compared and where remaining life expectancy was determined together with environmental quality measures. For particles in ambient air these impacts have been shown to be much more severe than those found in studies of short-term correlation.

The figures given above for VSL may be translated to life expectancy by looking at accidental mortality and assuming this to be randomly distributed in the population at risk. Even if it in reality is not randomly distributed, it may be argued that the people responsible for the safety decisions and thus the WTP figures hardly decide on the basis of skewed risk distributions.

The average life expectancy at birth in the OECD countries is around 75 years. Thus the average shortening of life due to random accidents are 37.5 years, which would give a value for the best estimate of WTP for one YOLL to 3200000/37.5 = 85000 EUR. This is the same value as used by ExternE, but recalculated to 1998 values.

The uncertainty range in the estimation of WTP for YOLL is estimated to a factor of five and it is assumed that it may be represented by a log-normal distribution with a standard deviation corresponding to a factor of two. (The uncertainty range ~ two standard deviations)

Choice of weighting factor
85000 ELU/YOLL with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.1.2. Severe morbidity

In earlier EPS default versions severe morbidity has been estimated to 100000 EUR/person-year. The ExternE classify morbidity costs in groups like

a) estimation of restrictive activity days
b) cost of chronic illness
c) valuation of symptom days
d) altruistic costs

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[1] Uncertainty caused by using data in an other context than in which it was measured

ExternE uses the figure 62 EUR per RAD (restrictive activity day) corresponding to 22600 EUR/person-year. For chronic illness they use the same value as for a statistical life (85000 EUR/person-year). The unit used is person-year, but most studies of WTP for morbidity is made on shorter periods of morbidity. As pointed out by ExternE, the willingness to pay for avoiding morbidity is probably not additive, in the sense that WTP for 10 days is ten times the WTP for one day. However for the purpose of the analysis by the EPS system and particularly in regard of the demand for transparency, a standard value per morbidity-time is to prefer.

Given the estimations by ExternE and the fact that much of the environmental severe health effects on a global scale is about lung diseases, starvation, infectious diseases and poisoning, it seems relevant to keep a "severe morbidity"-class at a rather high level of WTP. However there seems to be little evidence for increasing the figure above the 100 000 EUR/person-year which was used in earlier EPS versions.

The uncertainty range in the estimation of WTP for a person-year of severe morbidity is estimated to a factor of ten and it is assumed that it may be represented by a log-normal distribution with a standard deviation corresponding to a factor of three. The uncertainty is partly due to the variety of effects that may be classified as severe morbidity and partly due to a variety of values within the global OECD population.

Choice of weighting factor
100 000 ELU/person-year with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 3.

2.1.3. Morbidity

ExternE:s estimation of the cost for restricted activity days also included loss of income and the cost for expenditures caused by the illness. It is logical that their estimation of WTP for 'normal' illness is higher than what is estimated by the EPS default method, where economics are not part of the safeguard subjects, and only the WTP to avoid the illness itself is estimated. These are estimated to 10000 EUR/personyear. This may be a bit low compared to what is found in various studies of WTP for avoiding symptoms. (see table 2.2)

Table 2.2 shows that there is a large variation in WTP for symptom reduction and that the distribution is strongly skewed. The difference between mean and median values is striking. The difference is larger when the symptoms are more severe. A likely explanation to this is that various persons have had different experience of the symptoms and that there are great difficulties in describing the intensity in pain and nausea. For symptoms that are life-threatening, persons that have experienced them is likely to show WTP figures very much higher than others.

Table 2.2 Willingness to pay for acute symptom reduction (USD, 1984). Source: Strand (1991), reviewing Krupnik (1987). Numbers in parentheses refer to severe symptoms. Numbers above them refer to mild symptoms.

Symptom	Impact category	WTP for a one-day change in symptom					
		Dickie et al. (1987)		Tolley et al. (1986)		Loehman et al. (1979)	
		Mean WTP	Median WTP	Mean WTP	Median WTP	Mean WTP	Median WTP
Cannot breathe deeply	Severe morbidity	1140	1.00				
Pain on deep inspiration	Severe morbidity	954.13	3.50				
Shortness of breath	Nuisance to severe nuisance	7.88	0.00			78.00 (127.00)	8.00 (18.00)
Wheezing	Morbidity	58.00	2.00				
Chest tightness	Severe morbidity	813.72	5.00				
Cough	Morbidity	355.10	1.00	25.20	11.00	42.00 (73.00)	4.40 (11.00)
Throat irritation	Severe nuisance	15.00	3.00	28.97	13.00		
Sinus congestion	Morbidity	239.50	3.50	35.05	14.00	52.00 (85.00)	6.00 (13.00)
Headache	Severe nuisance	178.39	1.00	40.10	20.00		
Eye irritation	Nuisance to severe nuisance			27.73	12.50		
Dowsiness				31.41	15.00		
Nausea				50.28	17.50		

Table 2.2 also shows the variation between serious symptoms and mild symptoms and that various studies show differences of as much as an order of magnitude. The difference between mean and median values indicates a large variation in individual values. This variation is however not necessarily relevant for LCA and EPS issues. The impacts from products and product systems are likely to affect large population groups, why the uncertainty in the average is more relevant as a measure of the uncertainty value.

<u>Choice of weighting factor</u>

10 000 ELU/person-year with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 3.

2.1.4. Severe nuisance

From table 2.2 it may also be seen that the WTP to avoid severe nuisance is in the same order as WTP to avoid less severe forms of morbidity. The same values are thus used for severe nuisance as for morbidity, i.e. 10000 ELU/person-year and a factor of three for the standard deviation.

Choice of weighting factor
10 000 ELU/person-year with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 3.

2.1.5. Nuisance

Nuisance is here understood as a mild form of nuisance that does not constantly irritate people. Visibility reduction, dirty surfaces or a moderate noise level is regarded as nuisance. Part of the nuisance may be due to concern for health effects. (ExternE, 1995)

Hylland and Strand (1983) found a WTP of 112.5 EUR per person and year for a considerable improvement of the air quality in terms of visibility improvement.

The value 100 EUR/person-year is used as a best estimate of the average WTP with a standard deviation in a log-normal distribution corresponding to a factor of three.

Choice of weighting factor
100 ELU/person-year with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 3.

2.2. Ecosystem production capacity

2.2.1. Crop

Market prices for various crops are shown in table 2.3.

Table 2.3. Market prices for various types of crop.

Type of crop	World market price, (EUR)	Domestic prices, (EUR)	Note
Wheat	0.11		Financial Times (1999)
Wheat	0.11	0.168	FAO (1991)
Oats	0.065	0.139	FAO (1991)
Barley	0.11		Financial Times (1999)
Winter barley	0.069	0.142	FAO (1991)
Spring barley	0.069	0.162	FAO (1991)
Rye	0.056	0.157	FAO (1991)
Maize	0.11		Financial Times (1999)
Potatoes	0.14		Financial Times (1999), The water content is higher than in ordinary crops

The FAO international figures are used by ExternE (1995) as there is a considerable amount of local subsidiaries for agricultural production. The best estimate is set to 0.15 EUR/kg for the EPS default version 2000 and the standard deviation in a log normal distribution estimated to correspond to a factor of 2 representing variations in WTP for various crops and various countries.

Choice of weighting factor

0.15 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.2.2. Wood

Timber in the form of standing trees in Sweden are valued to about 20 EUR/m^3 (Braconier, 1999) corresponding to about 0.050 EUR/kg dry substance (DS). Wood taken out of the forests often have a DS content of 55%, while air-dry wood has about 70-75% DS. The global average wood price is assumed to be somewhat lower, but no world marked exists in the same way as for crops, why the Swedish values are used but lowered somewhat.

Choice of weighting factor

0.04 ELU/kg DS wood with an uncertainty represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.4.

2.2.3. Fish and meat

World market prices for meat (pork) is 1.1 EUR/kg (Financial Times 1999). The same price is paid for living cattle. Fish prices vary locally but seem to be of the same magnitude. Therefore, the best estimate for WTP is set to 1 EUR/kg and the uncertainty to a log-normal distribution with a standard deviation corresponding to a factor of 2.

Choice of weighting factor

1 ELU/kg fish or meat with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.2.4. Base cat-ion capacity of soil

The willingness to pay to avoid decrease of soil base cat-ion reserves is estimated from approximate liming costs. As a best estimate the figure 0.01 EUR/mole H^+ is used, corresponding to a liming cost of 20 EUR/ton applied dolomite.

Choice of weighting factor

0.01 ELU/mole H^+ with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.2.5. Water

The WTP for water as a local resource is set by the cost for alternative production and if there is a water deficiency or not. The cost for alternative production could involve purification or transport from other areas.

There are two category indicators defined for water, ‘production capacity for irrigation water’ and ‘production capacity for drinking water’.

The quality demands on irrigation water are modest. In practice the transportation costs are likely to be the largest, presumably around 10 EUR/m^3 for single m^3’s or 1 EUR/m^3 for larger volumes. For areas with water surplus, the WTP is assumed to be zero. 0.003 EUR/kg will be used as a best estimate for the global average, but the standard deviation is rather large and is estimated to a factor of 4 in a log-normal distribution.

The WTP for drinking water varies from practically zero in the northern countries (0.001EUR/kg) to the price of bottled mineral water in arid countries, about 1 EUR/kg. Choosing a best estimate of 0.03 EUR/kg and a log-normal distribution function with a standard deviation corresponding to a factor of 6, all values between 0.001 and 1 will be within two standard deviations.

Choice of weighting factor

Irrigation water: 0.003 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 4.

Drinking water: 0.03 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 6

2.3. Abiotic stock resources

When trying to find the WTP for category indicators of the safe guard subject 'abiotic stock resources’, we find that neither the market nor the customers are available for studying. You cannot use the CVM technique to determine the WTP for those that are concerned of resource depletion, because most of them belong to future generations. There is no one to ask. Therefore a market scenario is created, where all future generations are included and are imagined to bid on the present abiotic stock reserves. As future generations – in the sustainable society we strive for- is much more numerous than the present, their WTP will dominate even if their yearly consumption will be significant less than ours. In the long run the demand-supply curves will intersect where the supply cost curve approaches a near horisontal form representing the cost for a sustainable production (figure 2.1.). For instance, natural gas (methane) may be produced from oxygen free microbial decomposition processes and ores similar to the reserves of today may be produced from leaching and precipitation of metal sulphides or hydroxides. The cost of such a process is used as a rough estimate of marginal WTP for those who are affected by depletion of abiotic reserves.

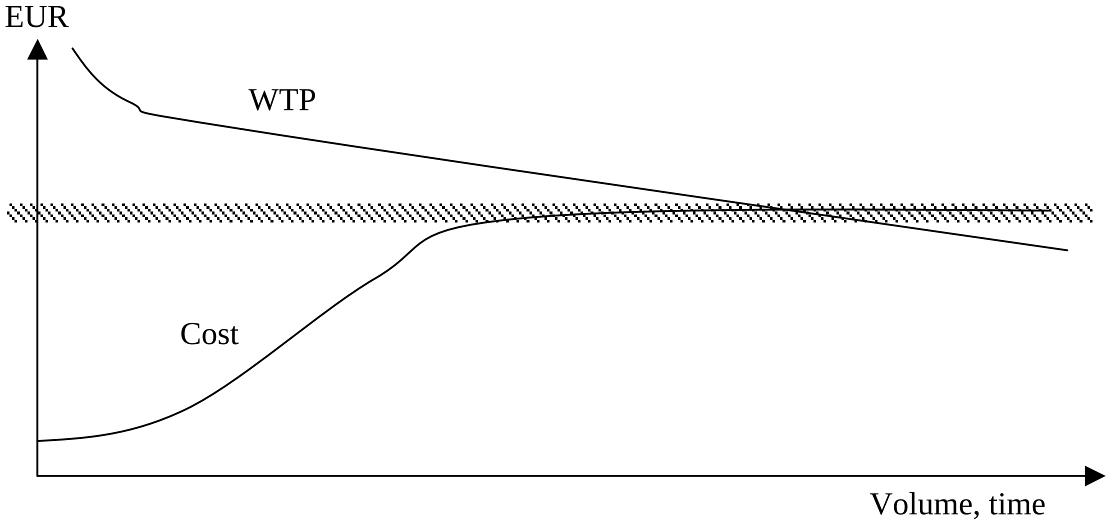

Figure 2.1 WTP on the marginal is likely to stabilise in the vicinity of the production cost when using very dilute concentrations, which represent large, sustainable reserves.

2.3.1. Fossil oil

The sustainable alternative to fossil oil is assumed to be vegetative oil. It seems unlikely that vegetative oil could replace the large amounts of fossil oil used today for energy production, but the potential production may be enough to substitute fossil oil in some working machines and to some extent as raw material for the chemical industry.

There are many types of vegetative oil available today: palm oil, corn oil, rapeseed oil, olive oil, etc. Rapeseed oil is the most commonly discussed alternative and will be used as a reference material to value fossil oil as a resource. The production of rapeseed oil is fairly well studied in terms of LCA and the production capacity is reasonably significant. Some kind of mix of vegetative oils would otherwise have been more appropriate.

Agnetun (1994) made one study of rapeseed oil as an alternative to diesel fuel. The emissions from production and use of rapeseed oil are shown in table 2.4.

	Production Transport *)	Refining	Distribution	Use in car	Total
HC, total (g/km)	0.04	0.08	<0.01	0.03	0.16
CO (g/km)	0.06	0.01	<0.01	0.13	0.20
NO_x (g/km)	0.31	0.02	0.03	0.70	1.06
Particles (g/km)	0.01	<0.01	<0.01	0.09	0.11
CO_2 (g/km)	84	20	2	11	117
SO_x (g/km)	0.14	0.03	<0.01	0.01	0.18
Energy(kWh/km)	0.82	0.15	0.01	0.69	1.67

Table 2.4. Emissions and energy use at various steps in production and use of rape seed oil as diesel engine fuel. *) Fossil diesel is used as an energy source.

Agnetun makes his calculations on a rapeseed yield of 2500 kg/hectare and year, which corresponds to a normal yield of rapeseed oil in Sweden of about 800 kg/hectare (Bingefors et al., 1978). Höök (1993) reports that France produces 40,000 tons rape seed diesel from 36000 hectare and that the fuel RME (Rape seed Methyl Ester) contains 90% rape seed oil and 10% methanol. An average figure of 1 ton rapeseed oil per hectare is used for the sustainable reference system. The car used in Agnetuns study use 0.69 kWh/km, which is about 0.07 kg rapeseed oil per km. This means that the production of 1 kg rape seed oil includes emissions equal to the sum of the figures in the two first columns in table 2.4 multiplied by 14.3 (1/0.07). These production figures are used in table 2.5 below to calculate the external costs. No figure is given for the use of fossil energy (table 2.4), but the CO_2 emissions indicate that 104 g/km are emitted and that the fossil energy used in agriculture including production of fertilisers is mainly oil. 104 g CO_2 corresponds to a fossil oil amount of 33 g, with an energy content of about 0.33 kWh.

In the review article by Höök (1993), it is mentioned that 2.75 kg rapeseed is needed to produce one litre of fuel. This means that the weight of oil being 1/3 of the seed. The rest has a high protein content (45% on dry basis, (Bingefors et al., 1978)) and is used as fodder cakes. Present costs of producing 1 kg of rapeseed oil is about 0.5 EUR (Höök, 1993).

The following reference system is used for the valuation of fossil oil (figure 2.2).

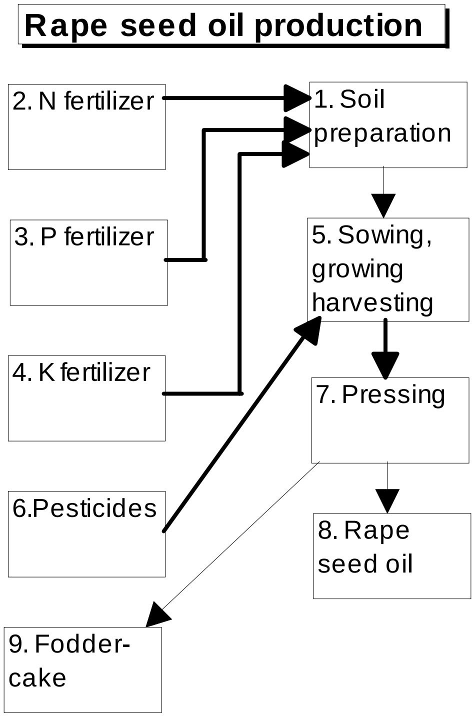

Figure 2.2 Production of rapeseed oil. Bold lines indicate transports. *System borders*: *technical*: Use of machinery in agricultural activities and processing, but no production of capital goods. *Time*: 1990 – 2000, *space*: global

In table 2.5 external environmental costs for emissions and use of resources are estimated and added to the direct cost when producing 1 kg of rape seed oil from the reference system in figure 2.1. The WTP for impacts are estimated from the weighting results for the emissions and resources.

Table 2.5. WTP for impacts from emissions, use of resources and direct cost of crop and rapeseed oil production.

Item	Amount per kg rape seed oil	WTP per item unit (EUR/kg)	WTP, present technology, (EUR)	WTP, optimised technology, (EUR)
NMVOC	0.0017	2.14	0.003638	0.000364
CO	0.0010	0.331	0.000331	3.31E-05
NO_x	0.0047	2.13	0.010011	0.005006
Particles	0.00014	36.1	0.00504	0.000504
CO_2	1.49	0.108	0.16092	0
SO_x	0.0024	3.30	0.007848	0
Fossil oil	0.47	0.507	0.23782	0
Production cost	1	0.5	0.5	0.5
		SUM	0.925608	0.505906

The emissions of CO_2 and SO_x and the use of fossil oil in present technology are not necessary from a technical standpoint. The process can be optimised in terms of sustainability in the way that agricultural vehicles are driven by rapeseed oil and renewable energy is used in the fertiliser production. Besides the emissions of NO_x could be half and the emissions of CO, NMVOC and particles could be lowered to by 90%. The CO_x, SO_x and fossil oil figures will then be zero and the overall value for fossil oil as a resource is 0.506 ELU/kg.

The uncertainty may be estimated from the difference between the value obtained by present technology and the optimised technology and from present price variations between different vegetation oils.

Choice of weighting factor

0.506 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 1.4.

2.3.2. Fossil coal

Coal is mainly an energy source, but it is also used in various processes as raw material. The production of steel and some other metals require coal for reducing the oxides. The element carbon is an important alloy component in steel. The volatile parts of coal are used as raw material for the chemical industry, but coal´s importance has decreased during the last decades in favour of oil.

The sustainable alternative to coal, as an *energyware* is energywares produced by sun radiation, wind and hydropower. Energy is however not included in the safe guard subjects and impact categories in the EPS default method. The basic reason is that the amount of energy in the environment cannot be changed by human activities. In the ISO 13600 standard the concept of *energyware* is introduced. It is the material or substance form, which is of interest and value to us. Therefore the reference system shall produce a substance similar to fossil coal.

The most important sustainable alternative to coal *as a source of the element carbon* is charcoal.

A sustainable alternative to the volatile components of coal could be the volatile components from the production charcoal or those extracted from various types of plants. As the technology of making char coal is well known and the capacity large compared to what may be obtained from agricultural areas, at least with a 100-years perspective, it seems reasonable to focus on the production of char coal as the sustainable process for "coal-equivalent" volatile organic compounds.

As the world´s use of coal for energyware production exceeds by far the available wood production, a reasonable assumption is that energyware like heat and electricity is produced by sun-, wind- and hydropower and that the coal source for industry is supplied via charcoal. This means that the greatest value of coal, from an environmental standpoint is as a source of the element carbon and of volatile organic components.

The technical reference system is described as in figure 2.3.

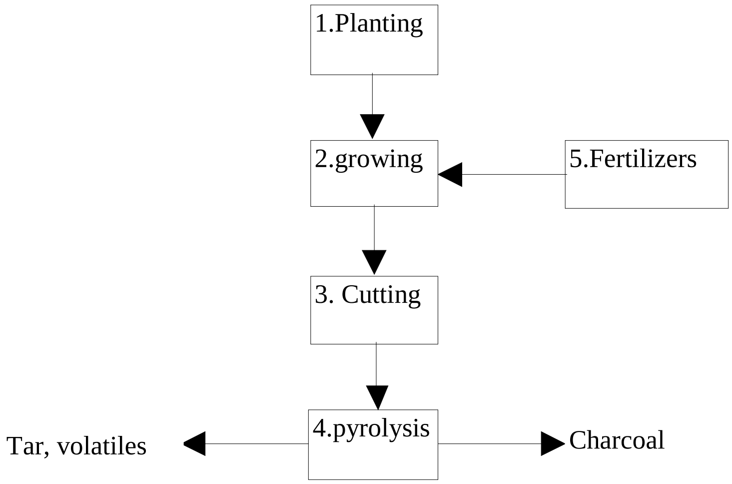

Figure 2.3. Reference system for coal *System borders*: *Technical*: according to figure 2.3. *Time*: 1990-2000. *Space*: Global.

In table 2.6 external environmental costs for emissions and use of resources are estimated and added to the direct cost when producing 1 kg of charcoal from the reference system shown in figure 2.2. The WTP for impacts (external costs) are estimated from the weighted results for the emissions and resources. The emissions and use of resources when making charcoal is given by Frischknecht et al., (1994) and summarised in table 2.6.

The processes analysed by Frischknecht et al (1994) are not optimised in terms of sustainability. If the fossil resources are exchanged by wood the CO_2-emissions can be assumed to disappear and the values for the resource use decrease (Table 2.6). In the optimized processes in table 2.6 it is also assumed that the depletion of metal reserves is decreasedby a factor of ten and that the impact on biodiversity from forestry is decreased by a factor of 4. The direct production cost is estimated to 0.04 EUR/kg.

Table 2.6. Impact values for charcoal production. The direct production cost is estimated from a wood price of 22 EUR/m^3, a price allocation on weight basis for volatiles and tar and a negligible processing cost.

Item	Unit	WTP per item unit (EUR/unit)	WTP			
			Present technology		Optimized process	
			Amount/kg charcoal	EUR/kg charcoal	amount/kg charcoal	EUR/kg charcoal
Impacts from use of						
Pb-reserves	kg	1.81E+02	2.32E-06	4.20E-04	2.32E-07	4.20E-05
Cr- reserves	kg	8.80E+01	3.55E-06	3.12E-04	3.55E-07	3.12E-05
Fe- reserves	kg	1.23E+00	7.49E-04	9.21E-04	7.49E-05	9.21E-05
Hardmade area	m2a	8.31E-02	5.65E-07	4.70E-08	5.65E-07	4.70E-08
Cu- reserves	kg	2.15E+01	3.29E-05	7.07E-04	3.29E-06	7.07E-05
Ni- reserves	kg	1.66E+02	1.80E-06	2.99E-04	1.80E-07	2.99E-05
Ag- reserves	kg	5.60E+04	3.90E-08	2.18E-03	3.90E-09	2.18E-04
Zn- reserves	kg	5.92E+01	2.09E-08	1.24E-06	2.09E-09	1.24E-07
Sn- reserves	kg	1.23E+03	2.17E-08	2.67E-05	2.17E-09	2.67E-06
Natural gas reserves	m3n	3.57E-01	7.33E-03	2.62E-03		
Wood (forestry)	Mg	2.23E+00	3.19E-03	7.11E-03	3.30E-03	1.84E-03
Lignite	kg	1.00E-01	4.33E-02	4.33E-03		
Coal- reserves	kg	4.98E-02	3.32E-02	1.65E-03		
Impacts from emission of						
CH4 Methane	kg	2.72E+00	3.21E-04	8.73E-04	3.21E-05	8.73E-05
CO2 m	kg	1.08E-01	1.47E-01	1.59E-02		
NMVOC p	kg	2.14E+00	2.32E-04	4.96E-04	2.32E-05	4.96E-05
PAH s	kg	6.43E+04	1.14E-06	7.33E-02	1.14E-07	7.33E-03
Production of charcoal	kg	4.00E-02	1	4.00E-02	1	4.00E-02
SUM				1.51E-01		4.98E-02

The value for coal is thus estimated to 0.0498 ELU/kg. The uncertainty in the value is partly from varying wood prices and partly from uncertainty in the allocation procedure. A factor of 4 is assumed.

Choice of weighting factor
0.0498 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.3.3. Natural gas

The sustainable alternative to natural gas is bio-gas. Natural gas as well as bio-gas consist mainly of methane. Costs for bio-gas production in agriculture has been investigated for the Swedish Ministry of Industry, Employment and Communication (SOU 1998). The results are summarised in table 2.7 together with external costs from emissions of the processes as determined by this version of the EPS default method.

Table 2.7. Cost of producing bio-gas at the same composition as natural gas. *)Assuming a density of 0.8 kg/l gasoline, an energy ratio of 1.25 of bio-gas to gasoline on a weight basis and an exchange ratio of 9.0 SEK/EUR.

Biogas produced by	SEK/ litre exchanged gasoline	EUR/kg bio-gas*)
Sludge from waste water treatment	5.83	0.65
Other waste	8.52	0.95
Manure	9.83	1.09
Other waste from agriculture	11.83	1.31
Grass, etc.	14.53	1.61

Choice of weighting factor
1.1 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.3.4. Al-ore (Bauxite)

Aluminium is one of the most abundant elements in earth crust. The average concentration in the upper continental crust is 7.74 %. (Wedepohl, 1995).

During the Second World War, aluminium was produced from silicate rock in Sweden. The mineral andalusite (Al_2OSiO_4) was leached by sodium hydroxide to produce aluminium oxide which was used in a similar way as bauxite (Lindberg, 1973). The exact details of the process is not documented, but it is possible to calculate the amount of NaOH (1.48 kg/kg Al) that would be necessary to dissolve Al_2O_3 as $Al(OH)_4^-$ ions according to the formula:

$$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2\ Al(OH)_4^- + 2Na^+$$

The dissolved aluminate ion is then transformed to aluminium hydroxide after neutralisation with sulphuric acid. The process tree is similar to that for iron, but the base treatment is made first and the acid later (figure 2.4). The inventory results are shown in table 2.8.

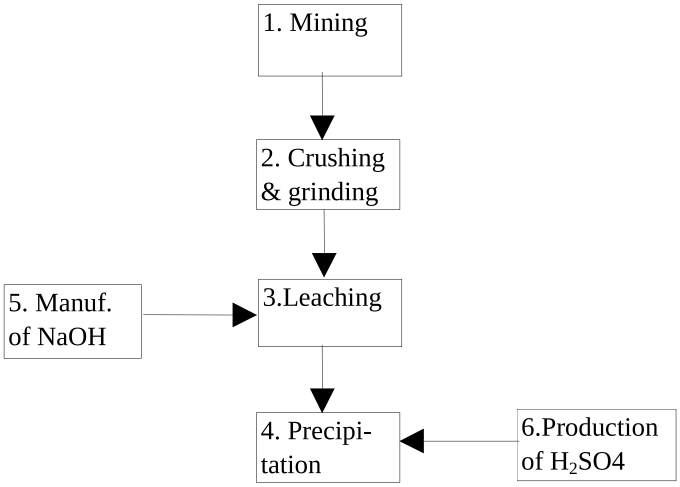

Figure 2.4 Reference system for sustainable production of Bauxite.

Table 2.8 Emissions and use of resources from today's technology and energy sources when producing Al-ore from average earth crust composition.

	1		2		5		6		
Emission or resource	Diesel power		Electricity		NaOH production		H_2SO_4 production		sum
	per MJ	per kg Al	/MJ	/kg Al	/kg NaOH	/kg Al	/kg H_2SO_4	/kg Al	per kg Al
Nat. gas, m^3_n			2.56E-05	1.65E-05	4.79E-02	7.54E-02	5.77E-02	1.11E-01	1.86E-01
Lignite, kg		0.00E+00	9.31E-05	6.02E-05	2.41E-01	3.80E-01	3.83E-02	7.38E-02	4.53E-01
Coal, kg		0.00E+00	2.76E-04	1.79E-04	1.92E-01	3.03E-01	3.13E-02	6.03E-02	3.64E-01
Crude oil, kg	2.85E-02	1.84E-02	7.75E-05	5.01E-05	5.48E-02	8.62E-02	1.07E-02	2.06E-02	1.25E-01
CH_4 to air, kg		0.00E+00	2.42E-06	1.56E-06	1.82E-03	2.86E-03	5.84E-04	1.13E-03	3.99E-03
CO_2 to air, kg	9.48E-02	6.12E-02	1.11E-03	7.16E-04	8.03E-01	1.27E+00	2.34E-01	4.50E-01	1.78E+00
NMVOC to air,kg	1.18E-04	7.59E-05	1.00E-06	6.46E-07	4.19E-04	6.60E-04	8.50E-05	1.64E-04	9.01E-04
NOx to air, kg	5.25E-04	3.39E-04	4.20E-06	2.71E-06	1.80E-03	2.83E-03	4.40E-04	8.46E-04	4.02E-03
SOx to air, kg		0.00E+00	3.00E-06	1.94E-06	4.00E-03	6.29E-03	5.36E-03	1.03E-02	1.66E-02

Using the indices for emissions and resources derived in this report we obtain external costs for the production of Al-ore according to table 2.9.

In table 2.9 external environmental costs for emissions and use of resources when producing 1 kg of Al-ore from the reference system are estimated. The WTP for impacts are estimated from the weighting results for the emissions and resources.

Table 2.9 Total environmental impact from present production processes in the reference system for Al-ore and for a optimised process in terms of sustainability.

	Impact index, v2000, ELU/kg o ELU/m^3 or ELU/MJ	Amount per kg Al kg or MJ	Energy MJ	ELU/kg Al with current technology	ELU/kg Al with sustainable technology.
Nat. gas, m^3_n	3.57E-01	1.86E-01	6.64E+00	1.46E-01	
Lignite, kg	4.98E-02	4.53E-01	7.71E+00	2.26E-02	
Coal, kg	4.98E-02	3.64E-01	1.09E+01	1.81E-02	
Crude oil, kg	5.06E-01	1.25E-01	5.01E+00	6.35E-02	
Wood energy, MJ	5.60E-04				1.69E-02
CH_4 to air, kg	2.72E+00	3.99E-03		1.08E-02	
CO_2 to air, kg	1.08E-01	1.78E+00		1.92E-01	
NMVOC to air, kg	2.14E+00	9.01E-04		1.93E-03	
NO_x to air, kg	2.14E+00	4.02E-03		8.56E-03	4.28E-03
SO_x to air, kg	3.30E+00	1.66E-02		5.43E-02	5.48E-03
		SUM	3.03E+01	5.18E-01	2.67E-02

If the energy in the production process comes from a more sustainable source like wood, the resource impact values decrease as well as the CO_2 and CH_4 emissions. The remaining impact values will be from wood based process energy at $5.50 \cdot 10^{-5}$ ELU/MJ. In the optimized process NMVOC emissions are assumed to be practically eliminated and NO_x and SO_x emissions are assumed to be reduced by 50 and 90% respectively. The ground use is assumed to correspond to a 10 m deep strip-mine, preventing forestry for 100 years. The ground use will therefore be 0.03 m^2 yr and kg Al. and the value for ground use will be negligible. We thus get a total value of the external environmental costs for Al-ore of 0.0267 ELU/kg Al. Adding this cost to the cost for mining, crushing, grinding, leaching and precipitating, (table 2.10) we obtain a total figure of 0.439 for 1 kg of Al as ore.

Table 2.10. Estimation of production cost for Al-ore containing 1 kg of Al.

Item	Production cost (EUR)
Veg.oil	8.65E-03
Wood based process energy	6.05E-02
NaOH for leaching	1.48E-01
Acid	7.25E-02
Processing	1.22E-01
sum	4.12E-01

Choice of weighting factor

0.412 + 0.0267 = 0.439 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.

2.3.5. Sulphide ores (Cu, Zn etc.)

The sustainable production of sulphide ores is assumed to be similar to the natural processes, which once contributed to the creation of the reserves: weathering, leaching and precipitation. However, in technical systems, the processes have to be speeded up. Weathering may therefore be exchanged by mining, crushing and grinding. The leaching by rain may be exchanged by leaching with something more active. Examples of ore leaching processes are frequent in literature, but little is known about leaching rocks representing the "earth's average crust". When extracting metals from rocks for chemical analysis hydrofluoric acid is used to eliminate the silicon matrix. Such a process could be used for producing small amounts of metals. Leaching by micro-organisms has also been mentioned and would probably be a more sustainable leaching process, but at this stage it is not considered realistic. Leaching by sulphuric or nitric acid is more realistic, but the extraction efficiency may be reduced compared to what would be obtained by hydrofluoric acid. Using nitric acid would probably be more efficient than sulphuric acid but a nitric acid process is less sustainable than sulphuric per unit of acid. To identify the most sustainable process is not possible at present. To approach a solution, two processes using strong acids will be considered below, one using hydrofluoric acid and one sulphuric acid. The metals in the leachate obtained from both processes are precipitated as sulphides using a sulphide containing solution, giving a mixed "sulphide ore" as a solid precipitate.

The HF process

The process using hydrofluoric acid is described in figure 2.4.

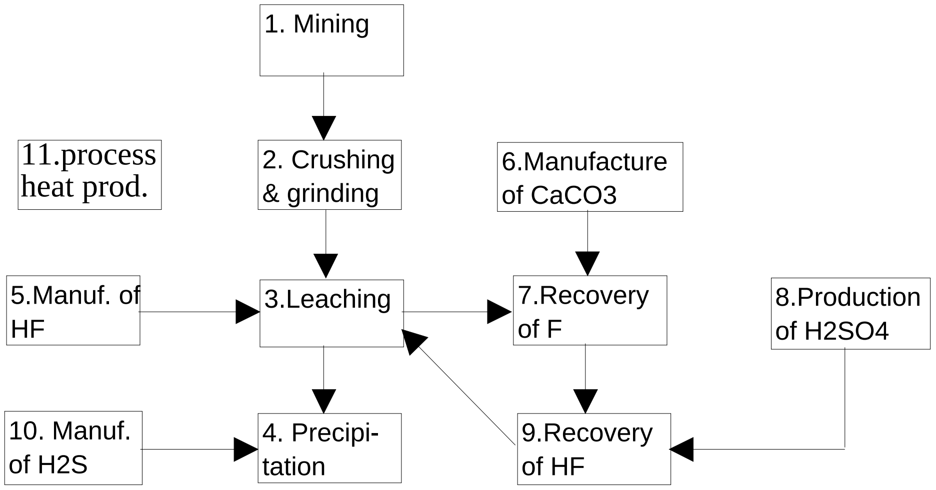

Figure 2.4 A possible process for near sustainable production of sulphide ore. *System borders*: *technical*: Use of equipment for processing is included, but no production of capital goods. Emissions to air and water and depositing of waste material are assumed to be handled to give low environmental impacts and are therefore excluded. *time*: 1990 and onward. There is no time limit except for the valuations, which are today's values. *space*: global

The process contains the following steps:

1. Mining. Strip-mining is assumed because average rock is used. The waste, which is almost all of the material, is returned to the mining area and 100 years after the mining, the area may be used for forestry or other purposes. The energy used is approximated to be 0.1 MJ/ kg rock (Perry 1997) and is assumed to come from biofuel diesel oil.

2. Crushing and grinding is assumed to be made down to a particle size below 60 µm. The energy used for step 2 is then approximately 0.1 MJ/ kg rock (Perry, 1997). The electricity is assumed to be produced by hydropower or other sustainable process.

3. Leaching. The ground rock is leached by HF, which produces SiF_4 as a gas. The leachate contains many salts of metals. It is assumed that ten different metals are recovered from the leachate. Allocation of emissions etc. from leaching and recovery of chemicals are made equally on each metal. This means that the emissions etc. from the system for each metal would be the same as if rock was used that contained ten times the average concentration in the earth crust. For simplicity the inventories of each metal are made separately under this condition.

4. Precipitation. The solubility of many metal sulphides is very low. If the leachate from one kg rock is 1 litre the following recovery of metals from the leachate at various molarities of sulphide ions would be obtained:

Table 2.11. Recovery of metals by sulphide precipitation at various sulphide concentrations. Sulphide concentrations of 10^{-15} and 10^{-22} mole/litre are obtained in a solution saturated with H_2S at a pH of 4 and 0.5 respectively. Solubility constants according to Lide (1994) are used.

Metal ion	Solubility product of sulphide	yield at 1E-6 M sulphide conc.	Yield at 1E-15 M sulphide conc	yield at 1E-22 M sulphide conc.
Ag+	6.00E-51	100	100	100
Bi+++	1.82E-99	100	100	100
Co++	7.00E-23	100	99.9835	0
Cu+	2.26E-48	100	100	100
Cu++	6.00E-37	100	100	100
Fe++	6.00E-19	100	99.93299	0
Hg+	1.00E-45	100	100	99.99925
Hg++	2.00E-53	100	100	100
Ni++	1.07E-21	100	99.92524	0
Mn++	3.00E-14	99.99983	0	0
Pb++	3.00E-28	100	100	95.55979
Pt++	9.91E-74	100	100	100
Sn++	1.00E-26	100	99.99999	48.3913
Tl+	1.20E-24	97.36591	0	0
Zn++	2.00E-25	100	99.99998	0

In order to obtain a reasonably high concentration in the synthetic ore, it is important that the precipitate does not contain the most abundant metals like Al, Fe, Na, Ca and Mg. Table 2.11 shows that FeS is not precipitated with solutions of sulphide concentrations of $1 \cdot 10^{-22}$ M. The sulphides of the other abundant metals are more soluble than FeS and will also remain in solution at low pH.

5. Manufacture of HF. Only a small part of the HF has to be added to the system from outside as F is recycled in the process. A makeup of 1% to the leaching acid is assumed. As 4 moles of HF are needed per mole of Si and as the average Si-concentration is 282 g/kg of rock (10.04 moles), 803 g of HF is needed per kg rock and as makeup 8 g. Energy is supplied from incineration of wood. HF is assumed to be produced from fluorides and sulphuric acid. The emissions and use of resources are assumed to be small compared to the other steps in sulphide ore production and are neglected, except for the sulphuric acid, which is included in step 8. This will give the same result as if the makeup of HF was 0%.

6, 7. Manufacture of $CaCO_3$. 20 moles (2.0 kg) per kg rock are required to recover the SiO_2 and fluoride. Energy is supplied to mining, crushing and grinding of $CaCO_3$ in the same way as for the rock. The emissions of CO_2 will be 0.88 kg/kg rock.

8, 9. Production of H_2SO_4. 20.08 moles (1.97 kg) are required to recover HF per kg of rock. Energy is supplied from wood combustion.

10. Manufacture of H_2S. Some of the H_2S will be used to precipitate the metals wanted, but some will react with other substances. 10% of the H_2S is assumed to react with the metals we want to recover. This means that 10 moles H_2S per mole Cu or Zn is required (5.35 and 5.20 kg H_2S /kg metal respectively).

11. Production of process energy from incineration of wood. LCA data for a 100 kW plant for production of heat from wood chips are given by Frischknecht et al., (1994) and summarised in table 2.13. The technical system described by Frischknecht et al. is existing today but not optimised for sustainability. An optimisation at a level that is thought to be realistic is expressed in table 2.12, last column. The fossil fuels are exchanged to wood and biofuel oil giving a net CO_2-emission of zero, the depletion of rare metals are reduced to at least 10% through exchange and recycling, and the emission of CO, VOC and PAH from wood incineration is practically eliminated.

Table 2.12 Environmental impact from heat production by wood incineration.

Emission or Resource	unit	Index 2000	Heat from woodchips 100 kW		
		ELU/unit	Emission or resource/TJ	ELU/TJ*	ELU/TJ **
Bauxite	kg Al	4.43E-01	3.64E+00	1.60E+00	1.60E-01
Pb-ore	kg Pb	1.81E+02	3.83E-01	6.93E+01	6.93E+00
Cr-ore	kg Cr	8.80E+01	2.46E-01	2.16E+01	2.16E+00
Fe-ore	kg Fe	9.62E-01	2.40E+02	2.31E+02	2.31E+01
Land use type type II-III	m2a	5.50E-04	3.56E+02	1.96E-01	1.96E-02
Land use type III-IV	m2a	1.56E-03	1.17E+02	1.83E-01	1.83E-02
Land use type IV-IV	m2a	2.55E-02	5.33E-02	1.36E-03	1.36E-04
Co-ore	kg Co	2.66E+02	2.05E-06	5.45E-04	5.45E-05
Cu-ore	kg Cu	2.15E+02	6.50E+00	1.40E+03	1.40E+02
Mn-ore	kg Mn	5.84E+00	2.12E-01	1.24E+00	1.24E-01
Mo-ore	kg Mo	2.20E+03	1.92E-06	4.22E-03	4.22E-04
Ni-ore	kg Ni	1.66E+02	6.26E-02	1.04E+01	1.04E+00
Pt-ore	kg Pt	7.70E+06	6.66E-07	5.13E+00	5.13E-01
Rh-ore	kg Rh	5.13E+07	6.01E-07	3.08E+01	3.08E+00
Ag-ore	kg Ag	5.60E+04	2.56E-03	1.43E+02	1.43E+01
Zn-ore	kg Zn	5.92E+01	1.30E-03	7.70E-02	7.70E-03
Sn-ore	kg Sn	1.23E+03	1.42E-03	1.75E+00	1.75E-01
Natural gas	m3n	7.86E-01	8.86E+01	6.96E+01	
Wood from forestry	Mg	1.25E+01	1.11E+02	1.39E+03	
Lignite	kg	4.98E-02	8.92E+01	4.44E+00	
Coal	kg	4.98E-02	2.57E+02	1.28E+01	
Crude oil	Mg	5.07E+02	8.46E-01	4.29E+02	
As to air	kg	9.53E+01	1.77E-04	1.69E-02	1.69E-02
CH_4 to air	kg	2.72E+00	9.87E+01	2.68E+02	
CO to air	kg	3.31E-01	1.20E+03	3.97E+02	
CO_2 to air	kg	1.08E-01	3.19E+03	3.45E+02	
Cr to air	kg	2.00E+01	2.67E-01	5.34E+00	
HCl to air	kg	2.19E+00	1.88E+00	4.12E+00	
N_2O to air	kg	4.00E+01	1.03E+00	4.12E+01	3.92E+01
NMVOC to air	kg	2.14E+00	4.80E+01	1.03E+02	
NO_x to air	kg	2.69E+00	1.92E+02	5.16E+02	2.58E+02
PAH to air	kg	6.43E+04	2.30E-01	1.48E+04	
Dust to air	kg	3.61E+01	1.48E+02	5.34E+03	
Pb to air	kg	2.91E+03	4.23E-02	1.23E+02	
SO_x to air	kg	3.30E+00	4.32E+01	1.43E+02	7.13E+01
			SUM	2.59E+04	5.60E+02

*) Present technology **) Scenario of performance when today's technology is optimised in terms of sustainability using today's technology and sustainable forestry.

Thus, the use of wood for process energy production results in an impact value of $5.60 \cdot 10^{-4}$ ELU/MJ.

Using inventory data from Frischknecht (1994) and and data on average Cu concentration in upper continental crust from Wedepohl (1995), (14.3 mg/kg) we obtain the following inventory results (table 2.13) for the energy and material supply to the production of Cu-ore. The production of H_2S and the leaching and precipitation processes is neglected in the inventory as inventory data has not been available and the emissions and use of resources are small compared to the production of H_2SO_4 and $CaCO_3$.

Table 2.13 Inventory data from various steps in a scenario of a near sustainable production of Cu with HF method.

Emission or Resource	1		2		5		7		8	
	Diesel power		Electricity		HF production		HF recovery		H2SO4 production	
	per MJ	per kg Cu	/MJ	/kg Cu	/kg HF	/kg Cu	/kg CaCO3	/kg Cu	/kg H2SO4	/kg Cu
Nat. gas, m^3_n		0.00E+00	2.56E-05	1.79E-01	3.13E-01	1.75E+02		0.00E+00	5.77E-02	7.93E+02
Lignite, kg		0.00E+00	9.31E-05	6.50E-01	2.55E-01	1.43E+02		0.00E+00	3.83E-02	5.29E+02
Coal, kg		0.00E+00	2.76E-04	1.93E+00	2.18E-01	1.23E+02		0.00E+00	3.13E-02	4.32E+02
Crude oil, kg	2.85E-02	1.99E+01	7.75E-05	5.41E-01	1.45E-07	8.18E-05		0.00E+00	1.07E-02	1.47E+02
CH_4 to air, kg		0.00E+00	2.42E-06	1.70E-02	3.82E-03	2.14E+00		0.00E+00	5.84E-04	8.06E+00
CO_2 to air, kg	9.48E-02	6.63E+01	1.11E-03	7.76E+00	1.67E+00	9.40E+02	4.40E-01	6.17E+03	2.34E-01	3.22E+03
NMVOC to air, kg	1.18E-04	8.22E-02	1.00E-06	7.01E-03	1.12E-03	6.25E-01		0.00E+00	8.50E-05	1.17E+00
NOx to air, kg	5.25E-04	3.67E-01	4.20E-06	2.94E-02	3.90E-03	2.19E+00		0.00E+00	4.40E-04	6.04E+00
SOx to air, kg		0.00E+00	3.00E-06	2.10E-02	2.72E-02	1.53E+01		0.00E+00	5.36E-03	7.38E+01

Using the indices for emissions and resources derived in this report we obtain values for environmental impacts of the entire production of Cu according to table 2.14. The last column represents a technology, which is as sustainable as possible using today's options.

Table 2.14 Total environmental impact from production processes in the near sustainable production of Cu by the HF process

	Index value ELU/kg or ELU/m3	Inventory result kg or m3_n per kg Cu (table 1.13)	Energy sum MJ	Impact value ELU/kg Cu with present technology	Impact value ELU/kg Cu with optimized techn.
Nat. gas, m^3_n	7.86E-01	9.68E+02	3.67E+04	7.61E+02	
Lignite, kg	4.98E-02	6.72E+02	1.68E+04	3.35E+01	
Coal, kg	4.98E-02	5.55E+02	1.67E+04	2.76E+01	
Crude oil, kg	5.06E-01	1.67E+02	6.71E+03	8.47E+01	
Forest ground use, m2yr	5.50E-04	3.50E+01		1.93E-02	
CH_4 to air, kg	2.72E+00	1.02E+01		2.77E+01	
CO_2 to air, kg	1.08E-01	1.04E+04		1.12E+03	
NMVOC to air,kg	2.14E+00	1.88E+00		4.02E+00	
NO_x to air, kg	2.13E+00	8.60E+00		1.84E+01	9.20E+00
SO_x to air, kg	3.30E+00	8.91E+01		2.94E+02	
		SUM	7.69E+04	2.39E+03	9.20E+01

. *) Represents the impact value of use of an amount of wood equivalent on energy basis with that of natural gas, lignite and coal. **) Represent the impact value of use of an amount (diesel power, table 1.13) of vegetative oil equivalent on energy basis with that of fossil oil.

If the energy in the production process comes from more sustainable sources like wood and vegetative oil, the resource impact values decrease as well as the CO_2, CH_4 and SO_x emissions. In the last column of table 2.14 the resulting emissions and use of resources are shown for an assumed optimised technology. The NO_x emissions are reduced to 50% in the scenario and the SO_x eliminated. The ground use is assumed to correspond to a 10 m deep strip-mine preventing forestry for 100 years. The total value of the impact becomes 9.2 ELU/kg Cu.

The conventional costs for the industrial production may be roughly estimated from raw material and energy demand assuming a general bulk processing cost of 0.01 EUR/kg of rock (Table 2.15).

Table 2.15 Rough cost estimate for production of Cu with HF-process.

Cost estimate for production of 1 kg Cu				
Item	amount	unit	price/unit EUR	cost
Energy, diesel	7.97E+02	MJ	0.0125	9.97E+00
Energy, electricity	6.99E+02	MJ	1.50E-02	1.05E+01
Energy, wood	7.09E+04	MJ	2.00E-03	1.42E+02
H_2SO_4	1.38E+04	kg	0.04	5.50E+02
$CaCO_3$	1.41E+04	kg	2.00E-02	2.81E+02
bulk processing	7.01E+03	kg	1.00E-02	7.01E+01
			Sum	1.06E+03

The total WTP would thus be 9.2+1060 EUR corresponding to 1069 ELU/kg Cu.

The sulphuric acid process

The process using sulphuric acid is described in figure 2.6.

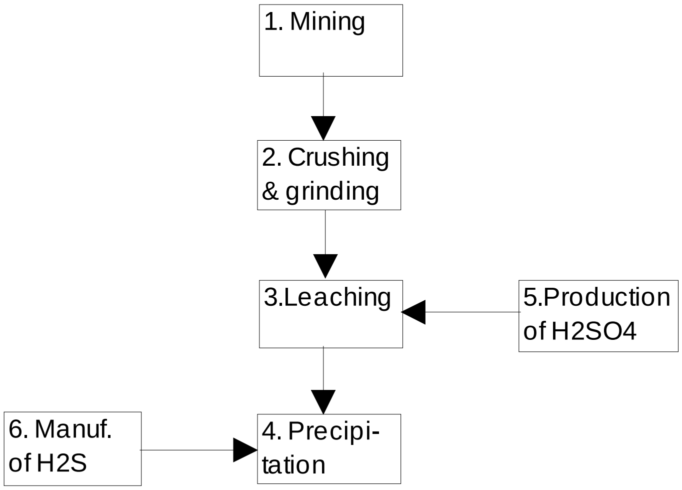

Figure 2.6 Production of sulphide ore by leaching with sulphuric acid.

Step 1 and 2 are equal to those of the HF process, but it is assumed that only a part of the metals in the silicate matrix will be extracted. The efficiency is unknown at present but assumed to be 50%, which means that 2 times as much rock has to be processed as for the HF method. In analytical chemistry a quantitative extraction of Cu from crustal rocks is obtained when using a 1/1 mixture of 5N sulphuric and nitric acids. In an industrial scale however it may not be the most suitable alternative to use the same excess amounts of acid as in the analytical case. Therefore a lower leaching efficiency is assumed.

Leaching is made with concentrated sulphuric acid. The ratio between the extracted metals and the alkali metals is assumed to be constant. This means that the acidity of the sulphuric acid will be consumed by the Na, K, Ca, and Mg content of the rock. The average concentration is 2.09% K, 2.36% Na, 2.33% Mg and 4.15% Ca. These ions are capable of neutralising 165 g sulphuric acid per kilogram of "dissolved" rock. This would mean that 1154 kg of sulphuric acid would be required (1/10 allocated on Cu, and the leaching efficiency as assumed for Cu, i.e. 50%) for the production of 1 kg of copper ore from an average rock.

4, 5 and 6 are the same as for the HF process.

The inventory data would thus be (table 2.16):

Table 2.16 Emissions and use of resources from production of copper sulphide ore by sulphuric acid leaching process.

	1, Diesel power		2, Electricity		5, H_2SO_4 production	
	per MJ	per kg Cu	/MJ	/kg Cu	/kg H_2SO_4	/kg Cu
Nat. gas, m^3_n			2.56E-05	3.58E-02	5.77E-02	6.66E+01
Lignite, kg			9.31E-05	1.30E-01	3.83E-02	4.42E+01
Coal, kg			2.76E-04	3.86E-01	3.13E-02	3.62E+01
Crude oil, kg	2.85E-02	3.99E+01	7.75E-05	1.08E-01	1.07E-02	1.23E+01
CH_4 to air, kg			2.42E-06	3.39E-03	5.84E-04	6.74E-01
CO_2 to air, kg	9.48E-02	1.33E+02	1.11E-03	1.55E+00	2.34E-01	2.70E+02
NMVOC to air, kg	1.18E-04	1.64E-01	1.00E-06	1.40E-03	8.50E-05	9.81E-02
NO_x to air, kg	5.25E-04	7.34E-01	4.20E-06	5.87E-03	4.40E-04	5.08E-01
SO_x to air, kg			3.00E-06	4.20E-03	5.36E-03	6.18E+00

Using the indices for emissions and resources derived in this report we obtain impact values for the entire production of Cu according to table 2.17. Impact values are estimated for current technology (inventory data from 2.16) and from an anticipated technology, which is optimised in terms of sustainability, but with present technology options. This means that energy is produced in a sustainable way in an industrial context (wood combustion), that forestry is certified in terms of impacts on biodiversity and that emissions of NO_x and SO_x are decreased to 50 and 10% respectively.

Table 2.17 Total environmental impact from production processes in the near sustainable production of Cu by the sulphuric acid process.

Emission or Resource	Impact index, (ELU/kg or ELU/m^{2}yr)	Inventory results, (kg or m^3_n/kg Cu	Energy content (MJ/kg Cu)	Impact value with present technology, (ELU/kg Cu)	Impact value with optimised technology. (ELU/kg Cu)
Nat. gas, m^3_n	7.86E-01	6.66E+01	2.52E+03	5.23E+01	
Lignite, kg	4.98E-02	4.44E+01	1.11E+03	2.21E+00	
Coal, kg	4.98E-02	3.65E+01	1.10E+03	1.82E+00	2.52E+00*)
Crude oil, kg	5.07E-01	5.23E+01	1.59E+03	2.65E+01	2.09E-01**)
Forest grund use, m^{2}yr	5.50E-04	3.50E+01		1.93E-02	
CH$_4$ to air, kg	2.72E+00	6.77E-01		1.84E+00	
CO$_2$ to air, kg	1.08E-01	4.04E+02		4.36E+01	
NMVOC to air,kg	2.14E+00	2.64E-01		5.65E-01	
NOx to air, kg	2.13E+00	1.25E+00		2.66E+00	1.33E+00
SOx to air, kg	3.30E+00	6.19E+00		2.04E+01	2.04E+00
		SUM	6.32E+03	1.52E+02	6.08E+00

*) Represents the impact value of use of an amount of wood, which is equivalent on energy basis with that of natural gas, lignite and coal. **) Represent the impact value of use of an amount of vegetative oil equivalent on energy basis with that of fossil oil

The WTP for the industrial production may be roughly estimated from raw material and energy demand assuming a general bulk processing cost of 0.01 EUR/kg of rock (Table 2.18).

Table 2.18 Estimation of production cost for of Cu-ore containing 1 kg of Cu by the sulphuric acid process.

Item	Unit	amount	price/unit, EUR	Production cost, EUR
Veg.oil (replacing crude oil)	kg	3.99E+01	5.00E-01	1.99E+01
Wood (replacing natural gas, lignite and coal)	MJ	4.72E+03	2.00E-03	9.45E+00
Sustainable electricity	MJ	1.40E+03	1.50E-02	2.10E+01
Acid for leaching	kg	2.89E+02	4.00E-02	1.15E+01
Processing ground rock	kg	1.40E+04	1.00E-02	1.40E+02
sum				2.02E+02

The total value of Cu-ore containing 1 kg of Cu will thus be 6.08+ 202 = 208 ELU.
The uncertainty in the valuation of Cu is estimated to be in the order of a factor of 5 mainly because of varying wood prices and uncertainties in leaching efficiency, “sustainable” acid price and consumption and in processing costs. The price of sustainable electricity is based on current price on electricity made by solar heating. Hydropower is normally much cheaper, but the amounts of hydropower available is not assumed to be sufficient for all applications. The processes are not specified and the assumed cost is what is normal for relatively uncomplicated processes like the leaching and precipitation. The estimated cost is likely to be too low because some parts of the sustainable technology are not identified. On the other hand the potential of improvement of the technology is not considered, why some of the costs identified may be too high.

Choice of weighting factor for Cu

As mentioned in section 2.3 the willingness to pay (WTP) will always be at least and approximately equal to what it takes to produce the concentrate, which substitutes the ore when the ore is depleted. The sulphuric acid process will produce the ore at the lowest cost and is the one determining the WTP for Cu-ore.

Thus the "best estimate" value for copper ore will be 208 ELU/kg. The uncertainty range is estimated to a factor of 5 corresponding to a standard deviation in a log-normal distribution of a factor of 2.2.

Sulphide ores containing Zn and other metals

If using the same procedure as for Cu, other metals produced sustainable via their sulphides from "synthetic ore" will get a value proportional to the inverse of its abundance in the earth's crust with the same proportionality constant as Cu. If the abundance in earth crust is A_x (weight/weight) for a certain metal and A_{Cu} for Copper ($=14.3 \cdot 10^{-6}$) the value for the metal x is obtained by multiplying $1/ A_x$ with 0.00297 ($=208 * A_{Cu}$). The impact value for the sustainable production scenario for zinc, with an abundance of $5.2 \cdot 10^{-5}$ is therefore $0.00297/5.2 \cdot 10^{-5} = 57.1$ ELU/kg. In table 2.19 below the value of other sulphide ores are calculated using abundance data given by Wedepohl (1995).

Choice of weighting factors

Table 2.19 Weighting factors of various sulphide metal ores.

Metal	abundance in earth's crust (mg/kg)	Value of ore ELU/ kg metal
Ag	5.50E-02	5.40E+04
As	2.00E+00	1.49E+03
Bi	1.23E-01	2.41E+04
Cd	1.02E-01	2.91E+04
Cu	1.43E+01	2.08E+02
Hg	5.60E-02	5.30E+04
Ni	1.86E+01	1.60E+02
Pb	1.70E+01	1.75E+02
Sn	2.50E+00	1.19E+03
Zn	5.20E+01	5.71E+01

The same uncertainty factor is assumed as for Cu, i.e. a factor of 5 totally and represented by a standard deviation of a factor of 2.2 in a log-normal distribution.

2.3.6. Fe-ore

Iron as a resource may be treated in the same way as Copper and Zinc, with a few exceptions. The average concentration of iron in earth's continental upper crust is 3.09% (Wedepohl, 1995). This means that iron may be mined separately or together with aluminium, which also is present in high concentrations and which may be requested in similar amounts. The allocation of impacts and costs on co-mined metals will therefore be different, compared to the scenario, which was assumed for sulphide metals above. Thus assuming that another metal will be mined together with iron and following the same allocation principle as for the sulphide ore metals, 50% of the impacts from production of iron ore is allocated on iron. This means that there are less metals to share the impact and consequently the proportionality factor will be higher, 0.0148 instead of 0.00297 as for sulphide ores. The value for iron ore would thus be around 0.50 ELU/kg Fe if the processes otherwise were equal.

There are however two circumstances that may give a somewhat higher value. First, iron ore is likely to be precipitated using sodium hydroxide instead of hydrogen sulphide. Second, the impact from this process step is not small compared to that of mining, grinding and leaching, because less rock is handled per kg of iron. The process tree for production of synthetic "iron ore" is shown in figure 2.7.

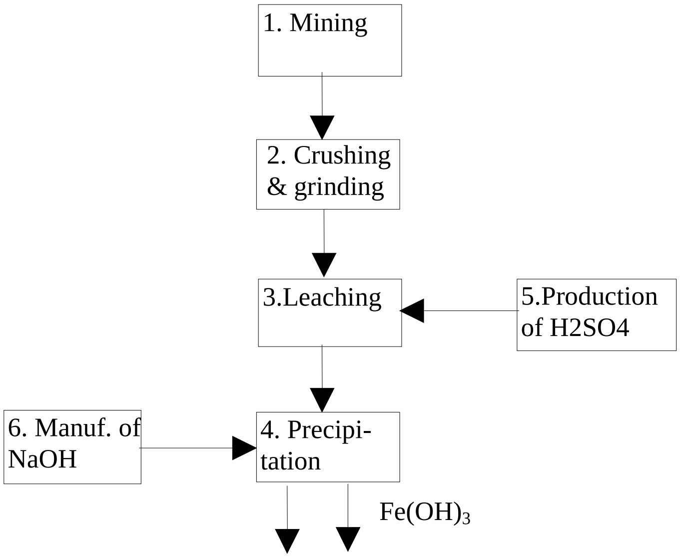

Figure 2.7 Default scenario for production of synthetic "iron ore" from average rock.

The different steps in the production scenario for synthetic "iron ore" are:

1. Mining. Strip-mining is assumed as average rock is used. The waste, which is almost all of the material, is returned to the mining area and 100 years after the mining, the area may be used for forestry or other purposes. The energy used is estimated to be

approximately 0.1 MJ/ kg rock and come from bio-fuel diesel oil. 50% of this is allocated to iron production.

2. Crushing and grinding. The energy used for step 2 is approximated to be 0.1 MJ/ kg rock as electricity, which is produced by hydropower. 50% of this is allocated to iron.

3. Leaching is made with concentrated sulphuric acid and the leaching efficiency 50%. The ratio between the extracted metals and the alkali metals is assumed to be constant. This means that the acidity of the sulphuric acid will be consumed by the Na, K, Ca, and Mg content of the rock. The average concentration is 2.09% K, 2.36% Na, 2.33% Mg and 4.15% Ca. These ions are capable of neutralising 165 g sulphuric acid per kilogram of "dissolved" rock. This would mean that 1.46 kg of sulphuric acid would be required (50% allocated to Fe) for the production of 1 kg of iron in ore form from an average rock.

4. Precipitation. Iron hydroxide is readily precipitated from the leachate when adding sodium hydroxide, especially when Fe is in the 3+ state. The leachate is assumed to be neutralised mainly by the alkali of the rock minerals. The extra sodium hydroxide necessary to precipitate $Fe(OH)_3$ is 2.06 kg/kg Fe.

5. Production of H_2SO_4 and NaOH is assumed to be a sustainable process where Na_2SO_4 from sea-salt is electrolysed.

After a calculation procedure similar to that in section 2.3.4, impact values as shown in table 2.20 are obtained.

Table 2.20 Calculation of impact values from near sustainable production of iron ore.

Emission or resource	Impact index, v2000, (ELU/kg , ELU/m3 or ELU/MJ)	Inventory results (kg or MJ per kg Fe)	Energy content (MJ/kg Fe)	Impact value with current technology (ELU/kg Fe)	Impact value with optimised technology. (ELU/kg Fe)
Nat. gas, m3n	7.87E-01	4.11E-01	1.47E+01	6.89E-02	
Lignite, kg	4.98E-02	7.23E-01	1.23E+01	2.14E-02	
Coal, kg	4.98E-02	5.81E-01	1.74E+01	1.72E-02	
Crude oil, kg	5.06E-01	2.67E-01	1.07E+01	5.91E-02	
Wood energy, MJ	5.60E-04				3.09E-02
CH4 to air, kg	2.72E+00	7.04E-03		1.91E-02	
CO2 to air, kg	1.08E-01	2.98E+00		3.22E-01	
NMVOC to air, kg	2.14E+00	1.55E-03		3.31E-03	
NOx to air, kg	2.13E+00	7.93E-03		1.69E-02	8.45E-03
SOx to air, kg	3.27E+00	3.72E-02		1.23E-01	1.22E-02
land occupation,m2yr	4.55E-02	3.20E-02		1.46E-03	1.46E-03
		SUM	5.51E+01	1.01E-00	5.29E-02

The production cost is shown in table 2.21.

Table 2.21 Estimation of production cost for Fe-ore per kg/Fe.

Item	Unit	Price/unit	Amount	Production cost (EUR/kgFe)
Veg.oil	kg	5.00E-01	9.22E-02	4.61E-02
Wood based process energy	MJ	2.00E-03	5.51E+01	1.10E-01
NaOH for precipitation	kg	1.00E-01	2.15E+00	2.15E-01
H_2SO4 for leaching	kg	4.00E-02	5.34E+00	2.14E-01
Processing ground rock	kg	1.00E-02	3.24E+01	3.24E-01
sum				9.08E-01

The total resource value for Fe-ore is thus 0.053 + 0.908 = 0.961 ELU/kg Fe as ore.

The uncertainty in the estimation of the Fe-ore value lies mainly in the wood price, in the leaching efficiency and allocation procedure when other metals are co-mined. A factor of 5 is assumed to be relevant for the default setting in the evaluation procedure.

Choice of weighting factor

0.961 ELU/kg with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 2.2.

2.3.7. Other elements sustainable available from earth's crust

As the main costs for sustainable production of concentrates of various elements in a mining-crushing-grinding-leaching-precipitation-process lies in the first 4 steps, the cost can be roughly estimated as inversely proportional to the average concentration in earth crust except for those that are extracted from sea water. Using the same proportionality constant as for copper the values in table 2.22 is obtained.

Table 2.22 Weighting factors for a number of elements determined through its abundance and assuming similarity with the sustainable production of Cu-ore.

Element formula	Element name	Abundance in earth crust (mg/kg)	Weighting factor (ELU/kg)
Au	Gold	2.50E-03	1.19E+06
Ba	Barium	6.68E+02	4.45E+00
Be	Beryllium	3.10E+00	9.58E+02
Ce	Cerium	6.57E+01	4.52E+01
Co	Cobolt	1.16E+01	2.56E+02
Cr	Chromium	3.50E+01	8.49E+01
Cs	Cesium	5.80E+00	5.12E+02
Dy	Dysprosium	2.90E+00	1.02E+03
Er	Erbium	2.10E+00	1.41E+03
Eu	Europium	9.50E-01	3.13E+03
F	Fluorine	6.11E+02	4.86E+00
Ga	Gallium	1.40E+01	2.12E+02
Gd	Gadolinium	2.80E+00	1.06E+03
Ge	Germanium	1.40E+00	2.12E+03
Hf	Hafnium	5.80E+00	5.12E+02

Table 2.22, continued (Weighting factors for a number of elements…..)

Element formula	Element name	Abundance in earth crust (mg/kg)	Weighting factor (ELU/kg)
Ho	Holmium	6.20E-01	4.79E+03
I	Iodine	1.40E+00	2.12E+03
In	Indium	6.10E-02	4.87E+04
Ir	Iridium	5.00E-05	5.94E+07
La	Lanthanum	3.23E+01	9.20E+01
Li	Lithium	2.20E+01	1.35E+02
Lu	Luthenium	2.70E-01	1.10E+04
Mn	Manganese	5.27E+02	5.64E+00
Mo	Molybdenum	1.40E+00	2.12E+03
Nb	Niob	2.60E+01	1.14E+02
Nd	Neodymium	2.59E+01	1.15E+02
Os	Osmium	5.00E-05	5.94E+07
P	Phosphorus	6.65E+02	4.47E+00
Pd	Palladium	4.00E-04	7.43E+06
Pr	Praseodymium	6.30E+00	4.71E+02
Pt	Platinum	4.00E-04	7.43E+06
Rb	Rubidium	1.10E+02	2.70E+01
Re	Rhenium	4.00E-04	7.43E+06
Rh	Rhodium	6.00E-05	4.95E+07
Ru	Ruthenium	1.00E-04	2.97E+07
Sb	Antimony	3.10E-01	9.58E+03
Sc	Scandium	7.00E+00	4.24E+02
Se	Selenium	8.30E-02	3.58E+04
Sm	Samarium	4.70E+00	6.32E+02
Sr	Strontium	3.16E+02	9.40E+00
Ta	Tantalum	1.50E+00	1.98E+03
Tb	Terbium	5.00E-01	5.94E+03
Te	Tellurium	5.00E-03	5.94E+05
Th	Thorium	1.03E+01	2.88E+02
Ti	Titanium	3.12E+03	9.52E-01
Tl	Thallium	7.50E-01	3.96E+03
Tm	Thulium	3.00E-01	9.90E+03
U	Uranium	2.50E+00	1.19E+03
V	Vanadium	5.30E+01	5.60E+01
W	Tungsten	1.40E+00	2.12E+03
Y	Yttrium	2.07E+01	1.43E+02
Yb	Ytterbium	1.50E+00	1.98E+03
Zr	Zirconium	2.37E+02	1.25E+01

The uncertainty is assumed to be described with a log-normal distribution with a standard deviation corresponding to a factor of 3.

The elements Si and Ca are mined from minerals, which are considered to be sustainable resources, and are thus having a weighting factors of 0 ELU/kg.

2.3.8. Elements available from sea water (Na, K, Cl, Mg, S, B, Br and I)

Today Na, Cl and Mg is commercially produced from sea salt. Sea salt is a sustainable resource, why the depletion value of Na, Cl and Mg-reserves is zero. For K it is estimated to be equal to the cost for concentration of K in sea salt brines to the same level as is present in K-rich rock salt, which is the main source of K today. This is a rather simple process, carried out in connection with the initial evaporation of seawater. KCl is somewhat less soluble in water (276 g/l) than NaCl (357 g/l). The first precipitates of salt in a batch of seawater, which is evaporated, is thus likely to be enriched in K. The estimated to cost for concentrating K is in the order of 10 EUR/ton K why the resource value of K-rich rock salt is 0.01 ELU/kg K.

Sulphur is today mined in elementary form or extracted from fossil fuel. If extracted from seawater, sulphates may be produced at low costs, probably in the same range as K, i.e. corresponding to a resource value of 0.01 ELU/kg. To produce elementary sulphur one would have to reduce the sulphates for instance with carbon. Theoretically there is at least a need for as much carbon mass as sulphur mass in this reaction. Having a resource value of coal of 0.05 ELU/kg we would get a resource value of elementary S in the order of 0.1 ELU/kg.

Part of the Br is today extracted from seawater, why its resource value may be estimated to 0 ELU/kg. Also iodine is extracted from seawater via kelp. As for bromine, there are other methods that are used today, but the fact that it is possible to use seawater in an economically competitive way, indicate a resource value close to zero for Br and I.

Today Li is mined in the form of the minerals amblygonite, $LiAlFPO_4$, spodumene, $LiAl(SiO_3)_2$ and lepidolite, $Li[F,OH]_2Al_2(SiO_3)_2$. Li may be extracted from sea salt, but the total available amount in the oceans is not more than $1.8\ 10^{13}$ kg. This means that a large scale use of Li in batteries for cars may not be sustainable unless a well organised recycling of Li takes place or that Li is leached from waste deposits and returned to the oceans.

However if extracted from sea salt, Li may be produced at a reasonable cost. LiCl and $LiSO_4$ is more soluble than the Na and K salts (see table 2.23) and will be concentrated in the brines of evaporating seawater. In present extraction technology when the minerals mentioned above are used, Li is separated from Na and K via its carbonates where $LiCO_3$ has a comparatively low solubility at 100 ^{o}C. The overall cost of extracting Li from seawater will depend on how much sea salt that is produced. If Li can be concentrated as a by-product to similar levels as the minerals, which are used today, the cost should be in the order of 0.1 EUR/kg representing a relatively simple process technology and moderate energy consumption. The resource value is thus assumed to be 0.1 ELU/kg as a best estimate with an uncertainty of a factor of 10. The uncertainty lies mainly in the uncertainty of the volumes of Li needed. If large volumes are needed, another technology must be used.

Table 2.23 Solubility of various ions of Li, Na, K and Mg.

Substance	Solubility, (g/l)	Water temp, (^oC)
LiCl	459	25
Li_2CO_3	7.2	100
Li_3PO_4	<0.34	
Li_2SO_4	257	20
NaCl	264	20
Na_2CO_3	485	100
Na_3PO_4	45	
Na_2SO_4	71	20
KCl	258	25
K_2CO_3	1560	100
K_3PO_4	1930	
K_2SO_4	107.5	25
$MgCl_2$	164	20
$MgCO_3$	0.1	100
$MgSO_4$	225	25

Borates are mined today from deposits originating from evaporated inland seas (Latimer 1963) This means that it is likely that it can be obtained from evaporating sea water at certain salt concentrations. The exact procedure is not identified, but its complexity and cost is assumed to be somewhere between that of Li and K.

Choice of weighting factors

The weighting factors for elements thus produced from sea water are given in table 2.24.

Table 2.24 Weighting factors for sources of elements that may be produced out of sea water in a sustainable way.

Element	Source	Concentration of element in sea water, ppm by weight	Weighting factor (ELU/kg element)	Uncertainty (factor)
Li	Lithium salt	0.18	0.1	10
B	Borates	4.44	0.05	10
Br	Bromide salt	67.3	0	1
H	Water	1.08E+05	0	1
Na	Sodium salt	1.08E+04	0	1
K	Potassium salt	3.99E+02	0.01	10
Mg	Magnesium salt	1.29E+03	0	1
S	Elementary S	9.05E+02	0.1	5
I	Iodide salt		0	1
Cl	Chloride salt	1.94E+04	0	1

2.3.9. Elements available from air

Today several elements are produced from air. This resource may be regarded as sustainable, in particular as the elements to a large extent are returned to the atmosphere when used. Thus the weighting factors as shown in table 2.25 are chosen.

Table 2.25 Weighting factors for elements that sustainably may be produced out of air

Substance	Value (ELU/kg)	Uncertainty (factor)
Ar	0	1
He	0	1
Ne	0	1
N	0	1
O	0	1

2.3.10. Elements sustainably available from the biosphere

Carbon has been evaluated earlier as charcoal. The weighting factor for elementary carbon is chosen to be the same, i.e. 0.0498 ELU/kg.

2.3.11. Natural gravel

Natural gravel may be substituted by crushed rock. The extra cost for crushing rock to similar sizes as gravel is in the order of 2 EUR/ton assuming an energy consumption of 4 MJ per ton, a capital cost of $86000 for a 20 ton/h jaw crusher (Perry, 1997b), an operating time of 4000 hours per year, a life time of 5 years and a demand of manpower of 1 person-hour/operating hour. This would give a total cost of $1.3 per ton. Adding some extra equipment like conveyor belts, and necessary vehicles the cost adds up to about a $2/ton. This would correspond to a resource value of 0.002 ELU/kg.

The uncertainty of this figure lies mostly in manpower cost and in the size of the plant. The uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of two.

2.4. Bio-diversity

2.4.1. NEX

The total WTP in OECD for avoiding 1 NEX is estimated from Swedish figures. The estimation is based on the Swedish governmental and private expenses for preservation measures. These are transferred to global scale by multiplying with the population ratio.

The Swedish expenses are estimated to 178 million EUR by (SCB, 1992). The figures are used as a sample from the OECD countries. The uncertainty of the estimate with respect to the OECD average is estimated to be in the order of a factor of 10, partly because

Swedish figures does not exactly represent OECD and partly because the value of different species varies and is poorly understood.

An alternative way of finding WTP for NEX is to use the CVM method for single species. ExternE (1995) presents values between 1 and 50 EUR/specie. However there are at least two shortcomings for this approach. First, the CVM values may not be directly added. Second, data only exists for some large mammals and birds.

The WTP for avoiding 1 NEX on the globe is thus $178 \cdot 10^6 * 5.28/8.56 * 10^3 = 1.1 \cdot 10^{11}$ EUR.

Choice of weighting factor

$1.1 \cdot 10^{11}$ ELU with an uncertainty represented by a log normal distribution with a standard deviation corresponding to a factor of 3.

2.5. Cultural & recreational values

There are so far no general values that have been identified. The WTP has to be found for each specific case.

3. Classification and characterisation of emissions of carbon oxides to air

There are only two substances in this group, carbon monoxide, CO and carbon dioxide, CO_2, but both have significant environmental impacts and is emitted in large quantities all over the world. Carbon dioxide will be dealt with first and then carbon monoxide, as some of the models for the determination of CO_2 characterisation factors also are used for CO.

3.1. Emissions of Carbon dioxide anywhere in the world

3.1.1. Definition of flow group:

Most carbon dioxide emissions occur as a result of combustion processes and biological respiration. Some CO_2 are also emitted from calcination of carbonates. The residence time of CO_2 in air is in the order of several years. Therefore the exact place and time when the emission occur on the globe is not important when calculating the total effects. Nor is the source strength for the impact per unit mass of CO_2.

The flow group characterised here is CO_2 emissions anywhere in the world the year 1990 and at any source strength.

3.1.2. Assignment to impact categories

A model for some commonly discussed effects of CO_2 emissions to the atmosphere is shown below in figure 3.1.

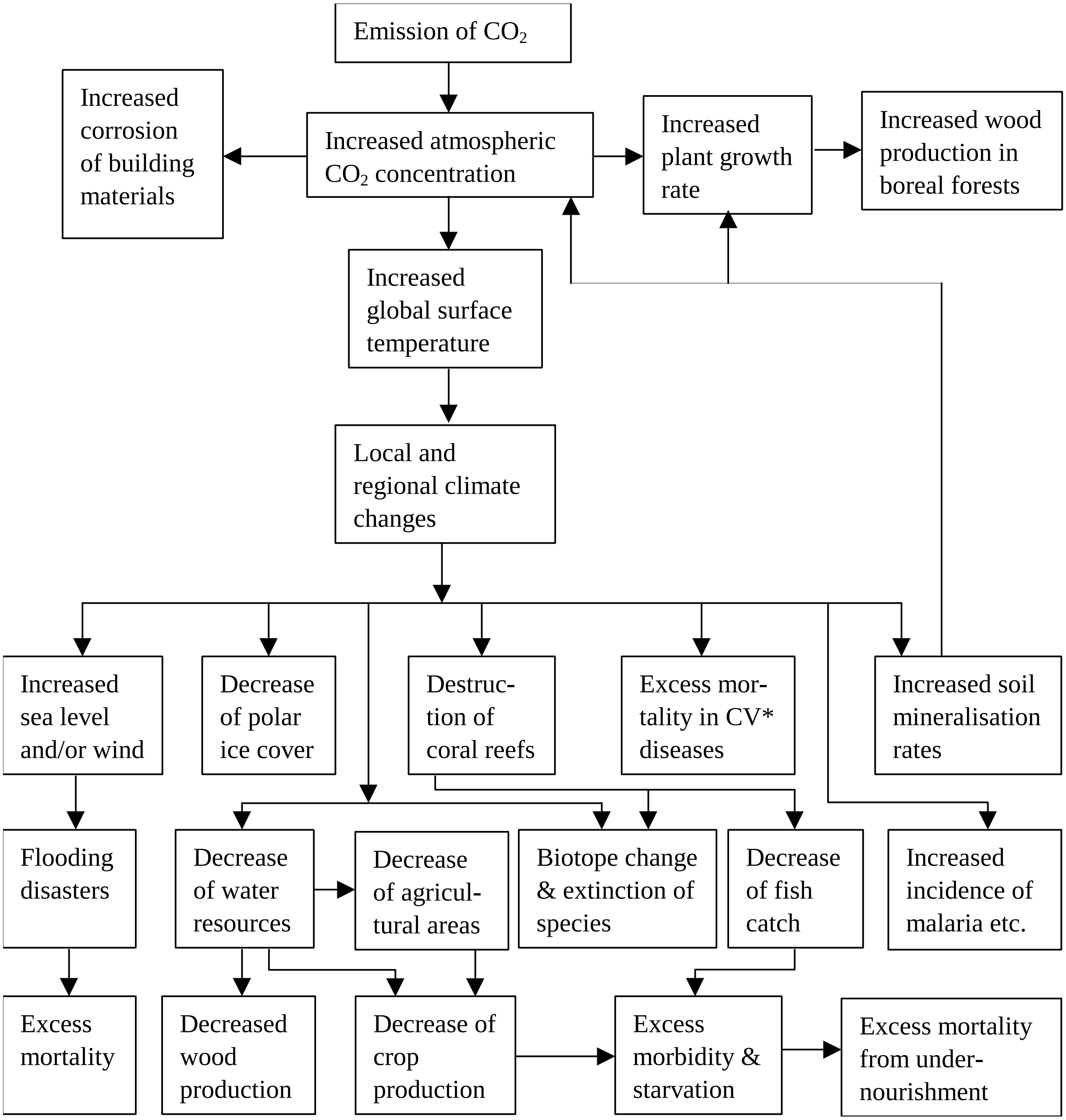

Figure 3.1 A model of CO_2 impact on the environment. *CV = Cardio-Vascular

Impacts on the safe guard subjects from increased CO_2 concentration in the atmosphere are almost entirely due to the greenhouse effect. Effects may however also occur through direct CO_2 effects like fertilisation of vegetation and increased corrosion rates of building materials, but these are not considered to be of a similar magnitude as the greenhouse effect and only the fertilisation effect is dealt with further in this version of the default method.

Hardly any of the impacts on category indicators associated with the greenhouse effect are known in such a way that their relation to CO_2 emissions can be modelled accurately enough to gain a general acceptance of a single characterisation model or factor. One reason for this is the long time span involved and the close relation with social factors. Therefore the impacts are described here as scenarios which are extrapolations of present trends. The scenarios are chosen with respect to the precautionary principle and with the requirement that there should be at least some scientific evidence that the scenario may occur if present trends continue.

Based on the discussion above and the possibility of finding models for the characterisation factors, CO_2 emissions to air are assigned to impact categories and category indicators selected as shown in table 3.1.

Table 3.1 Assignment of CO_2 emissions to impact categories and selection of category indicators.

Pathway	Impact category	Category indicator
Temperature stress	Life expectancy	YOLL
Starvation	Life expectancy	YOLL
Flooding	Life expectancy	YOLL
Malaria	Life expectancy	YOLL
Starvation	Severe morbidity	Severe morbidity
Malaria	Severe morbidity	Severe morbidity
Starvation	Morbidity	Morbidity
Malaria	Morbidity	Morbidity
Climate change, desertification	Crop production capacity	Crop
Temperature raise in forest zones,	Wood production capacity	Wood
CO_2 fertilisation	Wood production capacity	Wood
Too fast moving climate zones	Extinction of species	NEX

3.1.3. Characterisation of CO_2 to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The flow group and its impacts are of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society affected is the one described in IPCC scenario IS92A. (IPCC, 1990). The choice of 100 years as a temporal system border is made for two reasons. First, the rate of change, rather than the absolute change seems to be the main factor causing the effects. Many of the systems affected have time constants of their responses up to 100 years. The second reason is that most of the models of global warming consequences are on the 100-year basis.

Model 1, pathway via heat stress

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

Several studies have shown that an increased temperature during heat waves causes an excess mortality in urban areas. The effect becomes statistically significant at daily average values around 30 degrees centigrade (Weihe, 1986). Persons older than 65 years suffering from cardiovascular diseases are at high risk.

An increased absorbency of sun radiation and lack of shadowing and evaporative cooling from vegetation largely influence the urban climate in tropical and subtropical areas.

The increased absorbency, the large heat storing capacity in buildings, the increased burning of fossil fuel and decreased cooling capacity create a heat island in the centre of the city. The larger the city and the denser the population, the more expelled is the heat island compared to the surroundings. However large differences occur between different regions. In tropical humid regions buildings are mainly made in light materials to promote ventilation, while in tropical dry areas with large temperature variations between day and night the buildings are made in heavy stone, concrete, bricks etc. to level out indoor temperature (Oke, 1986).

The heat island problem may increase substantially in the future, depending on several factors. The population growth and migration to urban areas increase the number of exposed. In turn, the growth of the urban complexes increases the excess temperature. Adding a global warming on top of this will enhance the effects further.

The temperature difference between rural and urban areas is normally of the order of a few degrees, but sometimes it may be around ten (night time in Mexico city).

In a study by Weihe (1986), the results from an investigation in the New York-New Jersey area by Buechley was presented as a quantitative relation (table 3.2 below).

Table 3.2 Daily excess mortality as a function of maximum daily temperature.

Temperature (^oC)	Excess mortality to heat (% of annual means)
32.2	negligible
35.0	27
37.8	75
40.6	200
43.3	546

The dependency of excess mortality of daily temperature may vary between different areas, populations and dynamic temperature pattern, but statistics from other regions have not been available.

Another possibility to estimate the effects of elevated temperature is to compare death statistics with the average monthly temperatures. Weihe (1986) refers to a study of Sakamoto-Moniyama who correlated monthly mortality rates from cerebrovascular diseases with mean monthly temperatures for a number of countries. The death index varies linearly with temperature and has a minimum at 24 ^oC. The excess mortality at 26-28 ^oC was the same as at 6-8 ^oC. Combining this information with data given for Cairo the dose-response-curve in figure 3.2 was constructed.

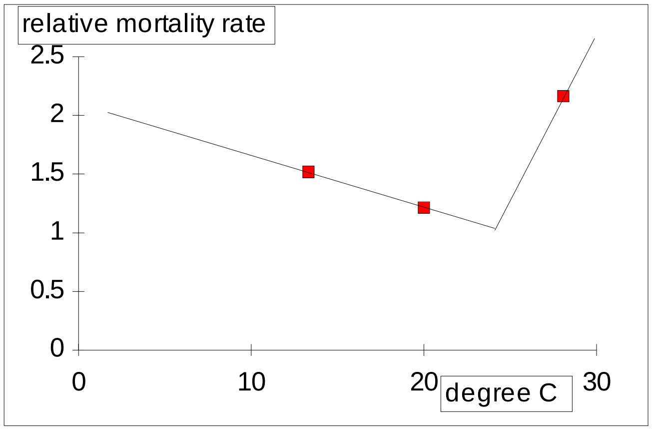

Figure 3.2 Monthly mean excess mortality as a function of temperature. The mortality at 24^{o}C is set equal to 1.

To estimate the the total YOLL, which an increase of global average temperature would cause, one has to estimate the average shortening of life for those individuals who die during heat periods, the number of persons exposed to high temperatures and the time per year they are exposed to various temperatures.

Average shortening of life

From the information that persons above 65 years are influenced the most, and that the median remaining life expectancy of these is about 10 years in Sri Lanka and China (Weihe, 1986), one could assume that the average life shortening would not be more than 10 years for those who die from heat if they would be struck at random. As the persons effected normally are suffering from cardiovascular diseases or sometimes lung diseases it is assumed that the average life shortening is less than 0.3 year, with an uncertainty of a factor of 2 (standard deviation in a log normal distribution).

Number of persons exposed at various temperatures

The number of persons living in various regions of the world are shown in table 3.3 together with the quarterly average temperatures (UN, 1992), (Times World Atlas, 1990). Using the assumption of an average shortening of life expectancy of 0.3 year, a temperature increase of 1.5 degrees, the total life shortening on a global basis will be 5.9 million YOLL per year as an average during 100 years.

Table 3.3 Persons exposed to various monthly average temperatures in various regions of the world. The average excess mortality per year for all periods will be 5.898 million YOLL.

Part of world	Region	Estimated popula-	Average monthly temperature, (deg. C).				Excess mortality million YOLL/yr			
		tion 2025 (million)	Jan-March	April-June	July-Sep	Oct-Dec	Jan-March	April-June	July-Sep	Oct-Dec
Europe	west	150	5	14	17	7	-0.0463	-0.0463	-0.0463	-0.0463
	south	159	11	15	23	14	-0.0491	-0.0491	-0.0491	-0.0491
	east	131	-10	8	15	-8	-0.0404	-0.0404	-0.0404	-0.0404
	north	84	2	9	14	6	-0.0259	-0.0259	-0.0259	-0.0259
Africa	west	558	27	26	25	25	1.0044	1.0044	1.0044	1.0044
	east	537	25	36	33	26	0.967	0.967	0.9666	0.967
	north	261	14	20	25	18	-0.0805	-0.0805	0.4698	-0.0805
	central	170	26	27	26	25	0.306	0.306	0.306	0.306
	south	91	17	14	14	18	-0.0281	-0.0281	-0.0281	-0.0281
Latin America	middle	779	19	22	22	20	-0.240	-0.240	-0.240	-0.240
	tropical south	223	26	24	24	25	0.401	0.401	0.401	0.401
	temperate	429	22	15	12	17	-0.132	-0.132	-0.132	-0.132
	Carribean	58	20	20	20	20	-0.018	-0.018	-0.0179	-0.0179
North America		345	4	17	22	18	-0.106	-0.106	-0.106	-0.106
East Asia	China	1475	8	22	24	14	-0.455	-0.455	2.655	-0.455
	Japan	132	7	18	24	14	-0.0407	-0.0407	0.238	-0.0407
	rest	114	0	17	21	4	-0.0352	-0.0352	-0.0352	-0.0352
South Asia	south central	1855	24	33	29	22	3.339	3.339	3.339	-0.572
	southeast	688	25	28	27	25	1.238	1.238	1.238	1.238
	southwest	271	8	20	26	10	-0.0836	-0.0836	0.4878	-0.0836
Oceania	Australia/N Z	27	21	16	14	18	-0.0083	-0.0083	-0.00833	-0.00833
	Melanesia	10	20	20	20	20	-0.0031	-0.0031	-0.0031	-0.0031
	M&Polynesia	1	20	20	20	20	-0.0003	-0.0003	-0.00031	-0.00031
Former Sovjet		368	-10	8	15	-8	-0.113	-0.113	-0.113	-0.113
						SUM	5.7484	5.7484	10.25866	1.837029

Contribution to category indicators value from a flow unit

Fossil CO_2 contributes to 63% of the global warming. (IPCC,1990, scenario A; business-as-usual;1765-2025) Total emission of CO_2 from burning of fossil fuel and deforestation plus industrial activity is during 1990 6.0 ± 0.5 Gton C, or 22 ± 1.8 Gton CO_2. For the ICPP scenario IS92A it is 14 Gton C as an average during the next 100-year period. This means that one kg CO_2 contributes with $1.26 \cdot 10^{-16}$ to the total greenhouse effect during 100 years.

Calculation of pathway specific characterisation factor

The characterisation factor will thus be $5.9 \cdot 10^{6} * 100 * 1.26 \cdot 10^{-16} = 7.43 \cdot 10^{-8}$ YOLL/kg CO_2.

Uncertainty

The uncertainty of the estimation lies in the dose-response relationships (in the order of tens of %), the assumed shortening of life expectancy (factor of 4, (corresponding to two standard deviations)), in the exposure estimation (in the order of tens of %), and in the estimated local temperature increase (a factor of 3). In total the uncertainty range is estimated to be in the order of a factor of 5.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.5.

Model 2, pathway via starvation

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

In present UN death statistics the classes AM 22 and AM 23 represent death from under nourishment and from insufficient protein supply. Typical values from OECD countries are 0.01-0.02%, while values from Guatemala and Mexico are 5.2 and 1.6% respectively for the sum of the two classes (UN Demographic Yearbook, 1992).

The increase of mortality due to starvation caused by global warming is estimated below in two ways.

The first is by using the estimation of the increased number of starving people and assume that the death cause among those people is mainly due to starvation (50%) and that the average life expectancy is reduced to 50 years. With Parry's figures on the increase of the starving population (Parry 1994) this would give 600 000 - 3.5 million cases per year, and a best estimate of 1.8 million cases per year.

The other way of estimating the excess mortality is by using the death frequency figures from Guatemala and Mexico on the poorest 1 billion of the earth's population and assume that the 5% decrease of world crop production estimated by Krol (1993) will occur amongst them. This will roughly mean a 25% decrease of food production in the poor regions and should result in more than a 25% increase of the death rates in classes AM 22 and AM 23. A 25% increase, using the average figures for Guatemala and Mexico (3.4%) would mean 0.85% of 1,000,000,000/50, which is 170,000 cases per year.

Other death causes, particularly from infectious diseases are also influenced by the nutrition status of the population.

Based on these considerations and applying the precautionary principle the figure 1.8 million cases per year will be used as a default value.

No information is at present available about the average shortening of life expectancy due to excess mortality, but the general impression from media reporting from areas where starvation occur is that it strikes at all ages. An average shortening of life of 30 years is therefore assumed resulting in 54 million YOLL per year or $5.4 \cdot 10^9$ YOLL per 100 year.

Contribution to category indicators value from a flow unit
The same value as for model 1 is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$5.4 \cdot 10^{9} * 1.26 \cdot 10^{-16} = 6.8 \cdot 10^{-7}$ YOLL/kg CO_2

Uncertainty
The prediction of the number excess deaths by starvation is speculative why the possible error is large. A factor of ten is guessed including a factor of two in the estimation of temperature raise.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 3, pathway via flooding accidents
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
The risk analysis made by ICCP (1992) includes increased wind and elevated sea level. UN statistics on natural disasters indicate what the consequences might be (Table 3.4). During the period 1980 to 1992 the flooding in Bangladesh 1991 is the one that has taken most lives and is two orders of magnitude larger than all others. The average for the period is therefore determined by the Bangladesh disaster. There is no evidence that the specific flooding in Bangladesh was caused by global warming. However IPCC considers it likely that the global warming causes the increased frequency of natural disasters in terms of flooding and cyclones. In that case the number of victims would at most be around 15,000 per year for the period. Compared to other effects by CO_2, this is small and for the purpose of this work and applying the precautionary principle it may be relevant to use this value.

Table 3.4 Number of deaths in floods including inland disasters.

Year	Number of victims in floods
1981	4560
1982	4300
1983	2068
1984	206
1985	2300
1986	1450
1987	6800
1988	7100
1989	4900
1990	400
1991	165000
1992	2900

Assuming excess mortality striking randomly at persons of different age, the average reduction of life expectancy will in the range of 30 years corresponding to 450000 YOLL per year or $4.5 \cdot 10^7$ YOLL per 100 years.

Contribution to category indicators value from a flow unit
The same value as for model 1 is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$4.5 \cdot 10^7 * 1.26 \cdot 10^{-16} = 5.7 \cdot 10^{-9}$ YOLL/kg CO_2

Uncertainty
The prediction of the number of drowned is speculative why the possible error is large. A factor of ten is assumed including a factor of 3 for the contribution.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 4, pathway via malaria
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
IPCC working group II reports on models indicating that the geographical zone of potential malaria transmission in response to world temperature increase at the upper part of IPCC projected range (3-5^{o}C by 2100) will increase. The increase would be from 45% of the world population at risk to approximately 60%. The model estimates the potential increase of malaria incidence to 50-80 million cases compared to the global background of 300 - 500 million cases. This means an increase about 10%. As the new cases of malaria probably occur outside Africa, where the medical treatment is better, the increase in average mortality rate is assumed to be somewhat lower.

WHO (http:/www.who.int) reports that at present 1.5 – 2.7 million persons (average 2.1) die annually from malaria, (= 0.5% of total incidence) and 1 million of these are children under 5 years. The average shortening of life expectancy is therefore estimated to 50 years.

However, the model used for estimating the increase in malaria incidence used a scenario with a temperature increase approximately twice the scenario used in the EPS default method. Not having an opportunity of recalculating the model we will extrapolate linearly the results of the model to give 30 million additional cases per year (5%).

The global average mortality rate relative to the incidence is today 0.5%, but the figure varies in different countries and regions. India reports a mortality of 0.05%, Cambodia 1.19%, Myanmar 3.3%, the Western Pacific Region 0.12 % and Eastern Mediterranean 0.27% (WHO 1997). Today most of the malaria cases occur in Africa (90%) and a majority of the deaths. The additional cases are assumed to occur in areas, where the medical services are better than average, and a conservative estimate of half the average mortality is made.

The total indicator value in the system considered will therefore be $0.5*0.05*2.1\cdot10^{6}*100*50 = 2.6\cdot10^{8}$ YOLL per hundred years.

Contribution to category indicators value from a flow unit
The same value as for model 1 is relevant, i.e. $1.26\cdot10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$2.6\cdot10^{8} *1.26\cdot10^{-16} = 3.3\cdot10^{-8}$ YOLL/kg CO_2

Uncertainty
The modelling of the geographical distribution is uncertain and the status of the health care at about 50 years from now is more or less impossible to forecast. However following the precautionary principle and keeping as close as possible to “business as usual”, the uncertainty is not worse than for models 2 and 3. We therefore assume an uncertainty of a factor of 10 as for the models 2 and 3.

There may be an overestimation of the number of actual cases resulting from the global warming, as the modellers seem to have been modelling an upper risk level. However, the model is made only on malaria, and a number of other diseases are also likely to increase (IPCC, 1995).

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor
Considering all pathways, the characterisation factor for CO_2 with respect to YOLL is $7.43\cdot10^{-8} + 6.8\cdot10^{-7} + 5.7\cdot10^{-9} + 3.3\cdot10^{-8} = 7.93\cdot10^{-7}$ YOLL/kg CO_2

3.1.4. Characterisation of CO_2 to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated
The impacts are of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, starvation pathway
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
An increased global temperature will move the climate zones towards the poles. In many parts of the world, crop production may follow the moving zones and the net changes be small. In Africa and some other places however, there are no areas that can substitute the

present production areas, and a total global decrease of crop production seems likely. In one model study this was estimated to about 5% if no counteracting actions were taken (Krol, 1993). Considering that those parts of the world already suffering from starvation and having a large population growth rate will have the most of the decrease, it is likely that the starvation will be of the same order, 5% of the population, which involves several hundred million people. Assuming that the starvation is predominant only during a part of the year, an estimate of the order of 50 million man-years annually can be made. The number of people today suffering from poverty and malnutrition is about one billion (UN, 1991). A recent study estimated the number of people affected by starvation as a consequence of global warming to 60-350 millions. (Parry, 1994).

Part of the starvation is severe and may be classified as severe suffering, while part of it may probably be classified as morbidity. The understanding of the character of starvation is presently poor in the default valuation method. Therefore, an average value is used in that half of the starvation is assumed to be severe and half of the starvation time equal to morbidity with moderate suffering. Thus as a default it is assumed that there are 25 million person-years per year of severe suffering from starvation and 25 million person-years per year of starvation associated with morbidity.

Contribution to category indicators value from a flow unit

The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor

$2.5 \cdot 10^{9} * 1.26 \cdot 10^{-16} = 3.15 \cdot 10^{-7}$ person-years/kg CO_2

Uncertainty

Modelling crop production as a function of climate change is very complicated and involves a large uncertainty. A factor of ten is assumed at this stage.

The prediction of the number of starving people is speculative why the possible error is large. A factor of ten is assumed including a factor of two in the estimation of the temperature raise and a factor of 3 for the contribution.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, malaria pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The IPCC working group 2 suggests a potential increase of 50 – 80 millions of malaria cases per year as cited in section 3.1.3 above. It was concluded in 3.1.3 that the figure 30 million cases were more relevant for the scenario used by the EPS default method.

Malaria is a disease, which has some severe fever symptoms during 5-11 hours and which can be latent for 2-60 days before the next fever attack. There are four different types of malaria parasites and a large number of manifestations of malaria illness. Varying immunity of infected persons and varying drug resistance of the malaria parasite adds to the complexity of its clinical features. No statistics on the severity of the clinical features of malaria has been found. Malaria seems to have its most severe consequences in areas where the reporting of health status is least effective. However it seems as the clinical manifestations can be grouped in chronic and acute morbidity. There are 300 million chronic cases in the world today and about and an incidence of 100 million new cases per year. It seems, as the chronic cases are by far the most severe. It is therefore assumed that severe morbidity occur during 10% of the time for the 30 million extra persons who are expected to be suffering from chronic malaria and morbidity at 90%. The total indicator value in the system considered is thus $0.1*30\cdot10^{6}*100 = 3\cdot10^{8}$ person-years.

Contribution to category indicators value from a flow unit
The same value as for modelling of YOLL is relevant, i.e. $1.26\cdot10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$3\cdot10^{8}*1.26\cdot10^{-16} = 3.8\cdot10^{-8}$ person-years/kg CO_2

Uncertainty
The same as for model 4 in 3.1.3 applies. We therefore assume an uncertainty of a factor of 10.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor
Considering both pathways we obtain: $3.15\cdot10^{-7} + 3.8\cdot10^{-8} = 3.53\cdot10^{-7}$ person-years/kg CO_2

3.1.5. Characterisation of CO_2 to air with respect to morbidity

Definition of environmental system in which the impact is estimated
The impacts are of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society affected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, starvation pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The indicator value was estimated in 3.1.4, model 1 to 25 million person-years per year.

Contribution to category indicators value from a flow unit
The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$2.5 \cdot 10^{9} * 1.26 \cdot 10^{-16} = 3.15 \cdot 10^{-7}$ person-years/kg CO_2

Uncertainty
The prediction of the number of starving people is speculative why the possible error is large. A factor of ten is assumed including a factor of two in the estimation of the temperature raise and a factor of 3 for the contribution.
Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, malaria pathway
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
From 3.1.4, model 2 we get the value of $0.9 * 30 \cdot 10^{6} * 100 = 2.7 \cdot 10^{9}$ million person-years

Contribution to category indicators value from a flow unit
The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$2.7 \cdot 10^{9} * 1.26 \cdot 10^{-16} = 3.4 \cdot 10^{-7}$ person-years/kg CO_2

Uncertainty
The same as for model 4 in 3.1.3 applies. We therefore assume an uncertainty of a factor of 10.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor
Adding the factors for both pathways we get $3.15 \cdot 10^{-7} + 3.4 \cdot 10^{-7} = 6.55 \cdot 10^{-7}$ person-years/kg CO_2.

3.1.6. Characterisation of CO_2 to air with respect to crop production

Definition of environmental system in which the impact is estimated
The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society affected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model
The characterisation factor is determined by an empirical method.

Category indicator value in system considered

As mentioned in paragraph 3.1.3 the decrease in wheat production may be in the order of 5%. Today the global crop production (including wheat, rye, barley, oats, corn, rice, sorghum and potatoes) is 2.4 billion tons. If a 5% decrease is assumed for all crop types by the year 2090 the decrease will be 0.12 billion tons per year. An average over the 100-year period is assumed to be 60 million tonnes per year.

Contribution to category indicators value from a flow unit

The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of characterisation factor

$60 \cdot 10^{11} * 1.26 \cdot 10^{-16} = 7.56 \cdot 10^{-4}$ kg crop/kg CO_2

Uncertainty

The uncertainty is large, but the estimation is based on extensive modelling so a factor of 5 is assumed.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2.

3.1.7. Characterisation of CO_2 to air with respect to wood production

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society affected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, elevated temperature pathway

The characterisation factor is determined by a mechanistic method.

Mechanism

No attempt to quantitatively forecast altered forest growth as a consequence of global warming has been found. In a very long time perspective the forest belts may move towards the poles in a similar way as the agricultural areas are expected to do. In the 100-year perspective often used for the greenhouse effects, there is only time for one generation of trees in the boreal region and if no diseases or insects or competitors attack the trees a net increase in production seems likely. However in the more arid areas and in the tropical areas, water is more important for the growth rate than temperature and the consequence of global warming is more difficult to forecast.

For the boreal region a model describing nitrogen mineralisation rates in soil at different temperatures (Jansson, 1999) may be used to estimate the growth increase. According to this an increased temperature of 1.5 ^{o}C would give an increased nitrogen mineralisation of 12% in the boreal and mixed temperate forests. Assuming that nitrogen availability is growth limiting to 50% (the rest mainly due to water deficiency) the growth increase would be 6%. The world production of round timber from this region is about 3.5 billion

m^3/year corresponding to roughly 1.5 billion ton DS wood. 6% of this is 92 million tons/yr or $9.2 \cdot 10^{12}$ kg per 100 year.

Contribution to category indicators value from a flow unit
The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
$-9.2 \cdot 10^{12} * 1.26 \cdot 10^{-16} = -1.16 \cdot 10^{-3}$ kg DS wood/kg CO_2

Uncertainty
The uncertainty in this estimate is partly due to possible changes in wind, precipitation and cloudiness but also to the fact that part of the boreal forests are at the southern border of its natural climate zone. A factor of 10 is assumed for the uncertainty, as the modelling is very limited.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, CO_2 fertilisation pathway
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
IPCC (1994) estimates that the increased uptake of CO_2 from the atmosphere from vegetation was between 0.5 to 2.0 Gton C/yr during the 1980ies. During the 80ies the CO_2 concentration was about 75 ppmv above pre-industrial levels. As an average the increased CO_2-levels for the next 100 years are estimated to about 220 ppmv for the IS92a scenario. However IPCC assumes that no direct linearity exists between the increased CO_2 concentration and the increased vegetation growth rate, as other factors like access to water and nutrients also influence the growth rate. It is reasonable to assume that the CO_2 fertilisation effect is less effective per molecule as the concentration increases. It is therefore assumed that the net increase of CO_2 uptake will be doubled as an average for the next 100 years, i.e. 2.5 Gton C/yr.

Roughly half of this is estimated to be bound in timber, thus resulting in a growth increase of $0.5 * 2.5 * 30/12 = 3.12$ Gton wood (dry substance)/yr = $3.12 \cdot 10^{12}$ kg wood/yr.
30 is the mole weight of CH_2O the average molecular element of wood and 12 is the mole weight of carbon.

Contribution to category indicators value from a flow unit
The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of pathway specific characterisation factor
For the time period of 100 years we get $-3.12 \cdot 10^{12}$ kg wood/yr$*$100yr$*1.26 \cdot 10^{-16}$ kg^{-1} = -0.0393 kg wood/kg CO_2.

Uncertainty

IPCC gives a range of 0.5 to 2.0 Gton C/yr in their estimate of the carbon sink caused by CO_2 fertilisation. Adding the uncertainty of the estimation of the proportion of C ending up as wood in tree stems and the uncertainty in residence time in wood and soil, a log normal distribution is assumed a standard deviation corresponding to a factor of two.

Calculation of characterisation factor

For both pathways the added characterisation factor is - 0.00116 + (- 0.0393) = - 0.0405 kg wood(DS)/kg CO_2.

3.1.8. Characterisation of CO_2 to air with respect to NEX

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The choice of temporal system borders may be made in several ways. In terms of endpoint impact duration, extinct species are extinct forever. In terms of system response time it is more relevant to use 100 years as temporal system borders. 100 years is the times scale necessary to establish a forest or a soil structure. It may vary between northern and southern latitudes and with the criteria's used to categorise a biotope, but a 100 years time period is not an unreasonable temporal system border for the category indicator used as default, i.e. contribution to the red-list. It is also practical as it is used for the other impacts caused by CO_2.

Model

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

A review of the current state of knowledge on Biodiversity and global climate change was made by van Vuuren and Kapelle (1998). The threat to bio-diversity lies mainly in the alteration of habitats for species that has no possibility to adapt to the moving climate zones. No quantitative estimation of the impact on bio-diversity from global warming has been found.

However, as it is regarded as one of the most serious threats, omitting it would also be a quantitative estimation in this priority setting context. It is assumed therefore until better knowledge is available that the present rate of extinction will be doubled, i.e. the total indicator value change is 1 NEX per year or 100 NEX in the environmental system considered. This assumption has little or no base in real experience, and should be regarded as a first guess and basis for improvement.

Contribution to category indicators value from a flow unit

The same value as for modelling of YOLL is relevant, i.e. $1.26 \cdot 10^{-16}$ kg^{-1}

Calculation of characterisation factor

The characterisation factor is thus equal to $100 * 1.26 \cdot 10^{-16} = 1.26 \cdot 10^{-14}$ NEX/kg CO_2.

Uncertainty
The estimation assumed to be correct within a factor of ten.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

3.1.9. Discussion

ICCP describes several other effects that may be given quantitative estimates, but which has not been possible to address in this study:

- Decreased forest production from altered local climate resulting in draughts, forest fires, insects and fungus attacks.
- Health effects due to decreased access to clean water
- Secondary effects on health due too flooding and natural disasters in coastal areas
- Impacts on aquatic systems and fishery, e.g. destruction of coral reefs

Secondary impacts on the climate has been suggested like a change of the direction of the Golf Stream and other Ocean Currents and the release of large amounts of methane as permafrost layers thaw. Several other effects may also occur like, decrease of life comfort due to “bad weather”, increase of accidents etc.

There is an upper limit in the possible excess mortality and morbidity in the regions that are most likely to suffer from flooding and decreased water supplies. If one billion is assumed to live in those areas and having about the same fertility and morbidity patterns as present except for an added mortality from the global warming effects, the maximum death rates could not considerably exceed the reproduction. This would mean that there is an upper limit in the order of 3% of the population or 300 million per year. The estimated total excess mortality in fertile ages by the models above is around 4 million per year.

3.2. Emissions of Carbon monoxide anywhere in the world

3.2.1. Definition of flow group:

Most of the CO emissions originate from gasoline driven cars and trucks. Some emission results from other sources with incomplete combustion like blast furnaces and uncontrolled wood fires.

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength.

3.2.2. Assignment to impact categories

Carbon monoxide is a well-known toxic gas. A large number of accidents and tests have revealed its toxicity (WHO, 1987). CO reacts with haemoglobin in blood and decreases its oxygen carrying capacity. At 10 -20 mg/m^3 there is a statistically significant decrease (3-7%) of the relation ‘work time’ to ‘exhaustion’ in healthy young men. At about 20 mg/m^3 as 8 hour mean (twice WHO recommended threshold limit value) there is statistically significant decrease of exercise capacity (=shorter duration of exercise before onset of pain) in patients with angina pectoris and increased duration of angina attacks. The first effect motivates an assignment of CO to moderate nuisance. It is hardly probable that the duration of severe exhaustion is influenced, because people tend to regulate their labour to a moderate degree of exhaustion. The second effect motivates an assignment to severe morbidity, a category to which heart attacks and pain must belong.

Carbon monoxide has also two other effects. It participates in photochemical reactions contributing to oxidant formation and it is a greenhouse gas, directly and indirectly through its reaction products. These mechanisms assign CO to all of the category indicators that CO_2 and ethylene is assigned to. (Table 3.5)

Table 3.5 Assignment of CO to impact categories and selection of category indicators.

Pathway(s)	Impact category	Category indicator
Global warming	Life expectancy	YOLL
Direct exposure	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Direct exposure	Nuisance	Nuisance
Global warming	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
CO_2 fertilisation	Wood production capacity	Wood
Global warming	Extinction of species	NEX

3.2.3. Characterisation of CO to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global.

Model for global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

GWP_{100} for CO is 3. (Houghton et. al, 1990)

Calculation of characterisation factor

The characterisation factor for CO_2 in relation to YOLL is $7.93\cdot10^{-7}$ YOLL/kg CO_2.
The characterisation factor for CO in relation to YOLL is therefore $3*7.93\cdot10^{-7} = 2.38\cdot10^{-6}$ YOLL/kg CO.

Uncertainty

Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11. This indicates an uncertainty range of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 3)^2} = 3.4$

3.2.4. Characterisation of CO to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

CO as a molecule has a residence time in air of approximately half a year. However rural background levels are in the order of 0.05 – 0.25 mg/m^3 which is several times below the WHO guidelines designed to protect from health effects (10 mg/m^3). This means that the direct impacts on health due to CO are mainly local, close to the sources. As the emissions and local exposure patterns considered is repeated on a global urban level (traffic) the system chosen is urban and global and during the year 1990.

Model 1, direct exposure pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

1.2 billion people live in urban OECD areas and 1.4 billion in urban areas in non-OECD countries. WHO criteria for CO is estimated to be exceeded in almost 50% of the cities (see results from GEMS/ UNEP/WHO report "assessment of urban air quality" 1988). It is likely that only a part of the population in these cities is exposed. This part is assumed to consist of those who work or live permanently in the centre of the cities, roughly less than a third of the population, i.e. $4.3 \cdot 10^8$.

0.1% of the population which experiences concentrations above the WHO recommendations is assumed to be effected. This figure is chosen because the sensitive group is people suffering from cardiovascular diseases. As CV diseases account for almost a third of the deaths as a global average (check, ref.) one can assume that the last percent of their lifetime is effected. Critical levels are estimated to be exceeded during 1% of the time. (99%-ile or 10 cases per year of exceedence of the 8-hour mean)
This would mean $4.3 \cdot 10^8 * 0.001 * 0.01 = 4300$ person-years per year of severe morbidity.

Contribution to category indicators value from a flow unit

Global emissions of CO are 2600 million tons. Man made emissions account for 1600 million tons (UNEP/GEMS Env. Library No 4, 1991) and dominate the urban exposure pattern. The contribution from 1 kg CO is at an average $1/(1600\cdot10^{9}) = 6.25\cdot10^{-13}$.

Calculation of pathway specific characterisation factor

The characterisation factor of CO for severe morbidity is thus equal to $4300*6.25\cdot10^{-13} = 2.69\cdot10^{-9}$ person-years/kg for the direct exposure pathway.

Uncertainty

The uncertainty in the category indicator value is in the order of a factor of 10 as is the uncertainty in contribution from a typical product system CO emission.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

GWP_{100} for CO is 3. (Houghton et. al, 1990)

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for severe morbidity was determined in 3.1.4 to $3.53\approx10^{-7}$ person-years/kg CO_2. We thus obtain $3*3.53\approx10^{-7} = 1.06\approx10^{-6}$ person-years/kg CO for the global warming pathway.

Uncertainty

Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11.This indicates an uncertainty of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation.. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 3)^2} = 3.4$

Calculation of characterisation factor

The characterisation factor for both pathways is thus $2.69\approx10^{-9} + 1.06\approx10^{-6} = 1.06\approx10^{-6}$ person-years/kg CO.

3.2.5. Characterisation of CO to air with respect to morbidity

Definition of environmental system in which the impact is estimated
The system is urban and global and during the year 1990.

Model for global warming pathway
The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor
GWP_{100} for CO is 3. (Houghton et. al, 1990)

Calculation of characterisation factor
The characterisation factor for CO_2 and morbidity is $6.55 \cdot 10^{-7}$ person-years/kg CO_2 which means that the characterisation factor for CO is $1.96 \cdot 10^{-6}$ person-years/kg CO.

Uncertainty
Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11.This indicates an uncertainty of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 3)^2} = 3.4$

3.2.6. Characterisation of CO to air with respect to nuisance

Definition of environmental system in which the impact is estimated
The system is urban and global and during the year 1990.

Model
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
At 10 - 20 mg/m^3 there is a statistically significant decrease (3-7%) of the relation work time to exhaustion in healthy young men. (23) This effect is assigned to the nuisance impact category.

1.2 billion people live in urban OECD areas and 1.4 billion in urban areas in non-OECD countries. WHO criteria for CO is estimated to be exceeded in almost 50% of the cities (24) (see results from GEMS/ UNEP/WHO report "assessment of urban air quality" 1988). It is likely that only a part of the population in these cities is exposed. In a

Swedish study (Steen, 1991) the ratio between the maximum and population-weighted average concentrations in three cities were estimated. Ratios between 0.4 and 0.7 were found depending on the urban geography and regional background. According to another UNEP/WHO study about air pollution in the megacities in the world (1992) the major problems occur in cities in countries where the economy has started to expand recently, like Seoul and Sao Paulo. These cities have had a heavy increase in the use of cars but not yet enforces catalytic converters. In Tokyo, the situation has improved quite significant since the introduction of catalytic converters. This would indicate that the part of the population, which is overexposed, is clearly less than half. This part is assumed to consist of those who work or live permanently in the centre of the cities, roughly less than a third of the population. This means that about 0.4 billion people would be exposed to more 10 mg/m^3 during more than 8 hours.

Considering the fact that most of the overexposed are in developing countries having a greater part of the population in physical exercise, 10% of the population which experiences concentrations above the WHO recommendations is assumed to be effected. Critical levels are assumed to be exceeded during 1% of the time. (99%-ile or 10 cases per year of exceedence of the 8-hour mean) The population exposure to more than 10 mg/m^3 expressed in number of person-years is then approximately 400 000 person-years.

Contribution to category indicators value from a flow unit

Global emissions of CO are 2600 million tons. Man made emissions account for 1600 million tons (UNEP/GEMS Env. Library No 4, 1991. The contribution from 1 kg CO is at an average $1/(1600 \cdot 10^9) = 6.25 \cdot 10^{-13}$.

Calculation of the characterisation factor

A characterisation factor for the global average of nuisance would thus be $400\,000 * 6{,}25 \cdot 10^{-13} = 2.50 \cdot 10^{-7}$ person-years per kg of CO.

Uncertainty

The population exposure is uncertain partly because spatial and temporal distribution patterns in the cities are not known in detail.

In some cities the exposure situation is fairly well examined. In a study made by Law et al. (1997) the exposure calculated on the basis of area-representative monitoring at a monitoring station was compared to that obtained by directly monitoring personal exposure. It was found that the monitoring at fixed ambient station tend to smooth out the variation in exposure. In the particular study at Denver, USA, this meant that the number of persons exposed to concentrations above the standards was underestimated with a factor of 1.5 using a method based on fixed ambient stations. This error are likely to decrease if a large part of the population in an urban area is overexposed and become an error in terms of overestimation when only a small part of the population is free from overexposure.

The total uncertainty in exposure is estimated to correspond to a standard deviation in the order of a factor of three. The population sensitivity to the exposure adds further uncertainty. This is also estimated to a factor of three.

There is also an uncertainty in the estimation of dose-response characteristics. In particular it is uncertain to what extent real life exhaustion patterns are similar to the experimental and how frequent these events are.

The contribution to nuisance from an emission of CO may vary considerably due to where the emission occurs and the size of the emission. If we consider an emission of a single gram anywhere, the contribution may differ quite a lot compared to the average. If we consider an emission from a car fleet, the contribution may differ less from the average, because the larger the sample, the more close we get between the sample average and the population average. (by population is here understood the population of "contributions" rather than the human population).

This leaves an uncertainty consisting of one part that is dependent on the sample size (random model errors) and one part that is independent of the sample size (systematic model errors). However, in life cycle assessments the sample size is seldom registered, and consequently we need at least state a sample size when talking about uncertainty in order to be able to estimate it. As a first step the uncertainty in the contribution figure estimated above will be estimated for an emission event of CO for one car during one year. For the estimation the following circumstances are considered:

> -1,3 billion live in areas where WHO guidelines are exceeded and a third of this population was assumed to be overexposed.

This means that roughly a tenth of the cars in the world are the main contributors to the nuisance effects. If we chose a log normal distribution to represent the probability of contribution to the indicator value, an average of $6.25\ 10^{-13}$ and a standard deviation corresponding to a factor of 4 would mean that approximately 10% of the cases would have contributions ten times the median. More precisely this would be $34 \cdot 10^{-13}$.

If, instead, the emission event was from a car fleet, for instance a new car model sold all over the world in equal market shares. Then the uncertainty in the contribution would be almost zero, corresponding to a factor of 1. The uncertainty in the determination of the extension of the nuisance problems remains, though, causing an overall uncertainty in the characterisation factor of a factor of 4.

In reality we can therefore expect uncertainties in the characterisation factor between 4 and several hundred. Mathematically the uncertainty for impacts from a normal product system is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 7.

3.2.7. Characterisation of CO to air with respect to crop production

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

GWP_{100} for CO is 3. (Houghton et. al, 1990)

Calculation of characterisation factor

The characterisation factor for CO_2 is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Therefore the Characterisation factor for CO will be $3*7.56 \cdot 10^{-4} = 2.27 \cdot 10^{-3}$ kg crop/kg CO.

Uncertainty

Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11. This indicates an uncertainty of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.7 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 2.2)^2} = 2.6$

3.2.8. Characterisation of CO to air with respect to wood production

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global.

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

GWP_{100} for CO is 3 in terms of global warming. (Houghton et. al, 1990)

Calculation of pathway specific characterisation factor

The global warming pathway specific characterisation factor for CO_2 is -0.00116 kg wood/kg CO_2 for the global warming Therefore the characterisation factor for CO will be $3*(-0.00116) = -0.00348$ kg wood/kg CO.

Uncertainty

Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11. This indicates an uncertainty of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.8 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 2)^2} = 2.4$

Model 2, CO_2 fertilisation pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

For CO_2 fertilisation an equivalency of 1 is used as almost all CO will be oxidised to CO_2 before leaving the atmosphere.

Calculation of pathway specific characterisation factor

The characterisation factor is - 0.0393 kg wood/kg CO_2 for the CO_2 fertilisation pathway. Therefore the characterisation factor for CO will be $1*(-0.0393) = -0.0393$ kg wood/kg CO.

Uncertainty

The only likely removal mechanism is via oxidation to CO_2. The solubility in water is low, why rainout or washout mechanisms may be expected to have negligible contribution to the removal rate. Therefore the added uncertainty of the equivalency factor is estimated to a few percent. In statistical terms the uncertainty is assumed to be a log-normal distribution with a standard deviation corresponding to a factor of 1.05. This means that the total uncertainty will be the same as for CO_2's fertilisation effects, i.e. described by be a log-normal distribution with a standard deviation corresponding to a factor of 2.

Calculation of characterisation factor

The characterisation factor for CO will thus be $-0.00348 - 0.0393 = -0.0428$ kg wood/kg CO.

3.2.9. Characterisation of CO to air with respect to NEX

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global.

Model
The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor
GWP_{100} for CO is 3. (Houghton et. al, 1990)

Calculation of characterisation factor
The characterisation factor for CO_2 is $1.26 \cdot 10^{-14}$ per kg CO_2. Therefore the Characterisation factor for CO will be $3 * 1.26 \cdot 10^{-14} = 3.78 \cdot 10^{-14}$ /kg CO.

Uncertainty
Indirect effects largely cause the GWP_{100} for CO. The GWP value 3 was presented in the first IPCC report but was withdrawn in later editions of IPCC assessments with reference to the large uncertainty involved. As CO will be oxidised to CO_2 in the atmosphere, it seems reasonable to assume that the GWP>1. On the other hand it is not as strong an oxidant precursor as most VOC's which were given the GWP 11. This indicates an uncertainty of a factor of three at most. In a log-normal distribution this would correspond to a factor of 1.7 as standard deviation. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.9 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 3)^2} = 3.4$

3.2.10. Discussion

The characterisation factors were estimated for the year 1990. The trend in non-OECD countries are not considered to be improving, while there are considerable improvements in some OECD countries.

USEPA (1996) states "*Over the past 10 years, ambient concentrations of CO decreased 37 percent, and the estimated number of exceedances of the 8-hour standard decreased 92 percent. Also, CO emissions decreased 18 percent, and CO emissions from highway vehicles decreased 26 percent. These improvements occurred despite a 28 percent increase in vehicle miles travelled during this 10-year period. Between 1995 and 1996, ambient CO concentrations decreased 7 percent and emissions of CO decreased 1 percent.*"

This means that the characterisation factor on a global basis may be considered relevant for present years too within the uncertainty estimations made.

4. Classification and characterisation of emissions of nitrogen oxides to air

4.1. Emissions of Nitrogen oxides (NO +NO_2) anywhere in the world

4.1.1. Definition of flow group:

Most NO_x emissions come from combustion engines and other combustion processes. High altitude emissions from aircraft are included, but are not typical for nitrogen oxide (NO_x) emissions with regards to its quantitative impact characteristics.

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength.

Any mass measures of NO_x are referring to NO_2. The unit is therefore kg of NO_2.

4.1.2. Assignment to impact categories

Nitrogen oxides participate in the formation of oxidants and act as a nutrient. They are also toxic to humans directly and indirectly via oxidants and secondary particles. They contribute to global warming and ozone depletion in a complicated way. They also contribute to acidification in areas where the critical load is exceeded.

There are at least four mechanisms through which nitrogen oxides could influence *life expectancy*. There are direct effects known through correlation between NOx-concentration in air and daily mortality rates and there are indirect effects through a similar impact from oxidants and secondary particles. There are also impacts on life expectancy via NO_x:s global warming potential.

As most of the NO_x-emissions consists of NO which reacts with ozone in ambient air to form NO_2, the net effect in urban areas may be positive. Ozone is considered to me more toxic than NO_2. NO is not considered to be particularly harmful. Therefore NO_x is assigned to life expectancy, but the mechanism for global warming and direct impact on life expectancy is not used in the modelling. ExternE (1995) also refrains from modelling direct impacts, claiming the impacts are small and the evidence weak.

NO_2 will give irritation in the respiratory tract. Asthmatics are the most sensitive group and respond to concentrations around 500 $\mu g/m^3$ for one hour (WHO, 1987). Via this mechanism NO_x is assigned to *severe nuisance*. This indicator is preferred before morbidity, as the effect typically do not lead to hospitalisation or people reporting themselves as being ill.

NO_x emitted to air is deposited to land or water after a few days as nitrates. Nitrates are nutrients that increase growth rates. However they do not increase the growth rate equally for all species in a biotope. Certain species are favoured more than others, which have specialised to live with low nitrogen supply. Nitrogen in water leads to oxygen deficiency and dead bottoms. Via these mechanisms NO_x is assigned to the NEX and to wood growth capacity. Crop growth capacity is not considered to be effected in this way as sufficient nitrogen is supplied to crops via fertilisers anyway.

If the deposition of nitrogen exceeds the uptake capacity of the soil and root systems, nitrate is leached into the ground water and contributes to acidification of soil and water. As a consequence, NO_x may be assigned to all indicators associated with acidification, i.e. fish&meat, wood and NEX. Health effects due to acid drinking water from wells are neglected.

NO_x is thus assigned to the category indicators as shown in table 4.1

Table 4.1 Assignment of NO_x emissions to impact categories and selection of category indicators.

Pathway(s)	Impact category	Category indicator
Secondary particles	Life expectancy	YOLL
Oxidant formation	Life expectancy	YOLL
Secondary particles	Severe morbidity	Severe morbidity
Direct exposure	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Secondary particles	Morbidity	Morbidity
Secondary particles	Nuisance	Nuisance
Visibility	Nuisance	Nuisance
Secondary particles	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
N-nutrification	Fish&meat production capacity	Fish&meat
Secondary particles	Wood production capacity	Wood
N-nutrification	Wood production capacity	Wood
Acidification	Base cat-ion capacity	Base cat-ion capacity
Secondary particles	Extinction of species	NEX
Eutrofication	Extinction of species	NEX

4.1.3. Characterisation of NO_x to air with respect to YOLL

As mentioned in 4.1.2 there are at least four mechanisms through which nitrogen oxides influence life expectancy and two of them will be modelled.

Definition of environmental system in which the impact is estimated

NO_x as a molecule has a residence time in air of several days to a week. When NO_2 is oxidised it may stay gaseous as nitrous or nitric acid, but most of it is found in the atmosphere as nitrate salt in particles. This means that the impacts on life expectancy due to NO_x occur on a regional scale. In some cases it may be of interest to define regional environmental systems, but for many whose products are spread and transported internationally, the environmental system of primary interest is the global one. As the emissions considered we thus define the system as global and during the year 1990.

Model 1, pathway via human exposure to secondary particles
The characterisation factor is determined by an empirical method.

Total category indicator value in system considered
The average US concentration of nitrates is in the order of 1-2 $\mu g/m^3$. (Spengler and Wilson 1996). In Sweden similar concentration have been measured at a rural site (Ferm, 1984). In Mexico City, the concentration is around 3 $\mu g/m^3$ in winter-time contributing to 3% of the $PM_{2.5}$ mass. (Vega et al., 1997) and the annual mean concentration of PM_{10} is estimated to around 200 µg/m3 (WHO, 1992).
The dose-response function associated with PM_{10} and YOLL is estimated in 9.1.3 to $2.61 \cdot 10^{-4}$ YOLL/$\mu g/m^3$ per person per year.

As nitrates are secondary particles, the correlation of general urban pollution components and nitrates are comparatively low. This means that regional levels as much as local determine the global average urban. Based on this a global average of 1.5 $\mu g/m^3$ is assumed, giving a total category indicator value of $2.61 \cdot 10^{-4} * 1.5 * 5.28 \cdot 10^9 = 2.07 \cdot 10^6$ YOLL/year.

Contribution to total category indicators value from a flow unit
The global anthropogenic emission is estimated to 153 tg NO_x/year (IPCC 1994). The natural is estimated to 180 tg NO_x/year (Stern, 1986) but claimed by IPCC (1994) to be much below the anthropogenic. Until better knowledge is gained, the figure 180 will be used for the sum total NO_x-emissions. Both natural and anthropogenic emissions contribute to nitrate exposure. As most of the PM_{10} impact is assumed to be caused by $PM_{2.5}$ and as the $PM_{2.5}$-concentration is about half of the PM_{10}, the contribution will be twice as high. The average contribution to the total cattegory value in the system is therefore $2 * 5.56 \; 10^{-12}$ per kg NO_x.

Calculation of pathway specific characterisation factor
$2.07 \cdot 10^6$ YOLL$*2*5.56 \; 10^{-12}$ per kg = $2.30 \cdot 10^{-5}$ YOLL/kg NO_x

Uncertainty
The uncertainty in the estimation of the total indicator value in the system modelled is estimated to a factor of two. The uncertainty in the contribution is larger, mainly because the contribution varies with time and space. The total uncertainty for the estimation of the pathway specific characterisation factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, pathway via oxidants
The characterisation factor is determined by an empirical method.

Category indicator value in system considered

The ozone concentration in central part of urban complexes normally decrease on a short time basis as a consequence of NO_x emissions, which mainly are NO. However, the regional background seems to have increased compared to pre-industrial levels. In Europe the regional pre-industrial levels were just below 10 ppbv (Volz, 1988). Today rural and city levels are around 25-30 ppbv 1990 in Scandinavia (TemaNord, 1994). In a global perspective the concentrations may vary considerably. Mexico city has annual average levels around 100 ppbv, while Jakarta has 1 –7 ppbv, Seoul 10 ppbv and Tokyo 20 ppbv (UNEP/WMO 1992). Considering the population distribution on the globe it seems likely that the global average ozone concentration is around 20 ppbv.

ExternE use an estimate of the dose-response function of ozone on mortality of 0.015 % per ppbv change of ozone concentration. As for acute effects of PM_{10}, it is assumed that the average shortening of life is 2.5 years per case. This would mean that for the global population, we would get $5.28\cdot10^9*1/75*0.015\cdot10^{-2}*2.5*20 = 5.28\cdot10^5$ YOLL per year.

Contribution to category indicators value from a flow unit

The mechanisms for production of ozone is fairly well mapped although the complexibility in the photochemical reactions between numerous different VOC’s and NO_x make model simplifications and approximations necessary. Depending on the situation NO_x or VOC may be rate limiting for the production of ozone. Until better knowledge has been gained on a global level, half of the ozone is allocated to NOx and half to VOC.

In model 1, the average contribution to was determined to $5.56\cdot10^{-12}$ per kg NO_x. If we allocate half of the oxidants to NO_x we obtain half the contribution, i.e. $2.78\cdot10^{-12}$ per kg NO_x

Calculation of pathway specific characterisation factor

$5.28\cdot10^5*2.78\cdot10^{-12} = 1.47\cdot10^{-6}$ YOLL/kg NO_x

Uncertainty

The uncertainty is large mainly because the contribution varies with time and space and partly because the estimation of the rate limiting effect of NO_x. Some of the potential variation in contribution is damped out because of the regional character of the effect. The uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor

For both pathways we thus obtain $2.30\cdot10^{-5} + 1.47\cdot10^{-6} = 2.45\cdot10^{-5}$ YOLL/kg NO_x

4.1.4. Characterisation of NO_x to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

NO_x as a molecule has a residence time in air of several days to a week. When NO_2 is oxidised it may stay gaseous as nitrous or nitric acid, but most of it is found in the atmosphere as nitrate salt in particles. This means that the health impacts on life expectancy due to NO_x occur on a regional scale. In some cases it may be of interest to define regional environmental systems, but for the default method, the environmental system of primary interest is the global one. As the emission flow groups considered are global, the system chosen is global and during the year 1990.

Model 1, secondary particles pathways

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

Regional background levels of nitrates are about half the concentration of NO_x. As nitrates and NO_x has about the same residence time in the atmosphere, we can roughly estimate an equivalency factor of 0.5 for NO_x versus PM_{10} i.e. half of the regional NO_x will become. As the effects of PM_{10} particles are believed to be mainly caused by particles less than 2.5 micron, as these are approximately half of the PM_{10} concentration and as nitrate particles are mainly less than 2.5 microns, the equivalency factor ought to be 1.0 instead of 0.5.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for severe morbidity is $-2.33 \cdot 10^{-6}$ person-years/kg, giving a characterisation factor for NO_x of $- 2.33 \cdot 10^{-6}$ person-years/kg NO_x.

Uncertainty

Depending on photochemical activity and rain frequency, the equivalency factor may vary, presumably with a factor of two from an average. As the uncertainty of the characterisation factor for PM_{10} was estimated to more than a factor of ten (standard deviation a factor of 4), the standard deviation in a log-normal distribution for the uncertainty will correspond to around a factor of $\exp\sqrt{(\ln 1.7)^2 + (\ln 4)^2}$ = 4.4.

Model 2, direct exposure pathway

The characterisation factor is determined by the empirical method.

Definition of environmental system in which the impact is estimated

NO_x as a molecule has a residence time in air of several days, but the direct impacts on health due to NO_x are mainly local. In some cases it may be of interest to define local environmental systems, but for many whose products are spread and transported internationally, the environmental system of primary interest is the global one. As the emission flow groups considered is global the system is defined as urban and global and during the year 1990.

Total category indicator value in system considered

NO_2 will give irritation in the respiratory tract. Asthmatics are the most sensitive group and respond to concentrations around 500 µg/m3 for one hour. The number of asthmatics varies considerably between different countries and time periods. From being a rather unknown type of symptom in the beginning of the 20th century asthma may be a reality for as much as 40% of school children. (Bråbäck, 1995)

About 10-15% of the urban population in North America and Western Europe is assumed to be exposed to NO_2 values exceeding WHO recommendations. The same figure is assumed to be true for all developed countries where 77% of totally 1.2 billion people lives in urban areas. 30% of these are assumed to be big cities and 10% of the overexposed is assumed to suffer from irritation in the respiratory tract (including asthmatics).

33% of 4.1 billion inhabitants live in urban areas in developing countries. 30% are assumed to live in large cities where air pollution is worse than in developed countries. 50% is assumed to be over-exposed to NO_2. Thus, the same share of the urban population,15%, is over exposed in the non-OECD as in the OECD countries.

WHO recommends that 400 µg/m3 never should be exceeded. In the preparatory work for the Swedish air quality criteria, "never" is interpreted as the 99.9 percentile. People living in areas with NO_2 concentrations exceeding WHO guidelines, are thus exposed to irritating concentrations in the order of 0.001 years per year. 10 % may be considered to be sensitive. This would give $(0.77*1.2\cdot10^9+0.33*4.1\cdot10^9)*0.1*0.15*0.001$ = 34000 person-years severe morbidity.

Contribution to total category indicator value from a flow unit

The global anthropogenic emission is estimated to 153 tg NO_x/year (IPCC 1994). The natural is estimated to 180 tg NO_x/year (Stern, air pollution, 3rd ed vol 6, AP 1986) but claimed by IPCC (1994) to be much below the anthropogenic. Until better knowledge is gained, the figure 180 will be used for the sum total NO_x-emissions. Both natural and anthropogenic emissions contribute to NO_2 exposure. The average contribution to NO_2 is therefore $5.56\ 10^{-12}$ per kg NO_x.

Calculation of pathway specific characterisation factor

$34\ 000*5.56\ 10^{-12} = 1.89\cdot10^{-7}$ person-years/kg NO_x

Uncertainty

The true variation in contribution to the indicator value from various combinations of NO_x-sources (relevant for product systems) is by far the highest uncertainty, presumably in the order of a factor of 10 or larger. The uncertainty in determination of the total indicator value in the system is much less, in the order of a factor of 2 to 3. The uncertainty is assumed to be described by a log-normal ditribution with a standard deviation corresponding to a factor of 5.

Model 3, oxidant pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The global average ozone concentration was estimated in 4.1.3 to 20 ppbv. The elasticity is used, which is determined by ExternE (1995). It includes change in hospital admissions

1.095 cases per 100000 persons per year and change in emergency room visits for asthma by 2.63 cases per 100000 persons per year per annual change in ozone concentration in ppbv are used. Assuming an average duration of hospital visits of one week, and emergency room visits of one day, we obtain a total value for the indicator of $20*5.28\cdot10^{9}*(1.095\cdot10^{-5}*7/365+ 2.63\cdot10^{-5}*1/365) = 2.98\cdot10^{4}$ person-years per year

Contribution to category indicators value from a flow unit

The same contribution as in 4.1.3 is used, i.e. $2.78\cdot10^{-12}$ per kg NO_x

Calculation of pathway specific characterisation factor

$2.98\cdot10^{4} * 2.78\cdot10^{-12} = 8.28\cdot10^{-8}$ person-years/kg NO_x

Uncertainty

The same uncertainty as for the oxidant pathway specific characterisation factor for YOLL is assumed (4.1.3), i.e. a log.normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor

$- 2.33\cdot10^{-6} + 1.89\cdot10^{-7} + 8.28\cdot10^{-8} = - 2.06\cdot10^{-6}$ person-years/kg NO_x

4.1.5. Characterisation of NO_x to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

In 4.1.4, the equivalent factor was estimated to 1.0.

Calculation of characterisation factor

The characterisation factor of PM_{10} for morbidity is $3.61\cdot10^{-6}$ person-years/kg. Thus the characterisation factor of NO_x for morbidity is $1.0*3.61\cdot10^{-6} = 3.61\cdot10^{-6}$ person-years/kg NO_x

Uncertainty

The uncertainty for the equivalency factor was estimated in 4.1.4 to a factor of two. The uncertainty in the characterisation factor of PM_{10} for morbidity is more difficult to describe, because it was obtained as a difference between two terms of about the same magnitude ($9.20\cdot10^{-6} – 5.57\cdot10^{-6} = 3.6\cdot10^{-6}$ person-years per kg). The total uncertainty may therefore be described by the difference between two log-normal distributions with best estimates of $4.60 \cdot 10^{-6}$ and $2.78 \cdot 10^{-6}$ and standard deviation corresponding to factors of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2} = 2.4$ and $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$.

4.1.6. Characterisation of NO_x to air with respect to nuisance

NO_2 is a brown gas, which may be seen in stagnant weather conditions as a brown haze over urban areas. Nitrogen oxides also transform to particles as nitrates in the same size range as the visible light wavelengths. Such particles scatter light very efficiently.

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990

Model 1, secondary particles pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

In 4.1.4 the equivalent factor was estimated to 1.0.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for nuisance is $2.28 \cdot 10^{-3}$ person-years/kg giving a characterisation factor for NO_x of $2.28 \cdot 10^{-3}$ person-years/kg NO_x.

Uncertainty

The uncertainty for the equivalency factor was estimated in 4.1.4 to be described by a log-normal distribution with a standard deviation corresponding to a factor of two. The uncertainty in the characterisation factor of PM_{10} for nuisance is determined in 9.1.6 to a log-normal distribution with a standard deviation correspond to 2.2. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2} = 2.4$

Model 2, NO_2 light absorption pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

Brown haze is estimated to occur mainly in connection with ground level inversions and heavy traffic. Such events occur in mainly in wintertime in northern latitudes, during a few percent of the time. 2% is used as a first approximation. The number of persons experiencing these episodes is estimated to 2 billion. Thus there will be $2 \cdot 10^9 * 0.02 = 4 \cdot 10^7$ person-years of nuisance.

Contribution to category indicators value from a flow unit

The brown colour of the haze is assumed to come from NO_2, which is brown, while the haze in itself and the visibility reduction is caused by particles. 50% of the nuisance is allocated to NO_2 gas and the rest to the particles.

Using the anthropogenic NO_x emission estimate mentioned in 4.1.4 (153 tg/yr) the contribution will be $0.5 * 6.53 \cdot 10^{-12} = 3.26 \cdot 10^{-12}$ per kg NO_x.

Calculation of pathway specific characterisation factor

$4 \cdot 10^{7}$ person-years of nuisance$*3.26 \cdot 10^{-12}$ per kg $NO_x = 1.31 \cdot 10^{-4}$ person-years/kg NO_x

Uncertainty

Being an impact on regional or urban region level, the variation in extension of and contribution to the indicator value may be estimated from variations in population numbers and concentrations of NO_2 in various urban areas. A maximum variation of a factor of ten from the best estimate may be possible for a single source. For a product system with 4 sources, the maximum variation would decrease to a factor of five. Based on these considerations the uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor

$2.28 \cdot 10^{-3} + 1.31 \cdot 10^{-4} = 2.41 \cdot 10^{-3}$ person-years/kg NO_x.

4.1.7. Characterisation of NO_x to air with respect to crop

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week and the residence time in soil is less than a year. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990

Model 1, secondary particle/global warming pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

As for 4.1.4 the equivalency factor is 1.0.

Calculation of pathway specific characterisation factor

The characterisation factor for PM_{10} was estimated to $-6.46 \cdot 10^{-3}$ kg crop per kg PM_{10} giving a characterisation factor for NO_x of $-6.46 \cdot 10^{-3}$ kg crop per kg NO_x.

Uncertainty

The uncertainty for the equivalency factor was estimated in 4.1.4 to be described by a log-normal distribution with a standard deviation corresponding to a factor of two. The uncertainty in the characterisation factor of PM_{10} for crop is determined in 9.1.7 to correspond to 2.4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.4)^2}$ = 2.6

Model 2, oxidant pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The loss in crop production during 1986-1988 was estimated to 300000 tons in Sweden by (Hasund, 1990). The mean reduction in harvest gain was 6-21% with a best estimate of 9%. The estimates in USA range from 10-100 billion dollars. The world production of crops, potatoes and sugar beats was about 2400 million tonnes 1990 according to FAO yearbook. A 9 % reduction means decreased harvests by 216 million tonnes.

Contribution to category indicators value from a flow unit
The global anthropogenic emission was determined in 4.1.3. to 153 tg NO_x/year (IPCC, 1994). Half of the oxidant formation is assumed to be rate controlled by NOx.

The reasons for only using anthropogenic emission in the model is that the reduction in crop yields reported by Hasund et al. was compared to pre industrial levels, and was thus caused by anthropogenic emissions.

Calculation of pathway specific characterisation factor
$2.16 \cdot 10^{11}/(2 * 153 \cdot 10^{9}) = 0.706$ kg crop/kg NO_x

Uncertainty
The uncertainty lies very much in the application of results from modern agriculture to agriculture in the third world and the variations in contribution to oxidant formation in different regions. The dose-response characteristics are fairly well known. The resulting uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor
$-6.46 \cdot 10^{-3} + 0.706 = 0.700$ kg crop/kg NO_x

4.1.8. Characterisation of NO_x to air with respect to fish&meat

Definition of environmental system in which the impact is estimated
The system is global and during the year 1990

Model, N-nutrification pathway
The characterisation factor is determined by a mechanistic method.

Calculation of characterisation factor
Nitrogen is assumed to be a rate-limiting factor for fish growth in a large part of the world’s ocean waters.

About 25% of the emissions of NO_x are assumed to deposit on ocean areas or transferred to ocean areas. Thus, from an emission of 1 kg of NO_x, 0.25 kg deposits as an average on water areas and contribute to increased fish production, where N deficiency is growth limiting. In a study in Skälderviken (a part of the Baltic Sea) the weight of the bottom fauna 1912 was 114 g/m^2. 1984 it was 399 g/m^2 (SNA 1991). The total addition of anthropgenic N to the southern part of the Baltic Sea (where Skälderviken is located) is about 1.2 million tons/year in an area of 214000 km^2. As an average the nitrogen added is thus 5.61 ton/ km^2 or 56.1 kg/hectare.

Assuming a linear relation between bottom fauna weight and fish production capacity, and comparing with the value used for average fish production in Swedish waters, 10 kg/hectare and year, the extra nitrogen would result in an increased fish production of (399-114)/114*10= 25 kg/hectare and year. 56.1 kg N is thus giving 25 kg extra fish, i.e. 0.446 kg fish/kgN.

For an emission of 1 kg NO_x to air this would mean an extra fish production of 0.25*14/46*0.446 = 0.0339 kg of fish, i.e the characterisation factor is –0.0339 kg fish&meat/kg NO_x.

Uncertainty

Part of the uncertainty comes from lack of specific data on fish production and nitrogen supply for Skälderviken, and part comes from transferring the model to a global scale. The uncertainty is assumed to be an order of magnitude, and to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

4.1.9. Characterisation of NO_x to air with respect to wood growth

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week and the residence time in soil is less than a year. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990

Model 1, N-nutrification pathway

The characterisation factor is determined by a mechanistic method.

Nitrogen is a rate limiting factor for wood growth in a large part of the world.

About 40% of the land area in the temperate regions are covered with forests, and about 50% of the emissions of NO_x are assumed to deposit on land areas. Most of the global emissions are estimated to origin in temperate regions. Thus, from an average global emission of 1 kg of NO_x, 0.2 deposits on temperate forests and contribute to increased growth, where N deficiency is growth limiting. If half of the N is used by the trees in the wood structure (ratio experienced when fertilising with calcium ammonium nitrate), if 10% of the forests have nitrogen deposition above the critical load, and if the wood consists of 1% N, (on dry basis), then 1 kg NO_x will result in 0.4*0.5*0.5*0.9*14/46*100 =2.74 kg wood.

Calculation of pathway specific characterisation factor

As the net effect is an increase of wood growth, we obtain a negative characterisation factor, -2.74 kg wood/kg NO_x.

Uncertainty

Depending on where on the globe the emissions occur and because other factors are rate limiting in other parts of the world, the uncertainty is assumed to be large and be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, secondary particles pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

As for 4.1.4 the equivalency factor is 1.0.

Calculation of pathway specific characterisation factor

The characterisation factor for PM_{10} was estimated to 0.00991 kg wood per kg PM_{10} giving a characterisation factor for NO_x of 0.00991 kg wood per kg NO_x.

Uncertainty

The uncertainty for the equivalency factor was estimated in 4.1.4 to a factor of two. The uncertainty in the characterisation factor of PM_{10} for wood is determined in 9.1.8 to correspond to 2.2 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}$ = 2.4

Calculation of characterisation factor

For both pathways we get -2.74 +0.00991 = -2.73 kg wood/kg NO_x.

4.1.10. Characterisation of NO_x to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week and the residence time in soil is less than a year. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990

Model

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

When reacting with water and oxygen, 1 kg of NO_2 may produce the same amount of protons as 0.5*64/46 = 0.70 kg SO_2. When adsorbed by biota reactions may occur where N is reduced again and the net acid production is decreased.

Calculation of characterisation factor

The characterisation factor of SO_2 for soil base-cat-ion capacity is determined in 5.1.10 to 1.56 equivalents of base cat-ions per kg SO_2. The characterisation factor of NO_x is therefore 0.70*1.56 = 1.09 equivalents of base cat-ions per kg NO_x.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of 1.2. The uncertainty has to do with the degree of denitrification of the nitrate deposited on soil. The uncertainty in the characterisation factor of SO_2 for base-cat-ion capacity was determined in 5.1.10 to correspond to 3 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2}$ = 3.0

4.1.11. Characterisation of NO_x to air with respect to NEX

Definition of environmental system in which the impact is estimated

The residence time in air in the order of a week and the residence time in soil is less than a year. The flow group is emissions anywhere on the globe during 1990.

The environmental system investigated is therefore chosen to be global during 1990.

Model 1, eutrofication pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

Approximately 10% of the red-listed species in Sweden are endangered due to eutrofication (Swedish faunavårdkommitte, 1988). This figure is used as a global average and assumed to be relevant for the contribution to extinction of species during 1990, i.e. the category indicator value in the system considered is 0.1 NEX.

Contribution to category indicators value from a flow unit

In the Baltic Sea region, only a third of the nitrogen is estimated to come from air. Using the same NO_x emission estimate as in 4.1.4 the contribution will be 0.33* $5.56 \cdot 10^{-12}$ = $1.83 \cdot 10^{-12}$ per kg NO_x. The same contribution (33%) is assumed to be relevant for deposition on land where the rest is due to N deposition on land, i.e. fertilisation.

Calculation of pathway specific characterisation factor

0.1* $1.83 \cdot 10^{-12} = 1.83 \cdot 10^{-13}$ NEX per kg NO_x

Uncertainty

The contribution to eutrofication varies in different parts of the world. As NO_x emitted to air contributes to regional eutrofication, the variation is moderate. Totally the uncertainty is assumed to be described with a log-normal distribution with a standard deviation corresponding to a factor of 2.5.

Model 2, secondary particles pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

As for 4.1.4 the equivalency factor is 1.0.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for NEX is $-1.08 \cdot 10^{-13}$, giving a characterisation factor for NO_x that is $1.0*(- 1.08 \cdot 10^{-13}) = - 1.08 \cdot 10^{-13}$ per kg NO_x.

Uncertainty

The uncertainty for the equivalency factor was estimated in 4.1.4 to be described by a log-normal distribution with a standard deviation corresponding to a factor of two. The uncertainty in the characterisation factor of PM_{10} for NEX was determined in 9.1.9 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$

Calculation of characterisation factor

Including both pathways the characterisation factor is $1.83 \cdot 10^{-13} + - 1.08 \cdot 10^{-13} = 7.50 \cdot 10^{-14}$ per kg NO_x.

4.1.12. Discussion

In USA trend studies indicate a slow change of air quality with respect to NO_2. USEPA states in a trend report (1996): “*Between 1987 and 1996, ambient concentrations of NO_2 decreased 10 percent, but total emissions of nitrogen oxides (NO_x) increased 3 percent, due primarily to increased emissions from non-utility fuel combustion. Between 1995 and 1996, national average annual mean NO_2 ambient concentrations remained unchanged, while total emissions of NO_x decreased 2 percent. Emissions from highway vehicles, also a source of NO_x emissions, decreased 6 percent between 1987 and 1996, while NO_x emissions from utility fuel combustion decreased 3 percent*”

The conclusion is that the characterisation factors are also applicable today.

4.2. Emissions of nitric acid and nitrous acid anywhere in the world

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength. Typical sources of nitric acid (HNO_3) and nitrous acid (HNO_2) are surface treatments plants or other chemical processes where nitric acid is used acidic or ogygenising agent.

In most cases nitric acid and nitrous acid have the same environmental impacts as NO_x. In a few cases, local effects may occur from acid droplets, which may be aggressive to materials or vegetation

As a default impact scenario however, HNO_2 and HNO_3 are added to the inventory results for NO_x. 1 kg of HNO_2 is treated as being equal to 0.941 kg NO_x and 1 kg of HNO_3 is set equal to 0.730 kg of NO_x.

4.3. Emissions of dinitrogen oxide (N_2O) anywhere in the world

4.3.1. Definition of flow group:

N_2O occur at low concentrations in combustion gases (a few percent of NOx). N_2O is also produced from biochemical processes, such as denitrification in sewage water treatment and agriculture.

The population of flows, which is characterised, is emissions to air, anyplace in the world 1990 and at any source strength.

4.3.2. Assignment to impact categories

N_2O is a greenhouse gas. It is relatively inert, has a residence time in the atmosphere of 120 years (IPCC,1994) and is well mixed in the atmosphere on a global scale. It will also reach the stratosphere, where it may be transformed to other nitrogen oxides. N_2O will influence the stratospheric ozone concentration, but it is uncertain to which extent and it is not considered to be one of the main threats to the stratospheric ozone layer.

N_2O is therefore assigned to the same impact categories as CO_2 and NO_x (table 4.2).

Table 4.2 Assignment of N_2O to impact categories and category indicators.

Pathway(s)	Impact categories	Category indicator
Global warming	Life expectancy	YOLL
NO_x formation	Life expectancy	YOLL
Global warming	Severe morbidity	Severe morbidity
NO_x formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
NO_x formation	Morbidity	Morbidity
NO_x formation	Nuisance	Nuisance
Global warming	Crop production capacity	Crop
NO_x formation	Crop production capacity	Crop
NO_x formation	Fish&meat production capacity	Fish&meat
Global warming	Wood production capacity	Wood
NO_x formation	Wood production capacity	Wood
NO_x formation	Base cat-ion capacity	Base cat-ion capacity
Global warming	Extinction of species	NEX
NO_x formation	Extinction of species	NEX

4.3.3. Characterisation of N_2O to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (IPCC 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL is determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. Therefore the characterisation factor of N_2O for YOLL is $320 * 7.93 \cdot 10^{-7} = 2.54 \cdot 10^{-4}$ YOLL/kg N_2O.

Uncertainty

The uncertainty in the GWP for N_2O is estimated by IPCC to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 4.1.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2} = 3.0$

Model 2, secondary NO_x pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

The transformation to nitrogen oxides and further to particles is difficult to model. However as a start and for this version of the EPS default method, 50% is assumed to be transferred to NO_x and the resulting contribution to the category indicators are calculated using the NO_x models developed in 4.1. The other 50% of the N_2O is assumed to be transformed to N_2. At 50% conversion efficiency 1 kg of N_2O will give 0.5*2*46/34 = 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for YOLL is determined in 4.1.3 to $2.45 \cdot 10^{-5}$ YOLL/kg NO_x. Therefore the characterisation factor of N_2O for YOLL is $1.35 * 2.45 \cdot 10^{-5} = 3.31 \cdot 10^{-5}$ YOLL/kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x, which is formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 3.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Calculation of characterisation factor

The total characterisation factor is thus $2.54 \cdot 10^{-4} + 3.31 \cdot 10^{-5} = 2.44 \cdot 10^{-4}$ YOLL/kg N_2O.

4.3.4. Characterisation of N_2O to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (ICCP 1995).

Calculation of patway specific characterisation factor

The characterisation factor of CO_2 for severe morbidity is determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg CO_2. Therefore the characterisation factor of N_2O for severe morbidity is $320 * 3.53 \cdot 10^{-7} = 1.13 \cdot 10^{-4}$ person-years /kg N_2O.

Uncertainty

The uncertainty is the estimation of the GWP is estimated by IPCC to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2}$ = 3.0

Model 2, secondary NO_x pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for severe morbidity is determined in 4.1.4 to $-2.06 \cdot 10^{-6}$ person-years/kg NO_x. Therefore the characterisation factor of N_2O for severe morbidity is $1.35 * (-2.06 \cdot 10^{-6}) = -2.78 \cdot 10^{-6}$ person-years /kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 4)^2}$ = 5.9

Calculation of characterisation factor

The total characterisation factor is thus $1.13 \cdot 10^{-4} - 2.78 \cdot 10^{-6} = 1.10 \cdot 10^{-4}$ person-years /kg N_2O.

4.3.5. Characterisation of N_2O to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (ICCP 1995).

Calculation of patway specific characterisation factor

The characterisation factor of CO_2 for morbidity is determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg CO_2. Therefore the characterisation factor of N_2O for severe morbidity is $320 * 6.55 \cdot 10^{-7} = 2.10 \cdot 10^{-4}$ person-years /kg N_2O.

Uncertainty

The uncertainty is the estimation of the GWP is estimated by IPCC to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2}$ = 3.0

Model 2, NO_x-tranformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for morbidity is determined in 4.1.5 to $3.61 \cdot 10^{-6}$ person-years/kg NOx. Therefore the characterisation factor of N_2O for morbidity is $1.35 * 3.61 \cdot 10^{-6} = 4.87 \cdot 10^{-6}$ person-years /kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.5 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.2. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 4.2)^2} = 6.1$

Calculation of characterisation factor
The total characterisation factor is thus $2.10 \cdot 10^{-4} + 4.87 \cdot 10^{-6} = 2.14 \cdot 10^{-4}$ person-years /kg N_2O.

4.3.6. Characterisation of N_2O to air with respect to nuisance

Definition of environmental system in which the impact is estimated
The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model for NO_x-transformation pathway
The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor
In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of characterisation factor
The characterisation factor of NO_x for nuisance is determined in 4.1.6 to $2.41 \cdot 10^{-3}$ person-years/kg NO_x. Therefore the characterisation factor of N_2O for morbidity is $1.35 * 2.41 \cdot 10^{-3} = 3.25 \cdot 10^{-3}$ person-years /kg N_2O.

Uncertainty
The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x, which is formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.4. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 2.4)^2} = 4.1$

4.3.7. Characterisation of N_2O to air with respect to crop

Definition of environmental system in which the impact is estimated
The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (ICCP 1995).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is determined in 3.1.6 to $7.56\cdot10^{-4}$ kg crop/kg CO_2. Therefore the characterisation factor of N_2O for crop is $320*7.56\cdot10^{-4} = 2.42\cdot10^{-1}$ kg crop/kg N_2O.

Uncertainty

The uncertainty is the estimation of the equivalency factor is estimated by to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 2.2)^2} = 2.2$

Model 2, NO_x-tranformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for crop is determined in 4.1.7 to $7.00\cdot10^{-1}$ kg crop per kg NO_x. Therefore the characterisation factor of N_2O for morbidity is $1.35*7.00\cdot10^{-1} = -0.944$ kg crop/kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x, which is formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.7 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Calculation of characterisation factor

The total characterisation factor is thus $2.42\cdot10^{-1} + 0.944 = 1.19\cdot$kg crop/kg N_2O.

4.3.8. Characterisation of N_2O to air with respect to fish&meat

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model for NO_x-transformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for crop is determined in 4.1.8 to –0.0399 kg fish&meat/kg NO_x. Therefore the characterisation factor of N_2O for morbidity is 1.35*(-0.0399) = $-4.85 \cdot 10^{-2}$ kg fish&meat/kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x, which is formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.8 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7

4.3.9. Characterisation of N_2O to air with respect to wood

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (ICCP 1995).

Calculation of pathway specific characterisation factor

The global warming pathway specific characterisation factor of CO_2 for wood loss is determined in 3.1.7 to - $1.16 \cdot 10^{-3}$ kg wood (DS)/kg CO_2. Therefore the characterisation factor of N_2O for wood is - $320 * 1.16 \cdot 10^{-3}$ = - 0.371 kg wood (DS)/kg N_2O.

Uncertainty

The uncertainty is the estimation of the equivalency factor is estimated by to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.7 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 2.2)^2}$ = 2.0

Model 2, NO_x-transformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for wood is determined in 4.1.10 to -2.74 kg wood /kg NO_x. Therefore the characterisation factor of N_2O for morbidity is 1.35*(-2.74) = -3.69 kg wood/kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.9 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7

Calculation of characterisation factor

The total characterisation factor is thus – (0.371+3.69) = –4.06 kg wood/kg N_2O.

4.3.10. Characterisation of N_2O to air with respect to soil base-cat-ion reserves

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model for NO_x-tranformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for base cat ion capacity is determined in 4.1.10 to 1.09 equivalents of base cat-ions per kg NO_x. Therefore the characterisation factor of N_2O for soil base-cat-ions is 1.35*1.09 = 1.47 equivalents of base cat-ions /kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x, which is formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.10 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7

4.3.11. Characterisation of N_2O to air with respect to NEX

Definition of environmental system in which the impact is estimated

The impact is of global character. The modelled system is therefore global. The temporal system borders are 100 years (1990-2090). The society effected is the one described in IPCC scenario IS92A. (IPCC, 1990).

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The global warming potential for N_2O on a 100 years basis is 320 (ICCP 1995).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for NEX is determined in 3.1.8 to $1.26 \cdot 10^{-14}$ /kg CO_2. Therefore the characterisation factor of N_2O for NEX is $320 * 1.26 \cdot 10^{-14} = 4.03 \cdot 10^{-12}$ /kg N_2O.

Uncertainty

The uncertainty is the estimation of the equivalency factor is estimated by to about 30%. Assuming a log-normal distribution 30% means a standard deviation corresponding to a factor of 1.1. The uncertainty of the characterisation factor for CO_2 was determined in 3.1.8 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2}$ = 3.0

Model 2, NO_x-transformation pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

In 4.3.3, the equivalency factor was determined to 1.35 kg NO_x (NO_2).

Calculation of pathway specific characterisation factor

The characterisation factor of NO_x for NEX is determined in 4.1.11 to $7.50 \cdot 10^{-14}$ per kg NO_x. Therefore the characterisation factor of N_2O for NEX is $1.35 * 7.50 \cdot 10^{-14} = 1.01 \cdot 10^{-13}$ /kg N_2O.

Uncertainty

The uncertainty in the estimation of the equivalency factor is estimated by to about a factor of 10. The reason is mainly that the exposure routes are different for NO_x formed in the stratosphere and NO_x emitted at ground level. Assuming a log-normal distribution this means a standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor for NO_x was determined in 4.1.11 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.5. The total uncertainty is therefore a log-normal normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 2.5)^2}$ = 4.2

Calculation of characterisation factor

The total characterisation factor is therefore estimated to $4.03 \cdot 10^{-12} + 1.01 \cdot 10^{-13} = 4.13 \cdot 10^{-12}$ /kg N_2O.

5. Classification and characterisation of emissions of sulphur compounds to air

5.1. *Emissions of sulphur dioxide anywhere in the world*

5.1.1. Definition of flow group

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength. Most of the emissions occur from stacks but they are widely distributed on the globe. Typical sources are combustion of fossil fuels, smelters and pulp manufacturing.

5.1.2. Assignment to impact categories

Sulphur dioxide is irritating to lung tissue, it is toxic to plants, it is corrosive and it contributes to acidification. It reacts in air to form particles which are in the micron to submicron range. Those particles have health effects and has impacts on the climate. The climate impacts occur via two mechanisms. The particles interfere with the radiation balance directly and they act as condensation nuclei to form cloud droplets.

This means that sulphur dioxide may be assigned to all of the impact categories used in the EPS default weighting method except abiotic resources. (table 5.1)

Table 5.1 Assignment of SO_2 emissions to impact categories and selection of category indicators.

Pathway(s)	Impact category	Category indicator
Direct acute effects	Life expectancy	YOLL
Secondary aerosol	Life expectancy	YOLL
Corrosion	Life expectancy	YOLL
Secondary aerosol	Severe morbidity	Severe morbidity
Corrosion	Severe morbidity	Severe morbidity
Secondary aerosol	Morbidity	Morbidity
Secondary aerosol	Nuisance	Nuisance
Secondary aerosol	Crop production capacity	Crop
Acidification	Fish&meat production capacity	Fish&meat
Secondary aerosol	Wood production capacity	Wood
Acidification	Base cat-ion capacity	Base cat-ion capacity
Acidification	Extinction of species	NEX
Secondary aerosol	Extinction of species	NEX

5.1.3. Characterisation of sulphur dioxide to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model 1, direct acute effect pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

One way to estimate the category indicator value is to identify those groups for which threshold limits for health effects are exceeded. Excess mortality occur at 500 $\mu g/m^3$ among elderly chronically ill people (WHO, 1987). These concentrations are very rare as daily means. UN environmental data report 91/92 indicates only a few cities with annual means above 200 $\mu g/m^3$ (Shenyang, China and Teheran, Iran). A rough estimate is that 5 million persons live in areas where the SO_2 concentration every third year as a daily average exceeds 500 $\mu g/m^3$. (Obtained from extrapolation of log-normal frequency distribution). Assuming an increase in death rate of 1% in respiratory diseases (less than 10% of all mortality causes) and a life shortening of 3 years, a normalised death incidence would be 375 YOLL per year.

Another way of estimating the excess mortality is to use elasticity figures obtained from epidemiological studies. Lipfert and Wyzga (1995) has reviewed various such studies. They find an elasticity of about 0.02 for SO_2, which means that if the concentration of SO_2 is decreased by 1% of the average, there is a decrease of 0.02% in the mortality rates. Taking away 100% would (if the dose- response function were linear) give a 2% reduction. The effect is mainly detected for elderly above 65 years and on a time scale of 0-4 days. Using one week of life shortening SO_2 would be responsible for about $5.28 \cdot 10^9$/65(average mortality per year)*1/50(YOLL/case) *0.02(part of population affected) = 32500 YOLL per year.

Although some epidemiologists seem to consider the elasticity figure for SO_2 showing something else than a causal effect of SO_2, the figure 32500 YOLL will be used as it still is small compared to changes in the category indicator induced via other pathways.

Contribution to category indicators value from a flow unit

The global emission of SO_x ($SO_2 + SO_3 + H_2SO_4$) is 170 million tons per year. SO_3 and H_2SO_4 have similar but not identical effects as SO_2. Their emissions are only a few percent of the SO_2 emissions. Thus the average contribution is estimated to $5.88 \cdot 10^{-12}$ per kg SO_2.

Calculation of pathway specific characterisation factor

The pathway specific characterisation factor is $32500 * 5.88 \cdot 10^{-12} = 1.91 \cdot 10^{-7}$ YOLL/kg SO_2.

Uncertainty

The contribution from an emission to the effect varies a lot with stack height, the magnitude of the emission, the background concentrations and the population density in the surroundings. As there seems to be only a few places on the globe were SO_2 emissions cause YOLL, the uncertainty is very large when having a global approach. As the characterisation factor is low compared to other impacts on YOLL, normally the uncertainty should not influence the conclusions drawn from the analysis of technical concepts.

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 10.

Model 2, secondary aerosol pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

The total indicator value for PM_{10} is determined in 9.1.3 to be $6.34 \cdot 10^{7}$ YOLL per year for the chronic effect pathway. For all pathways it would be $4.24/4.23 * 6.34 \cdot 10^{7} = 6.35 \cdot 10^{7}$ YOLL per year, where $4.24 \cdot 10^{-4}$ is the added characterisation factor for all pathways and $4.23 \cdot 10^{-4}$ is the characterisation factor for the chronic effect pathway.

In 9.1.3 the global average population exposure to PM_{10} is estimated to 46 $\mu g/m^3$. According to Brook et al. (1997), who studied the Canadian ambient aerosol, about 10% of the PM_{10} mass consist of sulphates. If used as a global average, the average exposure would be 4.6 $\mu g/m^3$ and the total indicator value allocated to sulphates $0.1 * 6.35 \cdot 10^{7} = 6.35 \cdot 10^{6}$ YOLLs per year.

Contribution to category indicators value from a flow unit

In model 1, the contribution was estimated to $5.88 \cdot 10^{-12}$ per kg SO_2.

Calculation of pathway specific characterisation factor

$6.35 \cdot 10^{6} * 5.88 \cdot 10^{-12} = 3.74 \cdot 10^{-5}$ YOLL/kg SO_2.

Uncertainty

The uncertainty in estimation of the average exposure to sulphates is in the order of a factor of two. The uncertainty for the characterisation factor of PM_{10} as determined in 9.1.3 is a log-normal uncertainty distribution with a standard deviation corresponding to a factor of 3. As the transformation from SO_2 to sulphate occur on an urban complex scale, the local variations in contribution are less than from a direct exposure from primary pollutants. Therefore an uncertainty distribution equal to that of PM_{10} is assumed, i.e. a log-normal uncertainty distribution with a standard deviation corresponding to a factor of 3.

Model 3, corrosion pathway

The characterisation factor is determined by a combined empirical and equivalency method using emissions and resources in steel production as a reference.

Category indicator value in system considered

The global replacement of steel caused by corrosion due to SO_x is estimated to $3.5\ 10^{9}$ kg/year. The estimations is based on assumptions of a 5 % reduction in the usage time for steel constructions, and a world steel production of around $700 \cdot 10^{9}$ kg. (UN 1996)

As the global SO_x-emission is 170 million tons per year the contribution is at an average $5.88 \cdot 10^{-12}$ per kg SO_2. The average demand of new steel is therefore 0.021 kg/kg SO_2.

When producing and disposing1 kg of steel, the net CO_2 emission is estimated to around 1.72 kg.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL is $7.93 \cdot 10^{-5}$. This will give a characterisation factor of SO_2 for YOLL of $0.021 * 1.72 * 7.93 \cdot 10^{-5} = 2.81 \cdot 10^{-8}$ YOLL/kg SO_2.

Uncertainty

The actual replacement of corroded steel is uncertain, with an uncertainty in the order of a factor of 10. The contribution is estimated to vary with a factor of 5. The total uncertainty is assumed to be described with a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor

Considering all three pathways, the total characterisation factor for SO_2 is $1.91 \cdot 10^{-7} + 3.74 \cdot 10^{-5} + 2.81 \cdot 10^{-8} = 3.76 \cdot 10^{-5}$ YOLL/kg SO_2

5.1.4. Characterisation of sulphur dioxide to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model 1, secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference. The reason for using PM_{10} and not SO_2 as a reference as in 5.1.3 is that the main contribution to severe morbidity is from global warming while the main contribution to YOLL was direct exposure for PM_{10}. For global warming effects, the local exposure patterns is of less importance, and the easiest model was chosen.

Equivalency factor

An equivalency factor with PM_{10} could be determined through the formula:

$$M_{SO4}/M_{SO2} * \eta_{trans} * C_{PM10}/C_{PM2.5} \text{ , where}$$

M_{SO4} and M_{SO2} are the molecular weights of SO_4^{--} and SO_2, respectively,
η_{trans} is the transformation efficiency of SO_2 to SO_4^{2-}, i.e. what part of the SO_2 entering the atmosphere that become particles (in the form of sulphates) and
C_{SO4} and C_{PM10} are the concentration of $PM_{2.5}$ particles compared to that of PM_{10}.

Many authors consider $PM_{2.5}$ particles to be responsible for the impact found to correlate with PM_{10} (Wilsson, 1996). As most of the sulphate particle mass consists of particles less than 2.5 the ratio $C_{PM10}/C_{PM2.5}$ is used as an approximation for the enhanced potency of sulphate particles.

$C_{PM10}/C_{PM2.5}$ has been determined in several studies. (Brook et al. 1997), (Haller et al., 1999). Brook et al. studied the $PM_{10}/PM_{2.5}$ ratio at 19 sites in Canada between 1984 and 1993, Their average value, 1.89 will be used here. (For arid areas, the ratio increase, e.g. to 2.5)

On the regional scale the transmission efficiency is very close to 1. The transformation rate is in the order of 1-2 % per hour, giving a residence time of the gas of a few days. If it would rain within that time, part of the SO_2 could be washed out without transformation to sulphate particles. For average global conditions, this part is considered to be small and is not used in the modelling.

Thus the equivalency factor is 96/64*1*1.89 = 2.83

Calculation of pathway specific characterisation factor

According to 9.1.4 there is - $2.33 \cdot 10^{-6}$ person-years/ kg PM_{10}. We thus obtain $-2.33 \cdot 10^{-6}$ $*2.83 = -6.59 \cdot 10^{-6}$ person-years of severe morbidity per kg of SO_2.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for severe morbidity is determined in 9.1.4 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2}$ = 4.2

Model 2, corrosion pathway

The characterisation factor is determined by a modified equivalency method using emissions and resources in steel production as a reference.

Equivalency factor

When producing and disposing1 kg of steel, the net CO_2 emission is estimated to around 1.72 kg (as described in 5.1.4) or 0.021*1.72 = 0.036 kg CO_2/kg SO_2.

Calculation of pathway specific characterisation factor

The characterisation factor for severe morbidity is $3.53 \cdot 10^{-7}$ person-years/kg CO_2. We thus obtain the pathway specific characterisation factor for SO_2 as $0.036 * 3.53 \cdot 10^{-7} = 1.27 \cdot 10^{-8}$ person-years/kg SO_2.

Uncertainty

A similar uncertainty is assumed as for 5.1.3, i.e. the total uncertainty is assumed to be described with a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor

Considering both pathways, the total characterisation factor for SO_2 for severe morbidity is $-6.59 \cdot 10^{-6} + 1.27 \cdot 10^{-8} = -6.58 \cdot 10^{-6}$ person-years/kg SO_2.

5.1.5. Characterisation of sulphur dioxide to air with respect to morbidity

Based on the results from 5.1.4 of the impacts via various possible pathways, the one from secondary aerosols is considered to be the most important. Direct exposure effects have been mentioned in literature, but often with doubt of causality relative to morbidity (ExternE, 1995). Therefore only a model for secondary aerosol pathway is used to estimate the characterisation factor.

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 5.1.4, i.e. 2.83 kg ‘effective’ PM_{10}/kg SO_2.

Calculation of characterisation factor

According to 9.1.5 there are $3.61 \cdot 10^{-6}$ person-years of morbidity/kg PM_{10}. We thus obtain $3.61 \cdot 10^{-6} * 2.83 = 1.02 \cdot 10^{-5}$ person-years of morbidity per kg of SO_2.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for morbidity is determined in 9.1.5 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$

5.1.6. Characterisation of sulphur dioxide to air with respect to nuisance

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 5.1.4, i.e. 2.83 kg ‘effective’ PM_{10}/kg SO_2.

Calculation of characterisation factor

According to 9.1.6 there are $2.28\cdot10^{-3}$ person-years of nuisance per kg PM_{10}. This will give $2.83*2.28\cdot10^{-3} = 6.45\cdot10^{-3}$ person-years per kg SO_2.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for nuisance is determined in 9.1.6 to correspond to a factor of 2.2 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2} = 2.4$

5.1.7. Characterisation of sulphur dioxide to air with respect to crop growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 5.1.4, i.e. 2.83 kg ‘effective’ PM_{10}/kg SO_2.

Calculation of characterisation factor

According to 9.1.7 there are $-6.46\cdot10^{-3}$ kg crop lost per kg PM_{10}. This will give $-2.83 *6.46\cdot10^{-3} = -1.83\cdot10^{-2}$ kg crop lost per kg SO_2.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for crop is determined in 9.1.7 to correspond to a factor of 2.4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.4)^2} = 2.6$

5.1.8. Characterisation of sulphur dioxide to air with respect to fish&meat

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

A rough estimation of decrease of fish production may be based on an estimation of land areas where the critical load are exceeded (10%) and on the total fresh water catch of fish (10 million tons annually, globally). Only a part of the lakes in a region with excess sulphur deposition is acidified, normally those that are small and in the most upstream regions. A rough guess is that 20% of the lake area in regions where the critical load is exceeded is acidified to an extent that no fish is reproduced. This will correspond to a loss of 200 000 ton of fish annually.

Contribution to category indicators value from a flow unit

The global emission of SO_x is 170 million tons per year. Therefore the contribution is as an average $5.88\cdot10^{-12}$ per kg SO_2.

Calculation of characterisation factor

$2\cdot10^{8} *5.88\cdot10^{-12} = 1.18\cdot10^{-3}$ kg fish per kg SO_2.

Uncertainty

The estimation of the indicator value is probably an overestimation, as most large lakes with high nutrient status and high fish production are not acidified. The uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of three.

5.1.9. Characterisation of sulphur dioxide to air with respect to wood growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 5.1.4, i.e. 2.83 kg ‘effective’ PM_{10}/kg SO_2.

Calculation of characterisation factor

According to 9.1.7 there are 0.00991 kg wood per kg PM_{10}. This will give 2.83*0.00991 = 0.0281 kg wood per kg SO_2.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for wood is determined in 9.1.8 to correspond to a factor of 2.2 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}$ = 2.4

5.1.10. Characterisation of sulphur dioxide to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by a mechanistic method.

Mechanism
When sulphur dioxide is oxidised in air, two protons (H^+) are produced per mole of SO_2. When the oxidised S in form of sulphate is deposited on soil, the protons will substitute base cat-ions, e.g Mg^{++} or K^+, which are important nutrient to plants.

Portion of emitted substance that will reach target
On a global scale the critical load for soil acidification is exceeded on approximately 10% of the land area. As much of the SO_2 sources are located near the sea, part of the emissions is deposited in the oceans and in inland water. As the average residence time is in the order of a week and the corresponding air transport of several 1000 km, it is reasonable to assume that 50% of the S is deposited at land. This means that approximately 5% of the SO_2 cause base cat-ion depletion.

Calculation of characterisation factor
For each kg of SO_2 there is thus 2*1000*0.05/64 = 1.56 equivalents of base cat-ions reserves depleted.

Uncertainty
The uncertainty in the characterisation factor lies mainly in the estimation of how much of the emitted SO_2 which is deposited in areas where the critical load is exceeded. There is an uncertainty in the estimation of the global average and there is an uncertainty in how relevant the global average is for a specific LCA. This uncertainty is assumed to be described by a log-normal distribution with a standard deviation of a factor of 3.

5.1.11. Characterisation of sulphur dioxide to air with respect to NEX

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model 1, acidification pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
In Sweden approximately 2 % of the threatened evertebrates are claimed to be threatened by acidification. (Faunavårdskommitten 1988). If this is assumed to be relevant for other acidified regions, roughly estimated to 10% of the earth's land area, this would indicate that as a global average 0.2 % of the NEX are endangered due to SO_2.

Contribution to category indicators value from a flow unit
The global emission of SO_x is 170 million tons per year resulting in an average contribution of $5.88 \cdot 10^{-12}$ per kg SO_2.

Calculation of pathway specific characterisation factor
$0.002 * 5.88 \cdot 10^{-12} = 1.18 \cdot 10^{-14}$ NEX per kg SO_2.

Uncertainty
The uncertainty is estimated to represented by a log-normal distribution with a standard deviation correspondning to a factor of 3.

Model 2, secondary aerosol pathway
The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor
The same equivalency factor is used as in 5.1.4, i.e. 2.83 kg ‘effective’ PM_{10}/kg SO_2.

Calculation of pathway specific characterisation factor
According to 9.1.8 there are $-1.08 \cdot 10^{-13}$ NEX per kg PM_{10}. This will give $-2.83 * 1.08 \cdot 10^{-13} = -3.06 \cdot 10^{-13}$ NEX per kg SO_2.

Uncertainty
The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for NEX is determined in 9.1.9 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$

Calculation of characterisation factor
The characterisation factor of SO_x for NEX is thus $1.18 \cdot 10^{-14}$
$-3.06 \cdot 10^{-13} = -2.94 \cdot 10^{-13}$ per kg SO_2.

5.1.12. Trends

There has been a considerable decrease of SO_2 emissions in the OECD countries since 1990, and the exposure pattern has changed somewhat. Combustion sources are still dominating the emissions but larger plants and higher stacks decrease concentrations more than emissions as in the US.

USEPA (1996) states: “*Between 1987 and 1996, ambient concentrations of* SO_2 *decreased 37 percent, while emissions of* SO_2 *decreased 14 percent. Between 1995 and 1996, nation-wide average ambient* SO_2 *concentrations remained unchanged, while* SO_2 *emissions increased 3 percent.* SO_2 *emissions from electric utilities decreased 20 percent between 1987 and 1996. Between 1995 and 1996,* SO_2 *emissions from electric utilities* *increased 4 percent. The recent reductions in SO_2 emissions from electric utilities (down 17 percent since 1993) are due, in large part, to controls implemented under EPA's Acid Rain Program. The increase in SO_2 emissions that occurred between 1995 and 1996 is primarily due to increased demand for electricity."*

As most of the characterisation factors are modelled from linear relations they would be relevant within about 20% for the year 2000. 20% is the difference between decreased emissions and ambient concentrations. As most of the impacts are of regional character, the local, urban SO_2-concentration is not so important, why the characterisation factors practically are the same.

5.2. Emissions of sulphur trioxide and sulphuric acid anywhere in the world

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength. Most of the emissions occur from stacks but they are widely distributed on the globe. Typical sources are the same as for SO_2 i.e. combustion of fossil fuels, smelters and pulp manufacturing. Sulphur trioxide (SO_3) is formed in combustion flames in the present of atomic oxygen. The presence of atomic oxygen is dependent of the flame temperature and oxygen supply. Normally only a few percent (up to five) of the sulphur is forming SO_3. SO_3 reacts readily with water at temperature below a few hundred degrees to form sulphuric acid.

In most cases SO_3 and sulphuric acid have the same environmental impacts as SO_2. In a few cases, local effects may occur from sulphuric acid droplets, which may be aggressive to materials. Soot from cleaning of heat exchangers and ducts may for instance destroy car paintings or sulphuric acid fumes from smelters may give foliage damage in vegetation.

As a default impact scenario however, SO_3 and sulphuric acid inventory results may be added to the SO_2 results. 1 kg of SO_3 is treated as being equal to 0.8 kg SO_2 and 1 kg of sulphuric acid is set equal to 0.653 kg of SO_2.

5.3. Emissions of sulphur hydrogen sulphide anywhere in the world

5.3.1. Definition of flow group

Kraft pulp mills, refineries and anaerobic processes in agriculture and waste management are typical sources of hydrogen sulphide (H_2S).

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength.

5.3.2. Assignment to impact categories

Most of the hydrogen sulphide is oxidised in air, or, when deposited, as sulphides. Therefore its environmental effects are the same as for SO_2, but with the addition of two that are specific for hydrogen sulphide. One of them, discoloration of lead paint (Stern, 1986), is not considered to be significant enough to be modelled here. The other one, nuisance due to odour may be significant on a local scale and is therefore used as a further reason to assign hydrogen sulphide to nuisance. The following assignments are thus made (table 5.2):

Table 5.2 Assignment of H_2S emissions to impact categories and selection of category indicators.

Pathway(s)	Impact category	Category indicator
Secondary SO_2	Life expectancy	YOLL
Secondary SO_2	Severe morbidity and suffering	Severe morbidity
Secondary SO_2	Morbidity	Morbidity
Secondary SO_2	Nuisance	Nuisance
Odour	Nuisance	Nuisance
Secondary SO_2	Crop production capacity	Crop
Secondary SO_2	Fish&meat production capacity	Fish&meat
Secondary SO_2	Wood production capacity	Wood
Secondary SO_2	Base cat-ion capacity	Base cat-ion capacity
Secondary SO_2	Extinction of species	NEX

5.3.3. Characterisation of hydrogen sulphide to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.3 to $3.76 \cdot 10^{-5}$ YOLL/kg SO_2. The characterisation factor for H_2S is therefore $1.49 * 3.76 \cdot 10^{-5} = 5.60 \cdot 10^{-5}$ YOLL/kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. This comes on top of the uncertainty for the equivalency factor for SO_2

versus PM_{10} (which was the most significant pathway) of a (σ corresponds to a factor of 2) and the uncertainty of the health effect of PM_{10} (σ corresponds to a factor of 3). The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 2)^2 + (\ln 3)^2} = 3.7$

5.3.4. Characterisation of hydrogen sulphide to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor
It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor
The characterisation factor for SO_2 was estimated in 5.1.4 to $-6.59\cdot10^{-6}$ person-years/kg SO_2. The characterisation factor for H_2S is therefore $1.49*(-6.59\cdot10^{-6}) = -9.80\cdot10^{-6}$ person-years/kg H_2S.

Uncertainty
Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for severe morbidity was determined in 5.1.4 to a log-normal distribution with a standard deviation corresponding to a factor of 4.2. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 4.2)^2} = 4.2$

5.3.5. Characterisation of hydrogen sulphide to air with respect to morbidity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.5 to $1.02\cdot10^{-5}$ person-years of morbidity per kg SO_2. The characterisation factor for H_2S is therefore $1.49*(1.02\cdot10^{-6})$ = $1.52\cdot10^{-6}$ person-years/kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for morbidity was determined in 5.1.5 to a log-normal distribution with a standard deviation corresponding to a factor of 4.2. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 4.2)^2}$ = 4.2

5.3.6. Characterisation of hydrogen sulphide to air with respect to nuisance

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model 1, secondary sulphur dioxide pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.6 to $6.45\cdot10^{-3}$ person-years per kg SO_2. The characterisation factor for H_2S is therefore $1.49*(6.45\cdot10^{-3})$ = $9.61\cdot10^{-3}$ person-years/kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for nuisance was determined in 5.1.6 to a log-normal distribution with a standard deviation corresponding to a factor of 2.4. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 2.4)^2} = 2.4$

Model 2, odour pathway

The characterisation factor is determined by the empirical method. Sweden is used as a sample of the global system. Having a large portion of industrial H_2S sources (pulp mills) it may give an overestimation of the global average characterisation factor as threshold levels more frequently are exceeded. On the other hand is the population density is lower than average, which could give an underestimation of the characterisation factor.

Category indicator value in system considered

Most inhabitants in Sweden have experienced odour from pulp mills. No data on odour frequency for the whole population has been available. However, approximately 10000 person live in areas close to pulp mills where the odour frequency exceeds 1% of the time. The 1% is the target level in many permits given to the pulp industry. A rough guess is that the total population exposure in person-years is about twice as high. From measurements in northern Sweden and by the use of source apportionment techniques it has been found that H_2S is contributing with about half of the odour. Organic sulphides and therpenes make up for the rest. Therefore, 0.01*10000*2*0.5 = 100 person-years of nuisance is allocated to H_2S emissions.

Contribution to category indicators value from a flow unit

The total process sulphur emissions from kraft pulp mills in Sweden was 5400 tons 1993. (Swedish EPA report 4348) A minor part of these is reduced in form of H_2S. A rough estimate is 100 tons.

Calculation of characterisation factor

100 person-years divided by 10^5 kg is 10^{-3} person-years of nuisance per kg of H_2S.

Uncertainty

The uncertainty in the figure given for the population exposure is estimated to one order of magnitude. The main reason is the unknown low exposure to large groups. The uncertainty in emission data is estimated to a factor of three.

Beside the uncertainty in the data there is a true variability within Sweden and when the Swedish figures is applied to global conditions. Considering which parameters that are most important for the population exposure in terms of person-years per kg H_2S (β), and looking at how these vary we may get a hint of how β may vary for different LCA:s.

The most important factors for β are population density (directly proportional), stack hight (less than proportional), source strength and atmospheric dispersion conditions and oxidation rates. If restricting the analysis to local conditions in the urban complex where the emissions occur, the oxidation rate may be disregarded. The source strength may be between ‘less than proportional’ to ‘quite fundamental’ for the value of β. In small urban areas the H_2S-conentration in the plume from a source may exceed the odour threshold with some marginal and β will not be affected at all by moderate variation in source strength. Some of the H_2S data collected in LCI studies may relate to emissions where the ground level concentrations never exceed the odour threshold, while others do. However, as the measurement of H_2S requires special measurement methods it is reasonable to assume that most LCI data on H_2S were collected where there were at least a small probability of having an odour problem.

On the basis of the information gathered above, it is assumed that the uncertainty of the odour characterisation factor may be represented by a log-normal distribution having a standard deviation corresponding to a factor of 10.

5.3.7. Characterisation of hydrogen sulphide to air with respect to crop growth

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model for secondary sulphur dioxide pathway
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor
It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor
The characterisation factor for SO_2 was estimated in 5.1.7 to $-1.83 \cdot 10^{-2}$ kg crop lost per kg SO_2. The characterisation factor for H_2S is therefore $1.49*(-1.83 \cdot 10^{-2}) = -2.73 \cdot 10^{-2}$ kg crop/kg H_2S.

Uncertainty
Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for crop was determined in 5.1.7 to a log-normal distribution with a standard deviation corresponding to a factor of 2.6. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 2.6)^2} = 2.6$

5.3.8. Characterisation of hydrogen sulphide to air with respect to fish&meat

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.8 to $1.18 \cdot 10^{-3}$ kg fish per kg SO_2. The characterisation factor for H_2S is therefore $1.49*(1.18 \cdot 10^{-3}) = 1.76 \cdot 10^{-3}$ kg fish per kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for fish&meat was determined in 5.1.8 to a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2}$ = 3.0

5.3.9. Characterisation of hydrogen sulphide to air with respect to wood growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.9 to 0.0281 kg wood per kg SO_2. The characterisation factor for H_2S is therefore $1.49*0.0281 = 4.18 \cdot 10^{-2}$ kg wood per kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for wood was determined in 5.1.9 to a log-normal distribution with a standard deviation corresponding to a factor of 2.4. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 2.4)^2}$ = 2.4

5.3.10. Characterisation of hydrogen sulphide to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor
It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor
The characterisation factor for SO_2 was estimated in 5.1.10 to 1.56 equivalents of base cat-ions reserves depleted per kg SO_2. The characterisation factor for H_2S is therefore 1.49*1.56 = 2.32 equivalents of base cat-ions reserves depleted per kg H_2S.

Uncertainty
Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for soil base cat-ion capacity was determined in 5.1.10 to a log-normal distribution with a standard deviation corresponding to a factor of 3. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2}$ = 3.0

5.3.11. Characterisation of hydrogen sulphide to air with respect to NEX

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor
It is assumed that almost all hydrogen sulphide is oxidised to SO_2 in the atmosphere. Therefore 1 kg of H_2S is equal to 1.49 kg SO_2.

Calculation of characterisation factor

The characterisation factor for SO_2 was estimated in 5.1.11 to $-2.94 \cdot 10^{-13}$ NEX per kg SO_2. The characterisation factor for H_2S is therefore $1.49*(-2.94 \cdot 10^{-13}) = -4.38 \cdot 10^{-13}$ NEX per kg SO_2 per kg H_2S.

Uncertainty

Due to a relatively small uncertainty in the estimation of which part of H_2S that was transformed to SO_2 in air, the added uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty of the characterisation factor of SO_2 for NEX was determined in 5.1.11 to a log-normal distribution with a standard deviation corresponding to a factor of 4.2. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 4.2)^2} = 4.2$

6. Classification and characterisation of emissions of other inorganic gases to air

6.1. Emissions of hydrogen fluoride anywhere in the world

6.1.1. Definition of flow group

Most of the emissions occur from stacks but they are widely distributed on the globe. Typical sources are glass and ceramic industries and manufacturing of fertilisers and aluminium.
The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength.

6.1.2. Assignment to impact categories

Hydrogen fluoride (HF) is a strong acid and contributes to acidification and corrosion. Some of the hydrogen fluoride is transformed to particles before depositing on the ground. The fluoride ion is toxic to plant tissue and have caused damage to plants. It has also caused damage to the skeleton of crazing cattle. Local damages due to fluorides are seldom seen around modern industries with environmental management practises. They belong mostly to the history of air pollution control. However they could occur in countries with no or low legal requirements on air pollution control or occasionally when cleaning equipment fail. The extension of local damage due to fluoride emissions in the world today is estimated to be low, and (as shown for SO_x) the contribution from corrosion to the category indicators negligible, why hydrogen fluoride emissions only are assigned to acidification and secondary aerosol effects (table 6.1.).

Table 6.1. Assignment of HF emissions to impact categories and selection of category indicators

Pathway(s)	Impact category	Category indicator
Secondary aerosols	Life expectancy	YOLL
Secondary aerosols	Severe morbidity and suffering	Severe morbidity
Secondary aerosols	Morbidity	Morbidity
Secondary aerosols	Severe nuisance	Severe nuisance
Secondary aerosols	Nuisance	Nuisance
Secondary aerosols	Crop production capacity	Crop
Acidification	Fish&meat production capacity	Fish&meat
Secondary aerosols	Wood production capacity	Wood
Acidification	Base cat-ion capacity	Base cat-ion capacity
Acidification	Extinction of species	NEX
Secondary aerosols	Extinction of species	NEX

6.1.3. Characterisation of hydrogen fluoride to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by a modified equivalency method using SO_2 as a reference. SO_2 is preferred before PM_{10} because it has a similar emission-dispersion-exposure pattern as SO_2.

Equivalency factor

An equivalency factor with SO_2 is determined through the formula:

$$(M_F/M_{HF}) / (M_{SO4}/M_{SO2}) = 0.633, \text{ where}$$

M_F and M_{HF} are the molecular weights of F^- and HF, respectively, and M_{SO4} and M_{SO2} are the molecular weights of SO_4^{2-} and SO_2, respectively.

Calculation of pathway specific characterisation factor

The secondary aerosol pathway specific characterisation factor of SO_2 for YOLL is $3.74 \cdot 10^{-5}$ YOLL/kg SO_2, which thus will result in a characterisation factor for HF of $0.633 * 3.74 \cdot 10^{-5} = 2.36 \cdot 10^{-5}$ YOLL/kg HF.

Uncertainty

The uncertainty in the equivalency factor is estimated to be log-normal distributed with a standard deviation corresponding to a factor of 1.4. The uncertainty in the pathway specific characterisation factor of SO_2 for YOLL was estimated in 5.1.3 to be described with a log-normal distribution with the standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor may therefore be described with a log-normal distribution with the standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 3)^2} = 3.2$

6.1.4. Characterisation of hydrogen fluoride to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference. The reason for using PM_{10} and not SO_2 as a reference as in 6.1.3 is that the main contribution to severe morbidity is from global warming while the main contribution to YOLL was direct exposure for PM_{10}. For global warming effects the local exposure patterns is of less importance, and the easiest model was chosen.

Equivalency factor

An equivalency factor with PM_{10} could be determined through the formula:

$$M_F/M_{HF} * \eta_{trans} * C_{PM10}/C_{PM2.5} \text{ , where}$$

M_F and M_{HF} are the molecular weights of F and HF, respectively,
η_{trans} is the transformation efficiency of HF(g) to F^-(s) i.e. what part of the HF entering the atmosphere that become particles (in the form of flourides) and
$C_{2.5}$ and C_{PM10} are the concentration of $PM_{2.5}$ particles compared to that of PM_{10}.

Many authors consider $PM_{2.5}$ particles to be responsible for the impact found to correlate with PM_{10} (Wilsson, 1996). As most of the sulphate particle mass consists of particles less than 2.5 the ratio $C_{PM10}/C_{PM2.5}$ is used as an approximation for the enhanced potency of flouride particles.

$C_{PM10}/C_{PM2.5}$ has been determined in several studies. (Brook et al. 1997), (Haller et al., 1999). Brook et al. studied the $PM_{10}/PM_{2.5}$ ratio at 19 sites in Canada between 1984 and 1993, Their average value, 1.89 will be used here. (For arid areas, the ratio increase, e.g. to 2.5)

On the regional scale the transmission efficiency is very close to 1.

Thus the equivalency factor is 19/20*1*1.89 = 1.80

Calculation of pathway specific characterisation factor

According to 9.1.4 there is - $2.33 \cdot 10^{-6}$ person-years/ kg PM_{10}. We thus obtain: $-2.33 \cdot 10^{-6} * 1.80 = -4.19 \cdot 10^{-6}$ person-years of severe morbidity per kg of HF.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for severe morbidity is determined in 9.1.4 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2}$ = 4.2
reference.

6.1.5. Characterisation of hydrogen fluoride to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.1.4, i.e. 1.80 kg ‘effective’ PM_{10}/kg HF.

Calculation of characterisation factor

According to 9.1.5 there is $3.61 \cdot 10^{-6}$ person-years morbidity/ kg PM_{10}. We thus obtain: $3.61 \cdot 10^{-6} * 1.80 = 6.50 \cdot 10^{-6}$ person-years of morbidity per kg of HF.

Uncertainty

The uncertainty in the factor 1.80 expressing the mass ratio of secondary particles to HF was estimated in 6.1.4 to be log-normal distributed with a standard deviation corresponding to a factor of 1.4. The uncertainty in the characterisation factor of PM_{10} for morbidity is estimated in 9.1.5 to be represented by two log-normal distributions with a standard deviation corresponding to a factor of 2.2 and 4. The characterisation factor for both pathways were $9.2 \cdot 10^{-6} - 5.57 \cdot 10^{-6} = 3.6 \cdot 10^{-6}$ person-years/ kg PM_{10}.
This means that the uncertainty of the characterisation factor of HF for severe morbidity may be represented by the difference between two log-normal distribution with standard deviations corresponding to a factor of 2.4 and 4.2 and with average values of $8.28 \cdot 10^{-6}$ and $5.01 \cdot 10^{-6}$.

6.1.6. Characterisation of hydrogen fluoride to air with respect to nuisance

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (visibility degradation). The response time for the environmental system is in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.1.4, i.e. 1.80 kg ‘effective’ PM_{10}/kg HF.

Calculation of characterisation factor

According to 9.1.6 there are $2.28 \cdot 10^{-3}$ person-years of nuisance per kg PM_{10}. This will give $1.80 * 2.28 \cdot 10^{-3} = 4.10 \cdot 10^{-3}$ person-years per kg HF.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.1.4) and the characterisation factor for PM_{10} (9.1.5). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp(\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}) = 2.4$.

6.1.7. Characterisation of hydrogen fluoride to air with respect to crop growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.1.4, i.e. 1.80 kg ‘effective’ PM_{10}/kg HF.

Calculation of characterisation factor

According to 9.1.7 there are $-6.46 \cdot 10^{-3}$ kg crop lost per kg PM_{10}. This will give $-1.80 * 6.46 \cdot 10^{-3} = -1.16 \cdot 10^{-2}$ kg crop lost per kg HF.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.1.3) and the characterisation factor for PM_{10} (9.1.7). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.4)^2} = 2.6$.

6.1.8. Characterisation of hydrogen fluoride to air with respect to fish&meat

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for acidification pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

Due to its lower molecular weight 1 kg of hydrogen fluoride will give (64/2)/20 = 1.60 times as much protons as one kg of sulphur dioxide.

Calculation of characterisation factor

The characterisation factor of SO_2 for decreased production capacity of fish&meat is $1.18 \cdot 10^{-3}$ kg fish per kg SO_2. The characterisation factor of HF for fish&meat is therefore $1.60 * 1.18 \cdot 10^{-3} = 1.89 \cdot 10^{-3}$ kg fish&meat/kg HF.

Uncertainty

As the uncertainty in calculation of the equivalency factor is negligible the uncertainty of the characterisation factor is equal to the uncertainty of the characterisation factor of SO_x (5.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to 3.

6.1.9. Characterisation of hydrogen fluoride to air with respect to wood growth

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model for secondary aerosol pathway
The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor
The same equivalency factor is used as in 6.1.4, i.e. 1.80 kg 'effective' PM_{10}/kg HF.

Calculation of characterisation factor
According to 9.1.8 there are 0.00991 kg wood lost per kg PM_{10}.
This will give 1.80*0.00991 = 0.0178 kg wood lost per kg HF.

Uncertainty
The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.1.3) and the characterisation factor for PM_{10} (9.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}$ = 2.4.

6.1.10. Characterisation of hydrogen fluoride to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (base cat-ion reserves). The response time for the modelled quantity is normally in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model
The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor
Due to its lower molecular weight 1 kg of hydrogen fluoride will give (64/2)/20 = 1.60 times as much protons as one kg of sulphur dioxide.

Calculation of characterisation factor
For each kg of SO_2 there is 1.56 equivalents of base cat-ions reserves depleted. (5.1.10)
The characterisation factor of HF for depletion of soil base cat-ions are therefore 1.60*1.56 = 2.50 equivalents/ kg HF.

Uncertainty
The uncertainty in the equivalency factor is negligible why the uncertainty in the characterisation factor of HF for soil base cat-ion capacity depletion is equal to that of

SOx for soil base cat-ion capacity depletion, i.e. may be represented by a log-normal distribution with a standard deviation of 3.

6.1.11. Characterisation of hydrogen fluoride to air with respect to NEX

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The spatial system borders are wide enough to contain all of the modelled impact quantity (NEX on a global or local level). The response time for the modelled quantity is normally in the order of several years to decades, depending on the reproduction cycles of the NEX and on the volumes and alkalinity of the inland waters at risk for acidification. This means that present observed impacts are mainly caused by emissions several years ago. Despite this the characterisation factor of HF for NEX will be modelled as if everything happened within 1990. The magnitude of the error, which may be introduced through this, is discussed and estimated later.

Model 1, acidification pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

Due to its lower molecular weight 1 kg of hydrogen fluoride will give (64/2)/20 = 1.6 times as much protons as one kg of sulphur dioxide.

Calculation of pathway specific characterisation factor

The acidification pathway specific characterisation factor of SO_2 for NEX is $1.18 \cdot 10^{-14}$ per kg SO_2. The characterisation factor of HF for NEX will thus be $1.6 * 1.18 \cdot 10^{-14} = 1.89 \cdot 10^{-14}$ per kg HF.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.1.10) and the characterisation factor for SO_x (5.1.11). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1)^2 + (\ln 3)^2} = 3$

Model 2, aerosol transformation pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.1.4, i.e. 1.8 kg ‘effective’ PM_{10}/kg HF.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for NEX is $-1.08 \cdot 10^{-13}$ per kg PM_{10}. The characterisation factor of HF for NEX will thus be $1.80*(-1.08 \cdot 10^{-13}) = -1.94 \cdot 10^{-13}$ per kg HF.

Uncertainty

The extra uncertainty compared to that for the characterisation factor of PM_{10} for NEX (a log-normal distribution with a standard deviation corresponding to a factor of 4) lies in the equivalence factor 0.9. The uncertainty in the factor 0.9 is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.4. The added uncertainty is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor

The added characterisation factor of HF for NEX considering both pathways is thus $1.92 \cdot 10^{-10} + 1.08 \cdot 10^{-13} = 1.92 \cdot 10^{-10}$ per kg HF.

6.2. Emissions of hydrogen chloride anywhere in the world

6.2.1. Definition of flow group

The population of flows characterised is emissions to air, anyplace in the world 1990 and at any source strength. Most of the emissions occur from stacks but they are widely distributed on the globe. Typical sources are incineration of waste (PVC and chloride hydrolysis) basic inorganic industry.

6.2.2. Assignment to impact categories

Hydrogen chloride (HCl) is a strong acid and contributes to acidification and corrosion. Some of the hydrogen chloride is transformed to particles before depositing on the ground.

As for HF, the contribution from corrosion to the category indicators are estimated to be negligible, why hydrogen fluoride emissions only are assigned to acidification and secondary aerosol effects. (table 6.2.)

Table 6.2. Assignment of HCl to impact categories and selection of category indicators

Pathway(s)	Impact category	Category indicator
Secondary aerosols	Life expectancy	YOLL
Secondary aerosols	Severe morbidity and suffering	Severe morbidity
Secondary aerosols	Morbidity	Morbidity
Secondary aerosols	Severe nuisance	Severe nuisance
Secondary aerosols	Nuisance	Nuisance
Secondary aerosols	Crop production capacity	Crop
Acidification	Fish&meat production capacity	Fish&meat
Secondary aerosols	Wood production capacity	Wood
Acidification	Base cat-ion capacity	Base cat-ion capacity
Acidification	Extinction of species	NEX
Secondary aerosols	Extinction of species	NEX

6.2.3. Characterisation of hydrogen chloride to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by a modified equivalency method using SO_2 as a reference.

Equivalency factor

An equivalency factor with SO_2 is determined through the formula:

$$(M_{Cl}/M_{HCl}) / (M_{SO4}/M_{SO2}) = 0.648\text{, where}$$

M_{Cl} and M_{HCl} are the molecular weights of F^- and HF, respectively, and M_{SO4} and M_{SO2} are the molecular weights of SO_4 and SO_2, respectively.

Calculation of pathway specific characterisation factor

The secondary aerosol pathway specific characterisation factor of SO_2 for YOLL is $3.74 \cdot 10^{-5}$ YOLL/kg SO_2, which thus will result in a characterisation factor for HCl of $0.648 * 3.74 \cdot 10^{-5} = 2.42 \cdot 10^{-5}$ YOLL/kg HCl.

Uncertainty

The uncertainty in the equivalency factor is estimated to be log-normal distributed with a standard deviation corresponding to a factor of 1.4. The uncertainty in the pathway specific characterisation factor of SO_2 for YOLL was estimated in 5.1.3 to be described with a log-normal distribution with the standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor may therefore be described with a log-normal distribution with the standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 3)^2} = 3.2$

6.2.4. Characterisation of hydrogen chloride to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model for secondary aerosol pathway
The characterisation factor is determined by an equivalency method using PM_{10} as a reference. The reason for using PM_{10} and not SO_2 as a reference as in 6.2.3 is that the main contribution to severe morbidity is from global warming while the main contribution to YOLL was direct exposure for PM_{10}. For global warming effects the local exposure patterns is of less importance, and the easiest model was chosen.

Equivalency factor
An equivalency factor with PM_{10} could be determined through the formula:

$$M_{Cl}/M_{HCl} * \eta_{trans} * C_{PM10}/C_{PM2.5} \text{ , where}$$

M_{Cl} and M_{HCl} are the molecular weights of Cl and HCl, respectively,
η_{trans} is the transformation efficiency of HCl(g) to Cl^{-}(s), i.e. what part of the HCl entering the atmosphere that become particles (in the form of chlorides) and
$C_{2.5}$ and C_{PM10} are the concentration of $PM_{2.5}$ particles compared to that of PM_{10}.

Many authors consider $PM_{2.5}$ particles to be responsible for the impact found to correlate with PM_{10} (Wilsson, 1996). As most of the sulphate particle mass consists of particles less than 2.5 the ratio $C_{PM10}/C_{PM2.5}$ is used as an approximation for the enhanced potency of chloride particles.

$C_{PM10}/C_{PM2.5}$ has been determined in several studies. (Brook et al. 1997), (Haller et al., 1999). Brook et al. studied the $PM_{10}/PM_{2.5}$ ratio at 19 sites in Canada between 1984 and 1993, Their average value, 1.89 will be used here. (For arid areas, the ratio increase, e.g. to 2.5)

If particles are basic or non-acid, the transmission efficiency is very close to 1. If it would rain within that time, part of the HCl could be washed out without transformation to chloride particles. As much of the aerosol today is acid, η_{trans} is probably less than 1, but for reasons of simplicity the value 1 is still used.

Thus the equivalency factor is 35/36*1*1.89 = 1.84

Calculation of pathway specific characterisation factor
According to 9.1.4 there is - $2.33 \cdot 10^{-6}$ person-years/ kg PM_{10}. We thus obtain $-2.33 \cdot 10^{-6} * 1.84 = -4.29 \cdot 10^{-6}$ person-years of severe morbidity per kg of HCl.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for severe morbidity is determined in 9.1.4 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$

6.2.5. Characterisation of hydrogen chloride to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.2.4, i.e. 1.84 kg 'effective' PM_{10}/kg HCl.

Calculation of characterisation factor

According to 9.1.5 there is $3.61 \cdot 10^{-6}$ person-years morbidity/ kg PM_{10}. We thus obtain: $3.61 \cdot 10^{-6} * 1.84 = 6.64 \cdot 10^{-6}$ person-years of morbidity per kg of HCl.

Uncertainty

The uncertainty in the factor 1.84 expressing the mass ratio of secondary particles to HCl was estimated in 6.2.4 to be log-normal distributed with a standard deviation corresponding to a factor of 1.4. The uncertainty in the characterisation factor of PM_{10} for morbidity is estimated in 9.1.5 to be represented by two log-normal distributions with a standard deviation corresponding to a factor of 2.2 and 4. The characterisation factor for both pathways were $9.2 \cdot 10^{-6} – 5.57 \cdot 10^{-6} = 3.6 \cdot 10^{-6}$ person-years/ kg PM_{10}.

This means that the uncertainty of the characterisation factor of HCl for morbidity may be represented by the difference between two log-normal distribution with standard deviations corresponding to a factor of 2.4 and 4.2 and with average values of $8.28 \cdot 10^{-6}$ and $5.01 \cdot 10^{-6}$.

6.2.6. Characterisation of hydrogen chloride to air with respect to nuisance

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (visibility degradation). The response time for the environmental system is in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.2.3, i.e. 1.84 kg ‘effective’ PM_{10}/kg HCl.

Calculation of characterisation factor

According to 9.1.6 there are $2.28\cdot10^{-3}$ person-years of nuisance per kg PM_{10}. This will give $1.84*2.28\cdot10^{-3} = 4.20\cdot10^{-3}$ person-years per kg HCl.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.2.4) and the characterisation factor for PM_{10} (9.1.5). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp(\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}) = 2.4$.

6.2.7. Characterisation of hydrogen chloride to air with respect to crop growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.2.3, i.e. 1.84 kg ‘effective’ PM_{10}/kg HCl.

Calculation of characterisation factor

According to 9.1.7 there are $-6.46\cdot10^{-3}$ kg crop lost per kg PM_{10}. This will give $-1.84 *6.46\cdot10^{-3} = -1.19\cdot10^{-2}$ kg crop lost per kg HCl.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.2.4) and the characterisation factor for PM_{10} (9.1.7). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.4)^2} = 2.6$.

6.2.8. Characterisation of hydrogen chloride to air with respect to fish&meat

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for acidification pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

Due to its molecular weight 1 kg of hydrogen chloride will give (64/2)/36 = 0.89 times as much protons as one kg of sulphur dioxide.

Calculation of characterisation factor

The characterisation factor of SO_2 for decreased production capacity of fish&meat is $1.18 \cdot 10^{-3}$ kg fish per kg SO_2. The characterisation factor of HCl for fish&meat is therefore $0.89 * 1.18 \cdot 10^{-3} = 1.05 \cdot 10^{-3}$ kg fish&meat/kg HCl.

Uncertainty

As the uncertainty in calculation of the equivalency factor is negligible the uncertainty of the characterisation factor is equal to the uncertainty of the characterisation factor of SO_x (5.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to 3.

6.2.9. Characterisation of hydrogen chloride to air with respect to wood growth

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.2.4, i.e. 1.84 kg ‘effective’ PM_{10}/kg HCl.

Calculation of characterisation factor

According to 9.1.8 there are 0.00991 kg wood lost per kg PM_{10}.
This will give 1.84*0.00991 = 0.0182 kg wood per kg HCl.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.2.4) and the characterisation factor for PM_{10} (9.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1.4)^2 + (\ln 2.2)^2}$ = 2.4.

6.2.10. Characterisation of hydrogen chloride to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (base cat-ion reserves). The response time for the modelled quantity is normally in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

Due to its lower molecular weight 1 kg of hydrogen chloride will give (64/2)/36 = 0.89 times as much protons as one kg of sulphur dioxide.

Calculation of characterisation factor

For each kg of SO_2 there is 1.56 equivalents of base cat-ions reserves depleted. (5.1.10)
The characterisation factor of HCl for depletion of soil base cat-ions are therefore 0.89*1.56 = 1.39 equivalents/ kg HCl.

Uncertainty

The uncertainty in the equivalency factor is negligible why the uncertainty in the characterisation factor of HCl for soil base cat-ion capacity depletion is equal to that of SO_2 for soil base cat-ion capacity depletion, i.e. may be represented by a log-normal distribution with a standard deviation of 3.

6.2.11. Characterisation of hydrogen chloride to air with respect to NEX

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The spatial system borders are wide enough to contain all of the modelled impact quantity (NEX on a global or local level). The response time for the modelled quantity is normally in the order of several years to decades, depending on the reproduction cycles of the NEX and on the volumes and alkalinity of the inland waters at risk for acidification. This means that present observed impacts are mainly caused by emissions several years ago. Despite this the characterisation factor of HCl for NEX will be modelled as if everything happened within 1990. The magnitude of the error, which may be introduced through this, is discussed and estimated later.

Model 1, acidification pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

Due to its lower molecular weight 1 kg of hydrogen chloride will give (64/2)/36 = 0.89 times as much protons as one kg of sulphur dioxide.

Calculation of pathway specific characterisation factor

The characterisation factor of SO_x for NEX is $1.18\cdot10^{-14}$ per kg SO_2. The characterisation factor of HCl for NEX will thus be $0.89 * 1.18\cdot10^{-14} = 1.05\cdot10^{-14}$ per kg HCl.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.2.10) and the characterisation factor for SO_x (5.1.11). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1)^2 + (\ln 3)^2} = 3$

Model 2, aerosol transformation pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.1.3, i.e. 1.84 kg 'effective' PM_{10}/kg HCl.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for NEX is $-1.08\cdot10^{-13}$ per kg PM_{10}. The characterisation factor of HCl for NEX will thus be $-1.84 * 1.08\cdot10^{-13} = -1.99\cdot10^{-13}$ NEX per kg HCl.

Uncertainty

The extra uncertainty compared to that for the characterisation factor of PM_{10} for NEX (a log-normal distribution with a standard deviation corresponding to a factor of 4) lies in the equivalence factor 1.84. The uncertainty in the factor 1.84 is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.4. The added uncertainty is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor

The added characterisation factor of HCl for NEX considering both pathways is thus $1.05\cdot10^{-14} + 1.99\cdot10^{-13} = -1.88\cdot10^{-13}$ per kg HCl.

6.3. Emissions of ammonia anywhere in the world

6.3.1. Definition of flow group

The flow group is emissions to air, anyplace in the world 1990 and at any source strength. Most of the emissions occur from agriculture and at ground level. Emissions are widely distributed around the world.

6.3.2. Assignment to impact categories

Ammonia is either deposited (dry or wet) directly from the atmosphere or transformed to secondary particles in the form of ammonia salts. Gaseous ammonia has an odour, but the odour threshold is rather high and environmental effects are very local and not considered a significant problem, why no assignment is made in the default version. Despite its basic character ammonia contributes to acidification. It also contributes to eutrofication as it is an inorganic nitrogen compound. The assignments of ammonia to impact categories and indicators are shown in table 6.3.

Table 6.3. Assignment of NH_3 emissions to impact categories and selection of category indicators

Pathway(s)	Impact category	Category indicator
Secondary aerosols	Life expectancy	YOLL
Secondary aerosols	Severe morbidity and starvation	Severe morbidity
Secondary aerosols	Morbidity	Morbidity
Secondary aerosols	Nuisance	Nuisance
Secondary aerosols	Crop production capacity	Crop
Acidification	Fish&meat production capacity	Fish&meat
Nutrification	Fish&meat production capacity	Fish&meat
Secondary aerosols	Wood production capacity	Wood
Nutrification	Wood production capacity	Wood
Acidification	Base cat-ion capacity	Base cat-ion capacity of soil
Acidification	Extinction of species	NEX
Secondary aerosols	Extinction of species	NEX
Eutrofication	Extinction of species	NEX

6.3.3. Characterisation of ammonia to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by a modified equivalency method using SO_2 as a reference.

Equivalency factor

An equivalency factor with SO_2 is determined through the formula:

$$(M_{NH4}/M_{NH3}) / (M_{SO4}/M_{SO2}) = 0.706, \text{ where}$$

M_{NH4} and M_{NH3} are the molecular weights of NH_4^+ and NH_3, respectively, and M_{SO4} and M_{SO2} are the molecular weights of SO_4 and SO_2, respectively.

Calculation of pathway specific characterisation factor

The secondary aerosol pathway specific characterisation factor of SO_2 for YOLL is $3.74 \cdot 10^{-5}$ YOLL/kg SO_2, which thus will result in a characterisation factor for NH_3 of $0.706 * 3.74 \cdot 10^{-5} = 2.64 \cdot 10^{-5}$ YOLL/kg NH_3.

Uncertainty

The uncertainty in the equivalency factor is estimated to be log-normal distributed with a standard deviation corresponding to a factor of 1.4. The uncertainty in the pathway specific characterisation factor of SO_2 for YOLL was estimated in 5.1.3 to be described with a log-normal distribution with the standard deviation corresponding to a factor of 3. The uncertainty of the characterisation factor may therefore be described with a log-normal distribution with the standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 3)^2} = 3.2$

6.3.4. Characterisation of ammonia to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model for secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference. The reason for using PM_{10} and not SO_2 as a reference as in 6.3.3 is that the main contribution to severe morbidity is from global warming while the main contribution to YOLL was direct exposure for PM_{10}. For global warming effects the local exposure patterns is of less importance, and the easiest model was chosen.

Equivalency factor

An equivalency factor with PM_{10} could be determined through the formula:

$$M_{NH4}/M_{NH3} * \eta_{trans} * C_{PM10}/C_{PM2.5} , \text{ where}$$

M_{NH4} and M_{NH3} are the molecular weights of NH_4^+ and NH_3, respectively,
η_{trans} is the transformation efficiency of NH_3 to NH_4^+, i.e. which part of the NH_3 entering the atmosphere that become particles (in the form of ammonium salts) and
$C_{2.5}$ and C_{PM10} is the concentration of $PM_{2.5}$ particles compared to that of PM_{10}.

Many authors consider $PM_{2.5}$ particles to be responsible for the impact found to correlate with PM_{10} (Wilsson, 1996). As most of the NH_4^+-salt particle mass consists of particles less than 2.5 μm the ratio $C_{PM10}/C_{PM2.5}$ is used as an approximation for the enhanced potency of NH_4^+-salt particles.

$C_{PM10}/C_{PM2.5}$ has been determined in several studies. (Brook et al. 1997), (Haller et al., 1999). Brook et al. studied the $PM_{10}/PM_{2.5}$ ratio at 19 sites in Canada between 1984 and 1993, Their average value, 1.89 will be used here. (For arid areas, the ratio increase, e.g. to 2.5)

On the regional scale the transmission efficiency is very close to 1.

Thus the equivalency factor is 18/17*1*1.89 = 2.00

Calculation of pathway specific characterisation factor

According to 9.1.4 there is - $2.33 \cdot 10^{-6}$ person-years/kg PM_{10}. We thus obtain $-2.33 \cdot 10^{-6} * 2.00 = -4.66 \cdot 10^{-6}$ person-years of severe morbidity per kg of NH_3.

Uncertainty

The uncertainty for the equivalency factor is estimated to a factor of two. The uncertainty in the characterisation factor of PM_{10} for severe morbidity is determined in 9.1.4 to correspond to a factor of 4 as a standard deviation in a log-normal distribution. Thus the total uncertainty may be expressed by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 4)^2} = 4.2$

6.3.5. Characterisation of ammonia to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.3.4, i.e. 2.00 kg 'effective' PM_{10}/kg NH_3.

Calculation of characterisation factor

According to 9.1.5 there is $3.61 \cdot 10^{-6}$ person-years morbidity/kg PM_{10}. We thus obtain $3.61 \cdot 10^{-6} * 2.00 = 7.22 \cdot 10^{-6}$ person-years of morbidity per kg of NH_3.

Uncertainty

The uncertainty in the factor 1.60 expressing the mass ratio of secondary particles to NH_3 was estimated in 6.3.4 to be log-normal distributed with a standard deviation corresponding to a factor of 1.2. The uncertainty in the characterisation factor of PM_{10} for morbidity is estimated in 9.1.5 to be represented by two log-normal distributions with a

standard deviation corresponding to a factor of 2.2 and 4. The characterisation factor for both pathways were $9.2 \cdot 10^{-6} - 5.57 \cdot 10^{-6} = 3.6 \cdot 10^{-6}$ person-years/ kg PM_{10}.
This means that the uncertainty of the characterisation factor of NH_3 for severe morbidity may be represented by the difference between two log-normal distribution with standard deviations corresponding to a factor of 2.2 and 4.0 and with average values of $8.28 \cdot 10^{-6}$ and $5.01 \cdot 10^{-6}$.

6.3.6. Characterisation of ammonia to air with respect to nuisance

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (visibility degradation). The response time for the environmental system is in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model
The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor
The same equivalency factor is used as in 6.3.4, i.e. 2.00 kg ‘effective’ PM_{10}/kg NH_3.

Calculation of characterisation factor
According to 9.1.6 there are $2.28 \cdot 10^{-3}$ person-years of nuisance per kg PM_{10}. This will give $2.00 * 2.28 \cdot 10^{-3} = 4.56 \cdot 10^{-3}$ person-years per kg NH_3.

Uncertainty
The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.3.4) and the characterisation factor for PM_{10} (9.1.5). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp(\sqrt{(\ln 1.2)^2 + (\ln 2.2)^2}) = 2.2$.

6.3.7. Characterisation of ammonia to air with respect to crop growth

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model for secondary aerosol pathway
The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor
The same equivalency factor is used as in 6.3.4, i.e. 2.00 kg ‘effective’ PM_{10}/kg NH_3.

Calculation of characterisation factor

According to 9.1.7 there are $-6.46 \cdot 10^{-3}$ kg crop lost per kg PM_{10}. This will give $-2.00 * 6.46 \cdot 10^{-3} = -1.29 \cdot 10^{-2}$ kg crop lost per kg NH_3.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.3.4) and the characterisation factor for PM_{10} (9.1.7). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 2.4)^2} = 2.4$.

6.3.8. Characterisation of ammonia to air with respect to fish&meat

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990.

Model 1, acidification pathway

The characterisation factor is determined by an equivalency method using SO_x as a reference.

Equivalency factor

When ammonia is oxidised in the environment there will be a net production of one proton per ammonia molecule. Part of the ammonia is however taken up by the vegetation as NH_4^+. This part is assumed to be 50%. Thus 1 kg of NH_3 will give the same amount of protons as $1/17 * 0.5 * (64/2) = 0.941$ kg SO_2.

Calculation of pathway specific characterisation factor

The characterisation factor of SO_2 for decreased production capacity of fish&meat is $1.18 \cdot 10^{-3}$ kg fish per kg SO_2. The characterisation factor of NH_3 for fish&meat is therefore $0.941 * 1.18 \cdot 10^{-3} = 1.11 \cdot 10^{-3}$ kg fish&meat/kg NH_3.

Uncertainty

The uncertainty in the equivalency factor lies partly in lack of knowledge of how large a part of NH_3 that is oxidised and partly in a true variability of this part. Some knowledge exists on the European level from the RAINS model, but it has not yet been evaluated here. Instead we assume an uncertainty described by a log-normal distribution with a standard deviation corresponding to a factor of 2. Then all values of the part oxidised between 12.5 and 87.5 % will be covered within two standard deviations. The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor and the characterisation factor for SOx (5.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2} = 3.7$.

Model 2, nutrification pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor
Ammonia is carrying more nitrogen per weight unit than NO_x, and one kg NH_3 is equal to 46/17 = 2.71 kg NOx in that respect.

Calculation of pathway specific characterisation factor
The characterisation factor of NO_x for decreased production capacity of fish&meat is -0.0339 kg fish per kg NO_x (4.1.8). The characterisation factor of NH_3 for fish&meat is therefore 2.71*(-0.0339) = -0.0919 kg fish&meat/kg NH_3.

Uncertainty
The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor and the characterisation factor for NO_x (4.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1)^2 + (\ln 3)^2}$ = 3.

Calculation of characterisation factor
$1.11 \cdot 10^{-3}$ - 0.0919 = - 0.0908 kg fish&meat/kg NH_3

6.3.9. Characterisation of ammonia to air with respect to wood growth

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990.

Model 1, secondary aerosol pathway
The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor
The same equivalency factor is used as in 6.3.4, i.e. 2.00 kg ‘effective’ PM_{10}/kg NH_3.

Calculation of pathway specific characterisation factor
According to 9.1.8 there are 0.00991 kg wood per kg PM_{10}.
This will give 2.00*0.00991 = 0.0198 kg wood per kg NH_3.

Uncertainty
The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.3.3) and the characterisation factor for PM_{10} (9.1.8). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1.2)^2 + (\ln 2.2)^2}$ = 2.2.

Model 2, nutrification pathway
The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

Ammonia is carrying more nitrogen per weight unit than NO_x, and one kg NH_3 is equal to 46/17 = 2.71 kg NO_x in that respect.

Calculation of pathway specific characterisation factor

The nutrification pathway specific characterisation factor of NO_x for wood was determined in 4.1.9 to -2.74 kg wood/kg NO_x. The characterisation factor for NH_3 is therefore 2.71*(-2.74) = -7.42 kg wood/kg NH_3.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor and the characterisation factor for NO_x (4.1.9). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1)^2 + (\ln 3)^2}$ = 3.

Calculation of characterisation factor

0.0198 – 7.42 = -7.40 kg wood/kg NH_3.

6.3.10. Characterisation of ammonia to air with respect to soil base-cat-ion capacity

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The system borders are wide enough to contain all of the modelled impact quantity (base cat-ion reserves). The response time for the modelled quantity is normally in the order of days to weeks. The area affected by a local emission is mainly within 1000 km.

Model

The characterisation factor is determined by an equivalency method using SO_x as a reference.

Equivalency factor

The equivalency factor was determined in 6.3.8 to 0.94.

Calculation of characterisation factor

For each kg of SO_2 there is 1.56 equivalents of base cat-ions reserves depleted. (5.1.10)
The characterisation factor of NH_3 for depletion of soil base cat-ions are therefore 0.94*1.56 = 1.47 equivalents/ kg NH_3.

Uncertainty

The uncertainty in the equivalency factor is negligible why the uncertainty in the characterisation factor of NH_3 for soil base cat-ion capacity depletion is equal to that of SO_x for soil base cat-ion capacity depletion, i.e. may be represented by a log-normal distribution with a standard deviation of 3.

6.3.11. Characterisation of ammonia to air with respect to NEX

Definition of environmental system in which the impact is estimated

The system is global and the time period is 1990. The spatial system borders are wide enough to contain all of the modelled impact quantity (NEX on a global or local level). The response time for the modelled quantity is normally in the order of several years to decades, depending on the reproduction cycles of the NEX and on the volumes and alkalinity of the inland waters at risk for acidification. This means that present observed impacts are mainly caused by emissions several years ago. Despite this the characterisation factor of NH_3 for NEX will be modelled as if everything happened within 1990. The magnitude of the error, which may be introduced through this, is discussed and estimated later.

Model 1, acidification pathway

The characterisation factor is determined by an equivalency method using SO_2 as a reference.

Equivalency factor

The equivalency factor was determined in 6.3.8 to 0.94.

Calculation of pathway specific characterisation factor

The characterisation factor of SO_2 for NEX is $1.18 \cdot 10^{-14}$ per kg SO_2. The characterisation factor of NH_3 for NEX will thus be $0.94 * 1.18 \cdot 10^{-14} = 1.11 \cdot 10^{-14}$ per kg NH_3.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.3.8) and the characterisation factor for SO_x (5.1.11). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2} = 3.7$.

Model 2, secondary aerosol pathway

The characterisation factor is determined by an equivalency method using PM_{10} as a reference.

Equivalency factor

The same equivalency factor is used as in 6.3.4, i.e. 2.00 kg ‘effective’ PM_{10}/kg NH_3.

Calculation of pathway specific characterisation factor

The characterisation factor of PM_{10} for NEX is $-1.08 \cdot 10^{-13}$ per kg PM_{10}. The characterisation factor of NH_3 for NEX will thus be $–2.00 * 1.08 \cdot 10^{-13} = -2.16 \cdot 10^{-13}$ per kg NH_3.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (6.3.3) and the characterisation factor for PM_{10}

(9.1.9). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1.2)^2 + (\ln 4)^2}$ = 4.0.

Model 3, eutrofication pathway

The characterisation factor is determined by an equivalency method using NO_x as a reference.

Equivalency factor

The equivalency factor is based on the N content, i.e. each kg of NH_3 equals 46/17 = 2.71 kg NO_x in terms of eutrofication capacity.

Calculation of pathway specific characterisation factor

The eutrofication pathway specific characterisation factor of NO_x is $1.83 \cdot 10^{-13}$ NEX per kg NO_x. The characterisation factor of NH_3 for NEX will thus be 2.71 * $1.83 \cdot 10^{-13}$ = $4.96 \cdot 10^{-13}$ NEX per kg NH_3.

Uncertainty

The uncertainty of the characterisation factor can be calculated by combining the uncertainty of the equivalency factor (relatively small) and the characterisation factor for PM_{10} (9.1.9). The combined uncertainty may thus be described by a log-normal distribution with a standard deviation equal to $\exp\sqrt{(\ln 1.2)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor

The added characterisation factor of HCl for NEX considering both pathways is thus $1.11 \cdot 10^{-14} + (-2.16 \cdot 10^{-13}) + 4.96 \cdot 10^{-13} = 2.78 \cdot 10^{-13}$ per kg NH_3.

7. Classification and characterisation of emissions of gaseous organic substances to air

There are several million known organic substances. Flue gases and other emissions to air may contain several thousand organic compounds. Therefore emissions of organic substances are often characterised by class names like "hydrocarbons" (shortened HC or CnHm), "non-methane hydrocarbons" (NMHC), "volatile organic compounds" (VOC), "polyaromatic hydrocarbons" (PAH) etc. Partly the basis for classification lies in the common properties of the substances, partly in the method used for measuring them.

Most of the characterisation models below are derived in a repeated way, why they are presented in a table form. However, some common organic substances are evaluated separately, either because they are frequently used in industrial processes or because they have significant environmental effects. Organic compounds have mostly 1–4 types of effects in the ambient environment. Some are direct toxic, most of them contribute to photochemical smog formation and global warming and some are odorous.

7.1. Emissions of Benzene to air anywhere in the world

7.1.1. Definition of flow group

As a common constituent in gasoline (up to 5 % is allowed), most benzene is emitted from traffic and from production and distribution of gasoline. For most product systems the sources are many, small and located at ground level in urban areas.

The flow group characterised is emissions of benzene to air, anyplace in the world 1990.

7.1.2. Assignment to impact categories

Benzene is a carcinogen and may have diffuse effects on CNS (Central nerve system). The levels are in most urban areas above safe levels, but no documentation has been found of any observed effects in ambient air. Benzene reacts in the atmosphere to form oxidants and is a greenhouse gas in itself and via its reaction products. The assignement of the flow group defined in 7.1.1 to impact categories and selection of category indicators are shown in table 7.1.

Table 7.1 Assignment of benzene emissions to impact categories and selection of indicators

Pathway(s)	**Impact category**	**Category indicator**
Benzene is a carcinogen when inhaled	Life expectancy	YOLL
Direct IR absorption and indirectly via ozone leads to global warming	Life expectancy	YOLL
Benzene is an oxidant precursor	Life expectancy	YOLL
Non-mortal cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.1.3. Characterisation of benzene to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The residence time of benzene is in the order of days to weeks. As the regional background concentration of benzene in a rural area is low compared to the one measured in an urban area, the main contribution to the population dose occurs in urban areas close to the sources and within hours of release. The main source of benzene is cars and the gasoline fuel system. Gasoline contains several percent of benzene. This means that emissions occur worldwide and mostly at ground level. The environmental system is therefore global with a focus on urban areas. The temporal system border is the year 1990 for oxidant effects and for the cancer pathway and 100 years for the global warming pathway. The cancer pathway has a longer time scale, maybe in the order of 20 years, but the model is assuming linearity, why it does not make any difference for the model if an instant dose-response is assumed.

Model 1, Cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The average population-weighted benzene concentration in Sweden 1985 was 3.7 $\mu g/m^3$ (Boström et al., 1994). The average population-weighted NO_2-concentration was determined to 23 µg/m3 and was used as a tracer for car exhaust. The average population-weighted benzene exposure was determined from the ratio of NO_x to benzene measured in several Swedish cities. The average 1990 NO_x-concentration in USA may be estimated from the yearly averages of 120 monitor sites to 0.030 ppm or 62 $\mu g/m^3$ (USEPA 1999). This would indicate an average concentration of 10 $\mu g/m^3$ of benzene. The measured 1990 average concentration of 64 monitoring stations was 6 $\mu g/m^3$ (USEPA 1999). Shah and Sing (1988) reported average US benzene concentrations of 2.8 ppbv, which corresponds to 9.7 $\mu g/m^3$.

In mega-cities in non-OECD countries the NO_x-concentration is typically twice as high compared to cities of similar size. (UNEP/WHO 1992) However, as half of the population in non-OECD countries lives in rural areas the average population exposure is assumed to be the same as for the OECD countries. This means that the global average population weighted benzene exposure would be between 4 and 20 µg/m3. A best estimate of 10 $\mu g/m^3$ is assumed.

USEPA estimates the lifetime cancer risk from exposure for benzene in air to be between $2.2 \cdot 10^{-6}$ and $7.8 \cdot 10^{-6}$ per $\mu g/m^3$. Here a best estimate of $5 \cdot 10^{-6}$ per $\mu g/m^3$ will be used.
Mortality for all sorts of cancer in the European union was 62 % 1990 (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC. (Parkin et al., 1990, Pisani et al., 1990). The average reduction of life expectancy is estimated from IARC statistics on cancer and WHO statistics on mortality and population. (Figure 7.1.)

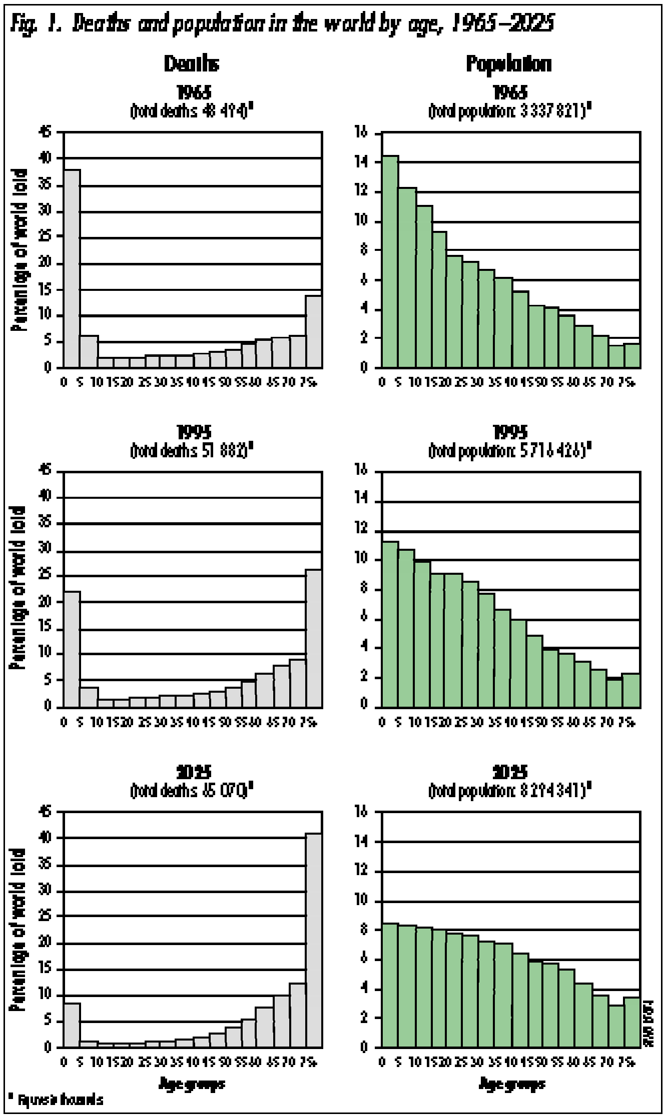

Figure 7.1 Distribution of age groups in global population according to WHO (1997).

For the present global population an average decrease in life expectancy is determined to 22.8 years (the sum of all YOLL's divided by the total number of mortal cancers) (table 7.2).

Table 7.2 Estimation of global average of decreased life expectancy from cancer.

Age group (years)	**assumed average age** (years)	**Estimated average life expectancy** (years)	**number of mortal cancers/yr**	**YOLL** (years)
65+	70	15	2522037	37830555
55-64	60	22	1286613	28305486
45-54	50	29	687833	19947157
15-44	30	45	594949	26772705
0-14	7	60	91200	5472000
sum			5182632	1.18E+08

As the cancer statistics is based on present figures and present distribution of ages of the global population an increase in the average YOLL from cancers may be expected as the average age increases. If WHO figures for the population distribution 2025 is used, the average decrease in life expectancy is 25.5 years. Assuming an incubation time of 20 years an appropriate figure would be around 24 years.

This means that as the global average life expectancy is 65 years and if, as an average, 1/65 of 1990 years population is assumed to die each year, there are $5.28 \cdot 10^{9} * 0.64 * 5 \cdot 10^{-6} * 10 * 24/65 = 6.24 \cdot 10^{4}$ YOLL during 1990.

Contribution to category indicators value from a flow unit

The main source of benzene is from car traffic. Emission ratio for real world traffic for benzene and CO may be estimated from street level measurements or measurements in road tunnels. The benzene/CO-ratio was determined in Stockholm by Persson and Almen (1990) and in a Brussel road tunnel by Vanderstraeten et al. (1991). Persson and Almen found a ratio of 0.0011 and Vanderstraeten et al. a ratio of 0.0068, both on weight basis. Gabele (1995) measured exhaust emissions from in-use vehicles with various fuels and found a ratio in the order of 0.001. Based on this, a best estimate of 0.002 is made.

The global anthropogenic CO emission was estimated to 1600 million tonnes in 2.2. Therefore the global anthropogenic benzene emission may be estimated to 0.002*1600 = 3.2 million tonnes and the average contribution to $1/(3.2 \cdot 10^{9}) = 3.12 \cdot 10^{-10}$ per kg benzene.

Calculation of pathway specific characterisation factor

The characterisation factor will thus be $6.24 \cdot 10^{4} * 3.12 \cdot 10^{-10} = 1.95 \cdot 10^{-5}$ YOLL/kg benzene

Uncertainty

The benzene/CO ratio is uncertain partly due to variation in the results quoted and partly because measurements are missing from non-OECD countries. There is also a basic uncertainty in the risk estimation. The largest part of this is due to uncertainties in the dose-response characteristics. Some uncertainty is also introduced via poor resolution in the cancer death statistics for people above 65 years, but this is probably less than 20%. The use of average YOLL for all cancers instead of data for the specific cancers caused by benzene may also introduce some uncertainty, but this is probably less than the uncertainty in the dose-response characteristics. The total uncertainty is estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of benzene for YOLL will therefore be $11 * 7.93 \cdot 10^{-7} = 8.72 \cdot 10^{-6}$ YOLL/kg benzene.

Uncertainty

Benzene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As benzene with a POCP of 0.317 then may produce about about 0.57 times as much ozone as the average VOC and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of benzene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, photochemical oxidant formation pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

Benzene has a photochemical peak oxidant formation potential (POCP-1) of 0.317 (Lindfors et.al 1994) relative to ethylene.

Calculation of pathway specific characterisation factor

In 7.3.3 the oxidant pathway specific characterisation factor of ethylene for YOLL in the oxidant pathway is determined to $1.20 \cdot 10^{-5}$ YOLL/kg ethylene. The oxidant pathway specific characterisation factor of benzene for YOLL is therefore $0.317 * 1.20 \cdot 10^{-5} = 3.80 \cdot 10^{-6}$ YOLL/kg benzene.

Uncertainty

The added uncertainty involved in the use of POCP to estimate the contribution from benzene to the ozone concentrations present in areas with adverse health effects due to oxidants are assumed to be represented by represented by a log-normal distribution with a standard deviation corresponding to a factor of 2. The uncertainty of the ethylene characterisation factor was estimated in 7.3.3 to be represented by a log-normal distribution with a standard deviation correpponding to a factor of 4. The total uncertainty therefore be represented by a log-normal distributiion with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 4)^2 + (\ln 2)^2} = 4.7$.

Calculation of characterisation factor

The characterisation factor for the added impacts from all pathways is $1.95 \cdot 10^{-5} + 8.72 \cdot 10^{-6} + 3.80 \cdot 10^{-6} = 3.20 \cdot 10^{-5}$ YOLL/kg benzene.

7.1.4. Characterisation of benzene to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The same system borders as 7.1.3 are used.

Model 1, cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The portion of cancer incidences not causing death (36%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is $(5/24)*(0.36/0.64)*6.24 \cdot 10^4 = 7.31 \cdot 10^3$person-years of severe morbidity, where $6.24 \cdot 10^4$ is the indicator value determined in 7.1.3.

Contribution to category indicators value from a flow unit

The same contribution as in 7.1.3 is valid, i.e. $3.12 \cdot 10^{-10}$ per kg benzene.

Calculation of characterisation factor

This would mean that the characterisation factor would be $(5/24)*(0.36/0.64)* 5.91 \cdot 10^4 *3.12 \cdot 10^{-10} = 2.28 \cdot 10^{-6}$ person-years/kg benzene.

Uncertainty

The benzene/CO ratio is uncertain partly due to variation in the results quoted and partly because measurements are missing from non-OECD countries. There is also a basic uncertainty in the risk estimation. The total uncertainty is estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

As the characterisation factor of CO_2 for severe morbidity is $3.53 \cdot 10^{-7}$ person-years/kg CO_2 (2.1.4) we obtain the pathway specific characterisation factor of benzene to severe morbidity to $11 * 3.53 \cdot 10^{-7} = 3.88 \cdot 10^{-6}$

Uncertainty

Benzene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As benzene with a POCP of 0.317 then may produce about about 0.57 times as much ozone as the average VOC and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of benzene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for severe morbidity was estimated in 3.1.4 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant pathway

The characterisation factor is determined by an equivalency method using ethene as a reference.

Equivalency factor

Benzene has a photochemical peak oxidant formation potential (POCP-1) of 0.317 (Lindfors et.al 1994) relative to ethylene.

Calculation of pathway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for severe morbidity is determined in 7.3.3 to $6.76 \cdot 10^{-7}$ person-years/kg ethylene. This gives an oxidant pathway specific characterisation factor of benzene for severe morbidity of $0.317 * 6.76 \cdot 10^{-7} = 2.14 \cdot 10^{-7}$ person-years/kg.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor

The characterisation factor for the added impacts from all pathways is $2.28 \cdot 10^{-6} + 3.88 \cdot 10^{-6} + 2.14 \cdot 10^{-7} = 6.16 \cdot 10^{-6}$ person-years/ kg benzene

7.1.5 Characterisation of benzene to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The same system borders as 7.1.3 is used.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

As the characterisation factor of CO_2 for morbidity is $6.55 \cdot 10^{-7}$ person-years/kg CO_2 (3.1.5) we obtain the pathway specific characterisation factor of benzene for severe morbidity to $11 * 6.55 \cdot 10^{-7} = 7.21 \cdot 10^{-6}$ person-years/kg benzene.

Uncertainty

Benzene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As benzene with a POCP of 0.317 then may produce about about 0.57 times as much ozone as the average VOC and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of benzene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7

7.1.6 Characterisation of benzene with respect to crop loss

Definition of environmental system in which the impact is estimated

The same system borders as 7.1.3 are used.

Model 1, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

Benzene has a photochemical peak oxidant formation potential (POCP-1) of 0.317 (Lindfors et.al 1994) relative to ethylene.

Calculation of pathway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for crop loss is estimated in 7.3.6 to 4.87 kg crop/kg ethylene. The oxidant pathway specific characterisation factor of benzene for crop loss is thus 0.317*4.87 = 1.54 kg crop/kg benzene.

Uncertainty

The added uncertainty involved in the use of POCP to estimate the contribution from benzene to the ozone concentrations present in areas with adverse health effects due to oxidants are assumed to be represented by represented by a log-normal distribution with a standard deviation corresponding to a factor of 2. The uncertainty of the ethylene characterisation factor was estimated in 7.3.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The total uncertainty may therefore be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 4)^2 + (\ln 2)^2}$ = 4.7.

Definition of environmental system in which the impact is estimated

The same system borders as 7.1.3 are used.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

As the characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2 (3.1.6) we obtain the pathway specific characterisation factor of benzene for crop loss to $11 * 7.56 \cdot 10^{-4} = 8.32 \cdot 10^{-3}$ kg crop/kg benzene.

Uncertainty

Benzene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As benzene with a POCP of 0.317 then may produce about about 0.57 times as much ozone as the average VOC and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of benzene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for crop loss was estimated in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2.2)^2 + (\ln 3)^2} = 3.9$

Calculation of characterisation factor

The characterisation factor for the added impacts from all pathways is $1.54 + 8.32\cdot10^{-3} = 1.55$ kg crop / kg benzene

7.1.7. Characterisation of benzene with respect to wood production capacity

Definition of environmental system in which the impact is estimated

The same system borders as 7.1.3 are used.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for benzene being 11 and the equivalency for CO_2 fertilisation being 46/13 = 3.54, the CO_2 fertilisation pathway is still 10 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to 46/13 = 3.54. 46 is the molecular weight of CO_2 and 13 a sixth of the molecular weight of benzene. (each benzene molecule will give six CO_2 molecules when it is oxidised. It is assumed that all benzene is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $-3.93\cdot10^{-2}$ kg wood/kg CO_2 (2.1.7) we obtain the pathway specific characterisation factor of benzene to wood to $3.54*(-3.93\cdot10^{-2}) = -1.39\cdot10^{-1}$ kg wood/kg benzene.

Uncertainty

When benzene is oxidised in air a water-soluble compound is formed. This may be washed out by rain and deposited on soil or in surface waters. If it is transferred to anaerobic environments, there is a certain possibility that it may end up as in sediments or similar. Then, the equivalency factor will be less than 3.54. As little is known about these processes in quantitative terms, a relatively large uncertainty is assumed, a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2} = 3.7$

7.1.8. Characterisation of benzene with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26 \cdot 10^{-14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $11 * (1.26 \cdot 10^{-14}) = 1.39 \cdot 10^{-13}$ NEX per kg benzene.

Uncertainty

Benzene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. The average POCP-value in table 7.1 is 0.56. As benzene with a POCP of 0.317 then may produce about about 0.57 times as much ozone as the average VOC and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of benzene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.2. Emissions of butadiene to air anywhere in the world

7.2.1. Definition of flow group

Butadiene is emitted as a tracer from many combustion processes, such as burning of wood and from car engines. Butadiene in air is present as a gas. The residence time is in the order of days to weeks, depending on the photochemical activity.

The flow group characterised is anthropogenic emissions of butadiene to air, anyplace in the world 1990 and at any source strength.

7.2.2. Assignment to impact categories

Butadiene is a carcinogen. Butadiene also takes part in smog forming photochemical reactions and is a greenhouse gas in itself and via its reaction products. Butadiene adsorbs infrared radiation and participates in formation of oxidants, mainly ozone, which also increase the radiative forcing.

Table 7.3 Assignment of butadiene emissions to impact categories and selection of indicators

Pathway(s)	**Impact category**	**Category indicator**
Cancer	Life expectancy	YOLL
Global warming	Life expectancy	YOLL
Butadiene is an oxidant precursor	Life expectancy	YOLL
Non-mortal cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.2.3. Characterisation of butadiene to air with respect to YOLL

<u>Definition of environmental system in which the impact is estimated</u>

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for butadiene and its reaction products, the environmental system will also be global. As butadiene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. In terms of qualitative system borders, we look at human health issues and ecosystem production capacity. No effects on bio-diversity, resources or aesthetics are included. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The entire population on earth is exposed to butadiene. Only a few measurements of butadiene have been made. Shah and Sing (1988) reports mean values for benzene and butadiene that indicates a ratio of 5. This would mean that a best estimate of the global average butadiene concentration would be 2 $\mu g/m^3$. This is also the value obtained from the USEPA AIRS database for 1990 as an average from 49 stations.

IARC has classified butadiene as a human carcinogen. Butadiene gives a net lifetime risk of $1 \cdot 10^{-5}$ for 0.02–0.1 ppb butadiene (Victorin, 1998). This corresponds to about $6.67 \cdot 10^{-5}$ per $\mu g/m^3$ as a best estimate.

Mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average is 64%. (Parkin et. al., 1990) The average reduction of life expectancy was estimated in 7.1.3 to 24 years. The global average life expectancy is 65 years.

This means that there are $5.28 \cdot 10^9 * 0.64 * 6.67 \cdot 10^{-5} * 2 * 24/65 = 1.64 \cdot 10^5$ YOLL during 1990.

Contribution to category indicators value from a flow unit

The main sources of butadiene are from combustion engines and from burning of wood. USEPA estimates the US national emissions to 109 000 metric tons. The main sources were mobile on- and off-road sources (about 82%) and bio-mass burning (16%) (USEPA, 1996). The same year the emissions of CO in the US were estimated to 85 million tonnes, mainly from mobile sources. This gives a ratio of $1.28 \cdot 10^{-3}$ for the US emissions of butadiene and CO.

The global anthropogenic CO emission was estimated to 1600 million tonnes in 2.2. Assuming the same butadiene/CO ratio as in the US, the global anthropogenic butadiene emission from traffic may be estimated to 0.00128*1600 = 2.05 million tonnes. Emissions from burning of bio-mass may increase this figure on a global level but at present it is assumed to be of less importance than the emissions from traffic. This means that the average contribution is $1/(2.05 \cdot 10^9) = 4.88 \cdot 10^{-10}$ per kg butadiene.

Calculation of pathway specific characterisation factor

The characterisation factor will thus be $1.64 \cdot 10^5 * 4.88 \cdot 10^{-10} = 8.00 \cdot 10^{-5}$ YOLL/kg butadiene.

Uncertainty

The butadiene/CO ratio is uncertain because US traffic conditions differ from global averages and because the global butadiene emission from burning of bio-mass is not known. The total uncertainty is therefore estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of butadiene for YOLL will therefore be $11 * 7.93 \cdot 10^{-7} = 8.72 \cdot 10^{-6}$ YOLL/kg butadiene.

Uncertainty

Butadiene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As butadiene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of butadiene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant formation pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for butadiene is not listed in Lindfors et.al.(1994), but extrapolating from n-butane, with a peak POCP of 0.554 and 1-butene with 0.799 it is likely that 1,3-butadiene has a POCP around 1.

Calculation of patway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for YOLL is $1.20\cdot10^{-5}$ YOLL/kg ethylene. This means that the oxidant pathway specific characterisation factor will be $1*1.20\cdot10^{-5} = 1.20\cdot10^{-5}$ YOLL/kg butadiene.

Uncertainty

Considering the variations in POCP for various substances reported by Lindfors et al., the uncertainty in the estimation of the equivalency factor is estimated to be in the order of 20%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of ethylene for YOLL was estimated in 7.3.3 to be described by a log-normal distribution with a standard deviation of a factor of 4. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2} = 4.0$

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $8.00\cdot10^{-5} + 8.72\cdot10^{-6} + 1.20\cdot10^{-5} = 1.01\cdot10^{-4}$ YOLL/kg butadiene.

7.2.4. Characterisation of butadiene to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for butadiene and its reaction products, the environmental system will also be global. As butadiene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The portion of cancer incidences not causing death (36%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is $(5/24)*(0.36/0.64)*\ 1.64\cdot10^{5}$ person-years of severe morbidity, where $1.64\cdot10^{5}$ is the indicator value determined in 6.2.3.

Contribution to category indicators value from a flow unit

The same contribution as in 7.2.3 is used i.e. $4.88\cdot10^{-10}$ per kg butadiene.

Calculation of pathway specific characterisation factor

$(5/24)*(0.36/0.64)*\ 1.64\cdot10^{5}*4.88\cdot10^{-10} = 9.38\cdot10^{-6}$ person-years/kg

Uncertainty

The total uncertainty is similar as in 7.2.3, i.e. represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for severe morbidity is determined in 3.1.4 to $3.53\cdot10^{-7}$ person-years/kg, which means that the characterisation factor of butadiene for severe morbidity is $11*3.53\cdot10^{-7} = 3.88\cdot10^{-6}$ person-years/kg.

Uncertainty

Butadiene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As butadiene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of butadiene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for severe morbidity was estimated in 3.1.4 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for butadiene is not listed in Lindfors et.al.(1994), but extrapolating from n-butane, with a peak POCP of 0.554 and 1-butene with 0.799 it is likely that 1,3-butadiene has a POCP around 1.

Calculation of pathway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for severe morbidity is determined in 7.3.3 to $6.76\cdot10^{-7}$ person-years/kg ethylene. This gives an oxidant pathway specific characterisation factor of butadiene for severe morbidity of $1*6.76\cdot10^{-7}$ = $6.76\cdot10^{-7}$ person-years/kg.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $9.38\cdot10^{-6}$ + $3.88\cdot10^{-6} + 6.76\cdot10^{-7} = 1.33\cdot10^{-5}$ person-years/kg

7.2.5. Characterisation of butadiene with respect to morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for butadiene and its reaction products, the environmental system will also be global. As butadiene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for morbidity is determined in 3.1.5 to $6.55\cdot10^{-7}$ person-years/kg, which means that the characterisation factor of butadiene for morbidity is $11*6.55\cdot10^{-7} = 7.21\cdot10^{-6}$ person-years/kg.

Uncertainty

Butadiene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As butadiene may produce about 1.8 as much ozone as the average

VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of butadiene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.2.6. Characterisation of butadiene with respect to decrease of crop production

Definition of environmental system in which the impact is estimated

The ozone level in rural areas has increased significantly since pre-industrial time. The reaction velocity for butadiene to form oxidants is normally in the order of days, but in the dark periods in the arctic regions the residence time of butadiene can be much longer. However a time system border of one year is believed to be sufficient for impact modelling. The system borders used for the oxidant model are thus global and the year 1990. For the global warming pathway the same system borders as for CO_2 apply, i.e. 100 years.

Model 1, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for butadiene is not listed in Lindfors et.al. (1994), but extrapolating from n-butane, with a peak POCP of 0.554 and 1-butene with 0.799 it is likely that 1,3-butadiene has a POCP around 1.

Calculation of characterisation factor

The oxidant pathway specific characterisation factor of ethylene for crop loss is determined in 7.3.6 to 4.86 kg crop/kg ethylene. This gives an oxidant pathway specific characterisation factor of butadiene for crop of 1*4.86 = 4.86 kg crop/kg butadiene.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2} = 4.0$.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the characterisation factor of butadiene for crop loss is $11*7.56 \cdot 10^{-4} = 8.32 \cdot 10^{-3}$ kg crop/kg butadiene.

Uncertainty

Butadiene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As butadiene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of butadiene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

Calculation of characterisation factor

The total characterisation factor for both pathways is thus $4.86 + 8.32 \cdot 10^{-3} = 4.87$ kg crop/kg butadiene.

7.2.7. Characterisation of butadiene with respect to wood production capacity

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for butadiene being 11 and the equivalency for CO_2 fertilisation being $46*4/54 = 3.41$, the CO_2 fertilisation pathway is still 10 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to $46*4/54 = 3.41$. 46*4 is the molecular weight of 4 CO_2 and 54 the molecular weight of butadiene. (Each butadiene molecule will give 4 CO_2 molecules when it is oxidised). It is assumed that all butadiene is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $–3.93·10^{-2}$ kg wood/kg CO_2 (3.1.7) we obtain the pathway specific characterisation factor of butadiene for wood to $3.41*(-3.93·10^{-2}) = -1.34·10^{-1}$ kg wood/kg.

Uncertainty

When butadiene is oxidised in air a water-soluble compound is formed. This may be washed out by rain and deposited on soil or in surface waters. If it is transferred to anaerobic environments, there is a certain possibility that it may end up as in sediments or similar. Then, the equivalency factor will be less than 3.54. As little is known about these processes in quantitative terms, a relatively large uncertainty is assumed, a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2}$ = 3.7

7.2.8. Characterisation of butadiene with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26·10^{–14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $11*(1.26·10^{–14}) = 1.39·10^{–13}$ NEX per kg butadiene.

Uncertainty

Butadiene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As butadiene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of butadiene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.3. Emissions of ethylene to air anywhere in the world

7.3.1. Definition of flow group

Ethylene is produced naturally from vegetation. Anthropogenic ethylene is emitted as a tracer from many combustion processes and from handling of gasoline. Emissions from petrochemical plants occur but are not a major source in a global perspective. Ethylene in air is present as a gas. The residence time is in the order of days to weeks, depending on the photochemical activity. Emissions from product systems are typically coming from many small ground level sources distributed over large areas.

The flow group characterised is anthropogenic emissions of ethylene to air, anyplace in the world 1990 and at any source strength.

7.3.2. Assignment to impact categories

Ethylene is not carcinogenic in itself but a few percent transforms to a carcinogen, ethylene oxide, when it is absorbed in human tissue. Ethylene also takes part in smog forming photochemical reactions and is a greenhouse gas in itself and via its reaction products. Ethylene is furthermore a stress hormone for plants. Ethylene adsorbs infrared radiation and participates in formation of oxidants, mainly ozone, which also increase the radiative forcing.

Table 7.4 Assignment of ethylene emissions to impact categories and selection of category indicators

Pathway(s)	Impact category	Category indicator
Cancer	Life expectancy	YOLL
Global warming	Life expectancy	YOLL
Oxidant	Life expectancy	YOLL
Non-mortal cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.3.3. Characterisation of ethylene to air with respect to YOLL

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for ethylene and its reaction products, the environmental system will also be global. As ethylene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. In terms of qualitative system borders, we look at human health issues and ecosystem production capacity. No effects on bio-diversity, resources or aesthetics are included. For the global warming pathways the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The entire population on earth is exposed to ethylene. In Sweden, the population weighted average ethylene concentration is estimated by Boström et al. (1994) to 1.8 $\mu g/m^3$. The main part comes from traffic, but 0.3 $\mu g/m^3$ from burning of wood.

In the US the average concentration at 83 monitoring stations as measured 1993 was 6.6 $\mu g/m^3$ (USEPA 1999).

In mega-cities in non-OECD countries the NO_x-concentration is typically twice as high compared to cities of similar size. (UNEP/WHO 1992) However, as half of the population in non-OECD countries lives in rural areas the average population exposure is assumed to be the same as for the OECD countries. This means that the average population weighted ethylene exposure would be between 2 and 7 $\mu g/m^3$. A best estimate of 4 $\mu g/m^3$ is assumed.

IARC has not classified ethylene as a human carcinogen. However, about 5% of ethylene is metabolised to ethylene oxide giving a net lifetime risk of 10^{-5} for 1 ppb ethylene (Victorin, 1998). This corresponds to about the same risk expressed in $\mu g/m^3$.

Mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC. (Parkin et al., 1990, Pisani et al.,1990). The average reduction of life expectancy was estimated in 7.1.3 to 24 years. The global average life expectancy at birth is 65 years.

This means that there are $5.28 \cdot 10^9 * 0.64 * 10^{-5} * 4 * 24/65 = 4.99 \cdot 10^4$ YOLL during 1990.

Contribution to category indicators value from a flow unit

The main source of ethylene is from car traffic and from burning of wood. Emission ratio for real world traffic for ethylene and CO may be estimated from street level measurements or measurements in road tunnels. The ethylene/CO-ratio was determined in Stockholm by Almén and Persson (1990). They found a ratio of 0.0059 on weight basis.

The global anthropogenic CO emission was estimated to 1600 million tonnes in 2.2. Therefore the global anthropogenic benzene emission from traffic may be estimated to 0.0059*1600 = 9.44 million tonnes. Emissions from burning of wood are not known at present but is assumed to be of less importance than the emissions from traffic. This means that the average contribution to $1/(9.44 \cdot 10^{9}) = 1.06 \cdot 10^{-10}$ per kg ethylene.

Calculation of pathway specific characterisation factor

The characterisation factor will thus be $4.99 \cdot 10^{4} * 1.06 \cdot 10^{-10} = 5.29 \cdot 10^{-6}$ YOLL/kg ethylene.

Uncertainty

The ethylene/CO ratio is uncertain mainly because few measurements are available and because the global ethylene emission from burning of wood is not known. The estimation of ethylene's metabolisation rate is not internationally established, why this adds an extra uncertainty to the already uncertain risk estimation of ethylene oxide. The total uncertainty is therefore estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of ethylene for YOLL will therefore be $11*7.93 \cdot 10^{-7} = 8.72 \cdot 10^{-6}$ YOLL/kg ethylene.

Uncertainty

Ethylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As ethylene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of ethylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for YOLL was estimated 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant formation pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The excess mortality due to ozone was estimated in 4.1.3 to $5.28 \cdot 10^5$ YOLL.

Contribution to category indicators value from a flow unit
In some areas NO_x is rate limiting for the production of ozone, in some areas it is VOC. Lacking good quantitative estimates of which part of the population living in areas where VOC is rate limiting a 50% value will be used. The global anthropogenic VOC emissions are in the order of 40 tg/year according to Stern (1986). Ethylene exhibits about 3-4% of the VOC (Lewis et al. 1999, Colbeck and Mackenzie 1994). This means that the global ethylene emissions are in the order of 1.4 tg/year. The average contribution from VOC is $0.5*(40 \cdot 10^9)^{-1} = 1.25 \cdot 10^{-11}$ per kg. As ethylene is somewhat more potent oxidant precursor than the average, 1.8 times, (table 7.9), the contribution is somewhat higher. Not knowing the percentage of other VOC substances and their share of the global VOC emissions, an approximate correction has to be made. In this the average contribution is multiplied with 1.8, i.e. the resulting contribution will be $2.27 \cdot 10^{-11}$ per kg ethylene.

Calculation of pathway specific characterisation factor
The oxidant formation specific characterisation factor of ethylene for YOLL is therefore $5.28 \cdot 10^5 * 2.27 \cdot 10^{-11} = 1.20 \cdot 10^{-5}$ YOLL/kg ethylene

Uncertainty
The estimation of global VOC emissions is a bit old. More modern figures for UK report emissions of 3.2 tg/year, which indicate that the global figures used are too low. The uncertainty in the estimation of the total extension of the indicator was made in 4.1.3 to a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for ethylene is assumed to be a little larger and be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor
The resulting characterisation factor from adding the three pathways is $2.02 \cdot 10^{-6} + 8.72 \cdot 10^{-6} + 1.20 \cdot 10^{-5} = 2.27 \cdot 10^{-5}$ YOLL/kg ethylene.

7.3.4. Characterisation of ethylene to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated
Including emissions from anywhere at the globe 1990 and considering a residence time of several days for ethylene and its reaction products, the environmental system will also be global. As ethylene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The portion of cancer incidences not being mortal (36%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is (5/24)*(0.36/0.64)* $4.99 \cdot 10^{4}$ person-years of severe morbidity, where $4.99 \cdot 10^{4}$ is the indicator value determined in 7.3.3.

Contribution to category indicators value from a flow unit

The same contribution as in 7.3.3 is used i.e. $1.06 \cdot 10^{-10}$ per kg.

Calculation of pathway specific characterisation factor

$(5/24)*(0.36/0.64)*\ 4.99 \cdot 10^{4}*1.06 \cdot 10^{-10} = 6.20 \cdot 10^{-7}$ person-years/kg

Uncertainty

The ethylene/CO ratio is uncertain mainly because few measurements are available and because the global ethylene emission from burning of wood is not known. The estimation of ethylene's metabolisation rate is not internationally established, why this adds an extra uncertainty to the already uncertain risk estimation of ethylene-oxide. The total uncertainty is therefore estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor for CO_2 is determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of ethylene for severe morbidity is $11*3.53 \cdot 10^{-7} = 3.88 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Ethylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As ethylene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of ethylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for severe morbidity was estimated in 3.1.4 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The global average ozone concentration was estimated in 4.1.3 to 20 ppbv. The elasticity determined by ExternE (1995) including change in hospital admissions 1.095 cases per 100000 persons per year and change in emergency room visits for asthma by 2.63 cases per 100000 persons per year per annual change in ozone concentration in ppbv are used. Assuming an average duration of hospital visits of one week, and emergency room visits of one day, we obtain a total value for the indicator of $20*5.28\cdot10^{9}*(1.095\cdot10^{-5}*7/365+ 2.63\cdot10^{-5}*1/365) = 2.98\cdot10^{4}$ person-years per year

Contribution to category indicators value from a flow unit
The same contribution is used as in 6.3.3 i.e. $2.27\cdot10^{-11}$ per kg ethylene.

Calculation of pathway specific characterisation factor
$2.98\cdot10^{4}$ person-years per year* $2.27\cdot10^{-11}$ kg^{-1} = $6.76\cdot10^{-7}$ person-years/kg ethylene

Uncertainty
The estimation of global VOC emissions is a bit old. More modern figures for UK report emissions of 3.2 tg/year, which indicate that the global figures used are too low. The uncertainty in the estimation of the total extension of the indicator was made for NO_x-induced ozone in 4.1.3 to a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for ethylene is assumed to be a little larger and be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor
The resulting characterisation factor from adding the three pathways is $6.20\cdot10^{-7}$ + $3.88\cdot10^{-6}$ + $6.76\cdot10^{-7}$ = $4.50\cdot10^{-6}$ person-years/kg

7.3.5. Characterisation of ethylene with respect to morbidity

Definition of environmental system in which the impact is estimated
Including emissions from anywhere at the globe 1990 and considering a residence time of several days for ethylene and its reaction products, the environmental system will also be global. As ethylene causes cancer, there is a reason for using a 20-year system border, but

as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor for CO_2 is determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of ethylene for morbidity is $11 * 6.55 \cdot 10^{-7} = 7.21 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Ethylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As ethylene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of ethylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.3.6. Characterisation of ethylene with respect to decrease of crop production

Definition of environmental system in which the impact is estimated

The ozone level in rural areas has increased significantly since pre-industrial time. The reaction velocity for ethylene to form oxidants is normally in the order of days, but during the dark periods in the arctic regions the residence time of ethylene can be much longer. However a time system border of one year is believed to be sufficient for impact modelling. The system borders used for the oxidant model are thus global and the year 1990. For the global warming pathway the same system borders as for CO_2 apply, i.e. 100 years.

Model 1, oxidant pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

Hasund, Hedvåg and Pleijel (1990) estimated the loss in crop production during 1986-1988 due to anthropogenic emissions to 300000 tons in Sweden. The mean reduction in harvest gain was 6-21% with a best estimate of 9%. The estimates in USA range from 10 -100 billion dollars, IVL-report B1080. The world production of crops, potatoes and sugar beats was about 2400 million tonnes 1990 according to FAO yearbook. A 9 % reduction means decreased harvests by 216 million tonnes.

Contribution to category indicators value from a flow unit

The anthropogenic emission of NMHC is 40 tg/year according to Stern (1986). VOC is assumed to be of about the same magnitude. The natural emission is much greater, but consists to a large part of therpenes, which are no strong oxidant precursors. The influence on oxidant formation in Atlanta, USA from natural VOC was determined by the C_{14}-method by Lewis et al. (1999). It was shown to have a minor influence.

It is not clear which part of tropospheric ozone on a global scale that is rate controlled by NO_x and which part that is controlled by VOC, methane and CO. It seems however as if NO_x is the dominating rate controller in the northern countries, while VOC is most important in central Europe and similar regions. Half of the oxidant formation is assumed to be rate controlled by VOC. In terms of ozone creation potential ethylene is somewhat more potent than other hydrocarbons, about 1.8 times (see table 7.9)

The contribution is therefore $1.8*0,5/4.0\cdot10^{10} = 2.25\cdot10^{-11}$ per kg ethylene.

Calculation of pathway specific characterisation factor

The characterisation factor of ethylene for crop loss is therefore $2.16\cdot10^{11}*2.25\cdot10^{-11}$ = 4.86 kg crop/kg ethylene.

Uncertainty

The estimation of global VOC emissions is a bit old. More modern figures for UK report emissions of 3.2 tg/year, which indicate that the global figures used are too low. The uncertainty in the estimation of the total extension of the indicator was made for NOx-induced ozone in 4.1.3 to a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for ethylene is assumed to be a little larger and be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the characterisation factor of ethylene for crop loss is $11 * 7.56 \cdot 10^{-4} = 8.32 \cdot 10^{-3}$ kg crop/kg ethylene.

Uncertainty

Ethylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As ethylene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of ethylene and other VOC's may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for crop loss was estimated in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2.2)^2 + (\ln 3)^2} = 3.9$

Calculation of characterisation factor

The total characterisation factor for both pathways is thus $4.86 + 8.32 \cdot 10^{-3} = 4.87$ kg crop/kg ethylene.

7.3.7. Characterisation of ethylene with respect to decrease of wood production

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for ethylene being 11 and the equivalency for CO_2 fertilisation being $46*2/28 = 3.29$, the CO_2 fertilisation pathway is still 10 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to $46*2/28 = 3.29$. 46*2 is the molecular weight of two CO_2 and 54 the molecular weight of ethylene. (Each ethylene molecule will give 2 CO_2 molecules when it is oxidised). It is assumed that all ethylene is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $-3.93 \cdot 10^{-2}$ kg wood/kg CO_2 (3.1.7) we obtain the pathway specific characterisation factor of ethylene to wood to $3.29*(-3.93 \cdot 10^{-2}) = -1.29 \cdot 10^{-1}$ kg wood/kg ethylene.

Uncertainty

When ethylene is oxidised in air a water-soluble compound is formed. This may be washed out by rain and deposited on soil or in surface waters. If it is transferred to anaerobic environments, there is a certain possibility that it may end up as in sediments or similar. Then, the equivalency factor will be less than 3.54. As little is known about these processes in quantitative terms, a relatively large uncertainty is assumed, a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2} = 3.7$

7.3.8. Characterisation of ethylene with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26 \cdot 10^{-14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $11*(1.26 \cdot 10^{-14}) = 1.39 \cdot 10^{-13}$ NEX per kg ethylene.

Uncertainty

Ethylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As ethylene may produce about 1.8 as much ozone as the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of ethylene and other VOC's may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.4. Emissions of formaldehyde to air anywhere in the world

Formaldehyde is a carcinogen. Formaldehyde reacts in the atmosphere to form oxidants and is a greenhouse gas in itself and via its reaction products.

7.4.1. Definition of flow group

The flow group characterised is anthropogenic emissions of formaldehyde to air, anyplace in the world 1990 and at any source strength.

Formaldehyde is emitted as a tracer from many combustion processes, such as from car engines. Formaldehyde is also produced from atmospheric reactions as a secondary pollutant. Formaldehyde in air is present as a gas. The residence time is in the order of days to weeks, depending on the photochemical activity.

7.4.2. Assignment to impact categories

Formaldehyde is a carcinogen. Formaldehyde also takes part in smog forming photochemical reactions and is a greenhouse gas in itself and via its reaction products. Formaldehyde adsorbs infrared radiation and participates in formation of oxidants, mainly ozone, which also increase the radiative forcing. It is assigned to the impact categories presented in table 7.5.

Table 7.5 Assignment of formaldehyde emissions to impact categories and selection of category indicators

Pathway	Impact category	Category indicator
Cancer	Life expectancy	YOLL
Global warming	Life expectancy	YOLL
Oxidant formation	Life expectancy	YOLL
Non-mortal cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop production capacity
Oxidant formation	Crop production capacity	Crop production capacity
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.4.3. Characterisation of formaldehyde to air with respect to YOLL

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for formaldehyde and its reaction products, the environmental system will also be global. As formaldehyde causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. In terms of qualitative system borders, we look at human health issues and ecosystem production capacity. No effects on resources or aesthetics are included. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by an equivalency method using benzene as a reference.

Equivalency factor

According to USEPA, IRIS database, the lifetime cancer risk for formaldehyde is $1.3 \cdot 10^{-5}$ per $\mu g/m^3$, which is 2.60 times the risk of benzene.

Calculation of characterisation factor

The cancer pathway specific characterisation factor of benzene for YOLL was determined in 7.1.3 to $1.95 \cdot 10^{-5}$ YOLL/kg benzene. Thus the characterisation factor of formaldehyde for YOLL is $2.60 * 1.95 \cdot 10^{-5} = 5.07 \cdot 10^{-5}$ YOLL/kg.

Uncertainty

The uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty in the benzene characterisation factor was estimated in 7.1.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2} = 3.0$.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of formaldehyde for YOLL will therefore be $11 * 7.93 \cdot 10^{-7} = 8.72 \cdot 10^{-6}$ YOLL/kg formaldehyde.

Uncertainty

Formaldehyde and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As formaldehyde may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of formaldehyde and other VOC's may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant formation pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for formaldehyde is 0.424 (Lindfors et al.,1994)

Calculation of characterisation factor

The characterisation factor of ethylene for YOLL is $1.20 \cdot 10^{-5}$ YOLL/kg ethylene. This means that the characterisation factor for formaldehyde will be $0.424 * 1.20 \cdot 10^{-5} = 0.509 \cdot 10^{-6}$ YOLL/kg.

Uncertainty

Considering the variations in POCP for various substances reported by Lindfors et al., the uncertainty in the equivalency factor is estimated to be in the order of 20%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of ethylene for YOLL was estimated in 7.3.3 to be described by a log-normal distribution with a standard deviation of a factor of 4. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2} = 4.0$

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $5.07 \cdot 10^{-5} + 8.72 \cdot 10^{-6} + 5.09 \cdot 10^{-7} = 5.99 \cdot 10^{-5}$ YOLL/kg formaldehyde.

7.4.4. Characterisation of formaldehyde to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for formaldehyde and its reaction products, the environmental system will also be global. As formaldehyde causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by an equivalency method using benzene as a reference.

Equivalency factor

The equivalency factor was determined in 7.4.3 to 2.60.

Calculation of pathway specific characterisation factor

The cancer pathway specific characterisation factor of benzene for severe morbidity was determined in 7.1.4 to $2.28 \cdot 10^{-6}$ person-years per kg. Thus the cancer pathway specific characterisation factor of formaldehyde for severe morbidity is $2.60 * 2.28 \cdot 10^{-6} = 5.93 \cdot 10^{-6}$ person-years per kg formaldehyde.

Uncertainty

The uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty in the benzene characterisation factor was estimated in 7.1.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2}$ = 3.0.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor for CO_2 is determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of formaldehyde for severe morbidity is $11 * 3.53 \cdot 10^{-7} = 3.88 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Formaldehyde and other VOC's have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As formaldehyde may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of formaldehyde and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty of the characterisation factor for CO_2 was determined in 7.1.4 and may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7.

Model 3, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for formaldehyde is 0.424 (Lindfors et al.,1994)

Calculation of characterisation factor

The oxidant pathway specific characterisation factor of ethylene for severe morbidity is determined in 7.3.3 to $6.76 \cdot 10^{-7}$ person-years/kg ethylene. This gives a oxidant pathway specific characterisation factor of formaldehyde for severe morbidity of $0.424 * 6.76 \cdot 10^{-7} = 2.87 \cdot 10^{-7}$ person-years/kg.

Uncertainty

The uncertainty for the POCP was estimated in 7.4.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $5.93 \cdot 10^{-6} + 3.88 \cdot 10^{-6} + 2.87 \cdot 10^{-7} = 1.01 \cdot 10^{-5}$ person-years/kg

7.4.5. Characterisation of formaldehyde with respect to morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for formaldehyde and its reaction products, the environmental system will also be global. As formaldehyde causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor for CO_2 is determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of formaldehyde for morbidity is $11 * 6.55 \cdot 10^{-7} = 7.21 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Formaldehyde and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As formaldehyde may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of formaldehyde and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.4.6. Characterisation of formaldehyde with respect to decrease of crop production

Definition of environmental system in which the impact is estimated

The ozone level in rural areas has increased significantly since pre-industrial time. The reaction velocity for formaldehyde to form oxidants is normally in the order of days, but in the dark periods in the arctic regions the residence time of formaldehyde can be much longer. However a time system border of one year is believed to be sufficient for impact modelling. The system borders used for the oxidant model are thus global and the year 1990. For the global warming pathway the same system borders as for CO_2 apply, i.e. 100 years.

Model 1, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for formaldehyde is 0.424 (Lindfors et al.,1994)

Calculation of characterisation factor

The oxidant pathway specific characterisation factor of ethylene for crop is determined in 7.3.6 to 4.86 kg crop/kg ethylene. This gives an oxidant pathway specific characterisation factor of formaldehyde for crop of 0.424*4.86 = 2.06 kg crop/kg formaldehyde.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the characterisation factor of formaldehyde for crop loss is $11*7.56 \cdot 10^{-4} = 8.32 \cdot 10^{-3}$ kg crop/kg formaldehyde.

Uncertainty

Formaldehyde and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As formaldehyde may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of formaldehyde and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for crop loss was estimated in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 2.2)^2} = 3.9$

Calculation of characterisation factor

The total characterisation factor for both pathways is thus $2.06 + 8.32 \cdot 10^{-3} = 2.07$ kg crop/kg formaldehyde.

7.4.7. Characterisation of formaldehyde with respect to decrease of wood production

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for formaldehyde being 11 and the equivalency for CO_2 fertilisation being 46/30 = 1.53, the CO_2 fertilisation pathway is still 5 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to 46/30 = 1.53. 46 is the molecular weight of CO_2 and 30 the molecular weight of formaldehyde. (Each formaldehyde molecule will give one CO_2 molecules when it is oxidised). It is assumed that all formaldehyde is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $-3.93 \cdot 10^{-2}$ kg wood/kg CO_2 (3.1.7) we obtain the pathway specific characterisation factor of formaldehyde to wood to $1.53 * (-3.93 \cdot 10^{-2}) = -6.01 \cdot 10^{-2}$ kg wood/kg formaldehyde.

Uncertainty

It is very likely that almost all of the formaldehyde really is oxidised to CO_2 and water. The uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.4. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2)^2} = 2.2$

7.4.8. Characterisation of formaldehyde with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26 \cdot 10^{-14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $11 * (1.26 \cdot 10^{-14}) = 1.39 \cdot 10^{-13}$ NEX per kg formaldehyde.

Uncertainty

Formaldehyde and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As formaldehyde may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of formaldehyde and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.5. Emissions of methane to air anywhere in the world

7.5.1. Definition of flow group

The flow group characterised is emissions of methane to air, anyplace in the world 1990 and at any source strength.

7.5.2. Assignment to impact categories

Methane reacts in the atmosphere to form oxidants and is a greenhouse gas in itself and via its reaction products. It is assigned to the impact categories in table 7.6.

Table 7.6 Assignment of methane emissions to impact categories and selection of category indicators

Pathway	**Impact category**	**Category indicator**
Global warming	Life expectancy	YOLL
Oxidant formation	Life expectancy	YOLL
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.5.3. Characterisation of methane to air with respect to YOLL

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a mean residence time of around 15 years for methane (IPCC, 1994), the environmental system be global. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} was estimated by IPCC to 24.5 (1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of methane for YOLL will therefore be $24.5 * 7.93 \cdot 10^{-7} = 1.94 \cdot 10^{-5}$ YOLL/kg methane.

Uncertainty

Methane and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone and stratospheric water vapor. Based on the discussions in IPCC (1994), the uncertainty for the GWP of methane is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.3.

The uncertainty for the characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp \sqrt{(\ln 1.3)^2 + (\ln 3)^2} = 3.1$

Model 2, oxidant formation pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for methane is 0.007 (Heijungs et al. in Lindfors et al.,1994)

Calculation of characterisation factor

The characterisation factor of ethylene for YOLL is $1.20 \cdot 10^{-5}$ YOLL/kg ethylene. This means that the characterisation factor for methane will be $0.007 * 1.20 \cdot 10^{-5} = 8.40 \cdot 10^{-8}$ YOLL/kg.

Uncertainty

Considering the variations in POCP for various substances reported by Lindfors et al., the uncertainty in the equivalency factor is estimated to be in the order of 20%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of ethylene for YOLL was estimated in 7.3.3 to be described by a log-normal distribution with a standard deviation of a factor of 4. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2} = 4.0$

Calculation of characterisation factor

The resulting characterisation factor from adding both pathways is $1.94 \cdot 10^{-5} + 8.40 \cdot 10^{-8} = 1.95 \cdot 10^{-5}$ YOLL/kg methane.

7.5.4. Characterisation of methane to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a mean residence time of around 15 years for methane and its reaction products (IPCC, 1994), the environmental system be global. No effects on biodiversity, resources or aesthetics are included. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 24.5 (1994).

Calculation of pathway specific characterisation factor

The characterisation factor for CO_2 is determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of methane for severe morbidity is $24.5*3.53 \cdot 10^{-7} = 8.65 \cdot 10^{-6}$ person-years/kg.

Uncertainty
Methane has an indirect global warming potential in that it creates tropospheric ozone and stratospheric water vapour. As for 7.4.3 the uncertainty for the GWP of methane is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.3.

The uncertainty of the characterisation factor for CO_2 was determined in 7.1.4 and may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.3)^2 + (\ln 3)^2}$ = 3.1.

Model 2, oxidant pathway
The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor
The POCP for methane is 0.007 (Heijungs et al. i Lindfors et. al., 1994)

Calculation of characterisation factor
The oxidant pathway specific characterisation factor of ethylene for severe morbidity is determined in 7.3.3 to $6.76 \cdot 10^{-7}$ person-years/kg ethylene. This gives an oxidant pathway specific characterisation factor of methane for severe morbidity of $0.007*6.76 \cdot 10^{-7} = 4.73 \cdot 10^{-9}$ person-years/kg.

Uncertainty
The uncertainty for the POCP was estimated in 7.4.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor
The resulting characterisation factor from adding the two pathways is $8.65 \cdot 10^{-6} + 4.73 \cdot 10^{-9} = 8.65 \cdot 10^{-6}$ person-years/kg

7.5.5. Characterisation of methane with respect to morbidity

Definition of environmental system in which the impact is estimated
Including emissions from anywhere at the globe 1990 and considering a mean residence time of around 15 years for methane (IPCC, 1994), the environmental system be global.

For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 24.5 (1994).

Calculation of characterisation factor

The characterisation factor for CO_2 is determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of methane for morbidity is $24.5 * 6.55 \cdot 10^{-7} = 1.60 \cdot 10^{-5}$ person-years/kg.

Uncertainty

Methane has an indirect global warming potential in that it creates tropospheric ozone and stratospheric water vapour. As for 7.4.3 the uncertainty for the GWP of methane is assumed to be may be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.3.

The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.3)^2 + (\ln 3)^2} = 3.1$

7.5.6. Characterisation of methane with respect to decrease of crop production

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a mean residence time of around 15 years for methane (IPCC, 1994), the environmental system be global. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for methane is 0.007 (Heijungs et al. i Lindfors et al.,1994)

Calculation of characterisation factor

The oxidant pathway specific characterisation factor of ethylene for crop loss is determined in 7.3.6 to 4.86 kg crop/kg ethylene. This gives an oxidant pathway specific characterisation factor of methane for crop of 0.007*4.86 = 0.0340 kg crop/kg methane.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} was estimated by IPCC to 24.5 (1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the characterisation factor of methane for crop loss is $24.5 * 7.56 \cdot 10^{-4} = 1.85 \cdot 10^{-2}$ kg crop/kg methane.

Uncertainty

Methane has an indirect global warming potential in that it creates tropospheric ozone and stratospheric water vapour. As for 7.4.3 the uncertainty for the GWP of methane is assumed to be may be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.3.

The uncertainty for the characterisation factor of CO_2 for crop loss was estimated in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.3)^2 + (\ln 2.2)^2}$ = 2.3

Calculation of characterisation factor

The total characterisation factor for both pathways is thus 0.0340 + 0.0185 = 0.0525 kg crop/kg methane.

7.5.7. Characterisation of methane with respect to decrease of wood production

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for methane being 24.5 and the equivalency for CO_2 fertilisation being 46/16 = 2.88, the CO_2 fertilisation pathway is still 10 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to 46/16 = 2.88. 46 represents the molecular weight of CO_2 and 16 the molecular weight of methane. (Each methane molecule will give one CO_2 molecules when it is oxidised). It is assumed that all methane is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $–3.93·10^{-2}$ kg wood/kg CO_2 (3.1.7) we obtain the pathway specific characterisation factor of formaldehyde to wood to $2.88*(-3.93·10^{-2}) = -1.13·10^{-1}$ kg wood/kg methane.

Uncertainty

It is very likely that almost all of the methane really is oxidised to CO_2 and water. The uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.4. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 2)^2} = 2.2$

7.5.8. Characterisation of methane with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 24.5 (1994).

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26·10^{–14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $24.5*(1.26·10^{–14}) = 3.09·10^{–13}$ per kg methane.

Uncertainty

Methane has an indirect global warming potential in that it creates tropospheric ozone and stratospheric water vapour. As for 7.4.3 the uncertainty for the GWP of methane is assumed to be may be described by a log-normal distribution with a standard deviation corresponding to a factor of 1.3.

The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.3)^2 + (\ln 3)^2} = 3.1$

7.6. Emissions of propylene to air anywhere in the world

7.6.1. Definition of flow group

Propylene is emitted as a tracer from combustion processes, such as from car engines. The residence time is in the order of days to weeks, depending on the photochemical activity.

The flow group characterised is anthropogenic emissions of propylene to air, anyplace in the world 1990 and at any source strength.

7.6.2. Assignment to impact categories

Propylene is an indirect carcinogen via its metabolisation to propylene-oxide after inhalation (Victorin, 1998). Propylene also takes part in smog forming photochemical reactions and is a greenhouse gas in itself and via its reaction products. Propylene adsorbs infrared radiation and participates in formation of oxidants, mainly ozone, which also increases the radiative forcing.

The assignment of propylene to impact categories, selection of category indicators and listing of corresponding pathways is made in table 7.7

Table 7.7 Assignment of propylene emissions to impact categories and selection of indicators

Pathway	**Impact category**	**Category indicator**
Cancer	Life expectancy	YOLL
Global warming	Life expectancy	YOLL
Oxidant formation	Life expectancy	YOLL
Non-mortal cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.6.3. Characterisation of propylene to air with respect to YOLL

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days to weeks for propylene, the environmental system chosen is global. As propylene causes cancer, there is a reason for using a 20-year system border, but because the use of a linear dose-response model, the system borders can be restricted to the year 1990. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by an equivalency method using benzene as a reference.

Equivalency factor

Victorin (1998) uses USEPA estimates of the lifetime cancer risk for propylene-oxide for which the lifetime inhalation unit risk is $3.7 \cdot 10^{-6}$ per $\mu g/m^3$ and assumes a metabolisation rate of 10% to estimate the cancer risk for propylene. This will give an estimate that is 0.074 times the risk of benzene ($5 \cdot 10^{-6}$).

Calculation of characterisation factor

The characterisation factor of benzene for YOLL was determined in 7.1.3 to $1.95 \cdot 10^{-5}$ YOLL/kg benzene. Thus the characterisation factor of propylene for YOLL is $0.074 * 1.95 \cdot 10^{-5} = 1.44 \cdot 10^{-6}$ YOLL/kg.

Uncertainty

The uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.4. The uncertainty in the benzene characterisation factor was estimated in 7.1.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.4)^2 + (\ln 3)^2}$ = 3.2.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. The characterisation factor of propylene for YOLL will therefore be $11 * 7.93 \cdot 10^{-7} = 8.72 \cdot 10^{-6}$ YOLL/kg propylene.

Uncertainty

Propylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As propylene may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of propylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

Model 3, oxidant formation pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for propylene is 0.734 (Lindfors et al.,1994)

Calculation of pathway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for YOLL is $1.20 \cdot 10^{-5}$ YOLL/kg ethylene. This means that the oxidant pathway specific characterisation factor for propylene will be $0.734 * 1.20 \cdot 10^{-5} = 8.81 \cdot 10^{-6}$ YOLL/kg.

Uncertainty

Considering the variations in POCP for various substances reported by Lindfors et al., the uncertainty in the equivalency factor is estimated to be in the order of 20%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of ethylene for YOLL was estimated in 7.3.3 to be described by a log-normal distribution with a standard deviation of a factor of 4. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2} = 4.0$

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $1.44 \cdot 10^{-6} + 8.72 \cdot 10^{-6} + 8.81 \cdot 10^{-6} = 1.90 \cdot 10^{-5}$ YOLL/kg propylene.

7.6.4. Characterisation of propylene to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for propylene and its reaction products, the environmental system will also be global. As propylene causes cancer, there is a reason for using a 20-year system border, but as we use a linear dose-response model, we restrict the system borders to the year 1990. For the global warming pathways the same system borders as for CO_2 is relevant, i.e. 100 years.

Model 1, cancer pathway

The characterisation factor is determined by an equivalency method using benzene as a reference.

Equivalency factor

The equivalency factor was determined in 7.6.3 to 0.074.

Calculation of pathway specific characterisation factor

The cancer pathway specific characterisation factor of benzene for severe morbidity was determined in 7.1.4 to $2.28 \cdot 10^{-6}$ person-years per kg. Thus the cancer pathway specific characterisation factor of propylene for severe morbidity is $0.074 * 2.28 \cdot 10^{-6} = 1.69 \cdot 10^{-7}$ person-years per kg propylene.

Uncertainty

The uncertainty in the equivalency factor is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.2. The uncertainty in the benzene characterisation factor was estimated in 7.1.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.2)^2 + (\ln 3)^2}$ = 3.0.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for severe morbidity is determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of propylene for severe morbidity is $11 * 3.53 \cdot 10^{-7} = 3.88 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Propylene and other VOC's have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas. As propylene may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of propylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty of the characterisation factor for CO_2 was determined in 7.1.4 and may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2}$ = 4.7.

Model 3, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for propylene is 0.734 (Lindfors et al.,1994)

Calculation of pathway specific characterisation factor

The oxidant pathway specific characterisation factor of ethylene for severe morbidity is determined in 7.3.3 to $6.76 \cdot 10^{-7}$ person-years/kg ethylene. This gives an oxidant pathway specific characterisation factor of propylene for severe morbidity of $0.734 * 6.76 \cdot 10^{-7} = 4.98 \cdot 10^{-7}$ person-years/kg.

Uncertainty

The uncertainty for the POCP was estimated in 7.4.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.4 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Calculation of characterisation factor

The resulting characterisation factor from adding the three pathways is $1.69 \cdot 10^{-7} + 3.88 \cdot 10^{-6} + 4.98 \cdot 10^{-7} = 4.05 \cdot 10^{-6}$ person-years/kg

7.6.5. Characterisation of propylene with respect to morbidity

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for propylene and its reaction products, the environmental system will also be global. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for morbidity is determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg, which means that the characterisation factor of propylene for morbidity is $11 * 6.55 \cdot 10^{-7} = 7.21 \cdot 10^{-6}$ person-years/kg.

Uncertainty

Propylene and other hydrocarbons have an indirect global warming potential in that it creates trospospheric ozone. This involves a higher uncertainty as it is unevenly distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As propylene may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of propylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for morbidity was estimated in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.6.6. Characterisation of propylene with respect to decrease of crop production

Definition of environmental system in which the impact is estimated

The ozone level in rural areas has increased significantly since pre-industrial time. The reaction velocity for propylene to form oxidants is normally in the order of days, but in the dark periods in the arctic regions the residence time of propylene can be much longer. However a time system border of one year is believed to be sufficient for impact modelling. The system borders used for the oxidant model are thus global and the year 1990. For the global warming pathway the same system borders as for CO_2 apply, i.e. 100 years.

Model 1, oxidant pathway

The characterisation factor is determined by an equivalency method using ethylene as a reference.

Equivalency factor

The POCP for propylene is 0.734 (Lindfors et al.,1994)

Calculation of pathway specific characterisation factor

The characterisation factor of ethylene for crop loss is determined in 7.3.6 to 4.86 kg crop/kg ethylene. This gives an oxidant pathway specific characterisation factor of propylene for severe morbidity of 0.734*4.86 = 3.57 kg crop/kg propylene.

Uncertainty

The uncertainty for the POCP was estimated in 7.2.3 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty in the ethylene characterisation factor is estimated in 7.3.6 to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4. The added uncertainty may thus be represented by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 4)^2}$ = 4.0.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop loss is $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the pathway specific characterisation factor of propylene for crop loss is $11 * 7.56 \cdot 10^{-4}$ = $8.32 \cdot 10^{-3}$ kg crop/kg propylene.

Uncertainty

Propylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As propylene may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of propylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for crop loss was estimated in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 2.2)^2}$ = 3.9

Calculation of characterisation factor

The total characterisation factor for both pathways is thus $3.57 + 8.32 \cdot 10^{-3} = 3.58$ kg crop/kg propylene.

7.6.7. Characterisation of propylene with respect to decrease of wood production

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference. There are two pathways for CO_2's impact on forest growth. One is the global warming and the other is CO_2 fertilisation. The CO_2 fertilisation is more than 30 times as efficient as the global warming. Considering the GWP_{100} for propylene being 11 and the equivalency for CO_2 fertilisation being 46*3/42 = 3.29, the CO_2 fertilisation pathway is still 10 times as efficient. Therefore the model will focus on the equivalency with CO_2 in the fertilising aspect.

Equivalency factor

The equivalency for CO_2 fertilisation was calculated above to 46*3/42 = 3.29. 46*3 is the molecular weight of 3 CO_2 and 42 the molecular weight of butadiene. (Each propylene molecule will give 3 CO_2 molecules when it is oxidised). It is assumed that all propylene is oxidised sooner or later to CO_2 and water.

Calculation of characterisation factor

As the fertilisation pathway specific characterisation factor of CO_2 for wood is $-3.93 \cdot 10^{-2}$ kg wood/kg CO_2 (3.1.7) we obtain the pathway specific characterisation factor of propylene to wood to $3.29*(-3.93 \cdot 10^{-2}) = -1.29 \cdot 10^{-1}$ kg wood/kg propylene.

Uncertainty

When propylene is oxidised in air a water-soluble compound is formed. This may be washed out by rain and deposited on soil or in surface waters. If it is transferred to anaerobic environments, there is a certain possibility that it may end up as in sediments or similar. Then, the equivalency factor will be less than 3.54. As little is known about these processes in quantitative terms, a relatively large uncertainty is assumed, a log-normal distribution with a standard deviation corresponding to a factor of 3. The uncertainty for the characterisation factor of CO_2 for wood was estimated in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 2)^2 + (\ln 3)^2} = 3.7$

7.6.8. Characterisation of propylene with respect to NEX

Definition of environmental system in which the impact is estimated

The pathway modelled is via global warming. The same system borders as for CO_2 is used i.e 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP100 was estimated by IPCC to 11 in one of the early reports. (1990). Later this statement was withdrawn by IPCC, with the motivation that the uncertainty was too large. In the EPS context however, omitting it would create a larger error than including it, so the equivalency factor 11 will still be used.

Calculation of characterisation factor

The characterisation factor of CO_2 for NEX is $1.26 \cdot 10^{-14}$ per kg CO_2 (3.1.8). Thus the characterisation factor of NEX is $11*(1.26 \cdot 10^{-14}) = 1.39 \cdot 10^{-13}$ per kg propylene.

Uncertainty

Propylene and other hydrocarbons have an indirect global warming potential in that it creates tropospheric ozone. This involves a higher uncertainty as it is uneven distributed in the atmosphere. A part of the global warming potential has to do with ozone being a greenhouse gas As propylene may produce about 76% of the ozone produced by the average VOC, (table 7.9) and as IPCC reports an uncertainty of 30% for the GWP of most other greenhouse gases, we assume that the uncertainty for the GWP of propylene and other VOC:s may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

The uncertainty for the characterisation factor of CO_2 for NEX was estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 3)^2 + (\ln 3)^2} = 4.7$

7.7. Emissions of other gaseous organic substances to air anywhere in the world

7.7.1. Definition of flow group

The flow group characterised is anthropogenic emissions of any of the VOC:s in table 6x to air, anyplace in the world 1990 and at any source strength.

VOC:s are emitted from processes where they are used as solvents and as a tracer from many combustion processes, such as burning of wood and from car engines. Most of the VOC:s in ambient air is present as a gas, but close to sources and when particles with an active surface are available they may be found in the particle phase. The residence time is in the order of days to weeks, depending on the photochemical activity.

7.7.2. Assignment to impact categories

Some VOC:s are is a carcinogens, but they are modelled separately and not included in table 7.9. Practically all of them take part in smog forming photochemical reactions and are greenhouse gases in themselves and via their reaction products. VOC's participate in formation of oxidants, mainly ozone, which also increase the radiative forcing. Assignments of VOC to impact categories are shown in table 7.8.

Table 7.8 Assignment of VOC emissions to impact categories and selection of category indicators.

Pathway	**Impact categories**	**Category indicator**
Global warming	Life expectancy	YOLL
Oxidant formation	Life expectancy	YOLL
Global warming	Severe morbidity	Severe morbidity
Oxidant formation	Severe morbidity	Severe morbidity
Global warming	Crop production capacity	Crop
Oxidant formation	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

7.7.3. Characterisation of VOC to air with respect to category indicators

Definition of environmental system in which the impact is estimated

Including emissions from anywhere at the globe 1990 and considering a residence time of several days for VOC and its reaction products, the environmental system will also be global. For the global warming pathways, the same system borders as for CO_2 is relevant, i.e. 100 years.

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference for global warming effects and ethylene as a reference for oxidant effects. Equivalency factors and resulting characterisation factors are given in table 7.9.

Table 7.9 Equivalency and characterisation factors for VOC's. The average POCP is 0.550

Substance	GWP 100	POCP-1	YOLL, global warming	YOLL, oxidants	Severe morbidity ,global warming	Severe morbidity ,oxidants	Crop, global warming	Crop, oxidants	Wood, oxidation to CO2	NEX, global warming
Ethan	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	0.841	-0.129	1.39E-13
Propane	11	0.604	8.72E-06	7.25E-06	3.88E-06	4.08E-07	8.32E-03	2.94	-0.129	1.39E-13
N-butane	11	0.554	8.72E-06	6.65E-06	3.88E-06	3.75E-07	8.32E-03	2.69	-0.129	1.39E-13
I-butane	11	0.331	8.72E-06	3.97E-06	3.88E-06	2.24E-07	8.32E-03	1.61	-0.129	1.39E-13
N-pentane	11	0.612	8.72E-06	7.34E-06	3.88E-06	4.14E-07	8.32E-03	2.97	-0.129	1.39E-13
I-pentane	11	0.36	8.72E-06	4.32E-06	3.88E-06	2.43E-07	8.32E-03	1.75	-0.129	1.39E-13
Hexane	11	0.784	8.72E-06	9.41E-06	3.88E-06	5.30E-07	8.32E-03	3.81	-0.129	1.39E-13
2-metylpentane	11	0.712	8.72E-06	8.54E-06	3.88E-06	4.81E-07	8.32E-03	3.46	-0.129	1.39E-13
3-metylpentane	11	0.647	8.72E-06	7.76E-06	3.88E-06	4.37E-07	8.32E-03	3.14	-0.129	1.39E-13
N-heptane	11	0.791	8.72E-06	9.49E-06	3.88E-06	5.35E-07	8.32E-03	3.84	-0.129	1.39E-13
N-oktane	11	0.698	8.72E-06	8.38E-06	3.88E-06	4.72E-07	8.32E-03	3.39	-0.129	1.39E-13
2-metylheptane	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36	-0.129	1.39E-13
N-nonane	11	0.633	8.72E-06	7.60E-06	3.88E-06	4.28E-07	8.32E-03	3.08	-0.129	1.39E-13
2-metyloktane	11	0.669	8.72E-06	8.03E-06	3.88E-06	4.52E-07	8.32E-03	3.25	-0.129	1.39E-13
N-decane	11	0.719	8.72E-06	8.63E-06	3.88E-06	4.86E-07	8.32E-03	3.49	-0.129	1.39E-13
2-methylnonane	11	0.719	8.72E-06	8.63E-06	3.88E-06	4.86E-07	8.32E-03	3.49	-0.129	1.39E-13
N-undecane	11	0.662	8.72E-06	7.94E-06	3.88E-06	4.48E-07	8.32E-03	3.22	-0.129	1.39E-13
N-dodecane	11	0.576	8.72E-06	6.91E-06	3.88E-06	3.89E-07	8.32E-03	2.80	-0.129	1.39E-13
Metyl-cyclohexane	11	0.403	8.72E-06	4.84E-06	3.88E-06	2.72E-07	8.32E-03	1.96	-0.129	1.39E-13
1-butene	11	0.799	8.72E-06	9.59E-06	3.88E-06	5.40E-07	8.32E-03	3.88	-0.129	1.39E-13
2-butene	11	0.784	8.72E-06	9.41E-06	3.88E-06	5.30E-07	8.32E-03	3.81	-0.129	1.39E-13
1-pentene	11	0.727	8.72E-06	8.72E-06	3.88E-06	4.91E-07	8.32E-03	3.53	-0.129	1.39E-13
2-pentene	11	0.77	8.72E-06	9.24E-06	3.88E-06	5.21E-07	8.32E-03	3.74	-0.129	1.39E-13
2-m-1-butene	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36	-0.129	1.39E-13
2-m-2-butene	11	0.935	8.72E-06	1.12E-05	3.88E-06	6.32E-07	8.32E-03	4.54	-0.129	1.39E-13
Butylene	11	0.791	8.72E-06	9.49E-06	3.88E-06	5.35E-07	8.32E-03	3.84	-0.129	1.39E-13
Isoprene	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59	-0.129	1.39E-13
Acetylene	11	0.273	8.72E-06	3.28E-06	3.88E-06	1.85E-07	8.32E-03	1.33	-0.129	1.39E-13
Toluene	11	0.446	8.72E-06	5.35E-06	3.88E-06	3.01E-07	8.32E-03	2.17	-0.129	1.39E-13
O-xylene	11	0.424	8.72E-06	5.09E-06	3.88E-06	2.87E-07	8.32E-03	2.06	-0.129	1.39E-13
M-xylene	11	0.583	8.72E-06	7.00E-06	3.88E-06	3.94E-07	8.32E-03	2.83	-0.129	1.39E-13
P-xylene	11	0.612	8.72E-06	7.34E-06	3.88E-06	4.14E-07	8.32E-03	2.97	-0.129	1.39E-13
Etylbenzene	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59	-0.129	1.39E-13
1,2,3-Trimetylbenzene	11	0.698	8.72E-06	8.38E-06	3.88E-06	4.72E-07	8.32E-03	3.39	-0.129	1.39E-13
1,2,4-Trimetylbenzene	11	0.683	8.72E-06	8.20E-06	3.88E-06	4.62E-07	8.32E-03	3.32	-0.129	1.39E-13
1,3,5-Trimetylbenzene	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36	-0.129	1.39E-13
O-ethyltoluene	11	0.597	8.72E-06	7.16E-06	3.88E-06	4.04E-07	8.32E-03	2.90	-0.129	1.39E-13
M-ethyltoluene	11	0.626	8.72E-06	7.51E-06	3.88E-06	4.23E-07	8.32E-03	3.04	-0.129	1.39E-13

Table 7.9, (Equivalency and characterisation factors for VOC’s ..) continued

Substance	GWP 100	POCP-1	YOLL, global warming	YOLL, oxidants	Severe morbidity ,global warming	Severe morbidity ,oxidants	Crop, global warming	Crop, oxidants	Wood, oxidation to CO2	NEX, global warming
P-ethyltoluene	11	0.626	8.72E-06	7.51E-06	3.88E-06	4.23E-07	8.32E-03	3.04	-0.129	1.39E-13
N-propylbenzene	11	0.511	8.72E-06	6.13E-06	3.88E-06	3.45E-07	8.32E-03	2.48	-0.129	1.39E-13
I-propylbenzene	11	0.511	8.72E-06	6.13E-06	3.88E-06	3.45E-07	8.32E-03	2.48	-0.129	1.39E-13
Methanol	11	0.165	8.72E-06	1.98E-06	3.88E-06	1.12E-07	8.32E-03	0.802	-0.129	1.39E-13
Ethanol	11	0.446	8.72E-06	5.35E-06	3.88E-06	3.01E-07	8.32E-03	2.17	-0.129	1.39E-13
I-propanol	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	0.841	-0.129	1.39E-13
Butanol	11	0.655	8.72E-06	7.86E-06	3.88E-06	4.43E-07	8.32E-03	3.18	-0.129	1.39E-13
I-butanol	11	0.388	8.72E-06	4.66E-06	3.88E-06	2.62E-07	8.32E-03	1.89	-0.129	1.39E-13
But-2-iol	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40	-0.129	1.39E-13
Acetone	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	0.841	-0.129	1.39E-13
Methyl ethyl ketone	11	0.388	8.72E-06	4.66E-06	3.88E-06	2.62E-07	8.32E-03	1.89	-0.129	1.39E-13
Methyl i-butyl ketone	11	0.676	8.72E-06	8.11E-06	3.88E-06	4.57E-07	8.32E-03	3.29	-0.129	1.39E-13
Acetaldehyde	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59	-0.129	1.39E-13
Propionaldehyde	11	0.655	8.72E-06	7.86E-06	3.88E-06	4.43E-07	8.32E-03	3.18	-0.129	1.39E-13
Butyraldehyde	11	0.64	8.72E-06	7.68E-06	3.88E-06	4.33E-07	8.32E-03	3.11	-0.129	1.39E-13
I-butyraldehyde	11	0.583	8.72E-06	7.00E-06	3.88E-06	3.94E-07	8.32E-03	2.83	-0.129	1.39E-13
Valeraldehyde	11	0.615	8.72E-06	7.38E-06	3.88E-06	4.16E-07	8.32E-03	2.99	-0.129	1.39E-13
Acrolein	11	1.201	8.72E-06	1.44E-05	3.88E-06	8.12E-07	8.32E-03	5.84	-0.129	1.39E-13
Methyl chloroform	11	0.007	8.72E-06	8.40E-08	3.88E-06	4.73E-09	8.32E-03	0.034	-0.129	1.39E-13
Allyl chloride	11	0.561	8.72E-06	6.73E-06	3.88E-06	3.79E-07	8.32E-03	2.73	-0.129	1.39E-13
Dimethylester	11	0.058	8.72E-06	6.96E-07	3.88E-06	3.92E-08	8.32E-03	0.282	-0.129	1.39E-13
Dimethylether	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40	-0.129	1.39E-13
Propylene glycol methyl ether	11	0.77	8.72E-06	9.24E-06	3.88E-06	5.21E-07	8.32E-03	3.74	-0.129	1.39E-13
Propylene glycol methyl ether acetate	11	0.309	8.72E-06	3.71E-06	3.88E-06	2.09E-07	8.32E-03	1.50	-0.129	1.39E-13
ethylacetate	11	0.295	8.72E-06	3.54E-06	3.88E-06	1.99E-07	8.32E-03	1.43	-0.129	1.39E-13
n-butylacetate	11	0.439	8.72E-06	5.27E-06	3.88E-06	2.97E-07	8.32E-03	2.13	-0.129	1.39E-13
i-butylacetate	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40	-0.129	1.39E-13
Uncertainty factor			4.7	4	4.7	4	3.9	4	3.7	4.7

The equivalency factor for CO_2 fertilisation is 46/14 = 3.29, where 46 is the molecular weight of CO_2 and 14 of CH_2.

Uncertainty

The uncertainty for the various models are the same as for the VOC’ in 7.1-7.3 and are shown in the last row of table 7.9.

8. Classification and characterisation of emissions of pesticides to air, water and soil

8.1. Emissions of pesticides anywhere in the world

8.1.1. Definition of flow group

The flow group considered is ‘spraying or other ways of application of pesticides to vegetation anywhere in the world 1990’. The reason for modelling all media at once is partly that emission flows to separate media like air are vaguely known, while the total use of pesticides are better known and partly that many pesticides is transferred between different media to a significant extent.

8.1.2. Assignment to impact categories

Pesticides have impacts on human health. Acute poisoning is documented and leads to YOLL, severe morbidity and morbidity. Pesticides are also likely to give some symptoms that may not be classified as morbidity. However, no assignment is made to severe nuisance or nuisance, although such impacts is likely to occur. For instance, many pesticides are odorous. The reason for not making such assignment is that the impacts are believed to be small compared to the morbidity classes and YOLL in terms of contribution in the weighting step and that the basis for modelling is insufficient.
Pesticides are also contributing to the extinction of species, and are therefore assigned to this impact category.

Much of the groundwater reserves are made unsuitable for drinking because of too high levels of pesticides. It is therefore assigned to the impact category ‘depletion of water reserves’, but the information available at present does not allow quantitative modelling of a characterisation factor.

Pesticides are used because they have an immediate, local, positive effect on the growth rate or on human health. Such consequences are considered in the modelling of the technical system, mostly through the functional unit.

In table 8.1 below, the assignments made are shown together with pathways considered and category indicators selected for modelling.

Table 8.1 Assignment of pesticide emissions to impact categories and selection of category indicators for modelling.

Pathway	Impact category	Category indicator
Direct exposure	Life expectancy	YOLL
Direct exposure	Severe morbidity	Severe morbidity
Direct exposure	Morbidity	Morbidity
Direct exposure	Severe nuisance	Not modelled
Direct exposure	Nuisance	Not modelled
	Extinction of species	NEX
	Production capacity for water	Not modelled

8.1.3. Characterisation of pesticides to all media with respect to YOLL

Definition of environmental system in which the impact is estimated

Some pesticides are transported globally. They may be found in areas where no use exists, like in the Arctic's. Some are persistent and have a long residence time in the environment. Pesticides may cause some long term effects like cancer.

As all effect models are linear, the system border will however be global and include the year 1990.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

According to WHO/FAO (1999), there are 20000 deaths per year due to acute poisoning from pesticides. The average YOLL per case is not known, but assumed to be 30 years, because most of the accidents occur in third world countries and presumably among the younger less experienced part of the population. Consequently, the total indicator value in the system is $20000*30 = 6\cdot10^5$.

Contribution to category indicators value from a flow unit

The global use of pesticides in terms of active substance is growing. 1985 it was 3 million tonnes and 1975 1.8 million tonnes (WHO/UNEP 1990). An extrapolation of the trend gives an estimate of the use to 3.6 million tonnes 1990. The average contribution (disregarding varying toxicity and exposure pattern) is therefore $2.78\cdot10^{-10}$ per kg pesticide. To some extent it is possible to improve the estimations by identifying the pesticide and considering the toxicity of the pesticide in use. When doing so it would be an advantage of knowing the total amounts of various pesticides used globally. However, such figures have not been found and do not seem to be available. Therefore, instead of determining the specific contribution for a certain pesticide according to

$$(1/Rfd_i)/\Sigma(\alpha_i/Rfd_i), \text{ where}$$

α_i is the total used of pesticide nr i, in kg/year and Rfd is the reference dose in kg, a correction is made of the average contribution a with a potency factor of

$$Rfd_{mean}/Rfd_i,$$

where $Rfd_{mean} = n/\Sigma(1/Rfd_i)$. It is thus assumed that all pesticides are use in equal amounts. Below, estimation is made of the uncertainty introduced by this simplification.

Calculation of characterisation factor
In table 8.2 reference doses for various pesticides are given and the characterisation factors calculated. For the average pesticide, the characterisation factor is estimated to $6\cdot10^5*2.78\cdot10^{-10} = 1.67\cdot10^{-4}$ YOLL/kg.

Uncertainty
There is no systematic register where the amount of pesticides, which are used globally may be found. Nor has an estimate been available of how many percent of the global use that may be ascribed to different pesticides. The health statistics are also uncertain, partly because all cases are not reported and because, the duration and severity are not compiled in a way that is suitable for impact valuation.
Together this is thought to result in an uncertainty that may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

8.1.4. Characterisation of pesticides to all media with respect to severe morbidity

Definition of environmental system in which the impact is estimated
The same system borders are used as for YOLL, i.e. global and for the year 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
According to WHO/FAO there is about 2 – 3.5 million cases of acute poisoning from pesticides annually. A best estimate of 3 million will be used here. The average duration of the morbidity or the severity is not reported. It is assumed here, that the average duration of severe morbidity is 0.01 year and equally for morbidity. This would imply a total indicator value of 30 000 person-years per year.

Contribution to category indicators value from a flow unit
The contributions are the same as for 8.1.3, i.e. $Rfd_{mean}/Rfd_i*2.78\cdot10^{-10}$ per kg pesticide

Calculation of characterisation factor
See table 8.2

Uncertainty
There is no systematic register where the amount of pesticides, which are used globally may be found. Nor has an estimate been available of how many percent of the global use

that may be ascribed to different pesticides. The health statistics are also uncertain, partly because all cases are not reported and because, the duration and severity are not compiled in a way that is suitable for impact valuation.

Together this is thought to result in an uncertainty that may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

8.1.5. Characterisation of pesticides to all media with respect to morbidity

Definition of environmental system in which the impact is estimated
The same system borders are used as for YOLL, i.e. global and for the year 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
According to WHO/FAO there is about 2 – 3.5 million cases of acute poisoning from pesticides annually. A best estimate of 3 million will be used here. The average duration of the morbidity or the severity is not reported. It is assumed here, that the average duration of severe morbidity is 0.01 year and equally for morbidity. This would imply a total indicator value of 30 000 person-years of severe morbidity per year.

Contribution to category indicators value from a flow unit
The contributions are the same as for 8.1.3.

Calculation of characterisation factor
See table 8.2

Uncertainty
There is no systematic register where the amount of pesticides, which are used globally may be found. Nor has an estimate been available of how many percent of the global use that may be ascribed to different pesticides. The health statistics are also uncertain, partly because all cases are not reported and because, the duration and severity are not compiled in a way that is suitable for impact valuation.

Together this is thought to result in an uncertainty that may be described by a log-normal distribution with a standard deviation corresponding to a factor of 3.

8.1.6. Characterisation of pesticides to all media with respect to NEX

Definition of environmental system in which the impact is estimated
The same system borders are used as for YOLL, i.e. global and for the year 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered

Pesticides are often claimed to be a significant threat to some species. Only a few studies has been found that quantify what part of the red-listed species that is threatened by chemicals (Järvinen and Miettinen, 1987). One is from Sweden, where 13 out of 140 (9%) red-listed species were found to be threatened by “environmental toxins” and one from Finland where 72 out of 1041 species (7%) were threatened due to “chemicals”.

It is not clear what part of these chemicals or toxins that constitutes of pesticides, but it seems reasonable to assume that it is a major part and in the order of 5%.

Contribution to category indicators value from a flow unit

The contributions are the same as for 8.1.3.

Calculation of characterisation factor

See table 8.2

Uncertainty

There is no systematic register where the amount of pesticides, which are used globally may be found. Nor has an estimate been available of how many percent of the global use that may be ascribed to different pesticides. The statistics on impacts on endangered species are also uncertain, mainly because of impacts from other stress forms at the same time. Together this is thought to result in an uncertainty that may be described by a log-normal distribution with a standard deviation corresponding to a factor of 5.

Table 8.2 Characterisation factors for pesticides

Substance name	CASRN	Reference dose (Rfd) for chronical oral exposure (mg/kg,day)	1/Rfd	Potency factor	YOLL/kg	Severe morbidity, p-yr/kg	Morbidity, p-yr/kg	Bio-diversity, NEX
Alachlor	15972-60-8	0.01	100	0.0215	3.579E-06	1.79E-07	1.79E-07	2.98E-13
Aldicarb	116-06-3	0.001	1000	0.215	3.579E-05	1.79E-06	1.79E-06	2.98E-12
Aldrin	309-00-2	0.00003	33333	7.15	0.0011929	5.96E-05	5.96E-05	9.94E-11
Atrazine	1912-24-9	0.035	28.571	0.00613	1.023E-06	5.11E-08	5.11E-08	8.52E-14
Benomyl	17804-35-2	0.05	20	0.00429	7.158E-07	3.58E-08	3.58E-08	5.96E-14
Captan	133-06-3	0.13	7.6923	0.00165	2.753E-07	1.38E-08	1.38E-08	2.29E-14
Carbaryl	63-25-2	0.1	10	0.00215	3.579E-07	1.79E-08	1.79E-08	2.98E-14
Carbofuran	1563-66-2	0.005	200	0.0429	7.158E-06	3.58E-07	3.58E-07	5.96E-13
Chlordane	12789-03-6	0.0005	2000	0.429	7.158E-05	3.58E-06	3.58E-06	5.96E-12
Chlorpyrifos	2921-88-2	0.003	333.33	0.0715	1.193E-05	5.96E-07	5.96E-07	9.94E-13
Cypermethrin	52315-07-8	0.01	100	0.0214	3.579E-06	1.79E-07	1.79E-07	2.98E-13
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	0.01	100	0.0214	3.579E-06	1.79E-07	1.79E-07	2.98E-13
Demeton	8065-48-3	0.00004	25000	5.36	0.0008947	4.47E-05	4.47E-05	7.45E-11

Table 8.2, Characterisation factors for pesticides, continued

Substance name	CASRN	Reference dose (Rfd) for chronical oral exposure (mg/kg,day)	1/Rfd	Potency factor	YOLL/kg	Severe morbidity, p-yr/kg	Morbidity, p-yr/kg	Bio-diversity, NEX
Dichlorvos (DDVP)	62-73-7	0.0005	2000	0.429	7.158E-05	3.58E-06	3.58E-06	5.96E-12
Dieldrin	60-57-1	0.00005	20000	4.291	0.0007158	3.58E-05	3.58E-05	5.96E-11
Diflubenzuron	35367-38-5	0.02	50	0.0107	1.789E-06	8.95E-08	8.95E-08	1.49E-13
Dimethoate	60-51-5	0.0004	2500	0.536	8.947E-05	4.47E-06	4.47E-06	7.45E-12
Diquat	80-00-7	0.0022	455	0.0975	1.627E-05	8.13E-07	8.13E-07	1.35E-12
Disulfoton	298-04-4	0.00004	25000	5.36	0.0008947	4.47E-05	4.47E-05	7.45E-11
Endosulfan	115-29-7	0.006	166.6	0.0357	5.965E-06	2.98E-07	2.98E-07	4.97E-13
Endrin	72-20-8	0.0003	3330.	0.715	0.0001193	5.96E-06	5.96E-06	9.94E-12
Fenamiphos	22224-92-6	0.00025	4000	0.858	0.0001432	7.16E-06	7.16E-06	1.19E-11
Glyphosate	1071-83-6	0.1	10	0.00215	3.579E-07	1.79E-08	1.79E-08	2.98E-14
Heptachlor	76-44-8	0.0005	2000	0.429	7.158E-05	3.58E-06	3.58E-06	5.96E-12
Hexachlorbenzene	118-74-1	0.0008	1250	0.268	4.474E-05	2.24E-06	2.24E-06	3.73E-12
Lindane	58-89-9	0.0003	3330	0.715	0.0001193	5.96E-06	5.96E-06	9.94E-12
Malathion	121-75-5	0.02	50	0.0107	1.789E-06	8.95E-08	8.95E-08	1.49E-13
Methomyl	16752-77-5	0.025	40	0.00858	1.432E-06	7.16E-08	7.16E-08	1.19E-13
Methoxychlor	72-43-5	0.005	200	0.0429	7.158E-06	3.58E-07	3.58E-07	5.96E-13
Naled	300-76-5	0.002	500	0.107	1.789E-05	8.95E-07	8.95E-07	1.49E-12
Oxamyl	23135-22-0	0.025	40	0.00858	1.432E-06	7.16E-08	7.16E-08	1.19E-13
Paraquat	1910-42-5	0.0045	222	0.0476	7.953E-06	3.98E-07	3.98E-07	6.63E-13
Permethrin	52645-53-1	0.05	20	0.00429	7.158E-07	3.58E-08	3.58E-08	5.96E-14
Phosphine	7803-51-2	0.0003	3330	0.715	0.0001193	5.96E-06	5.96E-06	9.94E-12
Pirimifos-methyl	29232-93-7	0.01	100	0.0214	3.579E-06	1.79E-07	1.79E-07	2.98E-13
Propachlor	1918-16-7	0.013	76.9	0.0165	2.753E-06	1.38E-07	1.38E-07	2.29E-13
Resmethrin	10453-86-8	0.03	33.3	0.00715	1.193E-06	5.96E-08	5.96E-08	9.94E-14
Sodium fluoracetate	62-74-8	0.00002	50000	10.7	0.0017894	8.95E-05	8.95E-05	1.49E-10
Thallium sulfate	7446-18-6	0.00008	12500	2.68	0.0004474	2.24E-05	2.24E-05	3.73E-11
Thiram	137-26-8	0.005	200	0.0429	7.158E-06	3.58E-07	3.58E-07	5.96E-13
2,4,5,-Trichlorophenoxyacetic acid (2,4,5-T)	93-76-5	0.01	100	0.0214	3.579E-06	1.79E-07	1.79E-07	2.98E-13
Warfarin	81-81-2	0.0003	3330	0.715	0.0001193	5.96E-06	5.96E-06	9.94E-12
Zinc phosphide	1314-84-7	0.0003	3330	0.715	0.0001193	5.96E-06	5.96E-06	9.94E-12
	average	0.0002146	4660					

9. Classification and characterisation of emissions of particles to air

There are several types of emissions contributing to particle concentrations in ambient air. In many LCA studies the information available only says that there is an emission of dust or particles. This means that there is at least a need for a characterisation model for particle emissions in general, regardless of where on earth it occurs but relevant for our time. This type of elementary flow population will be referred to below as dust-global.
Other types of elementary dust flow populations of interest are fractions with defined particle size, like PM_{10} and $PM_{2.5}$ representing particles with aerodynamic diameters less than 10 or 2.5 micrometer. In the same way as for dust-global they will be referred to below as PM_{10}-global and $PM_{2.5}$-global.

9.1. Emissions of PM_{10} to air anywhere in the world

9.1.1. Definition of flow group:

Particles with diameters less than 10 μm, PM_{10} are emitted from industrial processes, from traffic and from land use activities. There are also large quantities of particles dispersed into air from natural processes, such as wind erosion, sea spray, forest fires and volcanoes.

The population of flows characterised includes anthropogenic emissions of particles having an aerodynamic diameter less than 10 μm to ambient air, anyplace in the world 1990, at any source strength. The particles are assumed to be of normal chemical composition compared to what is found in ambient air. Toxic effects due to components in the particles are included but only from substances present in normal quantities. This means that there is a risk for double counting if for instance impacts of PAC are treated separately and they are present in particles at normal quantities.

Considering the global population exposure, a major contribution comes from indoor combustion sources. Indoor impacts are not included in this assessment, but the outdoor impacts caused by the part of emissions entering the ambient atmosphere are treated in the same way as direct emissions.

9.1.2. Assignment to impact categories

Particles in ambient air have mainly two types of effects, health effects and soiling effects.

The health effects are believed to be mainly caused by two mechanisms, cancer induction and decreased lung capacity. The cancer effects are in turn mainly caused by polyaromatic compounds and the decreased lung capacity from secondary effects of lung clearing. Decreased lung capacity may be of acute inflammatory type and of more chronic type from long time exposure. Evans and Wolf (1996) suggest a model for chronic impacts based on similarity of aerosol stress with natural ageing of the lung. Category indicators such as YOLL, severe morbidity, morbidity and nuisance will be affected.

Some effects may be classified as severe nuisance, such as heavy dust-fall and irritation in eyes and respiratory tract. These impact are not modelled here as the basis for modelling is weak and as other health issues are expected to be more significant.

Soiling effects have mostly to do with the optical properties of the particles. Some effects are also caused by skin contact. Soiling on walls and other surfaces is to a large extent caused by particles larger than 10 microns, but some of these may be agglomerates of PM_{10} particles. Particles suspended in air absorbs and scatters light and will nuisance (from haze) and impact on the regional radiation balance of the atmosphere. In case of impacts on the radiation balance the whole spectrum of category indicators influenced by CO_2 and other greenhouse gases apply, i.e. YOLL, severe morbidity, morbidity, NEX, wood and crop growth. The possibilities of modelling characterisation factors for greenhouse effects are however limited. Equivalency factors for particles are not available, as its theory require uniform mixing in the atmosphere to apply. Particles are unevenly distributed and influence the radiation balance directly through light scattering and absorption and indirectly via acting as condensation nuclei. Calculations made by Rodhe et al (IPPC, 1995) indicate that particles may counteract almost the entire surface temperature raise in certain northern areas.

There are thus two conflicting arguments for and against the assignment of PM_{10} to greenhouse effects. The significant size of impact is speaking for an assignment. The lack of acceptable models speaks against it. However, following the hierarchy of principles the requirement for completeness win and particle emissions are assigned to category indicators affected by global warming. The assignments are specified in table 9.1

Table 9.1 Assignment of PM_{10} emissions to impact categories and selection of category indicators

Pathway(s)	**Impact category**	**Category indicator**
Direct exposure, acute effects	Life expectancy	YOLL
Direct exposure, chronic effects	Life expectancy	YOLL
Global warming	Life expectancy	YOLL
Direct exposure, acute effects	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Direct exposure, acute effects	Morbidity	Morbidity
Global warming	Morbidity	Morbidity
Direct exposure and soiling	Severe nuisance	Not modelled
Direct exposure	Nuisance	Nuisance
Global warming	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

9.1.3. Characterisation of PM_{10} to air with respect to YOLL

Definition of environmental system in which the impact is estimated

Particles become airborne through two types of processes: dispersion and condensation. Dispersion aerosols consist of comparatively large particles: from a few microns to several hundred microns, while condensation aerosols consist of particles from 0.001 to a few microns.

The residence time of particles in air strongly depends of its size. A 10 μm particle has a settling velocity hundred times that of a 1 μm particle. The residence time is also influenced by condensation of water. During rain, particles are either trapped in the clouds when water vapour condense or by the falling drops through impaction. Particles between 0.1 and 1 microns are effective condensation nuclei, but are not efficiently caught by falling raindrops. For this, the size has to be larger than about 2 μm.

The processes of emissions and depositions tend to stabilise the particle size distribution in air into a two-peak pattern. The fine particles often called the accommodation mode, are normally less than 2.5 μm and have a residence time in air in the order of several days. The large particles stay airborne during minutes to hours, and those found in air are normally of local origin. The emission of large particles depends heavily on humidity and wind velocity. In terms of mass concentration large particles may dominate occasionally while small particles have more stable concentrations and are considered to have a more severe impact on the environment such as human health effects after inhalation and effects due to soiling when deposited on surfaces.

Sources of particles are widespread and frequent. Energy production, traffic, agriculture and various industrial activities contribute.

Considering the location of sources to urban areas and the dispersion patterns, most of the exposure and effects on humans are likely to occur in the urban area where the emission occur. It would thus be possible to make characterisation models for each urban area without having to allocate effects to trans-boundary flows.

For this characterisation model, we chose global system borders. The time period investigated is the year 1990.

Model 1, pathways via acute effects

The characterisation factor is determined by the empirical method.

Total category indicator value in system considered

The first studies that were made on correlation between concentration of particles in ambient air and excess mortality were made on a day to day basis. Daily statistics were compared. Many studies were performed, with varying results. Typical values found of elasticity were in the range of 0.63 to 1.30 excess cases per 1000 deaths and $\mu g/m^3$ PM_{10} concentration with an average of 0.96 (Rosendahl, 1998).
When estimating the social costs of these effects the problem arises to estimate if this was a one-day premature death or more. When looking at the age statistics it shows that the increase of mortality mainly concerns elderly above 65 years. Rosendahl, (1998) concludes that there is no information about to which extent life shortening takes place, but if the average life time is in the order of 75 years, it seems reasonable to assume (applying the precautionary principle) that the years of lost life is less than 5 years, with an average reduction of 2.5 and an uncertainty range of 0.1-10 years. Rabl (1997) assumes that the mean reduction of life expectancy is 0.5 years corresponding to $4.68 \cdot 10^{-6}$ YOLL per person per $\mu g/m^3$ per year. In view of the more severe chronic impacts ($2.6 \cdot 10^{-4}$ YOLL per $\mu g/m^3$, year and person, (see below)) the uncertainty does not seem to be crucial for the estimation of the overall effect. Considering the pattern of variation in particle concentrations it seems as even Rabl's estimation is conservative, why this figure will be used in the modelling of characterisation factors below.

The concentrations in various parts of the world vary, and few estimations have been made on a regional basis. Some are shown below in table 9.2

Table 9.2 Estimated average concentrations from various parts of the world. *) calculated from TSP/PM_{10} ratio. xx) Darlington et al (1997), yy) EAA, zz) Brook, (1997)

Concentration, µg/m3	Population, mill. inhab.			
		PM2.5	PM10	TSP
USA	250		27 (xx)	
Europe, E15	364		35 (yy)	
Canada	26		18 *)	40 (zz)

Typical values in Tokyo are in the order of 50 $\mu g/m^3$ for TSP. For the non-OECD world, TSP concentrations are considerably higher than in OECD countries. UNEP/WHO made a study in 20 megacities (1992) and found concentration levels as shown in table 9.3.

Table 9.3 Measured concentrations of total suspended particular matter (TSP) in twenty megacities in the world. UNEP/WHO (1992). * Smoke, **PM_{10}.

City	Population	TSP-level,(μg/m3)
Bankok	7.16	150
Beijing	9.74	350
Bombay	11.13	220
Buenos Aires	11.58	300
Cairo	9.08	120
Calcutta	11.83	400
Dehli	8.62	400
Jakarta	9.42	300
Karachi	7.67	400
London	10.57	20*
Los Angeles	10.47	50**
Manila	8.4	150
Mexico City	19.37	350
Moscow	9.39	100
New York	15.65	60
Rio de Janerio	11.12	100
Sao Paulo	18.42	70
Seoul	11.33	150
Shanghai	13.3	250
Tokyo	20.52	50

The concentration ratio between the non-OECD and OECD cities is about (should be 3.5?) 4.5. As 50% of the population in non OECD countries live in urban rural areas and as more than 80 % of the population in OECD countries live in urban areas, the ratio ought to be a little less in terms of exposure to the entire population. Assuming that the ratio also is relevant for PM_{10}, that there is negligible exposure on the countryside and as about 1.2 billion live in the OECD world and 4.1 outside, the population weighted average concentration will be about 46 $\mu g/m^3$, causing $1.14 \cdot 10^6$ YOLLs per year.

Contribution to total category indicators value from a flow unit

The global emission of PM_{10} contributing to the population exposure is not known, but attempt have been made in some areas to estimate emissions of particles and gases that form particles in the atmosphere.

Table 9.4 Emissions of PM_{10} primary and secondary in various areas. The US figures include road dust and other fugitive emissions.

Substance\area	EU	USA	World
	Primary emissions, (million tonnes)		
Dust	4 ***)	10 ***)	57 ***)
PM_{10}		42 **)	
$PM_{2.5}$		10 **)	
Emissions of precursors to secondary particles			
SO_2	11 ***)	21 ***)	99 ***)
SO_2	17.0 *)	22 **)	
NO_x	13 ***)	20 ***)	68 ***)
NO_x	13.6 *)	23 **)	
NH_3			
Total $PM_{2.5}$		55 **)	
Total PM_{10}		97 **)	

*) EU15, EEA 1997, **) USEPA 1996, ***) OECD 1991

When comparing estimations of particulate emissions from different regions it is apparent that the knowledge about which emissions that really occur is insufficient, and that the use of official figures of known emissions will give results that are too low. The best figures seem to come from the US.

To estimate the global emission of PM_{10} from technical processes an indirect method will be used. This assumes that SO_2 emissions are fairly well known as well as the average concentration of SO_2 and TSP in some of the worlds megacities and that the per capita emission of particles is representative for the rest of the worlds urban areas. It also assumes that the ratio of total yearly emission in megacities is the same as the ratio of yearly averages of concentrations in ambient air. The rational for this is that the sink processes are not fast enough to considerably decrease the amount of SO_2 and TSP that is emitted from technical processes and that megacities are big enough to allow good mixing of emitted SO_2 and TSP. The residence time for SO_2 is in the order of several days and the wind velocity is in the order of meters per second, bringing emitted SO_2 out of the area in a few hours. Some of the emitted TSP particles may be deposited giving a lower TSP-concentration than expected from the emission ratios. In table 9.5 below it can be seen that in cities where the knowledge of the air pollution situation is good, such as in New York and Los Angeles, the TSP/SO_2 ratio are approximately the same for emissions and concentrations in ambient air, while they are very different in Bangkok, Beijing and Bombay. In Beijing, a large contribution from soil can explain some of the difference. In Bombay, there may also be diffuse emissions, but the difference may also be explained by the separation of the various source areas. Table 9.5 represents a spreadsheet calculation of the per capita emission of TSP in various megacities. The average per capita emission is 50 kg per year, when Beijing and Bombay are excluded. Using a typical TSP to PM_{10} ratio of 2, and assuming that the megacities in table 9.5 represents an average urban life style in the world, we obtain a total emission from the worlds 3 billion urban inhabitants of 74 million tons per year. Assuming the rural emissions from technical processes is about half of the urban (excluding industrial processes but including domestic and traffic) we obtain a total global PM_{10} emission of about 100 million tons per year.

Table 9.5 Spreadsheet calculation of average per capita TSP emission in 12 megacities. In London and Los Angeles the original figures on particles are for smoke and PM_{10}. The TSP figures have been calculated through multiplying with a factor of two. This has no effect on the ratio of TSP/SO_2 in emissions to TSP/SO_2 in air or the adjusted per capita emission.

A	B	C	D	E	F	G	H	I	J	K	L	M
City	Population	Year of measurements	SOx-emission	TSP-emission	SO_2-level	TSP-level,	TSP/ SO_2, emissions E/D	TSP/ SO_2, in air G/F	Ratio emission/air H/I	Per capita emission E/B	Adjusted per capita emission, 1 K/J	Adjusted per capita emission, 2 K/J
	million inhabitants		kton/yr	kton/yr	μg/m3	μg/m3				kg/p, yr	kg/p, yr	Kg/p, yr
Bangkok	7.16	1980	120	40	16	150	0.333	9.37	0.0355	5.6	158	158
Beijing	9.74	1985	526	115	80	350	0.218	4.37	0.0500	11.8	236	
Bombay	11.13	1990	157	50	20	220	0.318	11	0.0295	4.5	155	
Calcutta	11.83	1990	25.5	200	50	400	7.84	8	0.981	16.9	17.2	17.2
Dehli	8.62	1990	46	116	30	400	2.52	13.3	0.189	13.5	71.2	71.2
London	10.57	1983	49	22	40	40	0.449	1	0.449	2.08	4.63	4.63
Los Angeles	10.47	1987	50	800	5	100	16	20	0.8	76.4	95.5	95.5
Manila	8.4	1987	148	69	30	150	0.466	5	0.0932	8.2	88.1	88.1
Mexico City	19.37	1989	206	451	150	350	2.19	2.33	0.9388	23.3	24.8	24.8
New York	15.65	1985	55	112	40	60	2.04	1.5	1.36	7.16	5.27	5.27
Rio de Janerio	11.12	1978	188	194	90	180	1.03	2	0.516	17.4	33.8	33.8
Sao Paulo	18.42	1990	122	77	45	70	0.63	1.55	0.405	4.18	10.3	10.3
Seoul	11.33	1989	380	90	160	150	0.237	0.937	0.253	7.94	31.4	31.4
Shanghai	13.3	1983	267	324	80	250	1.21	3.12	0.388	24.4	62.7	62.7
									mv	16.0	71.0	50.2

When calculating the contribution to the total YOLLs estimated above it is however necessary to consider the secondary particles formed from SO_2, NO_x and VOC emissions. According to USEPA cited by Wilson and Spengler (1996) PM_{10} consists of about 1/3 ammonium sulphates + nitrates, 1/3 of organic substances and 1/3 of minerals. Primary particles are therefore estimated to contribute with 2/3 as an average to the YOLLs estimated above. If one looks at the situation in rural areas the contribution is much smaller, but as a population exposure weighted average the 2/3-factor may be relevant for a large part of the world. The contribution to the YOLLs will therefore be $2/3 \cdot 10^{-11}$ per kg of PM_{10}.

Calculation of pathway specific characterisation factor
$1.14 \cdot 10^{6}$ YOLLs per year $*2/3 \cdot 10^{-11}$ per kg of $PM_{10} = 7.60 \cdot 10^{-6}$ YOLL/kg of PM_{10}

Uncertainty
The main uncertainty in the determination of the global average PM_{10}-concentrations for 1990 lies in the lack of measurements in most of the areas where people are exposed. The measurements that are made are not random samples on global population exposure. They are primarily data from developed countries with environmental management programs and are primarily from areas and time periods where there is a risk of exceeding local standards. However as the sources of PM_{10} and geography of cities have similarities in various part of the world, the uncertainty in the overall global average is assumed to be less than 30%. As most PM_{10} exposures mainly are caused by local sources in the urban complex, the contribution factor may vary considerably. For ground level sources like cars and trucks, the probability of a particle being inhaled declines rapidly with the distance from the source and in a few hundred meters it is negligible compared to the initial. This means that the contribution to the population dose is highly dependent on the population density, which varies from a few persons per hectare to several hundreds in large cities. Depending on the size and distribution of the technical system investigated in the LCA (e.g. one piece of product or a series in various places) the uncertainty in the contribution estimate may vary from a factor of ten to a factor of two. As a default value a log-normal uncertainty distribution with a standard deviation corresponding to a factor of 3 is used.

Model 2, pathways via chronic effects, such as cancer and decreased lung capacity
The characterisation factor is determined by an empirical method.

Total category indicator value in system considered
The global population weighted average concentration was determined in model 1 to 46 $\mu g/m^3$. The risk, calculated by Rabl (1997) on the basis of results from Dockery and Pope, is $2.61 \cdot 10^{-4}$ YOLL per person per year per $\mu g/m^3$. The total impact on the globe will thus be $6.34 \cdot 10^{7}$ YOLLs per year.

Contribution to category indicators value from a flow unit
The same contribution apply as for model 1, i.e. $2/3 \cdot 10^{-11}$ per kg of PM_{10}.

Calculation of pathway specific characterisation factor
$6.34 \cdot 10^{7}$ YOLLs per year $*2/3 \cdot 10^{-11}$ per kg of $PM_{10} = 4.23 \cdot 10^{-4}$ YOLL/kg of PM_{10}

Uncertainty
The same type of uncertainty as for model 1 is assumed, i.e. a log-normal uncertainty distribution with a standard deviation corresponding to a factor of 3.

Model 3, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The radiative forcing from CO_2 is 1.5 W/m^2 (IPCC, 1994) and from tropospheric aerosols –0.9 W/m^2. The radiative forcing, F, is as a first approximation proportional to the global warming potential (GWP) and the global emission of a substance. The global emission is in turn proportional to the global average concentration C, divided by its average residence time, T. Thus

$$F = K*GWP*C/T \quad \text{or}$$

$$GWP_1*C_1/(T_1*F_1) = GWP_2*C_2/(T_2*F_2)$$

The global average concentrations of CO_2 and PM_{10} are 712 mg/m^3 and about 0.01 mg/m^{3}respectively. The residence time is about 100 and 0.02 years respectively. The GWP for CO_2 is 1. The GWP for PM_{10} may thus be derived as 712*(0.02*(-0.9))/(100*1.5*0.01) = – 8.54 relative to CO_2.

Calculation of pathway specific characterisation factor

The characterisation factor will be $-8.54 * 7.93 \cdot 10^{-7} = -6.77 \cdot 10^{-6}$ YOLL/kg PM_{10}, where $7.93 \cdot 10^{-7}$ is the added characterisation factors of four pathways for CO_2's impacts on YOLL.

Uncertainty

The uncertainty of the characterisation factors for CO_2 with respect to YOLL was estimated to a factor of ten. The uncertainty for the radiative forcing as indicated by IPCC (1994) is in the order of a factor of 3.

Mathematically the uncertainty is assumed to be represented by a lognormal distribution with a standard deviation corresponding to a factor of 4.

Calculation of the characterisation factor

The characterisation factor will be $7.60 \cdot 10^{-6} + 4.23 \cdot 10^{-4} - 6.77 \cdot 10^{-6} = 4.24 \cdot 10^{-4}$ YOLL/kg PM_{10}

9.1.4. Characterisation of PM_{10} to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

For reasons mentioned in 9.1.3 global system borders are chosen. The time period investigated is the year 1990

Model 1, acute effects and hospitalisation pathway

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

Rosendahl (1998) estimates the elasticity in hospitalisation due to increased mean PM_{10} concentrations for Norway to 20 – 30 'bed-days' per 100000 inhabitants and year and $\mu g/m^3$. The ExternE project (1995) estimates hospital admission for Respiratory Infections and Chronic Obstructive Pulmonary Disease to $1.87 \cdot 10^{-6}$ and $2.27 \cdot 10^{-6}$ cases per person per year per $\mu g/m^3$ respectively. They assume that the average time for hospitalisation is about 25 days. ExternE also use figures for changes in emergency room visits for asthma of $1.29\ 10^{-5}$, for emergency room visits for Chronic Obstructive Pulmonary Disease to $7.2 \cdot 10^{-6}$ and hospital visits for childhood croup of $2.91\ 10^{-5}$ cases per person per year per $\mu g/m^3$. The duration of the effect is assumed (here) to be 1 day.

Therefore the value $4.14 \cdot 10^{-6} * (25/365) + 4.92\ 10^{-5} * (1/365) = 4.18 \cdot 10^{-7}$ person-years per person per year per $\mu g/m^3$ is used as a model for the exposure-response function for average PM_{10} concentration and severe morbidity.

Using the global average of 46 $\mu g/m^3$, which was estimated in 9.1.3, a total global severe morbidity of 102000 person-years per year is obtained.

Contribution to category indicators value from a flow unit

The same contribution apply as for model 1 in section 9.1.3, i.e. $2/3 \cdot 10^{-11}$ per kg of PM_{10}.

Calculation of pathway specific characterisation factor

$102000 * 2/3 \cdot 10^{-11} = 6.80 \cdot 10^{-7}$ person-years/kg PM_{10}

Uncertainty

The uncertainty comes from lack of information of which hospitalisation that is severe morbidity and from not knowing the extent of cases not being taken to hospital and still being severe morbidity. There are also several asthma attacks that could be classified as severe morbidity, but according to ExternE the added duration of all attacks are short compared to the chronic effects. To some extent the elasticity found through epidemiological observations may not be causal. PM_{10} can be an indicator for other factors influencing the effects measured. Considering this the uncertainty is guessed to be a factor of five.

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP for PM_{10} was determined to – 8.54 in section 9.1.3

Calculation of pathway specific characterisation factor

The characterisation factors for CO_2 with respect to severe morbidity was determined in 3.1.4 to $3.53 \cdot 10^{-7}$ person-years/kg CO_2. Thus we obtain the characterisation factor for PM_{10} to $-8.54 * 3.53 \cdot 10^{-7} = -3.01 \cdot 10^{-6}$ person-years/ kg PM_{10}.

Uncertainty

The uncertainty of the characterisation factors for CO_2 with respect to morbidity was estimated to a factor of ten. The uncertainty for the global average radiative forcing as indicated by IPCC (1994) is in the order of a factor of 3.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor

The characterisation factor for both pathways is thus $6.80 \cdot 10^{-7} - 3.01 \cdot 10^{-6} = -2.33 \cdot 10^{-6}$ person-years/ kg PM_{10}.

9.1.5. Characterisation of PM_{10} to air with respect to morbidity

All the health effects on the respiratory system leading to hospital admission are classified as severe morbidity. The only effect listed by ExternE which are classified as morbidity is ‘shortness in breath’ days for asthmatics.

Definition of environmental system in which the impact is estimated

For reasons mentioned in 9.1.3 global system borders are chosen. The time period investigated is the year 1990

Model 1, acute effects

The characterisation factor is determined by an empirical method.

Category indicator value in system considered

ExternE (1995) estimate the exposure-response functions for ‘shortness in breath’ days for asthmatics to 0.14 per person-days per asthmatic per year per $\mu g/m^3$. A rough estimation of the number of asthmatics in the world is that 10% of the OECD population of 1.2 billion is asthmatics and none outside OECD. This gives $0.1 * 1.2 \cdot 10^9 * 0.14/365 * 30 = 1.38 \cdot 10^6$ person-years of morbidity, where 30 $\mu g/m^3$ is the estimated average PM_{10} concentration in the OECD countries (see 9.1.3).

Contribution to category indicators value from a flow unit

The same contribution apply as for model 1 in section 9.1.3, i.e. $2/3 \cdot 10^{-11}$ per kg of PM_{10}.

Calculation of pathway specific characterisation factor

$1.38 \cdot 10^6 * 2/3 \cdot 10^{-11} = 9.20 \cdot 10^{-6}$ person-years/kg PM_{10}.

Uncertainty

The same type of uncertainties apply as for 9.1.4

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2.

Model 2, global warming pathway
The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor
The GWP for PM_{10} was determined to – 8.54 in section 9.1.3

Calculation of pathway specific characterisation factor
The characterisation factor for CO_2 with respect to morbidity was determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg CO_2. Thus we obtain the characterisation factor for PM_{10} to $-8.54 * 6.55 \cdot 10^{-7} = -5.59 \cdot 10^{-6}$ person-years/ kg PM_{10}.

Uncertainty
The uncertainty of the characterisation factors for CO_2 with respect to morbidity was estimated to a factor of ten. The uncertainty for the global average radiative forcing as indicated by IPCC (1994) is in the order of a factor of 3.

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

Calculation of characterisation factor
The characterisation factor for both pathways is thus $9.20 \cdot 10^{-6} - 5.59 \cdot 10^{-6} = 3.61 \cdot 10^{-6}$ person-years/ kg PM_{10}.

9.1.6. Characterisation of PM_{10} to air with respect to nuisance

Definition of environmental system in which the impact is estimated
For reasons mentioned in 9.1.3 global system borders are chosen. The time period investigated is the year 1990

Model
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
ExternE (1995) use data from Ostro et al and Krupnick et al. on exposure-response functions for ‘restricted activity days’ and ‘symptom days’ of $49.9 \cdot 10^{-3}$ and $465 \cdot 10^{-3}$ per person per year per $\mu g/m^3$ respectively. This will result in $0.515/365 * 46 * 5.28 \cdot 10^9 = 3.43 \cdot 10^8$ person-years.

Contribution to category indicators value from a flow unit
The same contribution apply as for model 1 in section 9.1.3, i.e. $2/3 \cdot 10^{-11}$ per kg of PM_{10}.

Calculation of characterisation factor
$3.43 \cdot 10^8 * 2/3 \cdot 10^{-11} = 2.28 \cdot 10^{-3}$ person-years/kg PM_{10}

Uncertainty
The same type of uncertainties apply as for 9.1.4

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2.

9.1.7. Characterisation of PM_{10} to air with respect to crop

Definition of environmental system in which the impact is estimated
For reasons mentioned in 9.1.3 global system borders are chosen. The time period investigated is the year 1990

Model
The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor
The GWP for PM_{10} was determined to – 8.54 in section 9.1.3

Calculation of characterisation factor
The characterisation factor for CO_2 with respect to crop loss was determined in 3.1.6. to $7.56 \cdot 10^{-4}$ kg crop per kg CO_2. Thus we obtain the characterisation factor for PM_{10} to $-8.54 * 7.56 \cdot 10^{-4} = -6.46 \cdot 10^{-3}$ per kg PM_{10}.

Uncertainty
The uncertainty for the CO_2 characterisation factor was estimated in 3.1.6 to a factor of 5. An additional uncertainty for the global average radiative forcing of particles as indicated by IPCC (1994) is in the order of a factor of 3.

In statistical terms the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.4.

9.1.8. Characterisation of PM_{10} to air with respect to wood growth

Definition of environmental system in which the impact is estimated
For reasons mentioned in 9.1.3 global system borders are chosen. The time period investigated is the year 1990.

Model
The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP_{100} for PM_{10} was determined to – 8.54 in section 9.1.3.

Calculation of characterisation factor

The global warming pathway specific characterisation factor for CO_2 with respect to wood was determined in 3.1.7. to – 0.00116 kg wood per kg CO_2. Thus we obtain the characterisation factor for PM_{10} to $-8.54*(-0.00116) = 0.00991$ kg wood per kg PM_{10}.

Uncertainty

A log normal error distribution with a standard deviation corresponding to a factor of two was assumed in 3.1.7 to apply for the CO_2 fertilisation characterisation factor, which gives the largest contribution to the overall CO_2/wood growth characterisation factor. As for crop loss an extra uncertainty of a factor of three results from the equivalency factor of PM_{10} versus CO_2.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.2.

9.1.9. Characterisation of PM_{10} to air with respect to NEX

Definition of environmental system in which the impact is estimated

For reasons mentioned in 8.1.3 global system borders are chosen. The time period investigated is the year 1990

Model

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP for PM_{10} was determined to – 8.54 in section 9.1.3

Calculation of characterisation factor

The characterisation factor for CO_2 with respect to NEX was determined in 3.1.8. to $1.26 \cdot 10^{-14}$ per kg CO_2. Thus we obtain the characterisation factor for PM_{10} to $-8.54*1.26 \cdot 10^{-14} = -1.08 \cdot 10^{-13}$ NEX per kg PM_{10}.

Uncertainty

The uncertainty of the characterisation factors for CO_2 with respect to NEX was estimated to a factor of ten. The uncertainty for the global average radiative forcing as indicated by IPCC (1994) is in the order of a factor of 3.

Mathematically the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

9.1.10. Trends

The assessments above were mostly made with data relevant for 1990. It seems as PM_{10} concentrations have decreased in the OECD since 1990. USEPA says (1996)*"Ambient PM_{10} concentrations decreased 25 percent between 1988 and 1996 and decreased 4 percent between 1995 and 1996. PM_{10} estimated emissions (excluding fugitive emissions and emissions from natural sources) decreased 12 percent between 1988 and 1996 and remained unchanged between 1995 and 1996"*

As the most important exposure-response function is linear, the only things that substantially could alter the characterisation factors are altered dispersion-exposure patterns or a change in size distribution or composition of PM_{10} particles.

Trends such as the growth of urban areas in the developing countries, modernisation of car technology and urban planning may change the characterisation factors but such changes are assumed to be small compared to the uncertainty in the models used.

9.2. Emissions of $PM_{2.5}$ anywhere in the world

It is generally thought that except for soiling of surfaces the effects of PM_{10} in reality are caused by $PM_{2.5}$. As an average $PM_{2.5}$ constitutes about half of the PM_{10} mass. The characterisation factors for $PM_{2.5}$ is therefore approximately doubled.

9.3. Emissions of dust anywhere in the world

Most emissions from industrial plants with flue gas cleaning may be attributed to PM_{10} and $PM_{2.5}$. However, particles emitted from disintegration processes and from combustion without flue gas cleaning may consist of considerable amounts of particles >10μm. These particles may cause nuisance via dustfall in the vicinity. In ambient air the concentration of the TSP fraction (total suspended particulate matter) is typically twice the concentration of PM_{10} fraction.

As an approximation dust of unspecified particle size emitted from industrial plants is estimated to be similar to PM_{10} as an average, but the uncertainty increases with a factor of two for the characterisation factors.

10. Classification and characterisation of emissions of metals to air

Some types of environmental effects are common to several metals, such as soil toxicity and increase of cancer rates. When looking more closely on these effects there may be different mechanisms for the effects although the impact on environment in terms of safe guard subjects (human health, bio-diversity, production capacity of ecosystems, etc.) show similarities.

When estimating cancer effects it is general assumed that the cancer risks are linearly dependent of the concentration in a certain environment (Törnqvist and Ehrenberg 1992). IARC (International Association for Research on Cancer), WHO, USEPA (US Environmental Protection Agency) and others, release lists over substances, that "at sufficient evidence" may be regarded as carcinogenic to man. USEPA has also made an estimate of the risk level for a life time exposure to some metals in air. (USEPA, 1989). These estimates are used below.

Soil toxicity effects may be of two kinds: effects on bio-diversity and effects on the production capacity of ecosystems.

Effects on bio-diversity are known to occur locally around sources and on a regional scale for Hg. The local effects are estimated to be of relatively minor importance and the quantitative knowledge poor, why these effects are disregarded in the present modelling. The effects on bio-diversity from Hg are evaluated below.

Effects on ecosystem production capacity are of major interest for agriculture and forestry. In both systems the micro-organisms are influenced in such a way that the mineralisation rate decrease and that the available amount of nutrients (such as phosphorus and nitrogen) decrease. In agricultural systems this does not decrease the production as sufficient amounts of nutrients are added with fertilisers, but in forests in the boreal region growth is to a large extent limited by availability of nitrogen. The impact on mineralisation of the moor horizon of forest soils in Sweden (the most common soil type in Swedish forests) has been reviewed by Tyler (1992). Metals influence the soil enzyme activities and the general soil respiration, they influence the mineralisation rate, nitrification and nitrogen fixation, they influence the soil micro-flora (microbial populations, species composition and diversity) and the microbial processes and they influence soil invertebrates, vascular plants, lichens and bryophytes. The impact on soil respiration has been studied at several levels of Cu-Zn-pollution around a smelter. The results are summarised in figure 10.1 below.

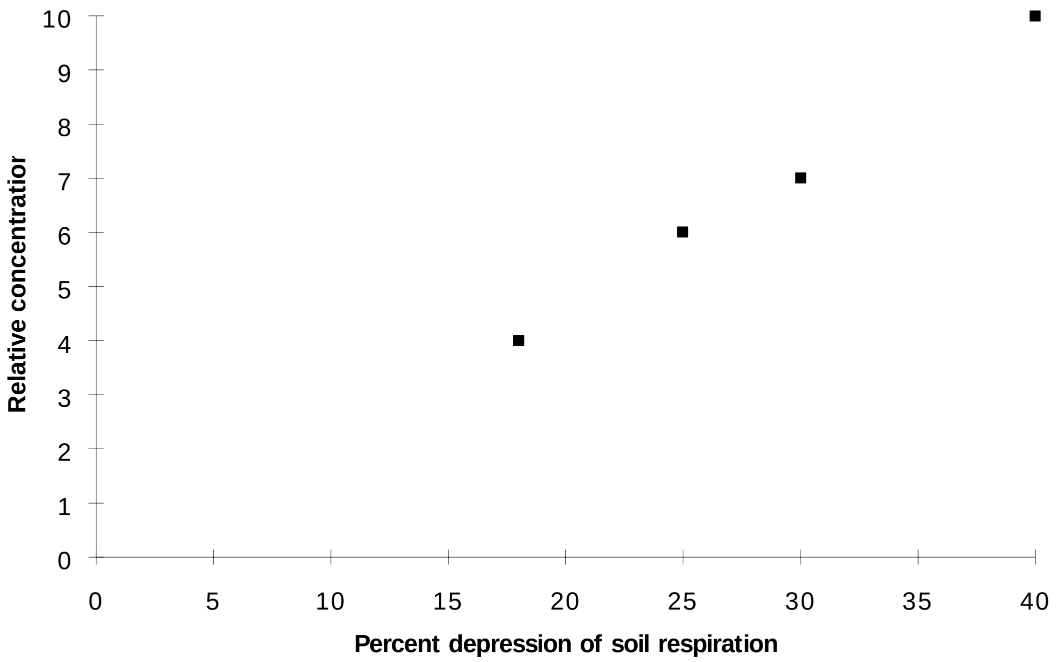

Figure 10.1 Percent depression of soil respiration at various relative enhancements (compared to background levels) of Cu-Zn concentrations in soil around a brass foundry (Tyler 1992)

It seems, as there were no lower limit where the effect disappears and that a linear approximation of a dose-effect-curve going through zero may be used for index purposes. A physical explanation for this may be that the particles containing the metals always create "hot spots" in the soil, regardless of the amount per bulk unit, and that there is no lack of Cu and Zn as essential trace metals in the background levels. On the basis of this it is assumed that the availability of nitrogen also decrease linearly with increasing concentration of Cu and Zn. It is further assumed that available nitrogen decreases at the same rate, because a study around the same brass foundry showed that the nitrogen mineralisation decreased with 20% when the concentration ratio was 3 times the background level (compare with soil respiration in figure 10.1.).

In the review made by Tyler (1992) critical concentrations were formulated as the lowest concentration (total content per unit dry weight of the moor) proved to exert or, for excellent reasons, suspected to exert a negative influence on the biology of the moor.
In the Cu-Zn case mentioned above the critical concentration occurred when there was a 20% reduction in soil respiration and N mineralisation. For other metals the available information is much less and in this index version of the EPS default method it is assumed that the lowest level, where effects are detected corresponds to the same effect on the soil mineralisation as for Cu-Zn (20% decrease).

It may be argued that in the long run there will be a new steady state in soil mineralisation where the rate of mineralisation is the same as for the unpolluted soil. An initial decrease in the mineralisation rate will leave more raw humus to be mineralised later, and the total amount of nutrients available will not be altered. Disregarding all effects on the distribution to various forms of nitrogen in the mineralisation process it may however be shown by a simplified model that this recovery of the soil mineralisation rate will need more than hundred years.

If N is the amount of organic nitrogen in the soil and k is the mineralisation rate in moles per kg and year in the unpolluted soil the mineralisation rate is

$$dN/dt = -kN \quad \text{and} \quad N = N_o * e^{-kt}\text{, or}$$

$$dN/dt = -k * N_o * e^{-kt}\text{ ,}$$

where N_o is the concentration at the time t = 0.

With a mean residence time for the organic molecule in Swedish mor soils of 100 years k becomes equal to 0.0069 years^{-1} In figure 10.2 below dN/dt is plotted against t for an unpolluted soil and a soil with k lowered by 20%. The time for the mineralisation rate in the polluted soil to catch up with the unpolluted is 161 years. Depending of system borders of the time scale the impact may be negative or none at all. In a 100 years time perspective the decrease in forest growth rate and wood production is in the order of 10%.

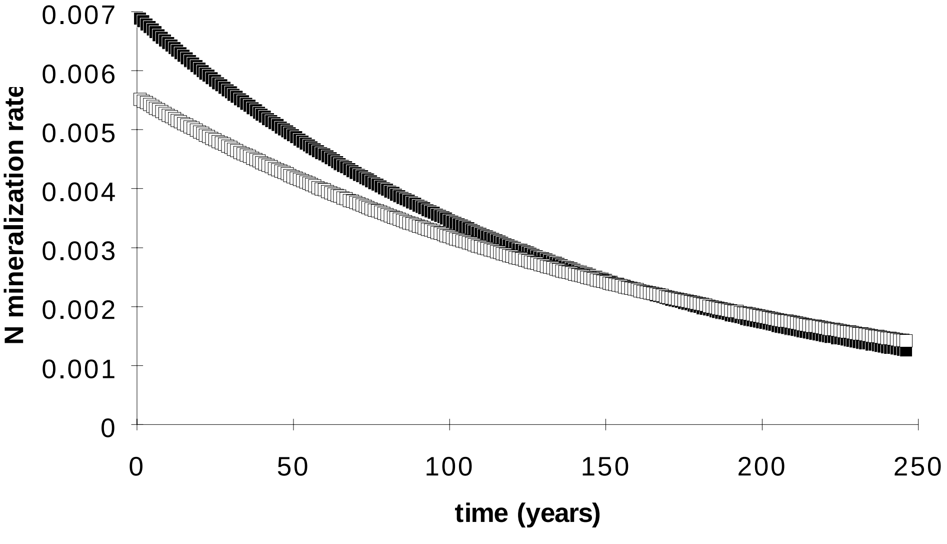

Figure 10.2. Production rate of mineralised N in an unpolluted (upper curve at start) and a polluted soil with 20 % decreased mineralisation rate.

In the model above it was assumed that the toxicity of the metal was unchanged during all years. This may of course not be the case, but the tendency of giving a negative effect during the first years and successively regaining what was lost seems reasonable to apply.

The negative effects of the metal on wood growth are therefore mainly economic and not contributing to an overall decrease of the quality of the safe guard subjects.

10.1. Emissions of Arsenic to air in Sweden

10.1.1. Definition of flow group

The flow group characterised is emissions of As to air, in any chemical and physical state, anyplace in Sweden 1985 and at source strengths that do not cause local acute toxic effects.

Arsenic is emitted as a tracer from many anthropogenic activities. Coal combustion and smelters are important sources. Arsenic in air is mainly present as particles, but a considerable part may be gaseous.

10.1.2. Assignment to impact categories

Arsenic is a known carcinogen and is toxic to humans and other organisms. The only known or reasonably well predicted impact mechanisms are increased cancer incidence and delayed mineralisation of soils. The delayed mineralisation is not assumed to have any significant long term effects on the production capacity of the ecosystems following the discussion in 9 above.
Arsenic is therefore assigned to YOLL, severe morbidity and wood production capacity.

10.1.3. Characterisation of Arsenic to air with respect to YOLL

Definition of environmental system in which the impact is estimated
The residence time in air for particles is in the order of days to weeks depending on particle size, precipitation, and concentration of other particles and condensable gases.
In terms of contribution to population exposure urban populations are receiving the highest doses and mainly from their local sources. The background levels are low compared to urban levels, which means that the trans-boundary pollution may be neglected. Considering an incubation time of the order of 20 years, and that most of the data available are from 1985 the system is defined as Sweden at the state of 1985 during 20 years. As the effects are regarded to be linear, only the year 1985 is studied and assumed to be representative for the 20-year period.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
At present source strengths and source configurations in Sweden the only mechanism causing excess mortality is that via increased cancer rates.

USEPA estimates the lifetime risk for cancer to be $3.4 \cdot 10^{-3}$ /μg/m^3 of As in air (1999) The mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC (Parkin et. al., 1990, Pisani et. al., 1990). The average reduction of life expectancy was estimated in 7.1.3 to 24 years. The Swedish average life expectancy is 78 years. The mean population exposure is about 7 ng/m3 in Sweden (Boström, 1994). This will give $0.62 * 3.4 \cdot 10^{-3} * 7 \cdot 10^{-3} * 8.6 \cdot 10^{6} / 78 * 24 = 39.0$ YOLL among the 8.6 million inhabitants.

Contribution to category indicators value from a flow unit

The total emission of As in Sweden was around 40000 kg 1985. The contribution to the annual category indicator value is therefore 1/40000.

Calculation of characterisation factor

A characterisation factor for Sweden would thus be $39.0/40000 = 9.75 \cdot 10^{-4}$ YOLL per kg of As emitted to air. The system border was actually 20 years and therefore the emission and effect should be summarised over 20 years before the calculation of the characterisation factor was made. However as the effect is linearly dependent of the emission the characterisation factor would still be $9.75 \cdot 10^{-4}$.

Uncertainty

There is an uncertainty in several of the figures used for the calculation. The chemical state of As is not defined, an average figure is used for the decreased life expectancy and the exposure varies depending on where you are. A small portion of the population living close to a smelter, have the highest risk while people on the countryside have the lowest. The uncertainty due to not having specified the chemical state and the uncertainty in the risk estimate for concentration levels of ambient air is estimated to a factor of ten. The uncertainty of not knowing the exposure conditions is estimated to a factor of three, implying that the concentration times population density in the areas of the highest concentrations may be nine times as high as those in areas with the lowest concentrations (two standard deviations). Together this will give an uncertainty of a little more than a factor of ten. The uncertainty is expressed as standard deviation in a log-normal distribution with a standard deviation corresponding to a factor of 3.

10.1.4. Characterisation of Arsenic to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The residence time in air for particles is in the order of days to weeks, depending on particle size, precipitation, and concentration of other particles and condensable gases.

In terms of contribution to population exposure urban populations are receiving the highest doses and mainly from their local sources. The background levels are low compared to urban levels, which means that the trans-boundary pollution may be neglected. Considering an incubation time of the order of 20 years, and that most of the data available are from 1985 the system is defined as Sweden at the state of 1985 during 20 years.

Model for cancer pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The portion of cancer incidences not causing death (38%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is (5/24)*(0.38/0.62)*39 = 4.98 person-years of severe morbidity, where 39 is the indicator value determined in 10.1.3.

Contribution to category indicators value from a flow unit
The same contribution as in 10.1.3 is valid, i.e. 1/40000 per kg arsenic.

Calculation of characterisation factor
This would mean that the characterisation factor would be 4.98/40000 = $1.24 \cdot 10^{-4}$ person-years/kg arsenic.

Uncertainty
As for 10.1.3, the total uncertainty is estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.1.5. Characterisation of Arsenic to air with respect to wood

The relation between metal emissions and the category indicator ‘wood’ was modelled in section 10. The characterisation factor was estimated to 0.

10.2. Emissions of Arsenic to air anywhere in the world

Sweden may be used as a sample of global conditions. Consequently the average risk would be the same or $9.75 \cdot 10^{-4}$ YOLL/kg As emitted, $1.24 \cdot 10^{-4}$ person-years severe morbidity/kg As and 0 for wood.

An alternative way of modelling the characterisation factor is to use estimates of urban concentrations in UK and Washington DC and of the global emission from Fergusson (1990). He reports concentrations of 3-5 ng/m3 from 1986 and estimates of the global emission of $23.6 \cdot 10^{6}$ kg/yr. This will give a risk estimate of $5.7 \cdot 10^{-4}$ YOLL/kg As indicating that the Swedish average is not unrealistic as a global average, but as could be expected a bit low. The reason for the under-estimation is probably the somewhat lower population density in Sweden than in the

The uncertainty in determining the contribution would increase as the flow group increased. It is assumed to be doubled, and by this the overall uncertainty increase to around a factor of 15, or a standard deviation corresponding to a factor of 4 in a log-normal distribution.

10.3. Emissions of Cd to air in Sweden

10.3.1. Definition of flow group

The flow group characterised is emissions of Cd to air, in any chemical and physical state, anyplace in Sweden 1985 and at source strengths that do not cause local acute toxic effects.

Cadmium is emitted as a tracer from many anthropogenic activities. Coal combustion, waste incineration and smelters are important sources. Cadmium in air is mainly present as particles. A typical source is a stack located at the outskirts of an urban area.

Other sources of Cd contributing to population exposure and excess mortality are fertilisers and cigarette smoke, but they are not included in this flow group.

10.3.2. Assignment to impact categories

Cadmium is a carcinogen. Cd is regarded as a carcinogen when inhaled, but no evidence is available that oral exposure gives an increased risk Cd is toxic to humans also in other ways and impacts on soil mineralisation. The kidneys are the most sensitive of the organs and their functions may be disturbed. Cadmium has a tendency to accumulate in the food chain. Cadmium is assigned to YOLL, severe morbidity, morbidity and wood.

10.3.3. Characterisation of Cadmium to air with respect to YOLL

Definition of environmental system in which the impact is estimated
In terms of contribution to population exposure urban populations are receiving the highest doses. The main contribution comes from sources in the urban area, but in Southern Sweden the regional background is also important. This means that the trans-boundary pollution can not be neglected (Sievertsen 1986) and that both to Swedish and external sources must be allocated to the category indicator value. Considering an incubation time of the order of 20 years, and that most of the data available are from 1985 the system is defined as Sweden at the state of 1985 during 20 years.

Model for direct inhalation pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
USEPA estimates the lifetime risk for cancer to be $1.8 \cdot 10^{-3}/\mu g/m^3$ of Cd in air (1999).

The mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC. (Parkin et al., 1990, Pisani et al.,1990). The average reduction of life expectancy was estimated in 6.1.3 to 24 years. The Swedish average life expectancy is 78 years. The mean population exposure is about 0.2 ng/m3 in Sweden (Boström, 1994). This will give $0.62*1.8\cdot10^{-3}*2\cdot10^{-4}*8.6\cdot10^{6}/78*24 = 0.59$ YOLL among the 8.6 million inhabitants.

Contribution to category indicators value from a flow unit

The total emission of Cd in Sweden was around 5000 kg 1985 (Swedish EPA, 1992). The contribution from background levels is not negligible and it has to be decided on which emission that shall be allocated to the indicator value 0.61 YOLL. The contribution to human exposure concentrations from the regional background was estimated to about 50% in rural Belgium (Fergusson, 1990). In Olso the regional background was measured by Sivertsen and Vitols (1981). They found concentrations about 0.4 ng/m^3, about the same background levels as in Belgium. It seems reasonble to assume that the contributions in Sweden are about the same, i. e. 50%. However some of the 5000 kg's are contributing to human exposure outside Sweden. Considering the prevailing south-westerly winds, the trade balance ought to negative in terms of human exposure to ambient air concentrations. We therefor allocate more than 5000 kg but less than 1.5 times the 5000 kg. As a rough estimate 1,25*5000= 6250 kg is allocated to the indicator value. Thus the contribution to the annual category indicator value is therefore 1/6250

Calculation of characterisation factor

A characterisation factor for Sweden would thus be $0,59/6250 = 9.44\cdot10^{-5}$ YOLL per kg of Cd emitted to air. The system border was actually 20 years and therefore the emission and effect should be summarised over 20 years before the calculation of the characterisation factor was made. However as the effect is linearly dependent of the emission the characterisation factor would still be $9.44\cdot10^{-5}$ YOLL/kg Cd.

Uncertainty

There is an uncertainty in several of the figures used for the calculation. The chemical state of Cd is not defined, the shortening of life is not measured and the exposure varies depending on where you are. A small portion of the population living close to a smelter, have the highest risk while people on the countryside have the lowest. The uncertainty due to not having specified the chemical state and the uncertainty in the risk estimate for concentration levels of ambient air is estimated to a factor of ten. The uncertainty of not knowing the exposure conditions is estimated to a factor of three, implying that the concentration times population density in the areas of the highest concentrations are nine times as high as those in areas with the lowest concentrations (two standard deviations). Together this will give an uncertainty of a little more than a factor of ten. The uncertainty is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.3.4. Characterisation of Cadmium to air with respect to severe morbidity

The same system borders as 10.3.3 are used.

Model for cancer pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The portion of cancer incidences not causing death (38%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is (5/24)*(0.38/0.62)*0.59 = 0.075 person-years of severe morbidity per kg of Cd, where 0.59 YOLL was the indicator value determined in 10.3.3.

Contribution to category indicators value from a flow unit

The same contribution as in 10.3.3 is valid, i.e. 1/6250 per kg Cd.

Calculation of characterisation factor

This would mean that the characterisation factor would be $(5/24)*(0.38/0.62)*0.59*3.1\cdot10^{-10} = 2.23\cdot10^{-6}$ person-years/kg cadmium.

Uncertainty

The same type of uncertainty is involved as in the charcterisation model for YOLL. The total uncertainty is therefore estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.3.5. Characterisation of Cadmium to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The same system borders as 10.3.3 are used.

Model 1, direct inhalation pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The health effects of Cd on kidney functions are described in WHO air quality guidelines for Europe (1987). At about 200 mg/kg wet weight in renal cortex there is a dysfunction in the kidney. This corresponds approximately to an average air concentration of 2.9 μ g/m^3 and a liver concentration of 30 mg/kg. Assuming log normal distributions of the sensitivity to Cd and the exposure to Cd respectively, it will be possible to calculate the number of morbidity cases from Cd. In order to find the constants for the log normal distributions results from two studies are used. First a study quoted by WHO in which Cd concentration in liver is correlated to abnormal metabolic changes. (WHO1987) The result are cited in table 10.1 below.

Table 10.1 Relationship between liver cadmium level and prevalence of abnormal β_2-microbiobulinuria in a group of 148 workers from two zinc-cadmium-smelters with hepatic cadmium $\geq$10ppm and renal cortical cadmium $\geq$50 ppm.

Cadmium in liver (ppm)	Number of workers	Prevalence of abnormal beta-2-mU (tubular proteinuria) Number
10 - 19	54	0
20 - 29	27	1
30 - 39	28	3
40 - 49	18	3
50 - 59	8	2
60 - 69	5	2
70 - 160	8	8

An exposure to 2.9 $\mu g/m^3$ would thus give a liver concentration of 30 ppm and kidney dysfunction in 5% of the population. The sensitivity to Cd is approximately log-normal distributed among the persons examined. Assuming this distribution may be extrapolated to lower concentrations and being representative for the entire Swedish population of 8 million inhabitants about 1 person would be sensitive to 0.6, 10 persons to 0.7, 100 persons to 0.8 and 1000 persons to 0.9 $\mu g/m^3$. At an average exposure of 0.2 ng/m^3 and approximately 10% of the population being exposed to a doubled concentration (derived from what is normal to average NO_x-distribution) there will be no persons exposed to levels like 1 ng/m^3. The conclusion is that health effects merely from direct exposure in air are negligible. However as other routes of Cd intake exists (smoking, occupational exposure, food) the average concentration in renal cortex is about 20 mg/kg today (corresponding to about 1.5 mg/kg in the liver) indicating that a sensitive part of the population could be influenced. If we transform the data in table 10.1 to a dose-response curve and investigate the slope we see that each mg of an extra dose above 20 mg/kg will give and extra 0.5% of the population at the threshold level affected.(figure 10.3)

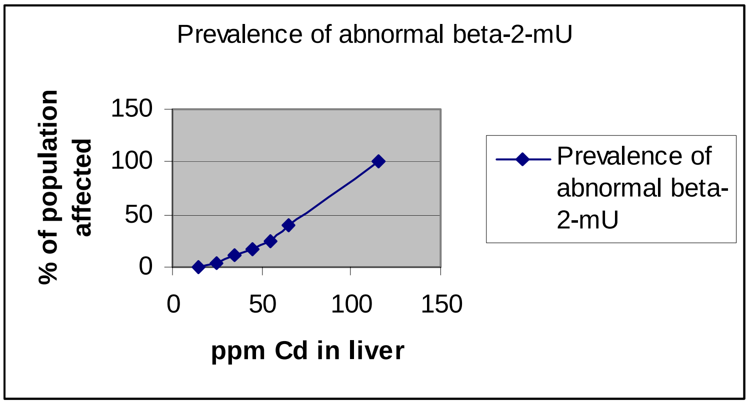

Figure 10.3 Dose-response curve for Cd in liver

The question is just: how many are on the threshold level?

According to WHO the threshold level for non-occupational exposure is 10 mg/kg in the liver. If we use the experience of air pollutant concentrations to be log-normal distributed and use the ratio of median to 90%ile values for NO_x (about 2), which like Cd to a large extent is generated from combustion sources, the 99.99 percentile would be around 10 mg/kg. Therefore, the part of the population at the threshold level would be $8.6 \cdot 10^6 * 10^{-4}$ = 860 persons

If the average population exposure is 0.2 ng/m3 this corresponds to 30*0.2/2900 = 0.00207 mg/kg or ppm by weight. This would cause $0.00207*0.005*8.6 \cdot 10^6 * 10^{-4}$ = 0.0089 person-years of morbidity.

Contribution to category indicators value from a flow unit

The same contribution as in 10.3.3 may be valid, i.e. 1/6250 per kg Cd.

Calculation of characterisation factor

The characterisation factor would therefore be 0.0089/6250 = $0.0142 \cdot 10^{-4}$ person-years/kg Cd.

Uncertainty

The uncertainty is comparatively large because of the extrapolation and weak models of marginal effects. The uncertainty is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

Model 2, oral pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

According to Sivertsen (1986), the danish population’s total exposure to Cd was approximately to 35% originating from air emissions which had been accumulated in soil or on crop surfaces. Less than 1% was inhaled directly. This means that there would be in the order of 35*0.0089 = 0.3115 person years of morbidity

Contribution to category indicators value from a flow unit
The same contribution as in 10.3.3 may be valid, i.e. 1/6250 per kg Cd.

Calculation of pathway specific characterisation factor
The characterisation factor is thus 0.3115/6250 = 0.498 10^{-4} person-years/kg Cd.

Uncertainty
There is an uncertainty in application of the dose response curves of a limited group of people to an entire population, but the largest uncertainty is probably the assignment of a kidney dysfunction to morbidity. It is not known in the present modelling which actual disability that the abnormal β_2-microbiobulinuria (beta-2-mU)-values will cause, so the precautionary principle is used. There is also an uncertainty involved in the lack of spatial information about the source configuration and population distribution in its vicinity. One particularly large source in Sweden is a smelter located in areas with low population density. However its contribution to the total Swedish emissions is less than a ton/year and there seems to be few other strong sources. Therefore, the total uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

Calculation of characterisation factor
The characterisation factor of Cd for the added impacts are 0.0142 10^{-4} + 0.498 10^{-4} = 0.512 10^{-4} person-years/kg Cd.

10.3.6. Characterisation of Cadmium to air with respect to wood

The relation between metal emissions and the category indicator ‘wood’ was modelled in section 10. The characterisation factor was estimated to 0.

10.4. Emissions of Cadmium to air anywhere in the world

Sweden may be used as a sample of global conditions. Consequently the average risk would be the same or $9.44\cdot10^{-5}$ YOLL/kg Cd, $2.23\cdot10^{-6}$ person-years of severe morbidity /kg Cd, 0.512 10^{-4} person-years of morbidity/kg Cd and 0 kg wood/kg Cd.

The uncertainty in determining the contribution would increase as the flow group increased. It is assumed to be doubled, and by this the overall uncertainty increase to around a factor of 15, or a standard deviation corresponding to a factor of 5 in a log-normal distribution for all three characterisation factors.

10.5. Emissions of Chromium to air in Sweden

10.5.1. Definition of flow group

The flow group characterised is emissions of Cr to air, in any chemical and physical state, anyplace in Sweden 1985 and at source strengths that do not cause local acute toxic effects.

10.5.2. Assignment to impact categories

Cr^{6+} is a potent human carcinogen. It seems likely that all Cr emitted to air and in contact with air reach a kind of equilibrium where a few percent of Cr is oxidised or remain in the VI valence state. Cr emissions may therefore be assigned to the category indicators YOLL and severe morbidity.

10.5.3. Characterisation of chromium to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The residence time in air for particles is in the order of days to weeks depending on particle size, precipitation, and concentration of other particles and condensable gases.

In terms of contribution to population exposure urban populations are receiving the highest doses and mainly from their local sources. The background levels are low compared to urban levels, which means that the trans-boundary pollution may be neglected. Considering an incubation time of the order of 20 years, and that most of the data available are from 1985 the system is defined as Sweden at the state of 1985 during 20 years. As the effects are regarded to be linear, only the year 1985 is studied and assumed to be representative for the 20-year period.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The cancer risk has been estimated by EPA to be in the order of $1.2\ 10^{-2}$ /µg/m3 expressed as a lifetime unit risk. The mean population exposure for Cr in Sweden was estimated by Steen to 3 ng/m^3.(Steen, 1991) The hexavalent part of this is not known in Sweden but was estimated by Scott et al (1997) in New Jersey at an average to 26% which would give a mean concentration on 0.78 ng/m3.

The mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC. (Parkin et al., 1990, Pisani et al.,1990). The average reduction of life expectancy was estimated in 6.1.3 to 24 years. The Swedish average life expectancy is 78 years. The mean population exposure was estimated to 0.78 ng/m3 in Sweden (Boström, 1994). This will give $0.62*1.2\cdot10^{-2}*0.78\cdot10^{-3}*8.6\cdot10^{6}/78*24 = 15.4$ YOLL among the 8.6 million inhabitants.

Contribution to category indicator value from a flow unit

The total anthropogenic emissions of Cr was estimated to 75 tons/year in Sweden (Swedish EPA, 1992). If Sweden is considered as a closed system, (which is a simplification as there is an import of Cr occurs from long range transport of air pollutants) the contribution to the exposure is 1.33 10^{-5}. As the Cr emitted in Sweden mainly are transported to less populated areas than the average Sweden, this simplification will result in a slight overestimation of the characterisation factor.

Calculation of characterisation factor

The impact value from an emission of Cr causing increased mortality in cancer is: $15.4 * 1.33\ 10^{-5} = 2.05\ 10^{-4}$YOLL/kg Cr.

Uncertainty

There is an uncertainty in several of the figures used for the calculation. The chemical and physical state of Cr is not defined, either in the emissions or in the atmosphere.

All Cr in air does not origin from anthropogenic sources. The contribution from natural Cr in mineral dust is not known directly, but it may be estimated from the average population exposure to Si, which is 0.7 $\mu g/m^3$. (Steen, 1991). This would correspond to a silicate mineral concentration of about 4 $\mu g/m^3$ (if it were all feldspar). The average Cr concentration in earth crust is 10^2 mg/kg. Therefore the “natural” background would be 0.4 ng/m^3. In comparison with the average Cr-concentration in air, 3 ng/m^3, it may only contribute to the uncertainty on the 10% level.

The shortening of life is not measured and the exposure varies depending on where you are. The part of the population living close to the sources have the highest risk while people on the countryside have the lowest. The uncertainty due to not having specified the chemical state and the uncertainty in the risk estimate for concentration levels of ambient air is estimated to a factor of ten. The uncertainty of not knowing the exposure conditions is estimated to a factor of three, implying that the concentration times population density in the areas of the highest concentrations are nine times as high as those in areas with the lowest concentrations (two standard deviations). Together this will give an uncertainty of a little more than a factor of ten.

Based on these considerations the uncertainty is assumed to be expressed as a log-normal distribution with a standard deviation corresponding to a factor of 4

10.5.4. Characterisation of chromium to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The residence time in air for particles is in the order of days to weeks depending on particle size, precipitation, and concentration of other particles and condensable gases.

In terms of contribution to population exposure urban populations are receiving the highest doses and mainly from their local sources. The background levels are low compared to urban levels, which means that the trans-boundary pollution may be neglected. Considering an incubation time of the order of 20 years, and that most of the data available are from 1985 the system is defined as Sweden at the state of 1985 during 20 years. As the effects are regarded to be linear, only the year 1985 is studied and assumed to be representative for the 20-year period.

Model for cancer pathway
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
The portion of cancer incidences not causing death (38%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is (5/24)*(0.38/0.62)*15.4 = 1.96 person-years of severe morbidity.

Contribution to category indicators value from a flow unit
The same contribution as in 10.5.3 is valid, i.e. 1/75000 per kg arsenic.

Calculation of characterisation factor
This would mean that the characterisation factor would be 1.96/75000 = $2.62 \cdot 10^{-5}$ person-years/kg chromium.

Uncertainty
As for 10.5.3, the total uncertainty is estimated to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.6. Emissions of Chromium to air anywhere in the world

Sweden may be used as a sample of global conditions. Consequently the average risk would be the same or $2.05\ 10^{-4}$YOLL/kg Cr emitted and $2.62 \cdot 10^{-5}$ person-years/kg As.

The uncertainty in determining the contribution would increase as the flow group increased. It is assumed to be doubled, and by this the overall uncertainty increase to around a factor of 20, or a standard deviation corresponding to a factor of 4.5 in a log-normal distribution.

10.7. Emission of Cu to air anywhere in the world

Copper has only one type of known effect at present concentration levels in the environment. It is toxic to soil micro-organisms. For tracer amounts there will thus be no impact on the safe guard subjects, i.e. the characterisation factor is 0 kg wood/kg Cu.

10.8. Emission of Hg to air anywhere in the world

10.8.1. Definition of flow group

Mercury is emitted to the atmosphere from various thermal processes, where its volatility transfers it from the solid or liquid state to the gas phase. Normally mercury is present as a tracer in these processes. A large part of the emissions come from waste incineration, from electrochemical production of chlorine and from primitive gold mining where the gold is extracted as amalgam, and from which the mercury is evaporated to the atmosphere.

Hg emissions are present world-wide and at elevation from ground level to tall stacks.

The flow group characterised is emissions of Hg to air, in any chemical and physical state, anyplace in the world 1985 and at source strengths that do not cause local acute toxic effects.

10.8.2. Assignment to impact categories

Mercury has several types of environmental effects. It is toxic to humans and animals and has an effect on soil mineralisation. Mercury accumulates in animals and humans. MAC values (Maximum Allowable Concentration) for fish are not toxic to fish but are set to protect human health. The presence of mercury in fish impacts in two ways on the environment. The production of eatable fish decrease and some effects occur where it is still used as food. Emissions of mercury are therefore assigned to morbidity, fish&meat and NEX.

10.8.3. Characterisation of Hg to air with respect to morbidity

Definition of environmental system in which the impact is estimated

Having the global extension of the emission flow group, there will also be a global extension of the environment system. The time borders may be considerable as Hg has a tendency to "move around" in the environment. After having been deposited it may be re-emitted again as it may be chemically transformed from volatile to non-volatile compounds. The knowledge about these processes is however very limited as far as quantitative aspects are concerned. We therefore assume a "steady state" and make the analysis on one-year basis. The reference year will be the same as for emissions, 1985.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

Some groups of the population in North America, Europe and New Zealand eating much locally caught fish tend to get high mercury concentrations in body tissue. This may lead to various health effects but the one of most concern is mental retardation of children due to prenatal exposure (Kjellström et al., 1988). In a New Zealand study, 1000 out of 11000 new mothers had consumed fish more than three times a week. 73 of these had hair mercury levels above 6 mg/kg. 50% of the high mercury level children had abnormal or questionable test results in a Denver Development Screening Test, whereas only 17% of the reference children had such results. This indicates that 0.2% of a “fish eating” population like New Zealand is affected. Globally the “fish eating” population is in the order of 200 millions. 0.2% of these are 400000.

Contribution to category indicators value from a flow unit

The global anthropogenic emission of Hg is estimated to 8600 tons per year (UNEP, 1992) and the bio-geochemical is around 70000 ton (Fergusson, 1989). The atmosphere is the main transport route for mercury and the run-off from the lithosphere to the oceans is only 3800 – 5000 ton compared to the mercury from precipitation, 25000 ton annually. Totally the emissions contributing to the population exposure via fish is 8600+70000+4600 = 83200 ton.

Calculation of characterisation factor

The characterisation factor is thus 400000/83200000 = $4.8 \cdot 10^{-3}$ person-years/kg Hg.

Uncertainty

There is an uncertainty introduced in the assigning of the effect to morbidity. It is not known at present what kind of handicap or suffering the Denver tests indicate. In terms of values or weights given to the category indicator there are two orders of magnitude that differ between morbidity and nuisance.

Other uncertainties involve the extrapolation of the results from New Zealand to other populations and the estimation of their size.

Based on these considerations the total uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

10.8.4. Characterisation of Hg to air with respect to fish production

Definition of environmental system in which the impact is estimated

The same as 10.8.3.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

In Sweden some 10% of the area contain lakes where the concentration of Hg in pike exceeds 1 mg/m^3 (UNEP, 1992). The total lake area in Sweden is 39000 km^2, and the fish production 100 - 1000 kg/km^2,year. Using 500 as a mean and assuming that globally the lake area, where the MAC values are exceeded is ten times as large (mainly located in the boreal region) the lost fish production would be $0.1 * 39000 * 500 * 10 = 1.85\ 10^7$ kg/year

Contribution to category indicators value from a flow unit

The global anthropogenic emission of Hg is estimated to 8600 tons per year (UNEP, 1992) and the biogeochemical is around 70000 ton (Fergusson, 1989). The atmosphere is the main transport route for mercury and the run-off from the lithosphere to the oceans is only 3800 – 5000 ton compared to the mercury from precipitation, 25000 ton annually. Totally the emissions contributing to the population exposure via fish is 8600+70000+4600 = 83200 ton.

Calculation of characterisation factor

The characterisation factor is thus 1.85 10^7 /83200000 = 0.224 kg fish/kg Hg.

Uncertainty

The uncertainty in the growth rate of fish in various global regions is estimated to a factor of two. The uncertainty in the estimation of the lake area where the MAC values is exceeded is probably a factor of four. Considering the volatility of mercury and its global dispersion pattern, the uncertainty in contribution is regarded to be less than normal, a factor of ten. The total uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.8.5. Characterisation of Hg to air with respect to NEX

Definition of environmental system in which the impact is estimated

The same as 10.8.3.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

Hg’s impact on bio-diversity is perhaps the most difficult part to evaluate The global threat to bio-diversity is only to a small part coming from mercury. In Sweden the Fauna Preservation Committee estimated (1988) that 13 out of 140 NEX was in danger because of toxic substances in the environment. The best knowns of these are PCB, DDT and mercury. A rough guess is that 1% of the NEX on the globe are threatened by mercury.

Contribution to category indicators value from a flow unit

The global anthropogenic emission of Hg is estimated to 8600 tons per year (UNEP, 1992) and the bio-geochemical is around 70000 ton (Fergusson, 1989). The atmosphere is the main transport route for mercury and the run-off from the lithosphere to the oceans is only 3800 – 5000 ton compared to the mercury from precipitation, 25000 ton annually. Totally the emissions contributing to the population exposure via fish is 8600 + 70000 + 4600 = 83200 ton.

Calculation of characterisation factor

The characterisation factor is thus 0.01/83200000 = $1.20 \cdot 10^{-10}$ /kg Hg.

Uncertainty

There is a likely upper level of the impact, which is at the 10% level. This is the contribution from all chemical agents. If the uncertainty is represented by a log-normal distribution with a standard deviation corresponding to a factor of 4 the error marginal will be somewhat more than a factor of ten (two standard deviations).

10.9. Emission of Ni to air

Nickel is a carcinogen in the subsulphide form, it is an allergen and toxic to soil micro-organisms. There has been no evidence so far of Ni being an allergen at the concentrations common in ambient air.
The cancer risk for the subsulphide has been estimated by EPA to be in the order of 4.8 10^{-8} /μg/m^3 expressed as a lifetime unit risk. As most of the Ni emissions not are in the subsulphide form normal Ni emissions are not assigned to any health indicators. Subsulphide emissions have to be treated in local assessments.

The relation between metal emissions and the category indicator ‘wood’ was modelled in section 10. The characterisation factor was estimated to 0.

10.10. Emission of Pb to air anywhere in Sweden

10.10.1. Definition of flow group

The flow group characterised is emissions of Pb to air, in any chemical and physical state, anyplace in Sweden 1985 and at source strengths not giving local acute toxic effects.

10.10.2. Assignment to impact categories

Lead is perhaps the most studied toxic metal in the environment. The main reason is its effects on the central nerve system and its extensive use as additive in gasoline. Children are most sensitive. Too high lead doses cause brain retardation. The doses present in ambient air are not high enough to give the most severe effects, but a loss of IQ has been seen in American studies. This effect is here classified as severe nuisance. The use of lead in gasoline sometimes gives high lead doses to people living in heavy trafficked areas. Lead also show effects on soil micro-organisms and soil invertebrates.

10.10.3. Characterisation of Pb to air with respect to severe nuisance

<u>Definition of environmental system in which the impact is estimated</u>
Cars and to some extent smelters are important sources of lead in Sweden. Lead particles are small, often sub-micron. Their residence time in air is several days, and a certain trans-boundary pollution exist. However in terms of population exposure and in particular for highly exposed groups the local interurban sources are dominant. Sweden 1990 is therefore used as a system border.

<u>Model</u>
The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The exposure to lead has decreased the last ten years considerably. At present, measurements show lower concentrations than what is regarded as giving risks for brain effects. In large populations however, the dose distributions tend to be log normal and so the sensitivity distribution. When extrapolating these it seems possible that one or two cases with some type of effect may occur per year. As brain retardation effects in some way remain during the entire life this is assumed to represent 78 person-years per case of severe nuisance. The total indicator value in the system is therefore assumed to be in the order of 150 person-years per year.

Contribution to category indicators value from a flow unit

The total emission of lead is 950 tons/year in Sweden

Calculation of characterisation factor

The average impact of Pb is 150/950000 = 1.58 10^{-4} person-years/kg Pb.

Uncertainty

The uncertainty is rather large, because of the long extrapolation. It is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

10.10.4. Characterisation of Pb to air with respect to wood

The relation between metal emissions and the category indicator ‘wood’ was modelled in section 9. The characterisation factor was estimated to 0.

10.11. Emission of Pb to air anywhere in the world

10.11.1. Definition of flow group

The flow group characterised is emissions of Pb to air, in any chemical and physical state, anyplace in the world and at source strengths not giving local acute toxic effects.

10.11.2. Assignment to impact categories

Lead is perhaps the most studied toxic metal in the environment. The main reason is its effects on the central nerve system and its extensive use as additive in gasoline. Children are most sensitive. Too high lead doses cause brain retardation. The doses present in ambient air are not high enough to give the most severe effects, but a loss of IQ has been seen in American studies. This effect is here classified as severe nuisance. The use of lead in gasoline sometimes gives high lead doses to people living in heavy trafficked areas. Lead also show effects on soil micro-organisms and soil invertebrates.

10.11.2. Characterisation of Pb to air with respect to severe nuisance

Definition of environmental system in which the impact is estimated
The system considered is anywhere in the world during 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
About 17% of the population in USA is estimated to have a decrease in IQ of three units in the beginning of the 90ies (Grant et al., 1993). Heavy car exhaust has mainly been a problem for OECD countries and some megacities outside OECD. This indicates that the problem is in the order of 100 million persons-years per year.

Contribution to category indicators value from a flow unit
The global lead emission was 344000 tons/year 1983 as estimated by Pacyna. (UNEP 1992)

Calculation of characterisation factor
This will result in a characterisation factor of $1 \cdot 10^8 / 3.44 \cdot 10^8 = 0.291$ person-years/kg Pb.

Uncertainty
Lead is being phased out as an additive to petrol in many countries, but the process has proceeded with different speed in different countries. It is therefore difficult to combine effects and emissions and to know the status in various countries. Trend investigation show decreasing lead levels in most countries but a few have no efficient abatement policy and is expected to contribute to the impact. USEPA (1996) states that "Between 1987 and 1996, ambient lead concentrations decreased 75 percent, and lead emissions decreased 50 percent. Lead emissions from highway vehicles have decreased 99 percent since 1987 as a result of the increased use of unleaded gasoline and the reduction of the lead content in leaded gasoline. Between 1995 and 1996, lead concentrations remained unchanged, total lead emissions decreased 2 percent, and lead emissions from transportation sources did not change. While lead emissions from industrial sources have dropped more than 90 percent since the late 1970s, some serious point-source lead problems remain."

As the number of persons affected were estimated roughly and the dose-effect is subject to heated debates, the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 4.

10.11.3. Characterisation of Pb to air with respect to wood

The relation between metal emissions and the category indicator 'wood' was modelled in section 10. The characterisation factor was estimated to 0.

10.12. Emission of zinc to air anywhere in the world.

Zinc is one of the most common metals in the environment. High concentrations may be poisonous, but zinc is an essential metal for all life as a constituent in various enzymes (Swedish EPA, 1988). Despite high concentrations few real effects have been shown to be caused by Zn in the environment. The main effect of Zn as a metal emitted to air in moderate amounts is to decrease soil mineralisation. Health effects have been observed in early days of environmental concern around factories at air pollution episodes.

The relation between metal emissions and the category indicator ‘wood’ was modelled in section 10. The characterisation factor was estimated to 0 kg wood/kg Zn.

11. Classification and characterisation of emissions of polyaromatic compounds (PAC) to air

11.1. Emissions of PAC anywhere in the world

11.1.1. Definition of flow group

PAC is emitted from incomplete combustion. It is present in fossil oil and coal, and some exposure to humans may occur from direct evaporation, such as from coal tar when used for sealing of roofs and from asphalt at road works. PAC is found in cigarette smoke.

PAC, polyaromatic compounds is a collective name for a group of substances having three to five benzene rings. Most of them are found in particles but some are also present as gases. Sometimes the name PAH, 'polyaromatic hydrocarbons' are used to cover almost the same group of substances. However PAH represents only the hydrocarbons, while PAC also includes compounds containing other elements such as oxygen and nitrogen. In practice, the group is defined through the measurement methods used. When using gas chromatography and extraction by acetone or other solvents, about 40 PAC substances (table 11.1) may be identified.

Table 11.1 PAC compounds typically detected by GC methods

Substance name	Substance name
Acenaphtylene	Benzo(b)fluorene
Acenaphtene	1-Metylpyrene
4-Metylbiphenyl	Benz(a)anthracene
Dibenzofuran	Chrysene
Fluorene	Triphenylene
9-Metylfluorene	Naphtancene
9,10-Dihydroanthracene	Benzo(bjk)fluoranthenes
1-Metylfluorene	Benzo(a)pyrene
Dibenzothiophene	Benzo(e)pyrene
Phenanthrene	Perylene
Anthracene	3-Methylcholanthrene
2-Metylanthracene	m-Quaterphenyl
1-Metylanthracene	Indeno(1,2,3-cd)pyrene
9-Metylanthracene	Dibenz(a,h)anthracene
3,6-Dimethylphenantrene	Picene
1,2-Dihydropyrene	1,2,3,4-Dibenzanthracene
Fluoranthene	Benzo(g,h,i)perylene
Pyrene	Anthanthrene
Benzo(a)fluorene	

The preparation of the samples for the GC method is quite time consuming and expensive. If high-pressure liquid chromatography (HPLC) is used the preparation step is quicker and more samples can be analysed on the same budget. However, by HPLC it is only possible to analyse about ten PAC’s. (table 10.2) Even if these PAC:s are those that occur in highest concentrations, PAC-values determined by the HPLC method tend to be lower than the GC values.

Table 11.2 PAC compounds typically detected by HPLC methods

Substance name
Phenanthrene
Anthracene
Flouranthene
Pyrene
Benzo(a)anthracene
Chrysene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Benzo(ghi)perylene
Indeno(cd)pyrene

In this impact assessment the flow group includes the substances in table 11.1.

The flow group characterised is emissions of PAC to ambient air, in any physical state, anyplace in the world 1990. The flow group does not include cigarette smoke and indoor activities, such as cooking.

11.1.2. Assignment to impact categories

Many of the PAC’s are known carcinogens, such as bens(a)pyrene. Therefore, PAC:s are assigned to 'Life expectancy' and 'severe morbidity'. PAC’s contribute to photo-oxidant formation and to global warming, but the amounts of PAC’s emitted to the atmosphere are so small that the contribution to the category indicators associated with these mechanisms are expected to be negligible compared to that from other substances. Therefore no assignment to other impact category indicators are made.

11.1.3. Characterisation of PAC to air with respect to YOLL

Definition of environmental system in which the impact is estimated

The system is global and the year is 1990. Most of the exposure occurs in urban areas why the characterisation modelling is focused on urban areas.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The average Swedish population exposure to PAC was estimated to 19 ng/m^3 (Boström et al 1994). Törnqvist and Ehrenberg (1990) estimate the number of cancer incidences from PAC to about 300. Only a fifth originates from direct exposure. The most important pathway is deposition to vegetation and uptake via the food chain.

If the PAH concentration is assumed to be proportional to the soot or black smoke concentration measured in urban locations, the global cancer rates may be estimated from the black smoke results obtained in the UN/GEMS monitoring network. The average, annual black smoke concentration in the cities participating in this network was in the order of 80 microgram per cubic meter 1980-84. In Sweden it is around 10. However, the GEMS network concentrates on large cities where the WHO air quality guidelines may be exceeded. To estimate the ratio between Swedish and global smoke concentrations the ratio between the Copenhagen and global averages in the GEMS network is used. This ratio is a factor of five. As a large part of the population outside OECD live in the countryside (about 50%) this ratio is probably lower for the entire global population. A factor of three seems reasonable.

The total number of cases in the world would therefore be 300*5300/8.6*3=554651.

The mortality for all sorts of cancer in the European union was 62 % 1990. (Berrino et.al. 1999). The global average 1990 may be calculated to 64% using statistics from IARC. (Parkin et al., 1990, Pisani et al., 1990). The average reduction of life expectancy was estimated in 7.1.3 to 24 years.

Thus, the category indicator value is $554651 \cdot 0.64 \cdot 24 = 8.52 \cdot 10^6$ YOLL.

Contribution to category indicators value from a flow unit

The global emission of PAH is estimated through its normal ratio to NO_x in Swedish urban air. This ratio is used as car exhausts probably is the main source to the population dose, with small-scale wood firing as the second most important and because there is no significant sink processes that would be able to change the PAH/NO_x ratio in the urban air. The ratio was determined in Gothenburg (Steen, B. IVL report B 1033, 1991) to be $0.2 \cdot 10^{-3}$. The global anthropogenic emission of NO_x is 75 tg/year. Thus the global PAH emission would be $0.2 \cdot 10^{-3} * 75 \cdot 10^{12}$ g = $1.5 \cdot 10^{10}$ g or $1.50 \cdot 10^{7}$ kg. The contribution is thus $1/1.5 \cdot 10^7 = 6.67 \cdot 10^{-8}\ kg^{-1}$.

Calculation of characterisation factor

The characterisation factor is $8.52 \cdot 10^6 * 6.67 \cdot 10^{-8} = 0.568$ YOLL/kg PAC.

Uncertainty

Due to the unclear definition of PAC and the general uncertainty of risk estimation for low dose exposures, the uncertainty in the risk estimate is set to a factor of 10. The PAC/NO_x ratio is uncertain partly due to variation in the results quoted and partly because measurements are missing from non-OECD countries. The uncertainty in the estimation of the global exposure is estimated to a factor of three. The total uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 4.

11.1.4. Characterisation of PAC to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The system is global and the year is 1990. Most of the exposure occurs in urban areas why the characterisation modelling is focused on urban areas.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The portion of cancer incidences not causing death (36%) is classified as severe morbidity. The average length of the morbidity is not known at present, but is assumed to be 5 years. This means that the total indicator value in the environmental system is $(5/10)*(0.36/0.64)* 8.52 \cdot 10^6 = 2.40 \cdot 10^6$ person-years of severe morbidity, where $8.52 \cdot 10^6$ was the indicator value determined in 10.1.3.

Contribution to category indicators value from a flow unit

The same contribution as in 11.1.3 is valid, i.e. $6.67 \cdot 10^{-8}$ per kg PAC.

Calculation of characterisation factor

This would mean that the characterisation factor would be $2.40 \cdot 10^6 * 6.67 \cdot 10^{-8} = 0.160$ person-years/kg PAC.

Uncertainty

Due to the unclear definition of PAC and the general uncertainty of risk estimation for low dose exposures, the uncertainty in the risk estimate is set to a factor of 10. The PAC/NO_x ratio is uncertain partly due to variation in the results quoted and partly because measurements are missing from non-OECD countries. The uncertainty in the estimation of the global exposure is estimated to a factor of three. The total uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 4.

11.1.3. Discussion

In this context the difference between PAC and PAH is small and the characterisation factors estimated for PAC may be used for PAH.

12. Classification and characterisation of emissions of freons to air

12.1. *Emissions of CFC-11 to air anywhere in the world*

12.1.1. Definition of flow group

The use of CFC-11 has decreased considerably due to the Montreal Convention and other international agreements. In this context it is used as a reference substance for freons and similar halocarbons. When emitted it is mostly as fugitive emission.

The flow group contains emissions to air anyplace on the globe anytime during 1990.

12.1.2. Assignment to impact categories

No toxic effects are known except at very high concentration in work environments, where neurological effects similar to those obtained from exposure to solvents occur. The residence time is several years, and the impacts are the same wherever the emissions occur. The main effects come from CFC-11 being a greenhouse gas and from its ability of depleting stratospheric ozone. Depletion of stratospheric ozone leads to an increased UV radiation which in turn leads to an increase of blindness, cancer and of infectious diseases. Excess UV radiation is suspected to promote cataract, which results in decreased visual capacity and blindness. No quantitative data is found. Skin cancer however seems to have a very low mortality (about 2%). Increased UV radiation decrease the capacity of the immune system, but no quantitative estimations was found.

The assignments made are summarised in table 12.1.

Table 12.1 Assignment of freons emissions to impact categories and selection of category indicators

Pathway	Impact categories	Category indicator
Direct IR absorption leads to global warming	Life expectancy	YOLL
Depletion of stratospheric ozone and increased skin cancer	Life expectancy	YOLL
Depletion of stratospheric ozone and increased skin cancer	Severe morbidity	Severe morbidity
Global warming	Severe morbidity	Severe morbidity
Global warming	Morbidity	Morbidity
Global warming	Crop production capacity	Crop
Global warming	Wood production capacity	Wood
Global warming	Extinction of species	NEX

12.1.3. Characterisation of CFC-11 to air with respect to YOLL

Definition of environmental system in which the impact is estimated

CFC-11 has a very long residence time in air. According to IPCC it is 50 years. The effects are global. The greenhouse end point effects are assumed largely to depend on how fast the temperature change is why the next 100 years have been chosen as a system border for CO_2 effects. The duration of effects caused by depletion of the ozone layer are much longer, but applying an emission scenario following the Montreal agreement and addendum of Copenhagen and London, most of the effects are likely to have occurred before 100 years.

The environmental system borders chosen are therefore global and 100 years.

Model 1, stratospheric ozone depletion pathway

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

The mortality in Holland due to skin cancers is expected to increase to 3 cases per million per year in the white population the year 2040 and then decrease (Slaper, 1993). If the white global population is around 1 billion this means 3000 cases per year. If compensated for population growth it will be slightly more. The global population is expected to grow to around 9-10 billion at the end of 2000. Most of the growth is however not in the white population, why the average incidence is assumed to be only slightly higher, 3500 cases per year.

The average reduction of life expectancy was estimated in 7.1.3 to 24 years.

Thus, the category indicator value is 3500*24*100 = 8400000 YOLL.

Contribution to category indicators value from a flow unit

According to IPCC business as usual estimate (including agreed emission reductions) the global emissions of freons in terms of CFC-11 equivalents will be $2.5\ 10^{10}$ kg for the next 100 years. Therefore the contribution of 1 kg CFC-11 (with respect to Ozone Depletion Potential) is $4 \cdot 10^{-11}$ kg^{-1}.

Calculation of pathway specific characterisation factor

The pathway specific characterisation factor is thus $8400000 * 4 \cdot 10^{-11} = 3.36 \cdot 10^{-4}$ YOLL/kg CFC-11.

Uncertainty

The largest risk factor is related to sunbathing habits, which makes it difficult to find a quantitative estimate of the additional incremental risk from increased UV-radiation. There is also a large uncertainty in estimating how the population dose will increase. Considering the complexity of the models used, and what is estimated to be the uncertainty in climate models, a factor of 5 seems to be a reasonable estimate of the uncertainty in estimating the indicator value.

The uncertainty in the contribution is somewhat less. A factor of 3 is assumed.

Totally the uncertainty is assume to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.5.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for YOLL was determined in 3.1.3 to $7.93 \cdot 10^{-7}$ YOLL/kg CO_2. Thus the global warming pathway specific characterisation factor for CFC-11 is $4000 * 7.93 \cdot 10^{-7} = 3.17 \cdot 10^{-3}$ YOLL/kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the most contributing pathway specific characterisation factor of CO_2 for YOLL was estimated in 3.1.3 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp \sqrt{(\ln 1.1)^2 + (\ln 3)^2} = 3.0$

Calculation of characterisation factor

The resulting characterisation factor from adding the two pathways is $3.36 \cdot 10^{-4} + 1.62 \cdot 10^{-2} = 1.65 \cdot 10^{-2}$ YOLL/kg CFC-11.

12.1.4. Characterisation of CFC-11 to air with respect to severe morbidity

Definition of environmental system in which the impact is estimated

The system borders are the same as for 12.1.3, i.e. global and 100 years.

Model 1, stratospheric ozone depletion pathway

The characterisation factor is determined by the empirical method, but using the same basic information as in 12.1.3.

Category indicator value in system considered

The mortality for skin cancer is estimated to 2%. The average duration of severe morbidity is assumed to be shorter than for other cancers. A one-year duration per case is assumed. Thus, the category indicator value is 3500*1*1/0.02*100 = 17500000 person-years.

Contribution to category indicators value from a flow unit

According to IPCC business as usual estimate (including agreed emission reductions) the global emissions of freons in terms of CFC-11 equivalents will be $2.5\ 10^{10}$ kg for the next 100 years. Therefore the contribution of 1 kg CFC-11 (with respect to Ozone Depletion Potential) is $4{\cdot}10^{-11}$ kg^{-1}.

Calculation of pathway specific characterisation factor

The pathway specific characterisation factor is thus $17500000*4{\cdot}10^{-11} = 0.0007$ person-years/kg CFC-11.

Uncertainty

The same uncertainty is assumed as for the estimation of the pathway specific characterisation factor for YOLL, i.e. the uncertainty is assume to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 2.5.

Model 2, global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for severe morbidity was determined in 3.1.4 to $3.53{\cdot}10^{-7}$ person-years/kg CO_2. Thus the global warming pathway specific characterisation factor of CFC-11 for severe morbidity is $4000*3.53{\cdot}10^{-7} = 1.41{\cdot}10^{-3}$ person-years/kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the most contributing pathway specific characterisation factor of CO_2 for YOLL was estimated in 3.1.4 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2} = 3.0$

Calculation of characterisation factor

The resulting characterisation factor from adding the two pathways is $0.0007 + 1.41{\cdot}10^{-3} = 2.11{\cdot}10^{-3}$ YOLL/kg CFC-11.

12.1.5. Characterisation of CFC-11 to air with respect to morbidity

Definition of environmental system in which the impact is estimated

The system borders are the same as for 12.1.3, i.e. global and 100 years.

Model for global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for morbidity was determined in 3.1.5 to $6.55 \cdot 10^{-7}$ person-years/kg CO_2. Thus the global warming pathway specific characterisation factor of CFC-11 for severe morbidity is $4000 * 6.55 \cdot 10^{-7} = 2.62 \cdot 10^{-3}$ person-years/kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of CO_2 for morbidity is estimated from the uncertainties of the pathway specific characterisation factors in 3.1.5 to be described by a log-normal distribution with a standard deviation of a factor of 3.5. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp \sqrt{(\ln 1.1)^2 + (\ln 3.5)^2} = 3.5$

12.1.6. Characterisation of CFC-11 to air with respect to crop production capacity

Definition of environmental system in which the impact is estimated

The system borders are the same as for 12.1.3, i.e. global and 100 years.

Model for global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for crop production capacity was determined in 3.1.6 to $7.56 \cdot 10^{-4}$ kg crop/kg CO_2. Thus the global warming pathway specific characterisation factor of CFC-11 for severe morbidity is $4000 * 7.56 \cdot 10^{-4} = 3.02$ kg crop/kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of CO_2 for morbidity is estimated from the uncertainties of the pathway specific characterisation factors in 3.1.6 to be described by a log-normal distribution with a standard deviation of a factor of 2.2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 2.2)^2}$ = 2.2

12.1.7. Characterisation of CFC-11 to air with respect to wood production capacity

Definition of environmental system in which the impact is estimated

The system borders are the same as for 12.1.3, i.e. global and 100 years.

Model for global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The global warming pathway specific characterisation factor of CO_2 for wood production capacity was determined in 3.1.7 to $-1.16 \cdot 10^{-3}$ kg wood(DS)/kg CO_2. Thus the global warming pathway specific characterisation factor of CFC-11 for wood production capacity is $4000*(-1.16 \cdot 10^{-3}) = -4.64$ kg wood/kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of CO_2 for wood production capacity is estimated from the uncertainties of the pathway specific characterisation factors in 3.1.7 to be described by a log-normal distribution with a standard deviation of a factor of 2. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 2)^2}$ = 2

12.1.8. Characterisation of CFC-11 to air with respect to NEX

Definition of environmental system in which the impact is estimated

The system borders are the same as for 12.1.3, i.e. global and 100 years.

Model for global warming pathway

The characterisation factor is determined by an equivalency method using CO_2 as a reference.

Equivalency factor

The GWP-100 for CFC-11 is 4000 (IPCC, 1994).

Calculation of pathway specific characterisation factor

The characterisation factor of CO_2 for normalised extinction of species (NEX) was determined in 3.1.8 to $1.26\cdot10^{-14}$ /kg CO_2. Thus the global warming pathway specific characterisation factor of CFC-11 for NEX is $4000*1.26\cdot10^{-14} = 5.04\cdot10^{-11}$ /kg CFC-11.

Uncertainty

The uncertainty in GWP reported by IPCC for most substances is in the order of 30%. It is therefore assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 1.1. The uncertainty for the characterisation factor of CO_2 for NEX is estimated in 3.1.8 to be described by a log-normal distribution with a standard deviation of a factor of 3. The total uncertainty may therefore be described by a log-normal distribution with a standard deviation corresponding to a factor of $\exp\sqrt{(\ln 1.1)^2 + (\ln 3)^2} = 3.0$

12.2. Emissions of other freons to air anywhere in the world

In the same way as for CFC-11, characterisation factor may be calculated, but applying other equivalency factors. The calculations are shown in table 12.2.

Table 12.2 Pathway specific characterisation factors for freons and similar substances

Substance name	ODP	GWP-100	YOLL, stratospheric ozone depletion pathway	YOLL, global warming pathway	Severe morbidity, stratospheric ozone depletion pathway	Severe morbidity, global warming pathway	Morbidity, global warming pathway	Crop production capacity, global warming pathway	Wood production capacity, global warming pathway	NEX, global warming pathway
CFC:s										
CFC-11	4000	1	3.36E-04	3.17E-03	7.00E-04	1.41E-03	2.62E-03	3.02E+00	-4.64E+00	5.04E-11
CFC-12	8500	1	3.36E-04	6.74E-03	7.00E-04	3.00E-03	5.57E-03	6.42E+00	-9.86E+00	1.07E-10
CFC-13	11700	1	3.36E-04	9.28E-03	7.00E-04	4.12E-03	7.66E-03	8.83E+00	-1.36E+01	1.47E-10
CFC-113	5000	1.07	3.60E-04	3.97E-03	7.49E-04	1.76E-03	3.28E-03	3.78E+00	-5.80E+00	6.30E-11
CFC-114	9300	0.8	2.69E-04	7.37E-03	5.60E-04	3.28E-03	6.09E-03	7.02E+00	-1.08E+01	1.17E-10
CFC-115	9300	0.5	1.68E-04	7.37E-03	3.50E-04	3.28E-03	6.09E-03	7.02E+00	-1.08E+01	1.17E-10
HCFC:s										
HCFC-22	1700	0.055	1.85E-05	1.35E-03	3.85E-05	5.99E-04	1.11E-03	1.28E+00	-1.97E+00	2.14E-11
HCFC-123	93	0.02	6.72E-06	7.37E-05	1.40E-05	3.28E-05	6.09E-05	7.02E-02	-1.08E-01	1.17E-12
HCFC-124	480	0.022	7.39E-06	3.81E-04	1.54E-05	1.69E-04	3.14E-04	3.62E-01	-5.57E-01	6.05E-12
HCFC-141b	630	0.11	3.70E-05	5.00E-04	7.70E-05	2.22E-04	4.13E-04	4.76E-01	-7.31E-01	7.94E-12
HCFC-142b	2000	0.065	2.18E-05	1.59E-03	4.55E-05	7.05E-04	1.31E-03	1.51E+00	-2.32E+00	2.52E-11
HCFC-225ca	170	0.025	8.40E-06	1.35E-04	1.75E-05	5.99E-05	1.11E-04	1.28E-01	-1.97E-01	2.14E-12
HCFC-225cb	530	0.033	1.11E-05	4.20E-04	2.31E-05	1.87E-04	3.47E-04	4.00E-01	-6.15E-01	6.68E-12
Bromocarbons										
H-1303	5600	16	5.38E-03	4.44E-03	1.12E-02	1.97E-03	3.67E-03	4.23E+00	-6.50E+00	7.06E-11
Others										
HFC-23	12100		0.00E+00	9.60E-03	0.00E+00	4.27E-03	7.93E-03	9.14E+00	-1.40E+01	1.52E-10
HFC-32	580		0.00E+00	4.60E-04	0.00E+00	2.04E-04	3.80E-04	4.38E-01	-6.73E-01	7.31E-12
HFC-43-10mee	1600		0.00E+00	1.27E-03	0.00E+00	5.64E-04	1.05E-03	1.21E+00	-1.86E+00	2.02E-11
HFC-125	3200		0.00E+00	2.54E-03	0.00E+00	1.13E-03	2.10E-03	2.42E+00	-3.71E+00	4.03E-11
HFC-134	1200		0.00E+00	9.52E-04	0.00E+00	4.23E-04	7.86E-04	9.06E-01	-1.39E+00	1.51E-11
HFC-134a	1300		0.00E+00	1.03E-03	0.00E+00	4.58E-04	8.52E-04	9.82E-01	-1.51E+00	1.64E-11
HFC-152a	140		0.00E+00	1.11E-04	0.00E+00	4.94E-05	9.17E-05	1.06E-01	-1.62E-01	1.76E-12
HFC-143	290		0.00E+00	2.30E-04	0.00E+00	1.02E-04	1.90E-04	2.19E-01	-3.36E-01	3.65E-12
HFC-143a	4400		0.00E+00	3.49E-03	0.00E+00	1.55E-03	2.88E-03	3.32E+00	-5.10E+00	5.54E-11
HFC-227ea	3300		0.00E+00	2.62E-03	0.00E+00	1.16E-03	2.16E-03	2.49E+00	-3.83E+00	4.16E-11
HFC-236fa	8000		0.00E+00	6.34E-03	0.00E+00	2.82E-03	5.24E-03	6.04E+00	-9.28E+00	1.01E-10
HFC-245ca	610		0.00E+00	4.84E-04	0.00E+00	2.15E-04	4.00E-04	4.61E-01	-7.08E-01	7.69E-12
SF6	24900		0.00E+00	1.97E-02	0.00E+00	8.78E-03	1.63E-02	1.88E+01	-2.89E+01	3.14E-10
CF4	6300		0.00E+00	5.00E-03	0.00E+00	2.22E-03	4.13E-03	4.76E+00	-7.31E+00	7.94E-11
C2F6	12500		0.00E+00	9.91E-03	0.00E+00	4.41E-03	8.19E-03	9.44E+00	-1.45E+01	1.58E-10
c-C4F8	9100		0.00E+00	7.22E-03	0.00E+00	3.21E-03	5.96E-03	6.87E+00	-1.06E+01	1.15E-10
C6F14	6800		0.00E+00	5.39E-03	0.00E+00	2.40E-03	4.45E-03	5.13E+00	-7.89E+00	8.57E-11

13. Classification and characterisation of emissions of noise to air

13.1. Emissions of traffic noise anywhere in the world

13.1.1. Definition of flow group

Noise is emitted from most human activities. Traffic noise is the most common noise of environmental concern today.

Emission of noise is normally not treated in the same way as emission of chemical substances to air. The proper analogue measure would be Watts. However as sound dispersion and propagation is different in different directions and extremely complicated to model, most noise tests are made by determining the noise impact at a certain distance from the source. The unit is normally dB(A) or sometimes dB(B), which are sound intensity measures transformed to simulate the perceived sound intensity and presented on a logarithmic scale.

In this particular case, the flow is not noise in itself, but rather the flow of vehicles in terms of vehicle km.

13.1.2. Assignment to impact categories

Noise is primarily a nuisance problem although it may have some indirect effects on morbidity and mortality through disturbing recovery processes. Here noise above 65 db is assigned to nuisance.

13.1.3. Characterisation of vehicle flow with respect to severe nuisance from noise.

Definition of environmental system in which the impact is estimated
The system considered is global and the year 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
Noise levels in most cities are above 65 dB (A), affecting between 10 and 20 per cent of inhabitants in Western Europe and up to 50 per cent in some cases in Central and Eastern Europe (EEA, 1995)

Considering the part of the inhabitants in Western and Eastern Europe that is exposed to noise levels above 65 dB(A) and considering that a large part of the population live in the countryside outside OECD, a best estimate of 25% of the global population is assumed.

Assuming that the disturbance mainly occur at rush hours, around 4/24 = 0,167 of the time there is a nuisance. The indicator value is thus around 5.28*0.25*0.167 = 0.22 billion person-years of nuisance.

Contribution to category indicators value from a flow unit

1990 there were 442 million passenger cars and 138 million commercial vehicles. The total mileage of the world fleet is not known, but may be roughly estimated. One way is to assume an average mileage of 15000 km/year. The total mileage will then be $(442+138)\cdot10^6*15000 = 8.7\cdot10^{12}$ km. Another way is to use world statistics on fuel production. According to UN (1994) the total production of light petroleum products was $1{,}67\cdot10^9$ metric tons 1991. Assuming an average fuel consumption of 1 kg/10km there would be fuel for $1.67\cdot10^{13}$ km. As not all of the light petroleum products are used as fuel for road vehicles, it seem reasonable to use the first estimate, $8.7\cdot10^{12}$ km.

Calculation of characterisation factor

The characterisation factor will thus be $0.22\cdot10^9/\ 8.7\cdot10^{12} = 2.53\cdot10^{-5}$ person-years/vehicle km.

Uncertainty

The choice of a distinct level, where nuisance starts is a simplification of a complex dose-response pattern. The ExternE-project reports a study of Fidell, (1991), who formulated a model for the probability of a person to be highly annoyed at various nose levels. The probability of being highly annoyed, P(HA) followed the expression:

$$P(HA) = \exp[-10^{p/10*(D-Ldn)}] \text{ ,where}$$

D is the noise level at which e^{-1} (37%) is highly annoyed by the noise and p is an elasticity which determines the spread of sensitivity to noise. Ldn is the ‘day-night’ noise level defined as the time averaged continuos level after the addition of 10 dB(A) to sound levels between 10 p.m. and 7.a.m. Typical values for D is 70-75 dB(A) and 0.3 for p.

When entering various typical noise levels into the expression P(HA) gets values in the range of 20-35 %.

This indicates that the uncertainty of the estimation of the indicator value is in the order of a factor of two, i.e the correct value is between 12.5 and 50% of the population.

In the estimation of the contribution the type of vehicle is not specified. A commercial truck is likely to contribute to the noise level more than a passenger car. This introduces an uncertainty, which is estimated to a factor of 5, which represents the ratio of energy consumption between trucks and passenger cars.

There is also an uncertainty in the level of nuisance. The assignment to severe nuisance may be questioned in large part of the world where noise is less objectionable to humans than in the western world. However the default weighting method is based on attitudes in the OECD world, why this assignment is kept.

Based on what is mentioned above, the total uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

14. Classification and characterisation of emissions of nutrients to water

14.1. *Emissions of BOD to water anywhere in the world*

BOD and COD are names for a group of substances, which have a demand for oxygen when decomposing in water. They are partly overlapping but normally BOD is a part of COD. BOD stands for biologic oxygen demand, while COD means chemical oxygen demand.

14.1.1. Definition of flow group

The flow group is any emission of BOD to water anyplace in the world 1990. This is a very heterogeneous group containing emissions to small streams as well as emissions to ocean water.

14.1.2. Assignment to impact categories

BOD emissions cause a decrease of oxygen and in some cases oxygen-free waters, which leads to fish kill and destroys most life forms. As a consequence recreational and cultural values may be lost. The latter impact category is not modelled here, as the background information has been insufficient.

BOD emissions are therefore assigned to production capacity of fish, recreational and cultural values and species extinction, but only the latter is modelled.

14.1.3. Characterisation of BOD to water with respect to NEX

Definition of environmental system in which the impact is estimated
All lakes, surface waters and oceans on the globe 1990.

Model
The characterisation factor is determined by an equivalency method using N-tot as a reference.

Equivalency factor
According to Lindfors et al. (1995), each mole of nitrogen corresponds to 8.6 mole of consumed oxygen in a N-limited aquatic system scenario. The equivalency factor is therefore equal to 14/(8.6*16) = 0.1017 kg N/kg BOD.

Calculation of characterisation factor
The characterisation factor for N-tot is determined in 14.3 to $1.8 \cdot 10^{-13}$. The characterisation factor for BOD is thus $0.1017 * 1.8 \cdot 10^{-13} = 1.83 \cdot 10^{-14}$ NEX/kg BOD.

Uncertainty
The uncertainty in the equivalency factor is estimated to be relatively small compared to the uncertainty in the characterisation factor. Thus the uncertainty is the same as for N-tot, i.e. described by a log-normal distribution with a standard deviation corresponding to a factor of 5.

14.2. Emissions of COD anywhere in the world

14.2.1. Definition of flow group

BOD and COD are names for a group of substances, which have a demand for oxygen when decomposing in water. They are partly overlapping but normally BOD is a part of COD. BOD stands for biologic oxygen demand, while COD means chemical oxygen demand.

14.2.2. Assignment to impact categories

COD emissions cause a decrease of oxygen and in some cases oxygen-free waters, which leads to fish kill and destroys most life forms. As a consequence recreational and cultural values may be lost. The latter impact category is not modelled here, as the background information has been insufficient.

COD emissions are therefore assigned to production capacity of fish, recreational and cultural values and species extinction, but only the latter is modelled.

14.2.3. Characterisation of COD to water with respect to NEX

Definition of environmental system in which the impact is estimated
All lakes, surface waters and oceans on the globe 1990.

Model
The characterisation factor is determined by an equivalency method using N-tot as a reference.

Equivalency factor
According to Lindfors et al. (1995), each mole of nitrogen corresponds to 8.6 mole of consumed oxygen in a N-limited aquatic system scenario. Normally, only a part of the COD is actually mineralised in such a way as it contributes to oxygen-free water. This part is assumed to be 50%. The equivalency factor is therefore equal to = 0.5*14/(8.6*16) = 0.0508 kg/kg

Calculation of characterisation factor
The characterisation factor for N-tot is determined in 14.3 to $1.8 \cdot 10^{-13}$. The characterisation factor for COD is thus $0.0508 * 1.8 \cdot 10^{-13} = 9.18 \cdot 10^{-15}$ NEX/kg BOD.

Uncertainty
The uncertainty in the equivalency factor is estimated to be relatively small compared to the uncertainty in the characterisation factor. Thus the uncertainty is the same as for N-tot, i.e. described by a log-normal distribution with a a standard devisation corresponding to a factor of 5.

14.3. Emissions of total nitrogen compounds (N-tot) anywhere in the world

14.3.1. Definition of flow group

The flow group is any emission of N-tot to water anyplace in the world 1990. This is a very heterogeneous group containing emissions to small streams as well as emissions to ocean water. N-tot stands for total nitrogen and is a collective name for nitrogen compounds including both organic and inorganic nitrogen, but excluding elementary nitrogen.

14.3.2. Assignment to impact categories

N-tot is a nutrient and emissions cause an increased growth of various organisms which, when dying cause decrease of oxygen and in some cases oxygen-free waters, which in turn leads to fish kill and destroys most life forms. As a consequence recreational and cultural values may be lost. The latter impact category is not modelled here, as the background information has been insufficient.

N-tot is assigned to production capacity of fish&meat, to extinction of species and to recreational and cultural values, but the latter is not modelled.

14.3.3. Characterisation of N-tot to water with respect to fish&meat

Definition of environmental system in which the impact is estimated
All lakes, surface waters and oceans on the globe 1990.

Model
The characterisation factor is determined by a mechanistic method.

Mechanism
In most of the ocean waters, nitrogen is a limiting growth factor. In inland waters, and in some other areas, like the northern Baltic Sea, phosphorus is growth limiting. The share of nitrogen emissions ending up in areas were the growth rate is limited by nitrogen, is estimated to 90%. Sooner or later most of the nitrogen will be transferred to fish flesh via the nutrient chains.

In a study in Skälderviken (a part of the Baltic Sea) the weight of the bottom fauna 1912 was 114 g/m^2. 1984 it was 399 g/m^2 (SNA 1991). The total addition of anthropgenic N to the southern part of the Baltic Sea (where Skälderviken is located) is about 1.2 million tons/year in an area of 214000 km^2. As an average the nitrogen added is thus 5.61 ton/ km^2 or 56.1 kg/hectare.

Comparing with the value used for average fish production in Swedish waters, 10 kg/hectare and year, the extra nitrogen would result in an increased fish production of (399-114)/114*10= 25 kg/hectare and year.

Calculation of characterisation factor

For each kg of nitrogen emitted to water we thus obtain 0.9*25/56.1= 0.401 kg fish and the characterisation factor of N-tot for fish&meat will be –0.401 kg/kg N-tot.

Uncertainty

The use of the result from Skälderviken in other parts of the world, introduce an uncertainty, which is assumed to be in the order of a factor of 4. This estimate is based on the fact that there can hardly be more than what is required of N to build proteins, i.e. in the order of 10 kg/kg.

14.3.4. Characterisation of N-tot to water with respect to NEX

Definition of environmental system in which the impact is estimated

All lakes, surface waters and oceans on the globe 1990.

Model

The characterisation factor is determined by the empirical method.

Category indicator value in system considered

10% of the threat to bio-diversity in Scandinavia are due to eutrofication. On a global scale, the threat to bio-diversity is assumed to be less, 1%, as warmer regions are less sensitive to excess nitrogen. The indicator value is thus 0.01NEX.

Contribution to category indicators value from a flow unit

The global emission of nitrogen to water during 1990 is estimated to $5 \cdot 10^{10}$ kg. 90% of the extinction caused by eutrofication is allocated to nitrogen. The figure is based on a rough estimation of the relative size of polluted ocean and sweet-water areas where oxygen-free bottoms may occur. 10% is thus allocated to phosphorous.

Calculation of characterisation factor

$0.9 * 0.01\text{NEX}/5 \cdot 10^{10}\text{ kg} = 1.8 \cdot 10^{-13}$ NEX/kg N-tot.

Uncertainty

The uncertainty depends both of the estimation of the extension and of the contribution. Each one is estimated to be in the order of a factor ten. Based on this, the uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to a factor of 5.

14.4. Emissions of total phosphorous compounds (P-tot) anywhere in the world

14.4.1. Definition of flow group

The flow group is any emission of P-tot to water anyplace in the world 1990. This is a very heterogeneous group containing emissions to small streams as well as emissions to ocean water. P-tot stands for total phosphorous and is a collective name for phosphorous compounds including both organic and inorganic nitrogen.

14.4.2. Assignment to impact categories

P-tot is a nutrient and emissions cause an increased growth of various organisms which, when dying cause decrease of oxygen and in some cases oxygen-free waters, which in turn leads to fish kill and destroys most life forms. As a consequence recreational and cultural values may be lost. The latter impact category is not modelled here, as the background information has been insufficient. The impact on fish production is mainly in inland waters. No modelling of the net change has been possible as in the case of N-tot, because the negative and positive impacts counteract each other and is difficult to grasp in a simple model.

P-tot is therefore assigned to extinction of species.

14.4.3. Characterisation of P-tot to water with respect to NEX

Definition of environmental system in which the impact is estimated
All lakes, surface waters and oceans on the globe 1990, but with a focus on lakes and surface waters, where phosphorus often is growth rate limiting.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
10% of the threat to bio-diversity in Scandinavia are due to eutrofication. On a global scale, the threat to bio-diversity is assumed to be less, 1%. The indicator value is thus 0.01NEX.

Contribution to category indicators value from a flow unit
Global emission of phosphorous to water is estimated to be in the order of 2E+9 kg, but is only contributing to a minor degree to eutrofication effects (10%, in lakes)

Calculation of characterisation factor

$0.01/2\cdot10^{9}*0.1 = 5\cdot10^{-13}$ NEX/kg P-tot.

Uncertainty

The uncertainty is estimate to be about the same as for nitrogen, i.e. be describe by a log-normal distribution with a standard deviation corresponding to a factor of 5.

15. Classification and characterisation of emissions of metals to water

Today, real impacts on the safeguard subjects from metals are mainly caused by mercury. Some local effects from other metals may also be found, e.g. where seafood is classified as not suitable for humans, or where use of contaminated drinking water leads to health effects, but these are as a global average small or negligible. If they constitute a significant local problem, the best way is to make a local model.

15.1. Emissions of mercury to water anywhere in the world

15.1.1. Definition of flow group

The flow group is emissions of mercury to water anywhere in the world, but at amounts that do not cause local thresholds to be exceeded.

15.1.2. Assignment to impact categories

The same assignments are made as for emissions of mercury to air, i.e. morbidity, fish&meat and NEX.

15.1.3. Characterisation of mercury to water with respect to morbidity

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.3), i.e. $4.80 \cdot 10^{-3}$ person-years/kg Hg.

15.1.4. Characterisation of mercury to water with respect to fish&meat

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.4), i.e. 0.224 kg/kg Hg.

15.1.5. Characterisation of mercury to water with respect to NEX

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.5), i.e. $1.20 \cdot 10^{-10}$ NEX/kg Hg.

16. Classification and characterisation of emissions of metals to soil

Like emissions to air and water emissions to soil vary in terms of magnitude and concentration. Deposition of sludge on arable land or wood-ash to forests may distribute metals evenly in a certain area at low concentrations. Littering and intentional deposition may introduce metals in high concentrations on small areas or spots. This may give large differences in impacts per mass unit of the metals.

16.1. Emissions of cadmium (Cd) to agricultural soil anywhere in the world

16.1.1. Definition of flow group

The flow group includes all types of emissions of Cd to soil, such as addition of sludge, ashes and fertilisers. The flow group includes any emission on the globe 1990.

16.1.2. Assignment to impact categories

Cadmium is a carcinogen. Cd is regarded as a carcinogen when inhaled, but no evidence is available that oral exposure gives an increased risk. Cd is toxic to humans also in other ways. The kidneys are the most sensitive of the organs and their functions may be disturbed. Cadmium has a tendency to accumulate in the food chain. Cadmium emissions to soil is therefore assigned to morbidity.

16.1.3. Characterisation of Cd to soil with respect to morbidity

In 10.3.5 the characterisation factor for Cd emitted to air and deposited to soil from air was estimated to 0.498 10^{-4} person-years/kg Cd. 10% of the air emissions is estimated to deposit on agricultural soils. Therefore the characterisation factor for Cd emissions directly to soil is ten times as large, i.e. $5 \cdot 10^{-4}$.

Uncertainty

The same uncertainty is assumed as in 10.4, i.e. a log-normal distribution with a standard deviation corresponding to a factor of 5.

16.2. Emissions of mercury to soil anywhere in the world

16.2.1. Definition of flow group

Any emission to soil of mercury at any place in the world and during 1990.

16.2.2. Assignment to impact categories

Mercury is an element that is highly volatile in some forms. When deposited on soil, an unknown part of the mercury will enter the atmosphere or surface waters. Some will be bound in the mineral soil. Due to its volatility, emissions of mercury are assigned to the same impact category indicators as mercury emitted to air, i.e. morbidity, fish and meat and NEX.

16.2.3. Characterisation of mercury to water with respect to morbidity

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.3), i.e. $4.8 \cdot 10^{-3}$ person-years/kg Hg.

16.2.4. Characterisation of mercury to water with respect to fish&meat

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.4), i.e. 0.224 kg fish/kg Hg.

16.2.5. Characterisation of mercury to water with respect to NEX

Due to the global mixing processes, the same characterisation is used as for emissions of mercury to air (10.8.5), i.e. $1.20 \cdot 10^{-10}$ NEX/kg Hg.

17. Classification and characterisation of direct impacts on humans

Direct impacts on humans are seldom included in LCA studies, as their consequences are very case specific and may vary much. In the EPS default method, the uncertainty of the corresponding characterisation factors would often be so large that including the impacts would add little to the overall precision in the priority setting.

For some impacts however, which occur frequently in product systems, the uncertainty will decrease because the average of a number of impacts is less uncertain than the individual events.

Traffic accidents and various types of occupational accidents from defined, repetitive work are impacts that may be included.

In practice, the assignment to impact categories and risk estimates of direct impact is made in the inventory step. For instance the YOLL and severe morbidity is determined directly for a type of human activity like ‘travelling 1 km in a car’. Then all characterisation factors of the impact assessment step are equal to 1.

18. Assigning physical land use parameters to impact categories and modelling of corresponding characterisation factors

18.1. Using arable land for agriculture anywhere in the world

18.1.1. Definition of activity group

The activity group includes the use of arable land everywhere on the globe in the form of intensive agriculture. It includes managing of arable land and pastureland. It does not include farming where large herds of cattle's move from place to place in a more or less natural environment. The activity does not include emissions and use of resources other than those depleted from the land area used. The activity default unit is m^2year.

18.1.2. Assignment to impact categories

Farming being an intensive activity has an impact on bio-diversity. Another environmental issue connected to farming is destruction of soil quality and subsequent decrease of production capacity of crop. No models have so far been developed for the latter mechanism, why using arable land for agriculture only is assigned to NEX.

18.1.3. Characterisation of arable land use with respect to NEX

Definition of environmental system in which the impact is estimated
The system is global, but limited to arable land. The time frame is 1990.

Model
The characterisation factor is determined by an empirical method.

Category indicator value in system considered
Järvinen (1987) presents statistics on threat causes for endangered species in Sweden and Finland. (table 18.1 and 18.2).

Table 18.1 Endangered vertebrates in Sweden according to the Swedish "Faunavårdskommitté". The threat categories are: 0=disappeared, 1=acute endangered, 2=vulnerable, 3=scarce, 4=concern dependent

Cause of threat	Category					
	0	1	2	3	4	Sum
Forestry	2	3	4	-	29	38
Farming	7	3	6	-	19	35
Disturbing, hunting	1	6	8	-	20	35
Pollution, eutrofication	1	2	6	-	8	17
Exploitations, settlements	2	3	5	-	5	15
Pollution of toxic substances	0	5	4	-	4	13
Unknown		2	2	-	2	6
Water control	0	2	0	-	4	6
Predation, competition, illness	1	1	2	-	0	4
Reed harvesting	0	0	1	-	3	4
Acidification	0	1	0	-	2	3
Fishing methods, over-fishing	1	0	1	-	1	3
Peat digging	0	0	0	-	1	1
SUM	15	28	39	-	98	180
Number of species in category	12	14	24	23	67	140

In Finland, which to a very large part is covered by forests, and where agriculture uses only a small part of the area, 1.5% of the endangered species have running agriculture as a major threat cause. In Sweden farming is responsible for the threat to 19% of the endangered species. Considering the pressure on land in many of the highly populated and bio-diversity rich tropical and temperate regions, it is assumed that the use of arable land for agriculture is responsible for at least the same magnitude of threat as in Sweden, i.e. 20%. Assuming that the contribution to the threat is the same as the contribution to extinction, this gives a category indicator value of 0.2 NEX in the environmental system considered.

Contribution to category indicators value from a flow unit

The global use of arable land is about $1.4 \cdot 10^{13}$ m^2year per year. The contribution from the use of 1 m^2 is therefore $7.1 \cdot 10^{-14}$ /m^2year.

Calculation of characterisation factor

The characterisation factor is thus 0.2 NEX*$7.1 \cdot 10^{-14}$ /m^2year = $1.42 \cdot 10^{-14}$ NEX/m^2year

Uncertainty

The variation in the intensity of various types of arable land use is considerable, and variations in the order of ten may be expected. The uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

Table 18.2 Threat causes for endangered species in Finland. According to the commission for protection of endangered species in Finland.

	Verte-brates	Inverte-brates	Vascular plants	Mosses and algae	Fungi and lichens	Total
Capture	41	1				42
Collecting	8	28	36	3	6	81
Disturbing	20	5				25
Wearing		26	12	16	12	66
Construction work	8	82	49	19	65	223
Mining		3	19	24	10	56
Changes of arable land	5	11	9		3	28
Overgrowing of meadows and pasture-land	6	101	78	3	43	231
Forestry	4	33	41	45	85	208
Change of tree species	5	77	6	12	91	191
Change in age structure of forests	5	93		2	39	139
Decrease of dead trees	8	115		11	50	184
Ditching and peat cutting	3	26	24	13	16	92
Water dams	17	28	26	25	3	99
Change in water quality	14	32	6	18	2	72
Chemical impacts	17	11	5	14	25	72
Other causes	14	8	5		1	28
Unknown cause	1	26	11	12	9	59

18.2. Using forest land for forestry anywhere in the world

18.2.1. Definition of activity group

The activity group includes the use of forestland everywhere on the globe in order to systematically grow and harvest timber. It includes managing of forests. The activity does not include emissions and use of resources other than those depleted from the land area used. The activity default unit is m^2year.

18.2.2. Assignment to impact categories

Forestry has an impact on bio-diversity. Other environmental issues related to forestry are destruction of soil quality and impacts on recreational and cultural values. No models have so far been developed for the latter mechanisms, why using forestland for forestry only is assigned to NEX.

18.2.3. Characterisation of forest land use with respect to NEX

Definition of environmental system in which the impact is estimated
The system is global, but limited to arable land. The time frame is 1990.

Model
The characterisation factor is determined by the empirical method.

Category indicator value in system considered
According to table 19.1 and 19.2, forestry in Finland and in Sweden is responsible for the threat to 38 and 21% of the NEX respectively. Assuming that the contribution to the threat is the same as the contribution to extinction, this gives a category indicator value of 0.38 and 0.21 NEX in Finland and Sweden respectively. For the global forestry it is assumed that the Swedish figure is the most representative and a best estimate of 0.2 NEX is used.

Contribution to category indicators value from a flow unit
The global use of forestland is about $4\cdot10^{13}$ m^2year per year. The contribution from the use of 1 m^2 is therefore $2.5\cdot10^{-14}$ /m^2year.

Another way to quantify forestry is via the harvesting of timber. The global harvesting of timber was 3521 million m^3 solid volume of roundwood without bark during 1990 (UN, 1994). Then the contribution is $2.84\cdot10^{-10}$/ m^3.

Calculation of characterisation factor
The characterisation factor is thus 0.2 NEX*$2.5\cdot10^{-14}$ /m^2year = $5.0\cdot10^{-15}$ NEX/m^2year or 0.2 NEX*$2.84\cdot10^{-10}$ = $5.68\cdot10^{-11}$ NEX/m^3.

Uncertainty
The variation in the intensity of various types of forestry use is considerable, and variations in the order of ten may be expected. The uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 5.

18.3. Use of forest land for roads and other hard-made surfaces anywhere in the world

18.3.1. Definition of activity group

Hard-making of forestland cause impacts on the environment during a number of years. There are many historical examples on how forests have regained hard-made areas, why the initial impacts may be allocated on an activity during a number of years. It is therefore chosen to define the activity as land use rather than land transformation.

18.3.2. Assignment to impact categories

The main impacts from hard-making is on bio-diversity and on the production capacity of ecosystems. The activity is therefore assigned to NEX and to production capacity of wood.

18.3.3. Characterisation of forest land use with respect to NEX

Definition of environmental system in which the impact is estimated
The system is global, but limited to arable land. The time frame is 1990.

Model
The characterisation factor is determined by an equivalency method using forestry as a reference.

Equivalency factor
There are no direct estimations available for the impact on bio-diversity from hard-making of surfaces. Roads have not only an impact through covering a surface. It also contributes to fragmentation of habitats. To some degree, there is also a positive effect on bio-diversity from building of roads. Roadsides are often rich in species. Due to lack of better estimates, the impact on bio diversity from hard-making of forestland is assumed to be at the upper range of the impact distribution from forestry, i.e. ten times the average.

Calculation of characterisation factor
The characterisation factor is thus $10*5.0\cdot10^{-15} = 5.0\cdot10^{-14}$ NEX/m^2year

Uncertainty
The uncertainty is assumed to be larger than for forestry and represented by a log-normal distribution with a standard deviation corresponding to a factor of 10.

18.3.4. Characterisation of forest land use with respect to wood production capacity

Definition of environmental system in which the impact is estimated
The system is global, but limited to arable land. The time frame is 1990.

Model
The characterisation factor is determined by a mechanistic method.

Mechanism
A typical growth rate in a boreal forest is 4-10 m^3 per year and hectare. A tropical forest can produce as much as 50m^3/hectare and year, at least temporarily. Based on this a best estimate of 0.5 kg dry substance per m^2 is made. Hard-making will decrease the production capacity by 0.5 kg dry substance per m^2 and year as long as the hard making remains. If we consider a road, it may be used for at least one hundred years and, if not demolished and removed, the impact will remain for another 100 years. A conservative

guess is therefore that the category indicator will be changed by 1 kg dry substance per m^2 and year the hard-made surface is used.

Calculation of characterisation factor
The characterisation factor of use of forest land for roads and other hard-made surfaces is thus 1 kg wood(DS)/m^2 year.

Uncertainty
As indicated, there is a large variation in the production capacity of forests (a factor of 3 from average) and there is an uncertainty of the recovery rate of about the same order of magnitude. Totally the uncertainty is assumed to be represented by a log-normal distribution with a standard deviation corresponding to a factor of 3.

18.4. Littering anywhere in the world

Litter and scrap thrown or left in the environment cause various grades of nuisance and sometimes other effects. It is extremely difficult to model these effects, but being one of the significant environmental problems it would be unsatisfactory to leave it out.

18.4.1. Definition of flow group

The flow group is litter or scrap thrown or left at the ground and measured in "surface flow", i.e. surface in area units.

18.4.2. Assignment to impact categories

Littering is classified as severe nuisance.

18.4.3. Characterisation of litter with respect to severe nuisance

Definition of environmental system in which the impact is estimated
The system is global and the time period is 1990. Most of the effect occurs in densely populated areas.

Model
The characterisation factor is determined by a mechanistic method.

Mechanism
The model is based on an assumed behaviour, where an empty package covering 0.02 m^2 is picked up at a cleaning operation by a person, who needs 10 seconds for this. Assuming a labour cost of 10 EUR/hour, the added willingness to pay for cleaning is thus around 10/3600*10 = 0.0278 EUR or 0.0278/0.02 = 1.39 EUR/m^2. Using the WTP value of severe nuisance of 1000 EUR/person-year, the nuisance of the package would correspond to $2.78 \cdot 10^{-5}$ person-years or 14.6 minutes of severe nuisance.

Calculation of characterisation factor
$2.78 \cdot 10^{-5}/0.02 = 1.39 \cdot 10^{-3}$ person-years/m^2

Uncertainty
The model is very approximate. The correlation between nuisance and area is probably weak. For scrap there is probably also a volume factor to be considered. Considering what litter looks like in a city or at seashore, the variation is not extremely large. Therefore it is assumed that the uncertainty may be represented by a log-normal distribution with a standard deviation of a factor of 4.

18.4.4. Characterisation of litter with respect to other category indicators

Depending on which material(s) that constitutes the litter, there may be other effects in the environment, like toxic effects and effects from emissions to air and water. These effects should be dealt with via ordinary emissions to air, water and soil.

19. Classification and characterisation of emissions of other substances

Several substances that occur as LCI results are not listed in the default method.

There may be several reasons for this like
1. The likely impacts are small or negligible.
2. The exposure situation causing an impact is very unusual, caused by very special conditions and difficult to foresee, like for accidents.
3. Our knowledge of quantitative matters is too limited for making a model.
4. The substance may be a part of a group of substances already modelled, or it may overlap or be very similar to emissions that are modelled elsewhere.

Most toxic substances are modelled as if they are trace substances being emitted in small quantities compared to other substances If they occur as major emissions from the product system(s) a separate classification and characterisation may be necessary.

In some cases where the emissions are small, it may be possible to include them as substances that are similar to them and eventually increase the uncertainty estimate of the corresponding characterisation factors than to exclude them from the product life cycle impact assessment. For instance CS_2, carbon disulphide may be included as H_2S because it has the same types of effects.

The assignment step in an impact assessment is where you chose to relate certain emissions and resources flows to certain impact indicators. The assignment in an LCA is normally made from the substance perspective, i.e. given a certain substance the practitioner tries to find which types of impacts the substance may cause. In the EPS default method there is also an assignment from the impact perspective. Given the real impacts occurring today or likely to occur and quantified by the category indicators, it is of interest to find which emissions and resource flows that contribute to these impacts. This means that the substances listed in the present default method cover all major environmental impacts.

20. Models and data used in inventory

Inventory data used in the EPS system is not different from conventional LCI data. But the tolerance for data gaps are less and larger for approximate data. In order to assist where there is scarce information for the LCI practitioner, several support methods have been developed for estimating LCI data.

20.1. Support method for estimating uncertainty in inventory data

If no determination of the uncertainty is made, the uncertainty is assumed to be represented by a log-normal probability-distribution. Default values for standard deviations in terms of the factor corresponding to the standard deviation are given in table 19.1 below for various emissions and resources. Two types of default values are given, one for the uncertainty from a known plant or plant system, σ_k, and one when using data from a known plant on another similar plant with unknown emissions, σ_s. The estimation are rough an based on ‘expert knowledge’ on Swedish conditions. There is a need to improve these data, but it is assumed to be better to use the data in table 19.1 than to ignore the uncertainty.

Table 20.1 Typical uncertainty characteristics for various inventory data. The uncertainty is assumed to be described by a log-normal distribution with a standard deviation corresponding to the factors presented. The first column of factors represents a typical uncertainty in measurements made on a specific plant. The second column represents a typical uncertainty when using inventory data from one plant on another with similar technology. *)The relative large values given for water emissions is caused by a difficulty of relating plant technology to emissions as all water emission normally are collected to a sewage plant. For air emissions flue gas treatments belong to the process equipment and is more frequently reported together with this. Most of the variations will occur within 2 standard deviations, i.e. a factor of 9 if the standard deviation corresponds to a factor of 3.

Emission or resource	Typical measurement method	$\exp\sigma_k$	$\exp\sigma_s$	Type of source
CO_2 to air	Analysis of fuel carbon	1.01	1.2	C in fuel is of economic value and well known
CO to air	Continuously monitored	1.5	2	Large incineration plants
CO to air	Random sampling	1.1	2	Car fleet
CH_4 to air	Gradient method or collection in hoods	1.5	3	Diffuse emissions from landfills etc.

Table 20.1 (continued)

Emission or resource	Typical measurement method	$\exp\sigma_k$	$\exp\sigma_s$	Type of source
VOC to air	Calculated from product declarations	1.1	1.1	VOC from paint and other products with solvents
VOC to air	Random sampling, Infrared or FID detectors	1.3	2	Car fleet, incomplete combustion
PAC to air	Random sampling, Gas or Liquid Chromatography	2	4	Power and heat generation
Metals to air	Random sampling of particles, volatile fractions included	2	4	Combustion processes and thermal processes, where the metals are trace elements
Metals to air	Random sampling of particles, volatile fractions included	1.2	2	Processes where the metal(s) are principal components
NH_3 to air	Gradient method or collection in hoods	1.5	2	Agriculture
NH_3 to air	Random sampling on acid substrate	1.2	2	Chemical processes including NO_x reduction plants
NO_x to air	Continuously monitored	1.2	1.5	Combustion
NO_x to air	Random sampling, IR absorption	1.2	1.5	Car fleet
N_2O to air	Random sampling, GC	1.2	3	Combustion
N_2O to air	Gradient method or collection in hoods	1.5	3	Agriculture, waste water treatment plants and similar
Particles	Random sampling	1.2	2	Power and heat generation
Metal&fossile reserves		1.1	1.2	
BOD to water	Random sampling	1.2	3 *)	
COD to water	Random sampling	1.2	3 *)	
P-tot to water	Random sampling	1.2	3 *)	
N-tot to water	Random sampling	1.2	3 *)	
Land use		1.1	1.1	

20.2. Support method for estimating emissions from waste incineration of organic material

The method is based on the elemental composition of the material to be incinerated, more precisely the content of C, H, O, Cl, S and N. If other atoms are present in considerable extent the model need to be modified.

It is assumed that C is completely transformed to CO_2, H to H_2O, Cl to HCl, S to SO_2 and 10% of the N to NO_x. No NO_x is assumed to be formed from N in air as the temperature is comparatively low in a waste incineration plant. The NO_x-model is a bit simplified in the sense that some NO_x is likely to be formed by 'hot cells' in the incineration bed. However, the error obtained by the simplification is not significant, as the figure 10% comes from empirical measurements of NO_x from waste incineration and from estimations of normal N-content in household waste.

If C_n, H_n, O_n, Cl_n, S_n and N_n is the relative number of atoms in the material, the mass of various emissions per mass of material is for

CO_2 equal to $44*C_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)$
HCl equal to $36*Cl_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)$
SO_2 equal to $64*S_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)$
NO_x equal to $46*0.1*N_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)$

For example if we incinerate 1 kg of polyethylene with the chemical formula of $(CH_2)_n$ the CO_2-emissions will be 44*1/(12*1+2+16*0+32*0+14*0+35*0) = 3.14 kg

20.3. Support method for estimating net emissions and resource depletion from waste incineration with energy recovery substituting coal.

If energy is recovered in connections with waste incineration some emissions and resource depletion is avoided. The extent to which emissions and resource depletion is avoided depends on the structure of the complementary energy system which load is decreased because of the energy recovery from waste.

In the support model used here the complementary energy system is based on coal combustion and the recovered energy is directly transformed to coal mass using a coal energy content of 30 MJ/kg.

The model calculates the avoided coal depletion in two sub-models. The first sub-model is used when the hydrogen content of the material is twice or greater than twice the oxygen content. In those cases the oxygen is assumed to react only with the hydrogen of the material and form water. The other sub-model is used when there is an excess of oxygen compared to hydrogen. In those cases the excess oxygen is assumed to react with coal to form carbon dioxide. The model calculates the heat of combustion of a material by subtracting the hydrogen and carbon masses that can react with the internal oxygen of the material, and assumes that the rest of the carbon and hydrogen contribute with 32 and 117 MJ/kg respectively to the heat of combustion of the material. S, N and Cl contribute with 10, -0.5 and –0.3 MJ/kg respectively. The contributions from S, N and Cl have been estimated assuming they change from bindings to C to bindings with O for S and N and to H for Cl.

If C_n, H_n, O_n, Cl_n, S_n and N_n is the relative number of atoms in the material, the net coal depletion, C_{net}, is

In case $O_n < 2*H_n$:

$$\begin{aligned}&C_{net} = (12*C_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*32+1*(H_n-2*On-Cl_n)/(\\&12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*117+32*S_n/(12*C_n+H_n+16*O_n+\\&32*S_n+14*N_n+35*Cl_n)*10 -14*N_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*0.5-\\&35*Cl_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*0.3)*(-1/30)\end{aligned}$$

In case $O_n > = 2*H_n$:

$$\begin{aligned}&C_{net} = ((12*(C_n-(O_n- 0.5*(H_n+Cl_n))*0.5))/((12*C_n+H_n+16*O_n+32*S_n+14*N_n+\\&35*Cl_n)*32+32*S_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*10-\\&14*N_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*0.5-\\&35*Cl_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)*0.3))*(-1/30)\end{aligned}$$

If substituting 100% coal, the mass of various emissions per mass of material is for
CO_2 equal to: $44*C_n/(12* C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)+C_{net}*30*0.11$, where 0.11 is the emission factor for CO_2 from coal in kg/MJ (Tillman et al.,1991).
SO_2 equal to $64*S_n/(12*C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)+ C_{net} *30*0.001667$, where 0.001667 is the emission factor for SO_2 from coal in kg/MJ (Tillman et al.,1991).
NO_x equal to $46*0.1*C_n/(12* C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n)+ C_{net} *30*0.0002$, where 0.0002 is the emission factor for NOx from coal in kg/MJ (Tillman et al.,1991).
HCl equals to $36*Cl_n/(12* C_n+H_n+16*O_n+32*S_n+14*N_n+35*Cl_n) + C_{net} *30*0.00005$, where emissions from coal combustion have been estimated from the average Cl-content of US coals (Lim, 1979) and assuming all Cl will be transferred to the flue gases.

The model can be tested with respect to its ability to predict the combustion heat of different organic substances. In table 20.2 the predicted versus literature data (Perry, 1997) on combustion heat values for a number of substances are compared.

Table 20.2 Comparison of values for heat of combustion determined by model with literature data.

Substance	Calculated(MJ/mol)	From literature(MJ/mol)
Acetamide	1.112	1.07
Decane	6.414	6.29
Propylene	1.854	1.92
1-butanol	2.472	2.45
ethylene glycol	1.002	1.06
methyl formate	0.768	0.89
diethylamine	2.816	2.8
methyl mercaptan	1.172	1.15
benzonitril	3.266	3.52
vinylchloride	0.9915	1.17
diethyl sulphide	3.026	2.96
ammonia	0.344	0.32
Average	2.103125	2.133333

In many energy systems there is less than 100% substitution of coal. In some cases these can be modelled by combining the energy recovery model described here in 20.3 and the incineration model described in 20.2. If for instance the energy demand only is sufficient during the winter season, resulting in utilisation of only half of the heat from the waste, then the model in 20.2 can be used for half of the material and the model 20.3 for the other half.

20.4. Support method for estimating emissions and land use from landfills

The waste pile is assumed to be of 10 m’s high and last for 200 years before it can be used as productive forest ground. Thus 1 kg waste prevents, at an average, forest production during 100 years on 10^{-4} square meters if the density is 1000 kg/m^3 i.e. totally 10^{-2} m^2 year. At other densities the ground occupied is reversibly proportional to the density. Part of the coal is assumed to be transformed to methane if the material is easily degradable. The amount can be calculated from the average elementary composition $C_aH_bO_cN_dS_e$ by the formula: a/2 + b/8 -c/4 -3d/8 - e/4 (Sundqvist et.al., 1994)

20.5. Support method for estimating emissions from composting

Waste of biological origin, like meat, paper, cotton is assumed to degrade to 100% in 100 years under aerobic conditions and emit only non-fossil CO_2. Synthetic polymers is assumed to degrade at 0.02 mm/year emitting fossil CO_2 at 100% from the degraded part. In reality this varies depending on various additives. The figure of 0.02 mm/year is obtained through observing the degradation of polyethylene foil in composts.

20.6. Support method for estimating net emissions from material recycling from production wastes and end of life waste

The default assumption is that the use of recycled material is supply driven in the long run. If enough amounts of material is available in specified qualities it will find its use. Therefore the act of leaving material to the recycling marked will in most cases lead to a net decrease of emissions and use of resources. Emissions and resource depletion from the primary material production are used as reference, and net emissions from material recycling are proportional to these according to table 20.3 below. The figures are to seen as interim solutions until better statistics on waste management processes become available. The present figures in table 20.9 are based on rough estimations on what part of the material left to recycling that actually substitutes virgin material, and what typical emissions and use of resources are in that process.

Table 20.3 Default decrease of emissions and resources from recycling of material for recovery of the material itself.

Material group	Primary production	Material recycling, production spill	Material recycling, end of life
Precious metals	100	-99	-98
Other metals	100	-90	-80
Glass	100	-90	-80
Thermoplastics	100	-80	-50
Other plastics	100	-30	-20
Rubber	100	-30	-20
Paper	100	-85	-50
Textiles	100	-60	-30
Wood	100	-70	-30
Ceramics	100	-40	-10
Concrete	100	-30	-10

20.7. Support method for estimating surface degradation from lost materials

The surface covered by the material is = 1/(AT5*AV5) m^2/kg, where AT5=density in kg/m^3 and AV5 the thickness of the material in meters.

21. Indices

Indices are combined characterisation and weighting factors for emissions and resourse depletion.

21.1. Indices for resource depletion

The indices for resource depletions are the same as the weighting indices in chapter 2.

21.2. Indices for emissions

21.2.1. Emissions to air, common substances

In table 21.1 characterisation factors are multiplied with weighting factors and the products added to an index for each substance. For instance for CO_2, the pathway specific characterisation factors for all impacts on YOLL are added to give 7.93E-07 YOLL/kg CO_2, which is multiplied with the weighting factors for YOLL, 85000 ELU/YOLL to give the YOLL indicator contribution to the total index, 6.74E-02 ELU/kg CO_2. Finally all contributions from the indicators affected by CO_2 is added to give 0.108 ELU/kg CO_2.

Table 21.1 Calculation of impact indices for common emissions to air

Sub-stance flow group	Indicator	Pathway	Pathway specific charcteris ation factor	Uncer-tainty factor	Characteris ation factor for all pathways	Indicators contribution to EPS default index	EPS default index, (ELU/kg)
CO_2	YOLL	heat stress	7.43E-08	2.5			
CO_2	YOLL	starvation	6.80E-07	3			
CO_2	YOLL	flooding	5.70E-09	3			
CO_2	YOLL	malaria	3.30E-08	3			
CO_2	YOLL	all			7.93E-07	6.74E-02	
CO_2	severe morbidity	starvation	3.15E-07	3			
CO_2	severe morbidity	malaria	3.80E-08	3			
CO_2	severe morbidity	all			3.53E-07	3.53E-02	
CO_2	morbidity	starvation	3.15E-07	3			
CO_2	morbidity	malaria	3.40E-07	3			
CO_2	morbidity	all			6.55E-07	6.55E-03	
CO_2	crop	desertification	7.56E-04	2.2	7.56E-04	1.13E-04	
CO_2	wood	global warming	-1.16E-03	3			
CO_2	wood	CO_2 fertilisation	-3.93E-02	2			
CO_2	wood	all			-4.05E-02	-8.09E-04	
CO_2	NEX	climate change	1.26E-14	3	1.26E-14	1.39E-03	
CO_2	all	all					1.08E-01

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncertainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
CO	YOLL	global warming	2.38E-06	3.4	2.38E-06	2.02E-01	
CO	severe morbidity	direct exposure	2.69E-09	5			
CO	severe morbidity	global warming	1.06E-06	3.4			
CO	severe morbidity	all			1.06E-06	1.06E-01	
CO	morbidity	global warming	1.96E-06	3.4	1.96E-06	1.96E-02	
CO	nuisance	direct exposure	2.50E-07	7	2.50E-07	2.50E-05	
CO	crop	global warming	2.27E-03	2.6	2.27E-03	3.41E-04	
CO	wood	global warming	-3.48E-03	2.4			
CO	wood	CO_2 fertilisation	-3.93E-02	2			
CO	wood	all			-4.28E-02	-2.27E-03	
CO	NEX	global warming	3.78E-14	3.4	3.78E-14	4.16E-03	
CO	all	all					3.31E-01
NO_x	YOLL	secondary particles	2.30E-05	3			
NO_x	YOLL	oxidant formation	1.40E-06	3			
NO_x	YOLL	all			2.45E-05	2.08E+00	
NO_x	severe morbidity	secondary particles	-2.33E-06	4			
NO_x	severe morbidity	direct exposure	1.89E-07	5			
NO_x	severe morbidity	oxidant formation	8.28E-08	3			
NO_x	severe morbidity	all			-2.06E-06	-2.06E-01	
NO_x	morbidity	secondary particles	3.61E-06	*)	3.61E-06	3.61E-02	
NO_x	nuisance	secondary particles	2.28E-03	2.4			
NO_x	nuisance	visibility	1.31E-04	3			
NO_x	nuisance	all			2.41E-03	2.41E-01	
NO_x	crop	secondary particles	-6.46E-03	2.6			
NO_x	crop	oxidant formation	0.706	3			
NO_x	crop	all			7.00E-01	1.05E-01	
NO_x	fish&meat	N-nutrification	-0.0339	3	-0.0339	-0.0339	
NO_x	wood	N-nutrification	-2.74	3			
NO_x	wood	secondary particles	9.91E-03	2.4			
NO_x	wood	all			-2.73	-1.09E-01	
NO_x	base cat-ion capacity	acidification	1.09	3	1.09	0.0109	
NO_x	NEX	eutrofication	1.83E-13	2.5			
NO_x	NEX	secondary particles	-1.08E-13	4.2			
NO_x	NEX	all			7.50E-14	8.25E-03	
NO_x	all	all					2.13E+00
HNO_2	added to NOX. 1 kg HNO2 = 0.941 kg NOx						
HNO_3	added to NOX. 1 kg HNO3 = 0.730 kg NOx						

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncertainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
N_2O	YOLL	global warming	2.54E-04	3			
N_2O	YOLL	secondary NOx	3.31E-05	4.7			
N_2O	YOLL	all			2.87E-04	2.44E+01	
N_2O	severe morbidity	global warming	1.13E-04	3			
N_2O	severe morbidity	secondary NOx	-2.78E-06	5.9			
N_2O	severe morbidity	all			1.10E-04	1.10E+01	
N_2O	morbidity	global warming	2.10E-04	4.2	2.10E-04		
N_2O	morbidity	secondary NOx	4.87E-06	6.1			
N_2O	morbidity	all			2.14E-04	2.14E+00	
N_2O	nuisance	global warming	3.25E-03	4.1	3.25E-03	3.25E-01	
N_2O	crop	global warming	2.42E-01	2.2			
N_2O	crop	secondary NOx	9.44E-01	4.7			
N_2O	crop	all			1.19E+00	1.78E-01	
N_2O	fish&meat	secondary NOx	-4.58E-02	4.7	-4.58E-02	-4.58E-02	
N_2O	wood	global warming	-3.71E-01	2			
N_2O	wood	secondary NOx	-3.23E+00	4.7			
N_2O	wood	all			-4.06E+00	-1.62E-01	
N_2O	base cat-ion capacity	acidification	1.47E+00	4.7	1.47E+00	1.47E-02	
N_2O	NEX	global warming	4.03E-12	3			
N_2O	NEX	secondary NOx	1.01E-13	4.2			
N_2O	NEX	all			4.13E-12	4.55E-01	
N_2O	all	all					3.83E+01
SO_2	YOLL	direct exposure	1.91E-07	10			
SO_2	YOLL	secondary particles	3.74E-05	3			
SO_2	YOLL	corrosion	2.81E-08	4			
SO_2	YOLL	all			3.76E-05	3.19E+00	
SO_2	severe morbidity	secondary particles	-6.59E-06	4.2			
SO_2	severe morbidity	corrosion	1.27E-08	4			
SO_2	severe morbidity	all			-6.58E-06	-6.58E-01	
SO_2	morbidity	secondary particles	1.02E-05	4.2	1.02E-05	1.02E-01	
SO_2	nuisance	secondary particles	6.45E-03	2.4	6.45E-03	6.45E-01	
SO_2	crop	secondary particles	-1.83E-02	2.6	-1.83E-02	-2.75E-03	
SO_2	fish&meat	acidification	1.18E-03	3	1.18E-03	0.00118	
SO_2	wood	secondary particles	0.0281	2.4	2.81E-02	1.12E-03	
SO_2	base cat-ion capacity	acidification	1.56	3	1.56E+00	0.0156	
SO_2	NEX	acidification	1.18E-14	3			
SO_2	NEX	secondary particles	-3.06E-13	4.2			
SO_2	NEX	all			-2.94E-13	-3.24E-02	
SO_2	all	all					3.27E+00

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncertainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
H_2S	YOLL	secondary SO_2	5.60E-05	3.7	5.60E-05	4.76E+00	
H_2S	severe morbidity	secondary SO_2	-9.80E-06	4.2	-9.80E-06	-9.80E-01	
H_2S	morbidity	secondary SO_2	1.52E-06	4.2	1.52E-06	1.52E-02	
H_2S	nuisance	secondary SO_2	9.61E-03	2.4			
H_2S	nuisance	odour	1.00E-03	10			
H_2S	nuisance	all			1.06E-02	1.06E+00	
H_2S	crop	secondary SO_2	-2.73E-02	2.6	-2.73E-02	-4.09E-03	
H_2S	fish&meat	secondary SO_2	1.76E-03	3	1.76E-03	0.001758	
H_2S	wood	secondary SO_2	4.18E-02	2.4	4.18E-02	1.67E-03	
H_2S	base cat-ion capacity	secondary SO_2	2.32	3	2.32E+00	0.0232	
H_2S	NEX	secondary SO_2	4.38E-13	4.2	4.38E-13	4.82E-02	
H_2S	all	all					4.96E+00
HF	YOLL	secondary aerosol	2.36E-05	3.2	2.36E-05	2.01E+00	
HF	severe morbidity	secondary aerosol	-4.19E-06	4.2	-4.19E-06	-4.19E-01	
HF	morbidity	secondary aerosol	6.50E-06	*)	6.50E-06	6.50E-02	
HF	nuisance	secondary aerosol	4.10E-03	2.4	4.10E-03	4.10E-01	
HF	crop	secondary aerosol	-1.16E-02	2.6	-1.16E-02	-1.74E-03	
HF	fish&meat	acidification	1.89E-03	3	1.89E-03	0.00189	
HF	wood	secondary aerosol	1.78E-02	2.4	1.78E-02	7.12E-04	
HF	base cat-ion capacity	acidification	2.5	3	2.50E+00	0.025	
HF	NEX	acidification	1.89E-14	3			
HF	NEX	secondary aerosol	-1.94E-13	4			
HF	NEX	all			-1.75E-13	-1.90E-02	
HF	all	all					2.07E+00
HCl	YOLL	secondary aerosol	2.42E-05	3.2	2.42E-05	2.06E+00	
HCl	severe morbidity	secondary aerosol	-4.29E-06	4.2	-4.29E-06	-4.29E-01	
HCl	morbidity	secondary aerosol	6.64E-06	*)	6.64E-06	6.64E-02	
HCl	nuisance	secondary aerosol	4.20E-03	2.4	4.20E-03	4.20E-01	
HCl	crop	secondary aerosol	-1.19E-02	2.6	-1.19E-02	-1.79E-03	
HCl	fish&meat	acidification	1.05E-03	3	1.05E-03	0.00105	
HCl	wood	secondary aerosol	6.37E-01	2.4	6.37E-01	1.27E-02	
HCl	base cat-ion capacity	acidification	1.39	3	1.39E+00	0.0139	
HCl	NEX	acidification	1.05E-14	3			
HCl	NEX	secondary aerosol	-1.99E-13	4			
HCl	NEX	all			-1.89E-13	-2.07E-02	
HCl	all	all					2.13E+00

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncertainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
NH_3	YOLL	secondary aerosol	2.64E-05	3.2	2.64E-05	2.24E+00	
NH_3	severe morbidity	secondary aerosol	-4.66E-06	4.2	-4.66E-06	-4.66E-01	
NH_3	morbidity	secondary aerosol	7.22E-06	*)	7.22E-06	7.22E-02	
NH_3	nuisance	secondary aerosol	4.56E-03	2.2	4.56E-03	4.56E-01	
NH_3	crop	secondary aerosol	-1.29E-02	2.4	-1.29E-02	-1.94E-03	
NH_3	fish&meat	acidification	1.10E-03	3.7			
NH_3	fish&meat	nutrification	-9.19E-02	3			
NH_3	fish&meat	all			-9.08E-02	-0.0908	
NH_3	wood	secondary aerosol	1.98E-02	2.2			
NH_3	wood	nutrification	-7.42	3			
NH_3	wood	all			-7.4002	-2.96E-01	
NH_3	base cat-ion capacity	acidification	1.47	3	1.47E+00	0.0147	
NH_3	NEX	acidification	1.11E-14	3.7			
NH_3	NEX	secondary aerosol	-2.16E-13	4			
NH_3	NEX	eutrofication	4.96E-13	4			
NH_3	NEX	all			2.91E-13	3.20E-02	
NH_3	all						1.96E+00
Benzene	YOLL	cancer	1.95E-05	3			
Benzene	YOLL	global warming	8.72E-06	4.7			
Benzene	YOLL	oxidants	3.80E-06	4.7			
Benzene	YOLL	all			3.20E-05	2.72E+00	
Benzene	severe morbidity	cancer	2.28E-06	3			
Benzene	severe morbidity	global warming	3.88E-06	4.7			
Benzene	severe morbidity	oxidants	2.02E-07	4			
Benzene	severe morbidity	all			6.16E-06	6.16E-01	
Benzene	morbidity	global warming	7.21E-06	4.7	7.21E-06	7.21E-02	
Benzene	crop	oxidants	1.54	4.7			
Benzene	crop	global warming	8.32E-03	3.9			
Benzene	crop	all			1.55	2.32E-01	
Benzene	wood	CO_2 fertilisation	-1.39E-01	3.7	-1.39E-01	-2.78E-03	
Benzene	NEX	global warming	1.39E-13	4.7	1.39E-13	1.53E-02	
							3.65E+00

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncertainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
Butadiene	YOLL	cancer	8.00E-05	3			
Butadiene	YOLL	global warming	8.72E-06	4.7			
Butadiene	YOLL	oxidants	1.20E-05	4			
Butadiene	YOLL	all			1.01E-04	8.56E+00	
Butadiene	severe morbidity	cancer	9.38E-06	3			
Butadiene	severe morbidity	global warming	3.88E-06	4.7			
Butadiene	severe morbidity	oxidants	6.76E-07	4			
Butadiene	severe morbidity	all			1.33E-05	1.33E+00	
Butadiene	morbidity	global warming	7.21E-06	4.7	7.21E-06	7.21E-02	
Butadiene	crop	oxidants	4.86	4			
Butadiene	crop	global warming	8.32E-03	3			
Butadiene	crop	all			4.87	7.30E-01	
Butadiene	wood	CO$_2$ fertilisation	-0.134	3.7	-0.134	-2.68E-03	
Butadiene	NEX	global warming	1.39E-13	4.7	1.39E-13	1.53E-02	
							1.07E+01
Ethylene	YOLL	cancer	5.29E-06	4			
Ethylene	YOLL	global warming	8.72E-06	4.7			
Ethylene	YOLL	oxidants	1.20E-05	4			
Ethylene	YOLL	all			2.60E-05	2.21E+00	
Ethylene	severe morbidity	cancer	6.20E-07	4			
Ethylene	severe morbidity	global warming	3.88E-06	4.7			
Ethylene	severe morbidity	oxidants	6.76E-07	4			
Ethylene	severe morbidity	all			5.18E-06	5.18E-01	
Ethylene	morbidity	global warming	7.21E-06	4.7	7.21E-06	7.21E-02	
Ethylene	crop	oxidants	4.86	4			
Ethylene	crop	global warming	8.32E-03	3.9			
Ethylene	crop	all			4.87	7.30E-01	
Ethylene	wood	CO$_2$ fertilisation	-0.129	3.7	-0.129	-2.58E-03	
Ethylene	NEX	global warming	1.39E-13	4.7	1.39E-13	1.53E-02	
							3.54E+00
CH$_2$O	YOLL	cancer	5.07E-05	3			
CH$_2$O	YOLL	global warming	8.72E-06	4.7			
CH$_2$O	YOLL	oxidants	5.09E-07	4			
CH$_2$O	YOLL	all			5.99E-05	5.09E+00	
CH$_2$O	severe morbidity	cancer	3.81E-06	3			
CH$_2$O	severe morbidity	global warming	3.88E-06	4.7			
CH$_2$O	severe morbidity	oxidants	2.87E-07	4			
CH$_2$O	severe morbidity	all			7.69E-06	7.69E-01	
CH$_2$O	morbidity	global warming	7.21E-06	4.7	7.21E-06	7.21E-02	
CH$_2$O	crop	oxidants	2.06	4			
CH$_2$O	crop	global warming	8.32E-03	3.9			
CH$_2$O	crop	all			2.07	3.10E-01	
CH$_2$O	wood	CO$_2$ fertilisation	-6.01E-02	3.7	-6.01E-02	-1.20E-03	
CH$_2$O	NEX	global warming	1.39E-13	4.7	1.39E-13	1.53E-02	
							6.47E+00

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncer-tainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
CH_4	YOLL	global warming	1.94E-05	3.1			
CH_4	YOLL	oxidants	8.40E-08	4			
CH_4	YOLL	all			1.95E-05	1.66E+00	
CH_4	severe morbidity	global warming	8.65E-06	3.1			
CH_4	severe morbidity	oxidants	4.73E-09	4			
CH_4	severe morbidity	all			8.65E-06	8.65E-01	
CH_4	morbidity	global warming	1.60E-05	3.1	1.60E-05	1.60E-01	
CH_4	crop	oxidants	3.40E-02	4			
CH_4	crop	global warming	1.85E-02	2.3			
CH_4	crop	all			5.25E-02	7.88E-03	
CH_4	wood	CO_2 fertilisation	-1.13E-01	2.1	-1.13E-01	-2.26E-03	
CH_4	NEX	global warming	3.09E-13	3.1	3.09E-13	3.40E-02	
							2.72E+00
Propylene	YOLL	cancer	1.44E-06	3.2			
Propylene	YOLL	global warming	8.72E-06	4.7			
Propylene	YOLL	oxidants	8.81E-06	4			
Propylene	YOLL	all			1.90E-05	1.61E+00	
Propylene	severe morbidity	cancer	1.69E-07	3			
Propylene	severe morbidity	global warming	3.88E-06	4.7			
Propylene	severe morbidity	oxidants	4.98E-07	4			
Propylene	severe morbidity	all			4.05E-06	4.01E-01	
Propylene	morbidity	global warming	7.21E-06	4.7	7.21E-06	7.21E-02	
Propylene	crop	oxidants	3.57	4			
Propylene	crop	global warming	8.32E-03	3.9			
Propylene	crop	all			3.58	5.37E-01	
Propylene	wood	CO_2 fertilisation	-1.29E-01	3.7	-1.29E-01	-2.58E-03	
Propylene	NEX	global warming	1.39E-13	4.7	1.39E-13	1.53E-02	
							2.64E+00
PM_{10}	YOLL	acute health effects	7.60E-06	3			
PM_{10}	YOLL	chronic health effects	4.23E-04	3			
PM_{10}	YOLL	global warming	-6.77E-06	4			
PM_{10}	YOLL	all			4.24E-04	3.60E+01	
PM_{10}	severe morbidity	acute health effects	6.80E-07	2.2			
PM_{10}	severe morbidity	global warming	-3.01E-06	4			
PM_{10}	severe morbidity	all			-2.33E-06	-2.33E-01	
PM_{10}	morbidity	acute health effects	9.20E-06	2.2			
PM_{10}	morbidity	global warming	-5.59E-06	3			
PM_{10}	morbidity	all			3.61E-06	3.61E-02	
PM_{10}	nuisance	direct exposure	2.28E-03	2.2	2.28E-03	2.28E-01	
PM_{10}	crop	global warming	-6.46E-03	2.4	-6.46E-03	-9.69E-04	
PM_{10}	wood	global warming	9.91E-03	2.2	9.91E-03	3.96E-04	
PM_{10}	NEX	global warming	-1.08E-13	4	-1.08E-13	-1.19E-02	
PM_{10}	all	all					3.60E+01

Table 21.1 Calculation of impact indices for common emissions to air, continued

Sub-stance flow group	Indicator	Pathway	Pathway specific charcterisation factor	Uncer-tainty factor	Characterisation factor for all pathways	Indicators contribution to EPS default index	EPS default index
As	YOLL	Cancer	9.75E-04	3	9.75E-04	8.29E+01	
As	severe morbidity	acute health effects	1.24E-04	4	1.24E-04	1.24E+01	
As	all	all					9.53E+01
Cd	YOLL	Cancer	9.44E-05	4	9.44E-05	8.02E+00	
Cd	severe morbidity	Cancer	2.23E-06	4	2.23E-06	2.23E-01	
Cd	morbidity	inhalation	1.42E-04	5			
Cd	morbidity	oral intake	4.98E-05	5			
Cd	morbidity	all			1.92E-04	1.92E+00	
Cd	all	all					1.02E+01
Cr	YOLL	Cancer	2.05E-04	4	2.05E-04	1.74E+01	
Cr	severe morbidity	Cancer	2.62E-05	4	2.62E-05	2.62E+00	
Cr	all	all					2.00E+01
Hg	morbidity	brain damage	4.80E-03	5	4.80E-03	4.80E+01	
Hg	fish&meat	fishing restrictions	0.224	4	2.24E-01	2.24E-01	
Hg	NEX	reproduction	1.20E-10	4	1.20E-10	1.32E+01	
Hg	all	all					6.14E+01
Cu	all						0
Ni	all						0
Pb	Severe nuisance	brain damage	0.291	4	2.91E-01	2.91E+03	
Pb	all	all					2.91E+03
Zn	all	all					0
PAC	YOLL	Cancer	0.568	4	5.68E-01	4.83E+04	
PAC	severe morbidity	Cancer	0.160	4	1.60E-01	1.60E+04	
							6.43E+04

21.2.2. Emissions to air, specific volatile organic substances

In table 21.2 characterisation factors are multiplied with weighting factors and the products added to an index for each VOC.

Table 21.2 Calculation of impact indices for specific VOC:s. The average VOC index is 2.14 ELU/kg.

Substance	GWP 100	POCP-1	YOLL global warming	YOLL oxidants	Severe morbidity global w.	Severe morbidity oxidants	Crop loss global warming	Crop loss oxidants	Wood loss global w.	NEX from global warming	Indices
Ethan	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	8.41E-01	-0.129	1.39E-13	1.46E+00
Propane	11	0.604	8.72E-06	7.25E-06	3.88E-06	4.08E-07	8.32E-03	2.94E+00	-0.129	1.39E-13	2.24E+00
N-butane	11	0.554	8.72E-06	6.65E-06	3.88E-06	3.75E-07	8.32E-03	2.69E+00	-0.129	1.39E-13	2.15E+00
I-butane	11	0.331	8.72E-06	3.97E-06	3.88E-06	2.24E-07	8.32E-03	1.61E+00	-0.129	1.39E-13	1.74E+00
N-pentane	11	0.612	8.72E-06	7.34E-06	3.88E-06	4.14E-07	8.32E-03	2.97E+00	-0.129	1.39E-13	2.25E+00
I-pentane	11	0.36	8.72E-06	4.32E-06	3.88E-06	2.43E-07	8.32E-03	1.75E+00	-0.129	1.39E-13	1.80E+00
Hexane	11	0.784	8.72E-06	9.41E-06	3.88E-06	5.30E-07	8.32E-03	3.81E+00	-0.129	1.39E-13	2.57E+00
2-metylpentane	11	0.712	8.72E-06	8.54E-06	3.88E-06	4.81E-07	8.32E-03	3.46E+00	-0.129	1.39E-13	2.43E+00
3-metylpentane	11	0.647	8.72E-06	7.76E-06	3.88E-06	4.37E-07	8.32E-03	3.14E+00	-0.129	1.39E-13	2.32E+00
N-heptane	11	0.791	8.72E-06	9.49E-06	3.88E-06	5.35E-07	8.32E-03	3.84E+00	-0.129	1.39E-13	2.58E+00
N-oktane	11	0.698	8.72E-06	8.38E-06	3.88E-06	4.72E-07	8.32E-03	3.39E+00	-0.129	1.39E-13	2.41E+00
2-metylheptane	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36E+00	-0.129	1.39E-13	2.40E+00
N-nonane	11	0.633	8.72E-06	7.60E-06	3.88E-06	4.28E-07	8.32E-03	3.08E+00	-0.129	1.39E-13	2.29E+00
2-metyloktane	11	0.669	8.72E-06	8.03E-06	3.88E-06	4.52E-07	8.32E-03	3.25E+00	-0.129	1.39E-13	2.36E+00
N-decane	11	0.719	8.72E-06	8.63E-06	3.88E-06	4.86E-07	8.32E-03	3.49E+00	-0.129	1.39E-13	2.45E+00
2-methylnonane	11	0.719	8.72E-06	8.63E-06	3.88E-06	4.86E-07	8.32E-03	3.49E+00	-0.129	1.39E-13	2.45E+00
N-undecane	11	0.662	8.72E-06	7.94E-06	3.88E-06	4.48E-07	8.32E-03	3.22E+00	-0.129	1.39E-13	2.34E+00
N-dodecane	11	0.576	8.72E-06	6.91E-06	3.88E-06	3.89E-07	8.32E-03	2.80E+00	-0.129	1.39E-13	2.19E+00
Metyl-cyclohexane	11	0.403	8.72E-06	4.84E-06	3.88E-06	2.72E-07	8.32E-03	1.96E+00	-0.129	1.39E-13	1.87E+00
1-butene	11	0.799	8.72E-06	9.59E-06	3.88E-06	5.40E-07	8.32E-03	3.88E+00	-0.129	1.39E-13	2.59E+00
2-butene	11	0.784	8.72E-06	9.41E-06	3.88E-06	5.30E-07	8.32E-03	3.81E+00	-0.129	1.39E-13	2.57E+00
1-pentene	11	0.727	8.72E-06	8.72E-06	3.88E-06	4.91E-07	8.32E-03	3.53E+00	-0.129	1.39E-13	2.46E+00
2-pentene	11	0.77	8.72E-06	9.24E-06	3.88E-06	5.21E-07	8.32E-03	3.74E+00	-0.129	1.39E-13	2.54E+00
2-m-1-butene	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36E+00	-0.129	1.39E-13	2.40E+00
2-m-2-butene	11	0.935	8.72E-06	1.12E-05	3.88E-06	6.32E-07	8.32E-03	4.54E+00	-0.129	1.39E-13	2.84E+00
Butylene	11	0.791	8.72E-06	9.49E-06	3.88E-06	5.35E-07	8.32E-03	3.84E+00	-0.129	1.39E-13	2.58E+00
Isoprene	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59E+00	-0.129	1.39E-13	2.11E+00
Acetylene	11	0.273	8.72E-06	3.28E-06	3.88E-06	1.85E-07	8.32E-03	1.33E+00	-0.129	1.39E-13	1.64E+00
Toluene	11	0.446	8.72E-06	5.35E-06	3.88E-06	3.01E-07	8.32E-03	2.17E+00	-0.129	1.39E-13	1.95E+00
O-xylene	11	0.424	8.72E-06	5.09E-06	3.88E-06	2.87E-07	8.32E-03	2.06E+00	-0.129	1.39E-13	1.91E+00
M-xylene	11	0.583	8.72E-06	7.00E-06	3.88E-06	3.94E-07	8.32E-03	2.83E+00	-0.129	1.39E-13	2.20E+00
P-xylene	11	0.612	8.72E-06	7.34E-06	3.88E-06	4.14E-07	8.32E-03	2.97E+00	-0.129	1.39E-13	2.25E+00
Etylbenzene	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59E+00	-0.129	1.39E-13	2.11E+00
1,2,3-Tri-metylbenzene	11	0.698	8.72E-06	8.38E-06	3.88E-06	4.72E-07	8.32E-03	3.39E+00	-0.129	1.39E-13	2.41E+00
1,2,4-Tri-metylbenzene	11	0.683	8.72E-06	8.20E-06	3.88E-06	4.62E-07	8.32E-03	3.32E+00	-0.129	1.39E-13	2.38E+00
1,3,5-Tri-metylbenzene	11	0.691	8.72E-06	8.29E-06	3.88E-06	4.67E-07	8.32E-03	3.36E+00	-0.129	1.39E-13	2.40E+00
O-ethyltoluene	11	0.597	8.72E-06	7.16E-06	3.88E-06	4.04E-07	8.32E-03	2.90E+00	-0.129	1.39E-13	2.23E+00
M-ethyltoluene	11	0.626	8.72E-06	7.51E-06	3.88E-06	4.23E-07	8.32E-03	3.04E+00	-0.129	1.39E-13	2.28E+00
P-ethyltoluene	11	0.626	8.72E-06	7.51E-06	3.88E-06	4.23E-07	8.32E-03	3.04E+00	-0.129	1.39E-13	2.28E+00

Table 21.2, Calculation of impact indices for specific VOC's. The average VOC index is 2.14 ELU/kg, continued

Substance	GWP 100	POCP-1	YOLL global warming	YOLL oxidants	Severe morbidity global w.	Severe morbidity oxidants	Crop loss global warming	Crop loss oxidants	Wood loss global w.	NEX from global warming	Indices (ELU/kg)
N-propylbenzene	11	0.511	8.72E-06	6.13E-06	3.88E-06	3.45E-07	8.32E-03	2.48E+00	-0.129	1.39E-13	2.07E+00
I-propylbenzene	11	0.511	8.72E-06	6.13E-06	3.88E-06	3.45E-07	8.32E-03	2.48E+00	-0.129	1.39E-13	2.07E+00
Methanol	11	0.165	8.72E-06	1.98E-06	3.88E-06	1.12E-07	8.32E-03	8.02E-01	-0.129	1.39E-13	1.44E+00
Ethanol	11	0.446	8.72E-06	5.35E-06	3.88E-06	3.01E-07	8.32E-03	2.17E+00	-0.129	1.39E-13	1.95E+00
I-propanol	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	8.41E-01	-0.129	1.39E-13	1.46E+00
Butanol	11	0.655	8.72E-06	7.86E-06	3.88E-06	4.43E-07	8.32E-03	3.18E+00	-0.129	1.39E-13	2.33E+00
I-butanol	11	0.388	8.72E-06	4.66E-06	3.88E-06	2.62E-07	8.32E-03	1.89E+00	-0.129	1.39E-13	1.85E+00
But-2-iol	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40E+00	-0.129	1.39E-13	1.66E+00
Acetone	11	0.173	8.72E-06	2.08E-06	3.88E-06	1.17E-07	8.32E-03	8.41E-01	-0.129	1.39E-13	1.46E+00
Methyl ethyl ketone	11	0.388	8.72E-06	4.66E-06	3.88E-06	2.62E-07	8.32E-03	1.89E+00	-0.129	1.39E-13	1.85E+00
Methyl i-butyl ketone	11	0.676	8.72E-06	8.11E-06	3.88E-06	4.57E-07	8.32E-03	3.29E+00	-0.129	1.39E-13	2.37E+00
Acetaldehyde	11	0.532	8.72E-06	6.38E-06	3.88E-06	3.60E-07	8.32E-03	2.59E+00	-0.129	1.39E-13	2.11E+00
Propionaldehyde	11	0.655	8.72E-06	7.86E-06	3.88E-06	4.43E-07	8.32E-03	3.18E+00	-0.129	1.39E-13	2.33E+00
Butyraldehyde	11	0.64	8.72E-06	7.68E-06	3.88E-06	4.33E-07	8.32E-03	3.11E+00	-0.129	1.39E-13	2.30E+00
I-butyraldehyde	11	0.583	8.72E-06	7.00E-06	3.88E-06	3.94E-07	8.32E-03	2.83E+00	-0.129	1.39E-13	2.20E+00
Valeraldehyde	11	0.615	8.72E-06	7.38E-06	3.88E-06	4.16E-07	8.32E-03	2.99E+00	-0.129	1.39E-13	2.26E+00
Acrolein	11	1.201	8.72E-06	1.44E-05	3.88E-06	8.12E-07	8.32E-03	5.84E+00	-0.129	1.39E-13	3.32E+00
Methyl chloroform	11	0.007	8.72E-06	8.40E-08	3.88E-06	4.73E-09	8.32E-03	3.40E-02	-0.129	1.39E-13	1.15E+00
Allyl chloride	11	0.561	8.72E-06	6.73E-06	3.88E-06	3.79E-07	8.32E-03	2.73E+00	-0.129	1.39E-13	2.16E+00
Dimethylester	11	0.058	8.72E-06	6.96E-07	3.88E-06	3.92E-08	8.32E-03	2.82E-01	-0.129	1.39E-13	1.25E+00
Dimethylether	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40E+00	-0.129	1.39E-13	1.66E+00
Propylene glycol methyl ether	11	0.77	8.72E-06	9.24E-06	3.88E-06	5.21E-07	8.32E-03	3.74E+00	-0.129	1.39E-13	2.54E+00
Propylene glycol methyl ether acetate	11	0.309	8.72E-06	3.71E-06	3.88E-06	2.09E-07	8.32E-03	1.50E+00	-0.129	1.39E-13	1.70E+00
ethylacetate	11	0.295	8.72E-06	3.54E-06	3.88E-06	1.99E-07	8.32E-03	1.43E+00	-0.129	1.39E-13	1.68E+00
n-butylacetate	11	0.439	8.72E-06	5.27E-06	3.88E-06	2.97E-07	8.32E-03	2.13E+00	-0.129	1.39E-13	1.94E+00
i-butylacetate	11	0.288	8.72E-06	3.46E-06	3.88E-06	1.95E-07	8.32E-03	1.40E+00	-0.129	1.39E-13	1.66E+00
Uncertainty factor			4.7	4	4.7	4	3.9	4	3.7	4.7	

21.2.3. Emissions to air, freons

In table 21.3 characterisation factors (columns 2-9) are multiplied with weighting factors and the products added to an index for each substance (column 10).

Table 21.3 Calculation of impact indices for freons.

Substance	YOLL, ozone depletion	YOLL, global warming	Severe morbidity, ozone depletion	Severe morbidity, global warming	Morbidity, global warming	Crop, global warming	Wood, global warming	NEX, global warming	Indices (ELU/kg)
CFC:s									
CFC-11	3.36E-04	3.17E-03	7.00E-04	1.41E-03	2.62E-03	3.02E+00	-4.64E+00	5.04E-11	5.41E+02
CFC-12	3.36E-04	6.74E-03	7.00E-04	3.00E-03	5.57E-03	6.42E+00	-9.86E+00	1.07E-10	1.04E+03
CFC-13	3.36E-04	9.28E-03	7.00E-04	4.12E-03	7.66E-03	8.83E+00	-1.36E+01	1.47E-10	1.39E+03
CFC-113	3.60E-04	3.97E-03	7.49E-04	1.76E-03	3.28E-03	3.78E+00	-5.80E+00	6.30E-11	6.59E+02
CFC-114	2.69E-04	7.37E-03	5.60E-04	3.28E-03	6.09E-03	7.02E+00	-1.08E+01	1.17E-10	1.11E+03
CFC-115	1.68E-04	7.37E-03	3.50E-04	3.28E-03	6.09E-03	7.02E+00	-1.08E+01	1.17E-10	1.08E+03
HCFC:s									
HCFC-22	1.85E-05	1.35E-03	3.85E-05	5.99E-04	1.11E-03	1.28E+00	-1.97E+00	2.14E-11	1.94E+02
HCFC-123	6.72E-06	7.37E-05	1.40E-05	3.28E-05	6.09E-05	7.02E-02	-1.08E-01	1.17E-12	1.23E+01
HCFC-124	7.39E-06	3.81E-04	1.54E-05	1.69E-04	3.14E-04	3.62E-01	-5.57E-01	6.05E-12	5.53E+01
HCFC-141b	3.70E-05	5.00E-04	7.70E-05	2.22E-04	4.13E-04	4.76E-01	-7.31E-01	7.94E-12	8.06E+01
HCFC-142b	2.18E-05	1.59E-03	4.55E-05	7.05E-04	1.31E-03	1.51E+00	-2.32E+00	2.52E-11	2.28E+02
HCFC-225ca	8.40E-06	1.35E-04	1.75E-05	5.99E-05	1.11E-04	1.28E-01	-1.97E-01	2.14E-12	2.13E+01
HCFC-225cb	1.11E-05	4.20E-04	2.31E-05	1.87E-04	3.47E-04	4.00E-01	-6.15E-01	6.68E-12	6.19E+01
Bromocarbons									
H-1301	5.38E-03	4.44E-03	1.12E-02	1.97E-03	3.67E-03	4.23E+00	-6.50E+00	7.06E-11	2.20E+03
Others									
HFC-23	0.00E+00	9.60E-03	0.00E+00	4.27E-03	7.93E-03	9.14E+00	-1.40E+01	1.52E-10	1.34E+03
HFC-32	0.00E+00	4.60E-04	0.00E+00	2.04E-04	3.80E-04	4.38E-01	-6.73E-01	7.31E-12	6.42E+01
HFC-43-10mee	0.00E+00	1.27E-03	0.00E+00	5.64E-04	1.05E-03	1.21E+00	-1.86E+00	2.02E-11	1.77E+02
HFC-125	0.00E+00	2.54E-03	0.00E+00	1.13E-03	2.10E-03	2.42E+00	-3.71E+00	4.03E-11	3.54E+02
HFC-134	0.00E+00	9.52E-04	0.00E+00	4.23E-04	7.86E-04	9.06E-01	-1.39E+00	1.51E-11	1.33E+02
HFC-134a	0.00E+00	1.03E-03	0.00E+00	4.58E-04	8.52E-04	9.82E-01	-1.51E+00	1.64E-11	1.44E+02
HFC-152a	0.00E+00	1.11E-04	0.00E+00	4.94E-05	9.17E-05	1.06E-01	-1.62E-01	1.76E-12	1.55E+01
HFC-143	0.00E+00	2.30E-04	0.00E+00	1.02E-04	1.90E-04	2.19E-01	-3.36E-01	3.65E-12	3.21E+01
HFC-143a	0.00E+00	3.49E-03	0.00E+00	1.55E-03	2.88E-03	3.32E+00	-5.10E+00	5.54E-11	4.87E+02
HFC-227ea	0.00E+00	2.62E-03	0.00E+00	1.16E-03	2.16E-03	2.49E+00	-3.83E+00	4.16E-11	3.65E+02
HFC-236fa	0.00E+00	6.34E-03	0.00E+00	2.82E-03	5.24E-03	6.04E+00	-9.28E+00	1.01E-10	8.85E+02
HFC-245ca	0.00E+00	4.84E-04	0.00E+00	2.15E-04	4.00E-04	4.61E-01	-7.08E-01	7.69E-12	6.75E+01
SF6	0.00E+00	1.97E-02	0.00E+00	8.78E-03	1.63E-02	1.88E+01	-2.89E+01	3.14E-10	2.76E+03
CF4	0.00E+00	5.00E-03	0.00E+00	2.22E-03	4.13E-03	4.76E+00	-7.31E+00	7.94E-11	6.97E+02
C2F6	0.00E+00	9.91E-03	0.00E+00	4.41E-03	8.19E-03	9.44E+00	-1.45E+01	1.58E-10	1.38E+03
c-C4F8	0.00E+00	7.22E-03	0.00E+00	3.21E-03	5.96E-03	6.87E+00	-1.06E+01	1.15E-10	1.01E+03
C6F14	0.00E+00	5.39E-03	0.00E+00	2.40E-03	4.45E-03	5.13E+00	-7.89E+00	8.57E-11	7.52E+02

21.2.4. Noise

In chapter 13 the characterisation factor of traffic flow for nuisance by noise was determined to $2.53 \cdot 10^{-5}$ person-years/vehicle km. As the weighting factor for nuisance is 100 ELU/person-years the impact index will be $2.53 \cdot 10^{-3}$ ELU/vehicle km.

21.2.5. Emissions to water

In table 21.4 characterisation factors are multiplied with weighting factors and the products added to an index for each substance.

Table 21.4 Calculation of indices for some emissions to water

		Category indicator		
Substance flow group	Pathway	fish&meat, (kg)	NEX	EPS default index, (ELU/kg)
BOD	Eutrofication		1.83E-14	2.01E-03
COD	Eutrofication		9.18E-15	1.01E-03
N-tot	Eutrofication	-0.401	1.80E-13	-3.81E-01
P-tot	Eutrofication		5.00E-13	5.50E-02

Emissions of Hg to water has been given the same characterisation factors as emission to air (Chaper 15), i.e. the index is 180 ELU/kg.

21.3. Emissions to soil

21.3.1. Application of pesticides

In table 21.5 below, indices for application of pesticides are calculated. Characterisation factors are multiplied with weighting factors for corresponding category indicator and the products added to an index for each substance.

Table 21.5 Calculation of impact indices for pesticides

Substance name	CASRN	Reference dose (Rfd) for chronical oral exposure (mg/kg, day)	1/Rfd	Potency factor	YOLL/kg	Severe morbidity, p-yr/kg	Morbidity, p-yr/kg	Bio-diversity, NEX	Indices (ELU/kg)
Alachlor	15972-60-8	0.01	100	0.0215	3.58E-06	1.79E-07	1.79E-07	2.98E-13	3.57E-01
Aldicarb	116-06-3	0.001	1000	0.215	3.58E-05	1.79E-06	1.79E-06	2.98E-12	3.57E+00
Aldrin	309-00-2	0.00003	33333	7.15	0.001193	5.96E-05	5.96E-05	9.94E-11	1.19E+02
Atrazine	1912-24-9	0.035	28.571	0.00613	1.02E-06	5.11E-08	5.11E-08	8.52E-14	1.02E-01
Benomyl	17804-35-2	0.05	20	0.00429	7.16E-07	3.58E-08	3.58E-08	5.96E-14	7.13E-02
Captan	133-06-3	0.13	7.6923	0.00165	2.75E-07	1.38E-08	1.38E-08	2.29E-14	2.74E-02
Carbaryl	63-25-2	0.1	10	0.00215	3.58E-07	1.79E-08	1.79E-08	2.98E-14	3.57E-02

Table 21.5, Calculation of impact indices for pesticides, continued

Substance name	CASRN	(Rfd) (mg/kg, day)	1/Rfd	Potency factor	YOLL/kg	Severe morbidity, p-yr/kg	Morbidity, p-yr/kg	Bio-diversity, NEX	Indices (ELU/kg)
Carbofuran	1563-66-2	0.005	200	0.0429	7.16E-06	3.58E-07	3.58E-07	5.96E-13	7.13E-01
Chlordane	12789-03-6	0.0005	2000	0.429	7.16E-05	3.58E-06	3.58E-06	5.96E-12	7.13E+00
Chlorpyrifos	2921-88-2	0.003	333.33	0.0715	1.19E-05	5.96E-07	5.96E-07	9.94E-13	1.19E+00
Cypermethrin	52315-07-8	0.01	100	0.0214	3.58E-06	1.79E-07	1.79E-07	2.98E-13	3.57E-01
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	0.01	100	0.0214	3.58E-06	1.79E-07	1.79E-07	2.98E-13	3.57E-01
Demeton	8065-48-3	0.00004	25000	5.36	0.000895	4.47E-05	4.47E-05	7.45E-11	8.92E+01
Dichlorvos (DDVP)	62-73-7	0.0005	2000	0.429	7.16E-05	3.58E-06	3.58E-06	5.96E-12	7.13E+00
Dieldrin	60-57-1	0.00005	20000	4.291	0.000716	3.58E-05	3.58E-05	5.96E-11	7.13E+01
Diflubenzuron	35367-38-5	0.02	50	0.0107	1.79E-06	8.95E-08	8.95E-08	1.49E-13	1.78E-01
Dimethoate	60-51-5	0.0004	2500	0.536	8.95E-05	4.47E-06	4.47E-06	7.45E-12	8.92E+00
Diquat	80-00-7	0.0022	455	0.0975	1.63E-05	8.13E-07	8.13E-07	1.35E-12	1.62E+00
Disulfoton	298-04-4	0.00004	25000	5.36	0.000895	4.47E-05	4.47E-05	7.45E-11	8.92E+01
Endosulfan	115-29-7	0.006	166.6	0.0357	5.97E-06	2.98E-07	2.98E-07	4.97E-13	5.94E-01
Endrin	72-20-8	0.0003	3330	0.715	0.000119	5.96E-06	5.96E-06	9.94E-12	1.19E+01
Fenamiphos	22224-92-6	0.00025	4000	0.858	0.000143	7.16E-06	7.16E-06	1.19E-11	1.43E+01
Glyphosate	1071-83-6	0.1	10	0.00215	3.58E-07	1.79E-08	1.79E-08	2.98E-14	3.57E-02
Heptachlor	76-44-8	0.0005	2000	0.429	7.16E-05	3.58E-06	3.58E-06	5.96E-12	7.13E+00
Hexachlorbenzene	118-74-1	0.0008	1250	0.268	4.47E-05	2.24E-06	2.24E-06	3.73E-12	4.46E+00
Lindane	58-89-9	0.0003	3330	0.715	0.000119	5.96E-06	5.96E-06	9.94E-12	1.19E+01
Malathion	121-75-5	0.02	50	0.0107	1.79E-06	8.95E-08	8.95E-08	1.49E-13	1.78E-01
Methomyl	16752-77-5	0.025	40	0.00858	1.43E-06	7.16E-08	7.16E-08	1.19E-13	1.43E-01
Methoxychlor	72-43-5	0.005	200	0.0429	7.16E-06	3.58E-07	3.58E-07	5.96E-13	7.13E-01
Naled	300-76-5	0.002	500	0.107	1.79E-05	8.95E-07	8.95E-07	1.49E-12	1.78E+00
Oxamyl	23135-22-0	0.025	40	0.00858	1.43E-06	7.16E-08	7.16E-08	1.19E-13	1.43E-01
Paraquat	1910-42-5	0.0045	222	0.0476	7.95E-06	3.98E-07	3.98E-07	6.63E-13	7.93E-01
Permethrin	52645-53-1	0.05	20	0.00429	7.16E-07	3.58E-08	3.58E-08	5.96E-14	7.13E-02
Phosphine	7803-51-2	0.0003	3330	0.715	0.000119	5.96E-06	5.96E-06	9.94E-12	1.19E+01
Pirimifos-methyl	29232-93-7	0.01	100	0.0214	3.58E-06	1.79E-07	1.79E-07	2.98E-13	3.57E-01
Propachlor	1918-16-7	0.013	76.9	0.0165	2.75E-06	1.38E-07	1.38E-07	2.29E-13	2.74E-01
Resmethrin	10453-86-8	0.03	33.3	0.00715	1.19E-06	5.96E-08	5.96E-08	9.94E-14	1.19E-01
Sodium fluoracetate	62-74-8	0.00002	50000	10.7	0.001789	8.95E-05	8.95E-05	1.49E-10	1.78E+02
Thallium sulfate	7446-18-6	0.00008	12500	2.68	0.000447	2.24E-05	2.24E-05	3.73E-11	4.46E+01
Thiram	137-26-8	0.005	200	0.0429	7.16E-06	3.58E-07	3.58E-07	5.96E-13	7.13E-01
2,4,5,-Trichlorophenoxyacetic acid (2,4,5-T)	93-76-5	0.01	100	0.0214	3.58E-06	1.79E-07	1.79E-07	2.98E-13	3.57E-01
Warfarin	81-81-2	0.0003	3330	0.715	0.000119	5.96E-06	5.96E-06	9.94E-12	1.19E+01
Zinc phosphide	1314-84-7	0.0003	3330	0.715	0.000119	5.96E-06	5.96E-06	9.94E-12	1.19E+01

21.3.2. Emission of metals to soil

Only Cd and Hg is assumed to have any significant impacts on the category indicators when emitted to soil in amounts normal to product systems.

The characterisation factor of Cd for morbidity was estimated to $5 \cdot 10^{-4}$ person-years/kg Cd (Chapter 16.1), which will give an impact index of 5 ELU/kg Cd.

The characterisation factor of Hg for morbidity was estimated to $4.8 \cdot 10^{-3}$ person-years/kg Hg (Chapter 16.2). The characterisation factor of Hg for fish&meat was determined to 0.224 kg and for NEX to $1.20 \cdot 10^{-9}$. This will give an impact index of 180 ELU/kg.

21.4. Physical impacts

21.4.1. Land use

In table 21.5 characterisation factors are multiplied with weighting factors for corresponding category indicator and the products added to an index for each substance.

Activity	Unit	Severe nuisance	Wood	NEX	Index (ELU/unit)
Arable land use	m^2year			1.42E-14	1.56E-03
Forestry	m^2year			5.00E-15	5.50E-04
Forestry	m^3			5.68E-11	6.25E+00
Hardmaking of forest land	m^2year		1	5.00E-14	4.55E-02
Littering	m^2	1.39E-03			1.39E+01

Table 21.5 Calculation of impact indices for physical impacts on land areas

22. Validation

The estimation of uncertainties for each model is a type of validation, which is carried out in the various chapters above. A complete test of the models and weighting factors cannot be made, but a number of ways exist to see if the results are reasonable.

One way is to investigate whether the value of impacts from the total global emissions and resource depletions are reasonable. As there is a monetary base in the weighting factors, the magnitude of the total figures may be compared to the global GNP. The global GNP was $2.24 \cdot 10^{13}$ EUR during 1990. As the EPS default method use the WTP as determined in OECD countries, an alternative GNP is calculated for comparison, where the entire global population is assumed to have a per capita GNP:s as for typical OECD countries, i.e. 20000 EUR/person and year. Then the global GNP would be $2 \cdot 10^4 * 5.28 \cdot 10^9 = 10.6 \cdot 10^{13}$ EUR/year.

Such a comparison is made in table 22.1 for a number of indices.

Table 22.1. Weighted global emissions and resource depletions for 1990 as determined by the EPS default method. Global emission and mining data from UN and USGS.

Substance	Global emission or reserve depletion, kg/year	EPS default index, ELU/kg	Added global value	% of adjusted global GNP
CO2	2.20E+13	0.108	2.38E+12	2.24
SO2	1.70E+11	3.27	5.56E+11	0.52
NOx	1.53E+11	2.13	3.26E+11	0.31
Fossil oil	3.40E+12	0.506	1.72E+12	1.62
Fossil coal	3.17E+12	0.0498	1.58E+11	0.15
Natural gas	1.56E+12	1.1	1.72E+12	1.62
Ag-ore	1.30E+07	54000	7.02E+11	0.66
Al-ore	2.11E+10	0.439	9.26E+09	0.01
Au-ore	1.46E+06	1.19E+06	1.74E+12	1.64
Cu-ore	9.03E+09	208	1.88E+12	1.77
Fe-ore	5.07E+11	0.961	4.87E+11	0.46
Pt-ore	1.24E+05	7.43E+06	9.21E+11	0.87
Pd-ore	9.90E+04	7.43E+06	7.36E+11	0.69
Pb-ore	2.80E+09	175	4.90E+11	0.46
P-minerals	1.73E+10	4.47	7.73E+10	0.07

Indices can also be compared with taxes on emissions. For emissions there is “a polluter pays principle”. There is also a number of other considerations made when specifying taxes, why the value of such a comparison is limited. For instance the Swedish taxes on

NO_x and CO_2 are 4.5 EUR/kg (3.36 ELU/kg) and 0.01-0.04 EUR/kg (0.108 ELU/kg) respectively.

The indices of the EPS default method can also be compared with external costs determined in other contexts. Hohnmeyer et.al (1991) refer to external cost estimations made by Pace University Center and Massachusetts Department of public Utilities. (Table 22.2.)

Table 22.2. Comparison between various damge-cost estimates

Substance	Pace study $/kg	Massachusetts study $/kg	EPS default method, version 2000, ELU/kg
SO_2	4.47	1.5	3.27
NO_x	1.81	6.5	2.13
Particles	2.62	4.0	36.0
CO_2	0.015	0.022	0.108
CO		0.87	0.331
VOC		5.3	2.14

The estimates shown i table 22.2 are indicate impact valuation in the same magnitude for SO_2, NO_x, VOC and CO. 1 $ is approximately equal to 1 EUR. The differences in estimates for particles may be explained by the EPS values being estimated for PM_{10}, and that new impact models for long term exposure have been made available since the Massachusetts study were made. The large discrepancy for CO_2 has a similar type of explanation, but the absence of discounting and consideration of equity in the EPS default method may also contribute.

A comparison with the earlier version of EPS default method, version 1996, may also be relevant. (Table 22.3.)

Table 22.3. Comparison between two versions of the EPS default method.

Substance flow group	Impact index, v.2000 (ELU/kg)	Impact index, v.1996 (ELU/kg)	Substance flow group	Impact index, v.2000 (ELU/kg)	Impact index, v.1996 (ELU/kg)
As	95.3	10	HCl	2.13	
Butadiene	10.7		Hg	61.4	177
Cd	10.2	21.2	N_2O	38.3	20.3
CH_4	2.72	1.55	Ni	0	
CO	0.331	0.19	NOx	2.13	0.39
CO_2	0.108	0.0636	PAC	64300	
Cr	20.0	0.8	Pb	2910	291
Ethylene	3.45	3.4	Propylene	2.64	
H_2S	6.89	0.14	SO_2	3.27	0.0545
Ag-ore	54000	45000	Fe-ore	0.961	0.68
Cu-ore	208	57	Pt-ore	7430000	680000

The differences between the 1996 version and the 2000 version are mainly due to three general changes since the middle 90 ies.

The first is an update of the WTP for excess mortality, which is more than doubled. This change is made in order to harmonize the methodology with what is commonly used today.

The second is the new findings of health effects from particles. The very significant decrease of life expectancy detected at moderate particle concentrations increased the estimates of its impact value with several orders of magnitude. This caused an increase not only in the particle indices but also in any gaseous substance that forms secondary particles in the atmosphere, such as SO_2, NO_x and H_2S.

The third is an update of the average concentration of element in the upper crust of the earth. Modern investigations have shown that the concentrations of some strategic metals have to be revised considerably. The most significant revisions, (Cu and Pt) are shown in table 22.3. The other Pt-metals are also found to be scarcer than was earlier believed.

23. Discussion and conclusions

The modelling made in this report indicates that it is possible -despite large uncertainties- to find an estimate of the magnitude of various impacts. It seems as the large differency betweeen various impact types contribute to the impression of the estimates being meaningful after all. In reality it will be the single application or case that actually decides whether the precision is good enough or not.

The case studies made sofar indicates that it still is the global warming and the depletion of fossil and mineral reserves that cause the major impacts and uncertainties when chosing between product alternatives.

Looking at the large global environmental issues of today, there are still some, which are not sufficiently well covered by impact category indicators. Impacts on water resources and land quality are such issues.

To improve evaluation tools like the EPS default method, there is a need to develop better indicators and models for these issues and to increase the precision in the models for the global warming and resource depletions that was mentioned above.

There is also a need for a scientific community process that further validates, accepts or rejects models of these types. It is very unlikely that the users themselves will be able to evaluate the credibility of the models.

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