ReCiPe 2008

A life cycle impact assessment method

which comprises harmonised category indicators

at the midpoint and the endpoint level

First edition

Report I: Characterisation

SUPPORTING INFORMATION

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I. CLIMATE CHANGE

A. ADDITIONAL INFORMATION ON CLIMATE CHANGE STEP 1: MIDPOINT CHARACTERISATION FACTORS

Direct Global Warming Potentials (mass basis) relative to carbon dioxide, for gases for which the lifetimes have been adequately characterised (IPCC 2007).

Industrial Designation or Common Name	*Chemical Formula*	*Lifetime (years)*	*Radiative Efficiency (W m-2 ppb-1)*	*SAR (100-yr)*	*20 yr*	*100 yr*	*500 yr*
Carbon dioxide	CO2	See below[a]	[b]1.4x10–5	1	1	1	1
Methane[c]	CH4	12c	3.7x10–4	21	72	25	7.6
Nitrous oxide	N2O	114	3.03x10–3	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl2F2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	CClF3	640	0.25		10,800	14,400	16,400
CFC-113	CCl2FCClF2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	CClF2CClF2	300	0.31		8,040	10,000	8,730
CFC-115	CClF2CF3	1,700	0.18		5,310	7,370	9,990
Halon-1301	CBrF3	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	CBrClF2	16	0.3		4,750	1,890	575
Halon-2402	CBrF2CBrF2	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH3Br	0.7	0.01		17	5	1
Methyl chloroform	CH3CCl3	5	0.06		506	146	45
HCFC-22	CHClF2	12	0.2	1,500	5,160	1,810	549
HCFC-123	CHCl2CF3	1.3	0.14	90	273	77	24
HCFC-124	CHClFCF3	5.8	0.22	470	2,070	609	185
HCFC-141b	CH3CCl2F	9.3	0.14		2,250	725	220
HCFC-142b	CH3CClF2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	CHCl2CF2CF3	1.9	0.2		429	122	37
HCFC-225cb	CHClFCF2CClF2	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH2F2	4.9	0.11	650	2,330	675	205
HFC-125	CHF2CF3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH2FCF3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH3CF3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH3CHF2	1.4	0.09	140	437	124	38
HFC-227ea	CF3CHFCF3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	CF3CH2CF3	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	CHF2CH2CF3	7.6	0.28		3,380	1030	314
HFC-365mfc	CH3CF2CH2CF3	8.6	0.21		2,520	794	241
HFC-43-10mee	CF3CHFCHFCF2CF3	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF3	740	0.21		12,300	17,200	20,700
PFC-14	CF4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C2F6	10,000	0.26	9,200	8,630	12,200	18,200
PFC-218	C3F8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	c-C4F8	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C4F10	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C5F12	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C6F14	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	C10F18	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF5CF3	800	0.57		13,200	17,700	21,200
Fluorinated	ethers						
HFE-125	CHF2OCF3	136	0.44		13,800	14,900	8,490
HFE-134	CHF2OCHF2	26	0.45		12,200	6,320	1,960
HFE-143a	CH3OCF3	4.3	0.27		2,630	756	230
HCFE-235da2	CHF2OCHClCF3	2.6	0.38		1,230	350	106
HFE-245cb2	CH3OCF2CHF2	5.1	0.32		2,440	708	215

HFE-245fa2	CHF2OCH2CF3	4.9	0.31		2,280	659	200
HFE-254cb2	CH3OCF2CHF2	2.6	0.28		1,260	359	109
HFE-347mcc3	CH3OCF2CF2CF3	5.2	0.34		1,980	575	175
HFE-347pcf2	CHF2CF2OCH2CF3	7.1	0.25		1,900	580	175
HFE-356pcc3	CH3OCF2CF2CHF2	0.33	0.93		386	110	33
HFE-449sl (HFE-7100)	C4F9OCH3	3.8	0.31		1,040	297	90
HFE-569sf2 (HFE-7200)	C4F9OC2H5	0.77	0.3		207	59	18
HFE-43-10pccc124 (H-Galden1040x)	CHF2OCF2OC2F4OCHF2	6.3	1.37		6,320	1,870	569
HFE-236ca12 (HG-10)	CHF2OCF2OCHF2	12.1	0.66		8,000	2,800	860
HFE-338pcc13 (HG-01)	CHF2OCF2CF2OCHF2	6.2	0.87		5,100	1,500	460
Perfluoropolyethers							
PFPMIE	CF3OCF(CF3)CF2OCF2OCF3	800	0.65		7,620	10,300	12,400
Hydrocarbons and other compounds– Direct Effects							
Dimethylether	CH3OCH3	0.015	0.02		1	1	<<1
Methylene chloride	CH2Cl2	0.38	0.03		31	8.7	2.7
Methyl chloride	CH3Cl	1.0	0.01		45	13	4

Table 1: Global Warming potentials taken from IPCC 2007.

Notes:

a - The CO2 response function used is based on the revised version of the Bern Carbon cycle model (Bern2.5CC; Joos et al. 2001) using a background CO2 concentration value of 378 ppm. See IPCC 2007 report, chapter 10.

b - The radiative efficiency of CO2 is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).

c - The perturbation lifetime for methane is 12 years as in the TAR (see also IPCC 2007 report, Section 7.4). The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour (see IPCC 2007 report, Section 2.10.3.1).

d - Shine et al. (2005c), updated by the revised AGWP for CO2. The assumed lifetime of 1,000 years is a lower limit.

e - Hurley et al. (2005)

f - Robson et al. (2006)

g - Young et al. (2006)

B. ADDITIONAL INFORMATION ON CLIMATE CHANGE STEP 3A: HUMAN HEALTH

To calculate the climate change damage factor, we first needed to calculate the attributable burden for each health effect, due to a certain temperature rise. For five different health effects, calculations are made. Additional information about the assumptions, strategy and calculations are presented in this chapter.

Cardiovascular mortality

Cardiovascular diseases have the best characterized temperature mortality relationship. However, within a population there exist a range of sensitivity for heat strokes, due to age, socioeconomic status, housing conditions, air conditions and behaviour. In moderate regions more positive effects then negative will occur.

For calculating the RR, the WHO report looked at 4 climate zones. For cold and temperate regions the study of Kunst A (1993) ‘Outdoor air temperature and mortality in the Netherlands’ was used (quoted in McMichael, 2003). For tropical countries, hot and dry countries the report ‘ISOTHURM, 2003’ was used. Due to poor meteorological data one single city was chosen to define a representative daily temperature distribution for each region. Furthermore, only the change in temperature attributable deaths was calculated as an effect of climate change.

During the WHO calculations, several assumptions were made. The assumption of less sensitivity due to the improvement of socioeconomic status was not taken into account. Another variable that had to be taken into consideration is the ability of people to adapt to a certain temperature. Adaptation is very time dependent. While effects taking place at a long timescale allows adaptation, effects on a small timescale will keep their severity. When human adaptation to temperature rise is assumed, no additional effects will appear and thus no attributable deaths due to cardiovascular diseases will be caused. When the assumption of human adaptation to temperature rise is not taken into account, there will be an attributable burden. These are calculated for the tree emission scenarios. The mean adaptation scenario is shown in the table below.

Region	RR S550	RR S750	RR Unmit.	kDALY (1990)	At. burden (S550)	At. burden (S750)	At. burden (Unmit)
Temperature rise °C					0.5	0.68	1.2
African region	1,007	1,008	1,011	2,19E+04	7,66E+01	8,75E+01	1,20E+02
Eastern Mediterranean region	1,007	1,005	1,007	3,23E+04	1,13E+02	8,06E+01	1,13E+02
Latin American and Caribbean region	1,004	1,005	1,007	1,48E+04	2,96E+01	3,70E+01	5,18E+01
South-East Asian region	1,008	1,009	1,013	7,89E+04	3,15E+02	3,55E+02	5,13E+02
Western Pacific region	1,000	1,000	1,000	4,37E+04	0,00E+00	0,00E+00	0,00E+00
Developed countries	1,000	1,000	1,000	6,59E+04	0,00E+00	0,00E+00	0,00E+00
Total					5,35E+02	5,60E+02	7,98E+02

Table 2: The second, third and fourth column represent the mean estimated relative risks of cardio-vascular mortality, with mean adaptation, attributable to climate change in 2030. The last columns represent the attributable burden for cardio-vascular mortality in 2030 (expressed in years of life lost).

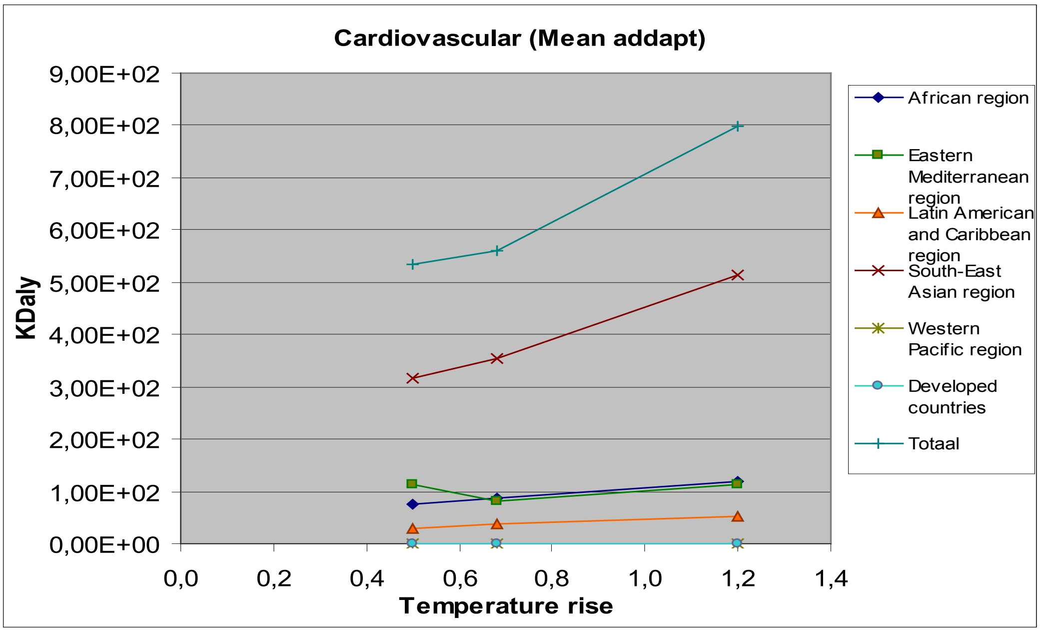


Figure 1: The attributable burden for cardiovascular mortality, without adaptation, in 2030.

Diarrhoeal disease

Diarrhoeal disease is mainly caused by cholera, E. coli and cryptosporidium. There are increased risks for diarrhoeal disease during rain season due to the pollution of water supplies by animal or human waste. During dry season an increased risk appears due to less clean water and hygiene related diseases that cause diarrhoea. This means, changes in temperature and precipitation over different time periods greatly influence the risk of getting a diarrhoeal disease. Despite the knowledge of both influences, the assessment used by the WHO report only addresses the effects of increasing temperatures on the incidence of all-cause diarrhoea. The effects of rainfall patterns are not taken into consideration due to the difficulties in extrapolating the non-linear relationship.

Studies of Checkley et al., 2000 and Singh et al., 2001 (presented by the WHO report), describe a quantitative relationship between climate and overall diarrhoea incidence.

The analysis of Checkley indicated an 8% increase in admission per 1C increase. The analysis of Sighn indicated a 3% increase in incidence per 1C increase. The WHO report used a dose-response relationship that lies between these two indications, namely 5% increase in diarrhoea incidence per 1C increase (for all sexes and age groups).

This relationship was used for countries that have per capita incomes lower than 6000$ per year. These are defined as developing countries and in these cases a wide uncertainty range is assumed. For developed countries an increase of 0% in diarrhoea incidence per 1C temperature increase is assumed.

Region	**RR S750**	**RR S550**	**RR Unmit.**	**kDALY (1990)**	**At.burden (S550)**	**At.burden (S750)**	**At.burden (Unmit)**
Temperature rise °C					0.5	0.68	1.2
African region	1,06	1,05	1,075	7,35E+04	3,67E+03	4,41E+03	5,51E+03
Eastern Mediterranean region	1,045	1,045	1,07	3,46E+04	1,56E+03	1,56E+03	2,42E+03
Latin American and Caribbean region	1	1	1	12072	0,00E+00	0,00E+00	0,00E+00
South-East Asian region	1,06	1,055	1,08	9,94E+04	5,47E+03	5,97E+03	7,96E+03
Western Pacific region	1	1	1,005	6,59E+03	0,00E+00	0,00E+00	3,30E+01
Developed countries	1	1	1	8,46E+02	0,00E+00	0,00E+00	0,00E+00
Total					1,07E+04	1,19E+04	1,59E+04

Table 3: The second, third and fourth column represent the mid-range relative risks diarrhoeal disease attributable to climate change in 2030. The last columns represent the attributable burden for diarrhoeal disease in 2030 (dimensionless).

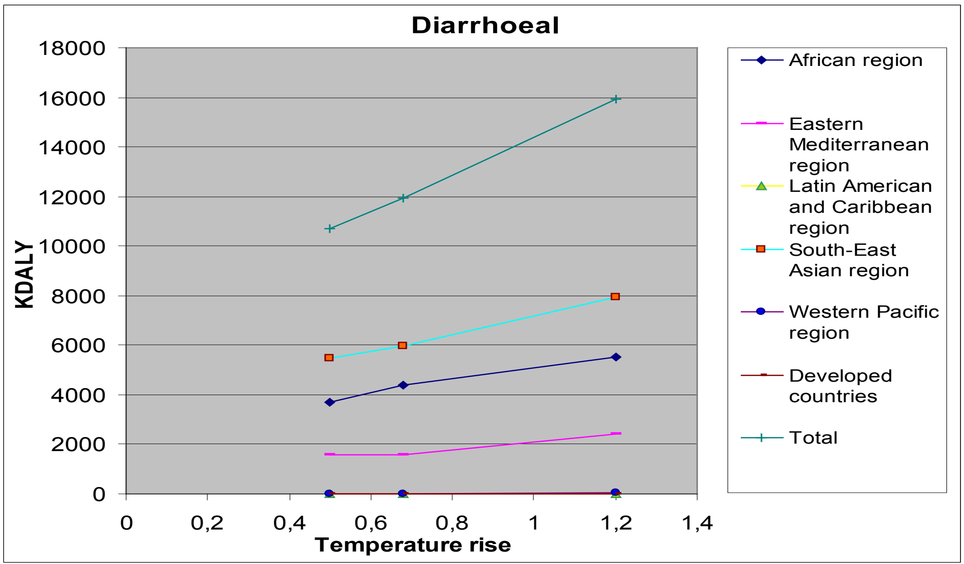


Figure 2: The mid-range attributable burden for diarrhoea disease in 2030 due to climate change.

Malnutrition

Temperature rise and precipitation decrease have both negative effects on the availability of staple foods. Meanwhile, higher carbon dioxide levels are assumed to have positive effects on yields of field crops.

One research group, Parry, 1999 (quoted by McMichael, 2003), has used their estimates to predict the number of people at risk of hunger, and these results are used in the WHO report. The growth models for grain cereals and soybean, which account for 85% of world cereal exports, were used to estimate the effects of changes in temperature, rainfall and CO_2 on future crop yields. This research, however, did not take the effects of fruit and vegetables availability, animal husbandry and the effect on micronutrient malnutrition into account.

Uncertainties around the estimates given by the WHO report are difficult to quantify. They are allocated to different sources, like variation in rainfall and socioeconomic conditions. But most important of all is the ability of the world food trade system to adapt to changes in production. The uncertainty intervals can be defined as ranging from no risk to doubling of the mid-range risk.

Developed countries are assumed to be immune to climate change effects on malnutrition.

When we assume the mid-range risk, the following attributable burdens can be derived:

Region	RR S750	RR S550	RR Unmit	kDALY (1990)	At.burden (S550)	At.burden (S750)	At.burden (Unmit)
Temperature rise °C					0.5	0.68	1.2
African region	1,03	1,04	1,02	1,70E+04	0,00E+00	7,65E+02	4,25E+02
Eastern Mediterranean region	1,05	1,09	1,04	1,27E+04	3,82E+02	1,27E+03	7,64E+02
Latin American and Caribbean region	1,05	1,11	1	6,41E+03	3,21E+02	7,05E+02	0,00E+00
South-East Asian region	1,09	1,14	1,09	3,15E+04	3,47E+03	5,04E+03	4,25E+03
Western Pacific region	1,01	1,02	1	1,29E+04	1,29E+02	3,23E+02	0,00E+00
Developed countries	1	1	1	1,00E+00	0,00E+00	0,00E+00	0,00E+00
Total					4,30E+03	8,10E+03	5,44E+03

Table 4: The second, third and fourth column represent the mean estimated mid-range relative risks of malnutrition attributable to climate change in 2030. The last columns represent the attributable burden for malnutrition in 2030 (dimensionless).

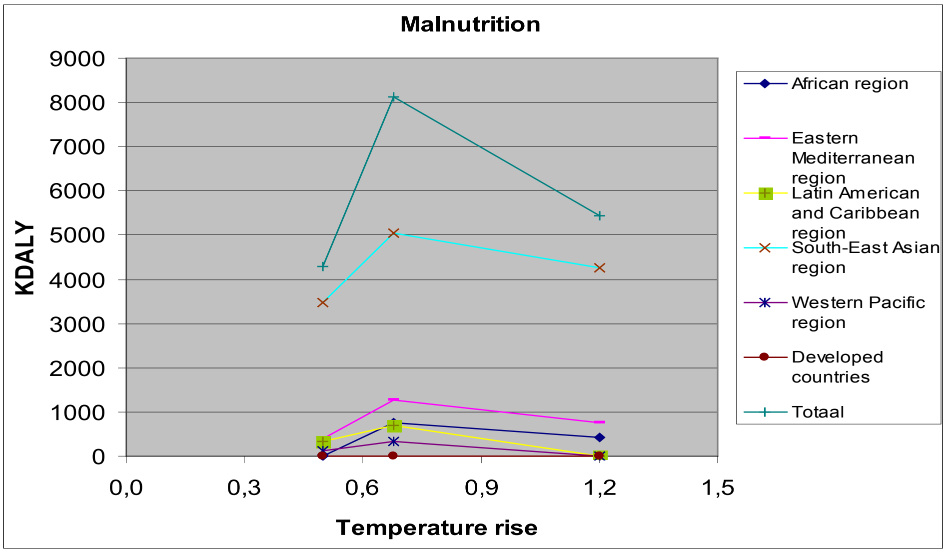


Figure 3: The mid-range attributable burden for malnutrition in 2030 due to climate change.

When we look at the figure above, we see for unmitigated emission scenario (1.2°C temperature rise) a surprising result. In this scenario, the damage for the unmitigated scenario is lower than for the S750 scenario. Unfortunately, no clear explanation can be found, except for a remark that hints at a higher economic growth at an unmitigated emission scenario. This would indicate that the economic development is actually much more important than the climate change. The WHO report does mentions that inconsistency in the estimates may be due to the high sensitivity of the models, which could be interpreted as a warning that our finding is caused by other model parameters.

Falciparum Malaria

When we look at vector-borne diseases a number of highly risking diseases can be listed, for example dengue, lime, plague and rabies. In this analysis, Malaria will be considered, due to the high influence of climate change on the spread of this disease.

For the transmission of vector-borne diseases three main groups are important to distinguish: the infectious agent, the vector (*Anopheles*) and the predator of the vector. All three are highly influenced by rainfall and temperature. Heavy rain can result in stagnant waters, which is free of predators at preference of the vector. Increasing temperature reduces the breeding time of the vector, stimulates the biting activity of the vector and shortens the incubation time of the infectious agent. Moreover, human has many influences on the abundance of this disease. For example, the effectiveness of the public health infrastructure, the population growth, the amount of travel and use of insecticide all influence the existence of malaria.

Of course, there is considerable debate on the amount of climate driven impact on water borne disease, which depend on all the factors previously mentioned. Due to few available global scale studies the WHO report restrict to the effects of Falciparum malaria.

Craig et al. (1999) presents the Mapping Malaria Risk in Africa (MARA) model. This model uses a combination of biological and statistical approaches to discover the properties of climate demanded by Falciparum malaria. Its model is used by the WHO. Despite several advantages, one disadvantage is important to mention. The WHO maps produced, does not see the difference between malaria caused by *P. falciparum* and *P. vivax* although both parasites reacts quite different at different temperatures.

Some important features, mentioned in the WHO report, of the model are:

- It only looks at the effects of climate and not at socioeconomic factors.
- The people at risk are considered as the population living in areas climatically suitable for more than one month of malaria transmission per year.
- This method is conservative as it accounts only for malaria in the additional population at risk and not for increasing incidence within already endemic populations.
- Climate change will not cause expansion of the disease into developed regions, even if they become climatically suitable. Here the model estimated climate-driven changes in the population at risk within those regions where current and predicted future socioeconomic conditions are suitable for malaria transmission.

Region	**RR S750**	**RR S550**	**RR Unmit**	**kDALY (1990)**	**At.burden (S550)**	**At.burden (S750)**	**At.burden (unmit)**
Temperature rise °C					0.5	0.68	1.2
African region	1,055	1,045	1,085	5,95E+04	2,68E+03	3,27E+03	5,06E+03
Eastern Mediterranean region	1,135	1,045	1,215	5,87E+02	2,64E+01	7,92E+01	1,26E+02
Latin American and Caribbean region	1,09	1,075	1,14	8,19E+02	6,14E+01	7,37E+01	1,15E+02
South-East Asian region	1,005	1,005	1,01	6,60E+03	3,30E+01	3,30E+01	6,60E+01
Western Pacific region	1,265	1,215	1,415	6,60E+01	1,42E+01	1,75E+01	2,74E+01
Developed countries	1,165	1,26	1,135	3,00E+00	7,80E-01	4,95E-01	4,05E-01
Total					2,81E+03	3,48E+03	5,39E+03

Table 5: The second, third and fourth column represent the mean estimated relative risks of malaria attributable to climate change in 2030. The last columns represent the attributable burden for malaria in 2030 (dimensionless).

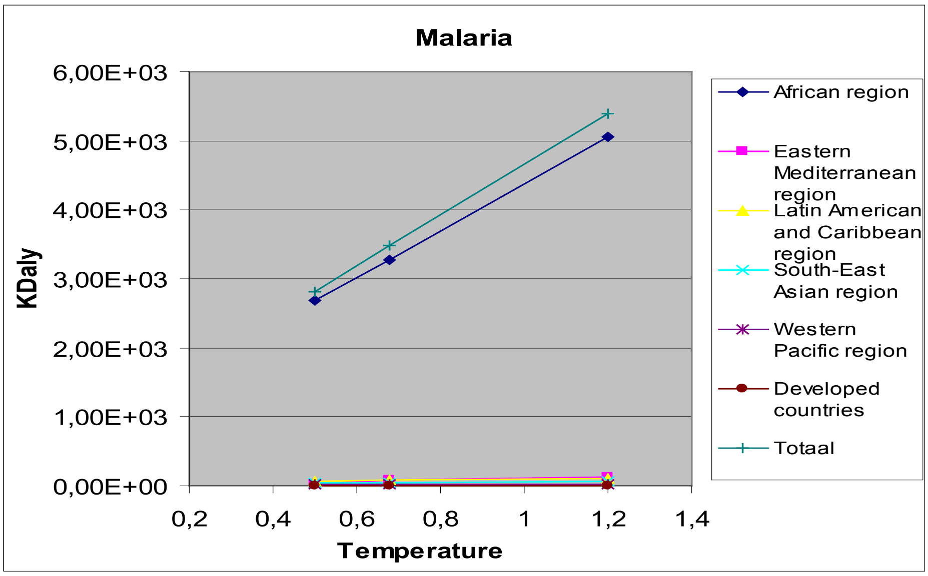


Figure 4: The attributable burden for malaria in 2030 due to climate change.

Natural disasters

Some examples of health impacts of natural disasters are physical injury, decrease in nutritional status and increase in diseases. Globally there is an increase trend in natural disasters and so in the future, the number of disasters will rise. But due to the rising concentration of people living in high-risk areas like coastal zones and urban areas, the losses to each event will tend to increase.

The natural disasters taken into account are coastal flooding, driven by sea level rise, and inland flooding and mudslides, caused by intensive precipitation. The damage of these two effects are measured separately and finally added. The climate effects causing changes in frequency of coastal floods were calculated by the WHO using the models of Hoozemans and Hulsburgen (1995), and Nicholls et al. (1999). Inland floods are mainly influenced by increasing frequency of intense precipitation. Because no published analyses about this effect is available, the WHO calculated the damage based on the distribution of rainfall and the priori assumption `flood frequency is proportional to the frequency with which monthly rainfall exceeds the 1 in 10 year limit of the baseline scenario'. Detailed information about the calculations and assumptions they made can be found in the report 'Global and regional burden of disease attributable to selected major risk factors', chapter 20 'global climate change'.

The estimated Relative Risks incorporate an effect of increasing wealth and/or individual adaptation. Equal impacts for all age and sex groups were assumed. More details see table 6.

Assumptions	RR for coastal flooding	RR for inland flooding
Low-range	90% lower risk than the mid-range by highly efficient coastal defences or individual adaptation.	No increase in risk is assumed
Mid-range	Incorporated increasing wealth which allows better adaptive capacity	Incorporated increasing wealth which allows better adaptive capacity
High-range	No adaptation is assumed	A 50% greater risk than the mid-range and no adaptation with GDP
Comments	Uncertainties in the model relate to the degree and manner to which individuals respond.	Greater uncertainty over adaptive responses than coastal flooding, due to magnitude and temporal variation in precipitation.

Table 6: Ranges of estimated RR of natural disasters linked to assumptions.

In contrast to the other sub-endpoints, health effects due to natural disasters do not refer to a specific disease and so is not associated with a burden of disease, expressed as DALY, given by the WHO. Therefore, McMichael and Campbell-Lendrum[1], had to estimate the impacts attributable to inland and coastal flooding. They used the annual incidence of death per 10,000,000 population, given by the EM-DAT database. This number is used to calculate the amount of people killed per region and multiplied by the ½ average life expectancy for that region. All the numbers are derived from the WHO-website.

	At. Burden (S570)	At. Burden (S750)	At. Burden (Unmit)
Temperature rise °C	***0.5***	***0.68***	***1.2***
African region	1,82E+01	1,39E+01	1,16E+01
Eastern Mediterranean region	1,96E+02	1,71E+02	1,76E+02
Latin American and Caribbean region	1,47E+02	1,81E+02	1,73E+02
South-East Asian region	6,84E+01	4,93E+01	2,69E+01
Western Pacific region	4,63E+01	5,10E+01	6,63E+01
Developed countries	4,12E+01	4,47E+01	3,56E+01
Total	5,17E+02	5,11E+02	4,89E+02

Table 7: The attributable burden for natural disasters, based on the sum of coastal and inland flooding. For a mid-range RR.

Improving flood defences, population migration and rising population density all have impact on the vulnerability of a population to natural disasters. This vulnerability can change over time and so a changing baseline incidence rate, in proportion to increases in GDP (Gross domestic product), was taken into account.

[1] Ezzati, M. et al., 2004. Global and regional burden of disease attributable to selected major risk factors. World Health organization, ISBN 92 4 158031 3.

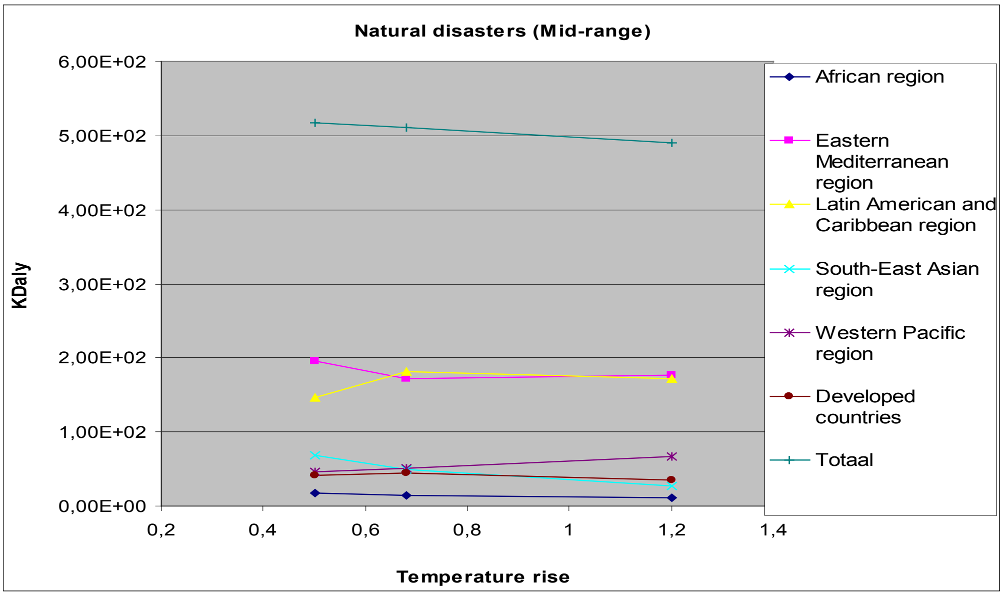


Figure 5: The attributable burden for natural disasters in 2030 due to climate change, for a mid-range RR.

The data shows that according to the models used, the impacts are not dependent on the assumed emission scenarios. This means there is apparently no Marginal effect of increased CO2 levels.

C. ADDITIONAL INFORMATION ON CLIMATE CHANGE STEP 3B: ECOSYSTEMS.

Extrapolation over natural area's

We excluded agricultural area's deserts and ice regions. The FAO Global Arable-ecological Zones database gives the following overview (percentage) of the main types of land (see also http://www.fao.org/ag/agl/agll/gaez/index.htm). We combined this data with the total land surface on earth, 148.3 E6 km^2 according to Charles R. Coble et al. (1987). This results in a damage area of 96.1 E6 km^2.

	Grass -land	*Wood -land*	*Fores t*	*Mosaics including crop-land*	*Cropl and*	*Irrigated cropland*	*Wetla nd*	*Desert and barren land*	*Water (coastal fringes)*	*Ice, cold desert*	*Urban*	*Total*
% of world total	13.6%	14.5%	21.2%	8.50%	8.30%	3%	0.70%	20.90%	3.30%	5.90%	0.20%	
included y/n	yes	yes	yes	yes	yes	yes	yes	no	yes	no	no	
Calculated area in million km^2	20.17	21.50	31.44	12.61	12.31	4.45	1.04	0.00	4.89	0.00	0.00	108.4 1

Table 8: Calculated natural surface area.

The data available per region

In the accompanying information of the paper of Thomas *et al.* details are given for the studies in different parts of the world; they all attempt to describe the difference between the current situation (2000) and the situation in 2050 using different emission scenarios. Often a low, medium or high emission scenario is assumed, but there is no standard assumption on what is a high or low emission scenario. The table below provides an overview of the assumed emission scenario's, the CO2 concentrations and temperatures. The data for the studies in South Africa are reported as they would be a mid estimate for the temperature increase, but as the reported temperature increase is 3°C, we found it more appropriate to interpret these studies in the category maximum temperature.

Data set.		*Queensland: Mammals, birds, frogs & reptiles*	*Australia: butterflies*	*Mexico: mammals, birds & butterflies*	*South Africa: mammals, birds, reptiles & butterflies*	*Europe: birds*	*Brazil: Cerrado plants*	*South Africa: Proteaceae*	*Europe: plants*	*Amazon: plants*
Climate model used			*HadCM2*	*HadCM2*	*HadCM2*	*HadCM3*	*HadCM2*	*HadCM2*	*HadCM2*	*HadCM2*
Minimum expected climate change scenarios	*Climate change scenario & end date*		SRES B1 2050	HHGSDX 2050			HHGSDX 2050		2050	
	Global mean temp incr. °C		0.9	1.35*			1.35*		1.7	
	Local mean temp incr. °C	1	0.8 to 1.4							
	End CO_2 level p.p.m.v.	No data	480	443*			443*		450	
Mid-range climate change scenarios	*Climate change scenario & end date*		SRES A1 2050	HHGGAX 2050	GGa 2050		HHGGAX 2050	GGa (IS92a) 2050	2050	
	Global mean temp incr. °C		1.8	2*	3		2*	2	1.9	
	Local mean temp incr. °C		1.4 to 2.6		2.5 to 3					
	End CO_2 level p.p.m.v.		555	554*	Doubled since pre-industrial levels		554*	550	550	
Maximum expected climate change scenarios	*Climate change scenario & end date*		SRES A2 2050			SRES B2 2070-2099			2100	GSa1 2095
	Global mean temp incr. °C		2.6			3.0* *			2.3	2.58*
	Local mean temp incr. °C	3.5	2.1 to 3.9			3.7 (1.5 to 7.4)				
	End CO_2 level p.p.m.v.	No data	560			1360*** (780-1157)			550	679*

Table 9: Overview of the studies used in the articles and the climate conditions assumed to be applicable in 2050, often using several scenarios.

Extinction data per study

The extinction data per study in the article was edited to get a more easily usable format. This format is presented below. The study listing is repeated three times, for the low, mid and max temperature assumption. Not all studies have data for all assumptions.

						With dispersal				Without dispersal			
		n	Global mean temp incr. °C	Local mean temp incr. °C	End CO_2 level p.p.m.v.	PDF method 1 WD	PDF method 2 WD	PDF method 3 WD	PDF red list species WD	PDF method 1	PDF method 2	PDF method 3	PDF red list species
Low temperature assumption	*Queensland: Mammals*	11		1		10	13	15	16				
	Queensland: Birds	13		1		7	9	10	12				
	Queensland:Frogs	23		1		8	12	18	13				
	Queensland:Reptiles	18		1		7	11	14	9				
	Australia: butterflies	24	0.9	0.8 - 1.4	480	5	7	7	7	9	11	12	16
	Mexico: mammals	96	1.35		443	2	4	5	5	9	14	18	24
	Mexico, birds	186	1.35		443	2	2	3	4	5	7	8	9
	Mexico:butterflies	41	1.35		443	1	3	4	7	6	9	11	13
	Sout Africa: Mammals	5											
	South Africa: Birds	5											
	South Africa: Reptiles	26											
	South Africa: Butterflies	4											
	Brazil: Cerrado plants	163	1.35		443					38	39	45	66
	Europe: birds	34											
	South Africa: Proteaceae	243											
	Europe: plants	192	1.7		450	3	4	5	6	9	11	14	18
	All species					9	10	13	11	22	25	31	34
Mid temperature assumption	*Queensland: Mammals*	11											
	Queensland: Birds	13											
	Queensland:Frogs	23											
	Queensland:Reptiles	18											
	Australia: butterflies	24	1.8	1.4 - 2.6	555	13	15	16	23	18	21	23	35
	Mexico: mammals	96	2		554	2	5	7	8	10	15	20	26
	Mexico, birds	186	2		554	3	3	4	5	5	7	8	8
	Mexico:butterflies	41	2		554	3	4	5	7	9	12	15	19
	South Africa: Mammals												
	South Africa: Birds												
	South Africa: Reptiles												
	South Africa: Butterflies												
	Brazil: Cerrado plants	163	2		554					48	48	57	75
	Europe: birds	34											
	South Africa: Proteaceae	243	2		550	24	21	27	38	32	30	40	52
	Europe: plants	192	1.9		550	3	5	6	7	10	13	16	22
	All species					15	15	20	19	26	29	37	45
Max temperature assumption	*Queensland: Mammals*	11		3.5		48	54	80	77				
	Queensland: Birds	13		3.5		49	54	72	85				
	Queensland:Frogs	23		3.5		38	47	67	68				
	Queensland:Reptiles	18		3.5		43	49	46	76				
	Australia: butterflies	24	2.6	3	560	21	22	26	33	29	32	36	54
	Mexico: mammals	96											
	Mexico, birds	186											
	Mexico:butterflies	41											
	Sout Africa: Mammals	5	3	2.5 to 3	720	24	32	46	0	28	36	59	69
	South Africa: Birds	5	3	2.5 to 3	720	28	29	32	0	33	35	40	51
	South Africa: Reptiles	26	3	2.5 to 3	720	21	22	27		33	36	45	59
	South Africa: Butterflies	4	3	2.5 to 3	720	13	7	8		35	45	70	78
	Brazil: Cerrado plants	163											
	Europe: birds	34	3	3.7	1360	4	6	6	7	13	25	38	48
	South Africa: Proteaceae	243											
	Europe: plants	192	2.3		550	4	5	6	8	13	17	21	29
	All species	1084				21	23	32	33	38	42	52	58

Table 10: Extinction data of Thomas et al.

Calculation of the damage factors

The table below specifies the damage factors for the four different methods used.

	Sample	Assumed temperatures			With dispersal				Without dispersal				Note
		low [°C]	*mid [°C]*	*high [°C]*	*PDF meth 1*	*PDF meth. 2*	*PDF meth. 3*	*PDF red list species*	*PDF meth. 1*	*PDF meth. 2*	*PDF meth. 3*	*PDF red list species*	
Queensland: Mammals	11	1		3,5	15,2	16,4	26,0	24,4					1
Queensland: Birds	13	1		3,5	16,8	18,0	24,8	29,2					1
Queensland:Frogs	23	1		3,5	12,0	14,0	19,6	22,0					1
Queensland:Reptiles	18	1		3,5	14,4	15,2	12,8	26,8					1
Australia: butterflies	24	0,9	1,8	3	9,4	8,8	11,2	15,3	11,8	12,4	14,1	22,4	2
Mexico: mammals	96	1,35	2		0,0	1,5	3,1	4,6	1,5	1,5	3,1	3,1	4
Mexico, birds	186	1,35	2		1,5	1,5	1,5	1,5	0,0	0,0	0,0	-1,5	4
Mexico:butterflies	41	1,35	2		3,1	1,5	1,5	0,0	4,6	4,6	6,2	9,2	4
South Africa: Mammals	5			3	8,0	10,7	15,3	0,0	9,3	12,0	19,7	23,0	3
South Africa: Birds	5			3	9,3	9,7	10,7	0,0	11,0	11,7	13,3	17,0	3
South Africa: Reptiles	26			3	7,0	7,3	9,0	0,0	11,0	12,0	15,0	19,7	3
South Africa: Butterflies	4			3	4,3	2,3	2,7	0,0	11,7	15,0	23,3	26,0	3
Brazil: Cerrado plants	163	1,35	2						15,4	13,8	18,5	48,9	4
Europe: birds	34			3	1,1	1,6	1,6	1,9	3,5	6,8	10,3	13,0	1
South Africa: Proteaceae	243		2		12,0	10,5	13,5	19,0	16,0	15,0	20,0	26,0	3
Europe: plants	192	1,7	1,9	2,3	1,7	1,7	1,7	3,3	6,7	10,0	11,7	18,3	2
Average for all studies	**1084**				**8,3**	**8,1**	**10,3**	**14,8**	**9,3**	**10,4**	**14,1**	**20,5**	
Average for sample>100	**784**				5,1	4,6	5,6	8,0	12,7	12,9	16,7	30,6	
Average for plants only	**639**				5,6	4,6	5,6	11,2	10,7	10,9	14,1	25,6	
Average for plants and butterflies	**667**				6,1	5,0	6,1	12,5	11,0	11,8	15,6	25,1	

Table 11: Calculation of the damage factor, using 3 different methods and the red list species.

Slope from origin, or slope between datapoints

The slopes that linked temperature change with PDFs are sometimes determined by linking the origin to a single predicted PDF. In case sufficient data is available the slope was determined between two PDFs at different temperature. We prefer the latter, as this gives a marginal damage.

We investigated how much difference we would get if all slopes were determined between the origin and a given PDF/Temperature combination. The table below summarizes the available data for the case with Dispersal.

Column number	*1*	*2*	*3*	*4*	*5*	*6*
	PDF/ºC, as used	*PDF/ºC, zero-low*	*PDF/ºC, zero-mid*	*PDF/ºC, zero-high*	*PDF/ºC, average of zero to....*	*Difference*
Australia: butterflies	8,8	7,8	8,3	7,3	7,81	113%
Mexico:butterflies	1,5	2,2	2,0		2,11	73%
South Africa: Butterflies	2,3			2,3	2,3	100%
Brazil: Cerrado plants		0	0,0		0	
South Africa: Proteaceae	10,5		10,5		10,5	100%
Europe: plants	1,7	2,4	2,6	2,2	2,39	70%
Average with dispersal	4,97	4,12	4,69	3,95	5,03	

Table 12: Determination of the slope, using different options. In the case of with dispersal. Column 1 contains the slopes as they are used; Column 2,3 and 4 give the slope factor between the origin and the low, mid or high temperature damage, as far as data are available; column 5 gives the average slope from column 2, 3 and 4. The last column gives the average results.

The table 12 shows that if we take an average of the zero to low, mid and high points, and we average these results, we get a total result that is very close to the originally calculated result. Apparently the way we take the slope ids not too relevant. If we would have taken the slopes between zero and low or zero and high, we would have obtained a 20% lower result. This can be explained as only three points contribute to this average.

In the case without dispersal the same analysis was made, and we found somewhat bigger differences. This can be explained by the surprisingly high value of the PDF between zero and low temperatures for Cerrado plants.

Column number	*1*	*2*	*3*	*4*	*5*
	PDF/ºC, as used	*PDF/ºC, zero-low*	*PDF/ºC, zero-mid*	*PDF/ºC, zero-high*	*PDF/ºC, average of zero to....*
Australia: butterflies	12,4	12,2	11,7	10,7	11,5
Mexico:butterflies	4,6	6,7	6,0	0,0	6,3
South Africa: Butterflies	15	0	0	15	15,0
Brazil: Cerrado plants	13,8	28,9	24,0	0	26,4
South Africa: Proteaceae	15	0,0	15,0	0,0	15,0
Europe: plants	10	6,5	6,8	7,4	6,9
	11,80	13,56	12,70	11,02	13,53

Table 13: Determination of the slope, using different options. In the case of without dispersal. Column 1 contains the slopes as they are used; Column 2,3 and 4 give the slope factor between the origin and the low, mid or high temperature damage, as far as data are available; column 5 gives the average slope from column 2, 3 and 4.

Overall we can conclude that the results are not too sensitive on the selection of the slopes.

II. OZONE DEPLETION

D. SUBSTANCE PROPERTIES AND ODPS

ODP: Equivalency factors: The Ozone Depletion Potential (Midpoints)

The ozone depletion potential (ODP) of a substance is a relative measure for the potency to form EESC. Under the assumption that the ratio of ∂EESC and the resulting depletion of stratospheric ozone (∂O3) be constant, the ODP can be defined in different fashions. The ODPs are equivalency factors that encompass the atmospheric residence time of ODSs, the formation of EESC and the resulting stratospheric ozone depletion.

ODP steady state

Steady-state ODPs represent the cumulative effects on ozone over an infinite time scale:

$$ODP_x(\infty) = \frac{\partial[O_3]_x}{\partial[O_3]_{CFC-11}} \qquad \textit{Equation 1}$$

where $\Delta[O3]_x$ and $\Delta\ [O3]_{CFC-11}$ denote the total changes in the stratospheric ozone in the equilibrium state due to annual emissions of halocarbon species x and CFC-11, respectively.

The most recent steady-state ODPs were published by the World Meteorological Organization in 1999 (World Meteorological Organization, 1999) and are the equivalency factors for the impact category ozone depletion. For all substances in Table 1 these values are given as midpoints.

ODP time dependent

Time-dependent ODPs describe the temporal evolution of this ozone impact over specific time horizons (Solomon and Albritton, 1992):

$$ODP_x(t) = \frac{F_x}{F_{CFC-11}} \frac{M_{CFC-11}}{M_x} \frac{(n_{xCl} + \alpha \cdot n_{xBr})}{3} \frac{\int_{t_s}^{t} e^{-(t-t_s)/\tau_x} dt}{\int_{t_s}^{t} e^{-(t-t_s)/\tau_{CFC-11}} dt} \qquad \textit{Equation 2}$$

$\frac{F_x}{F_{CFC-11}}$ denotes the fraction of the halocarbon species x, injected into the stratosphere, that has been dissociated compared to that of $CFC-11$. M_x and M_{CFC-11} are the molecular weights, τ_x, and τ_{CFC-11} indicate atmospheric lifetimes of species x and CFC-11, respectively, while n_{xCl} and n_{xBr} are the numbers of chlorine and bromine atoms, respectively, in halocarbon x (CFC-11 contains 3 chlorine atoms per molecule) and α is the Br/Cl ozone destroying ability ratio, i.e. the relative effectiveness of bromine compared with chlorine for ozone destruction. The time required for a molecule to be transported from the surface to the region of the stratosphere is denoted as t_s. The time lag between emission and ozone depleting effect varies from substance to substance.

ODS	Formula	Atmosph. lifetime (yr)	ODP	Group nr (j)	CAS nr
CFC-11 (R)	CCl_3F	45	1	1	75-69-4
CFC-12	CCl_2F_2	100	1 [a]	1	75-71-8
CFC-113	CCl_2FCClF_2	85	1 [a]	1	76-13-1
CFC-114	$CClF_2CClF_2$	300	0.94 [b]	1	76-14-2
CFC-115	$CClF_2CF_3$	1700	0.44 [b]	1	76-15-3
HCFC-123	CF_3CHCl_2	1.3	0.02 [a]	2	306-83-2
HCFC-124	CF_3CHFCl	5.8	0.02 [a]	2	2837-89-0

HCFC-141b	$CFCl_2CH_3$	9.3	0.12[a]	2	1717-00-6
HCFC-142b	CF_2ClCH_3	17.9	0.07[a]	2	75-68-3
HCFC-22	CHF_2Cl	12	0.05 [a]	2	75-45-6
HCFC-225ca	$CF_3CF2CHCl_2$	1.9	0.02[a]	2	442-56-0
HCFC-225cb	CF_2ClCF_2CHFCl	5.8	0.03[a]	2	507-55-1
Halon-1201 (HBFC 1201)	CF_2BrH	5.8	1.4 [c]	3	--
Halon-1202	CF_2Br_2	2.9	1.3 [a]	3	75-61-6
Halon-1211	CF_2ClBr	16	6 [a]	3	353-59-3
Halon-1301	CF_3Br	65	12 [a]	3	75-63-8
Halon-2311 (HBFC 2311)	$CF_3CClBrH$	1.2*	0.14 [c]	3	--
Halon-2401 (HBFC 2401)	CF_3CFBrH	3.3*	0.25 [c]	3	--
Halon-2402	$C_2F_4Br_2$	20	6 [a]	3	124-73-2
Carbontetrachloride	CCl_4	26	0.73[a]	4	56-23-5
Methylchloroform	CH_3CCl_3	5	0.12[a]	5	79-00-5
Methylbromide	CH_3Br	0.7	0.38[a]	6	74-83-9
Methylchloride	CH_3Cl	1.3	0.02	7	74-87-3

Table 1: Global lifetimes (WMO, 2003) and ODP values.
Notes:
a - Updated semiemperical from Table 1-5 Ch 1 (WMO, 2003)
b - Updated model derived from Table 1-5 Ch 1 (WMO, 2003)
c - (WMO, 1999)

Background information as to human health effects and demographic data

Calculation of incidence of cataract

De Gruijl and Van der Leun (2002) describe the overall yield or incidence rate for cataract as follows:

$$Inc_{cat}(a) = k_0 D^p (a-d)^6 \qquad \textit{Equation 3}$$

Inc_{cat} = yield, number of cataracts
k_0 = UV-dose independent rate constant
D = annual ambient cataractogenic UV-dose
a = age
d = a delay period, approximately 22 years for senile cataract
p = exponent describing the dose dependency, $p \approx 0.55$ (all cataracts)

Damage to humans (endpoint)

Calculation the damage to human health is complicated due to the fact that both the fate of halogen, measures of phasing out some ODS groups and effects of changed UVR exposure are attributed by lag phases. This requires dynamic fate modelling of ODSs up to the level of cumulative halogen loading in terms of EESC, considering the expected changes due to phasing out policies with respect to different ODS groups. The resulting changes in UV radiation and demographic developments have to evaluated and combined with dose response information for the various human health effects.

Future stratospheric ozone levels, influence of climate change

Differences in ozone levels due to ΔEESCj were calculated with AMOUR 2.0 (Assessment MOdel for Ultraviolet Radiation and Risks, Van Dijk et al, 2006), which accounts for gas-phase chlorine driven ozone depletion, ozone production in the stratosphere as a consequence of a drop in stratospheric temperature, non-vortex dynamics and the ozone depletion at mid-latitudes by intrusion of ozone poor air from the Arctic vortex. These effects are likely to be influenced by climate change caused by an enhanced greenhouse effect. Greenhouse gases disturb the radiative balance in the atmosphere, resulting in a temperature rise in the troposphere, but in a cooling in the stratosphere. The total effect of these interactions on the ozone layer is given by:

$$O_3(yr) = C_{temp}\left(O_3(yr_{ref}) + dO_3(polarvortex) + dO_3(nonvortex) + dO_3(gas)\right) \quad \text{Equation 4}$$

For the reference year (yr_{ref}) 1980 was adopted, coinciding with the time when the polar vortex is considered to have become active. Expressions for the temperature factor Ctemp, upspinning of the polar vortices, the non-vortex dynamics and the contribution to the ozone layer thickness, i.e. the classic term relating ozone depletion to halocarbons (gas-phase model), where only the fraction of the observed reference ozone depletion which is not yet attributed to either polar vortex dynamics or to non-vortex dynamics is used, are given in the manual of AMOUR 2.0 (Van Dijk et al, 2006).

III. ACIDIFICATION

Yearly emissions. Emissions of acidifying pollutants in Europe were used in the dynamic soil acidification model SMART2 to derive the marginal change in base cation saturation because of a marginal change in deposition in a forest area in Europe.

Year	SO_2	NO_2	NH_3
1990	43179	27955	8478
1991	40008	27120	8141
1992	36272	25785	7823
1993	34129	24960	7399
1994	31621	23789	7167
1995	29644	23426	7152
1996	27600	23189	6965
1997	25835	22514	6932
1998	24445	22207	6816
1999	22482	21780	6706
2000	21403	21218	6598
2001	20561	20417	6555
2002	19719	19617	6512
2003	18878	18816	6469
2004	18036	18015	6426
2005	17194	17215	6384
2006	16352	16414	6341
2007	15510	15613	6298
2008	14669	14813	6255
2009	13827	14012	6212
2010	12985	13211	6169
2011-2500	12985	13211	6169

Table 1: Yearly emissions in Europe of SO_2, NO_2 and NH_3 (kton/yr)[1-3].

References:

(1) EU. Richtlijn 2001/81/EG van het Europees Parlement en de Raad van 23 oktober 2001 inzake nationale emissieplafonds voor bepaalde luchtverontreinigende stoffen. 2001

(2) UN/ECE. Protocol to the 1979 convention on long-range transboundary air pollution to abate acidification, eutrophication and ground-level ozone. 2000

(3) Vestreng, V. "EMEP/MSC-W Technical report. Review and Revision. Emission data reported to CLRTAP. MSC-W Status Report 2003," EMEP/MSC-W Note 1/2003, 2003.

Plant species. To express the probability of occurrence of individual plant species as a function of variability in predefined environmental factors and their possible interactions, multiple regression equations can be used, which take the form of:

$$\ln\left(\frac{P_{crit,s}}{1-P_{crit,s}}\right) = a_s + b_s \cdot BCS_{crit} + c_s \cdot BCS_{crit}^{\ 2} \qquad \text{Equation 1}$$

where $P_{crit,s}$ is the critical Probability of occurrence of plant species s (-), BCS is Base Cation Saturation (-), a_s reflects the actual situation of all environmental variables, except BCS, relevant for species s, and b_s and c_s are constants.

#	*Family*	*Species*	P_{crit}[4]	a_s median	a_s 2.5th pc	a_s 97.5th pc	b_s	c_s
1	Aceraceae	Acer campestre	0.25	-3.2	-5.9	1.2	0	0
2	Aceraceae	Acer platanoides	0.25	-6.3	-12.3	0.1	0	0
3	Aceraceae	Acer pseudoplatanus	0.45	-5.2	-27.4	2.4	0	0
4	Adoxaceae	Adoxa moschatellina	0.35	-3.6	-21.3	-0.3	0	0
5	Apocynaceae	Vinca minor	0.30	-4.5	-5.7	-0.5	0	0
6	Aquifoliaceae	Ilex aquifolium	0.50	-2.3	-4.8	2.0	0	0
7	Araceae	Arum maculatum	0.40	-14.7	-45.2	17.6	0	0
8	Araliaceae	Hedera helix	0.50	-3.1	-14.2	5.8	0	0
9	Aristolochiaceae	Asarum europaeum	0.15	-5.1	-5.1	-5.1	0	$2.8\cdot10^{-4}$

#	*Family*	*Species*	P_{crit}[4]	a_s median	a_s 2.5th pc	a_s 97.5th pc	b_s	c_s
10	Balsaminaceae	Impatiens noli-tangere	0.40	-7.5	-17.0	1.6	0	0
11	Balsaminaceae	Impatiens parviflora	0.30	1.4	-3.2	8.9	0	0
12	Betulaceae	Betula pendula	0.50	-4.3	-8.1	-0.5	0	0
13	Betulaceae	Betula pubescens	0.35	-3.6	-9.1	1.8	0	0
14	Betulaceae	Betula sp.	0.15	-2.9	-4.8	-0.9	0	0
15	Blechnaceae	Blechnum spicant	0.25	-5.4	-18.5	-1.0	0	0
16	Boraginaceae	Myosotis scorpioides	0.25	-10.0	-22.3	1.9	0	0
17	Boraginaceae	Myosotis sylvatica	0.35	-5.0	-6.0	-2.2	$4.0 \cdot 10^{-2}$	0
18	Boraginaceae	Symphytum tuberosum	0.15	-3.4	-9.4	-1.7	0	0
19	Campanulaceae	Phyteuma spicatum	0.65	-75.2	-176.1	30.9	0	$1.5 \cdot 10^{-3}$
20	Caprifoliaceae	Linnaea borealis	0.45	-17.7	-44.9	-0.5	0	0
21	Caprifoliaceae	Lonicera nigra	0.45	-5.6	-19.2	5.2	0	$4.4 \cdot 10^{-4}$
22	Caprifoliaceae	Lonicera periclymenum	0.65	-8.8	-36.9	-0.3	0	0
23	Caprifoliaceae	Lonicera xylosteum	0.30	-2.2	-12.8	-0.4	0	0
24	Caprifoliaceae	Sambucus nigra	0.15	-4.2	-6.6	-1.8	0	0
25	Caprifoliaceae	Sambucus racemosa	0.35	-1.6	-6.0	2.8	0	0
26	Caprifoliaceae	Viburnum opulus	0.25	-10.9	-15.5	-6.3	$3.7 \cdot 10^{-1}$	$-2.6 \cdot 10^{-3}$
27	Caryophyllaceae	Moehringia trinervia	0.55	-2.0	-2.8	0.2	0	0
28	Caryophyllaceae	Silene dioica	0.25	-3.1	-5.3	-1.0	0	0
29	Caryophyllaceae	Silene italica	0.30	-4.6	-10.9	2.1	0	0
30	Caryophyllaceae	Stellaria holostea	0.45	-5.9	-12.0	-0.8	0	0
31	Caryophyllaceae	Stellaria media	0.35	-0.5	-3.7	3.9	$2.4 \cdot 10^{-2}$	0
32	Caryophyllaceae	Stellaria nemorum	0.40	-7.3	-16.2	0.1	0	0
33	Compositae	Hieracium murorum	0.15	-46.1	-96.5	4.4	0	0
34	Compositae	Hieracium sp.	0.25	-9.3	-17.1	-1.6	0	0
35	Compositae	Homogyne alpina	0.70	-11.8	-29.8	7.0	0	0
36	Compositae	Mycelis muralis	0.35	-5.3	-8.5	-2.1	$1.1 \cdot 10^{-1}$	$-7.6 \cdot 10^{-4}$
37	Compositae	Petasites albus	0.30	-4.2	-13.6	0.1	0	0
38	Compositae	Prenanthes purpurea	0.40	-0.8	-16.6	12.5	0	0
39	Compositae	Senecio nemorensis	0.35	-9.1	-23.3	3.6	0	0
40	Compositae	Senecio ovatus	0.20	-5.5	-33.5	-1.4	0	0
41	Compositae	Solidago virgaurea	0.65	-1.0	-11.5	10.4	0	$-2.2 \cdot 10^{-4}$
42	Compositae	Taraxacum officinale	0.25	-3.1	-5.3	-1.0	0	0
43	Corylaceae	Carpinus betulus	0.65	-3.7	-10.8	3.2	0	0
44	Corylaceae	Corylus avellana	0.55	-4.3	-6.4	-2.2	$2.4 \cdot 10^{-2}$	0
45	Cruciferae	Cardamine bulbifera	0.40	-2.2	-6.2	2.4	0	0
46	Cruciferae	Cardamine chelidonia	0.00	-117.9	-262.6	96.8	0	0
47	Cruciferae	Cardamine flexuosa	0.25	-3.5	-4.7	-0.5	0	0
48	Cruciferae	Cardamine heptaphylla	0.30	-6.5	-7.8	-3.3	$4.8 \cdot 10^{-2}$	0
49	Cruciferae	Cardamine pratensis	0.20	-5.1	-5.1	-5.1	0	$3.1 \cdot 10^{-4}$
50	Cupressaceae	Juniperus communis	0.15	-5.3	-8.9	-1.8	0	0
51	Cyperaceae	Carex alba	0.15	-7.6	-15.1	-0.1	0	$5.2 \cdot 10^{-4}$
52	Cyperaceae	Carex curta	0.05	-3.2	-4.6	0.6	0	0
53	Cyperaceae	Carex digitata	0.45	-6.5	-12.9	-0.2	$3.3 \cdot 10^{-2}$	0
54	Cyperaceae	Carex ericetorum	0.15	-11.4	-21.3	-1.5	0	0
55	Cyperaceae	Carex flacca	0.25	-2.6	-7.3	0.0	0	0
56	Cyperaceae	Carex ovalis	0.30	-2.1	-4.7	0.6	0	0
57	Cyperaceae	Carex pallescens	0.35	-3.1	-5.7	-0.5	0	0
58	Cyperaceae	Carex pendula	0.20	-32.6	-32.6	-32.6	$8.3 \cdot 10^{-1}$	$-5.5 \cdot 10^{-3}$
59	Cyperaceae	Carex pilulifera	0.65	-1.0	-5.4	0.9	$-2.4 \cdot 10^{-2}$	0
60	Cyperaceae	Carex remota	0.30	-3.8	-9.8	0.9	0	0
61	Cyperaceae	Carex sylvatica	0.55	-4.4	-11.6	2.1	0	0
62	Cyperaceae	Carex umbrosa	0.20	-4.7	-5.8	-1.1	0	0
63	Dennstaedtiaceae	Pteridium aquilinum	0.50	0.0	-1.9	2.2	0	0
64	Dioscoreaceae	Tamus communis	0.80	-4.5	-11.5	3.9	0	0
65	Dipsacaceae	Knautia dipsacifolia	0.25	-4.9	-8.1	-1.6	0	$4.8 \cdot 10^{-4}$
66	Dryopteridaceae	Dryopteris affinis	0.50	-13.8	-52.5	1.3	0	0
67	Dryopteridaceae	Dryopteris carthusiana	0.55	-5.8	-13.2	1.1	0	$3.0 \cdot 10^{-4}$
68	Dryopteridaceae	Dryopteris dilatata	0.80	1.3	-1.6	4.4	0	0
69	Dryopteridaceae	Dryopteris expansa	0.55	-1.5	-5.5	9.6	0	0

#	*Family*	*Species*	P_{crit}[4]	a_s median	a_s 2.5th pc	a_s 97.5th pc	b_s	c_s
70	Dryopteridaceae	Dryopteris filix-mas	0.40	-0.6	-6.6	4.3	$2.5\cdot10^{-2}$	0
71	Dryopteridaceae	Polystichum setiferum	0.45	-5.5	-7.3	0.1	0	0
72	Empetraceae	Empetrum nigrum	0.20	-6.2	-13.8	1.5	0	0
73	Equisetaceae	Equisetum arvense	0.30	-10.7	-20.8	-0.6	0	0
74	Ericaceae	Calluna vulgaris	0.50	0.5	-11.1	16.4	0	0
75	Ericaceae	Ledum palustre	0.35	-9.2	-29.0	13.1	0	0
76	Ericaceae	Vaccinium myrtillus	0.60	-2.4	-8.4	3.9	0	0
77	Ericaceae	Vaccinium uliginosum	0.40	-4.3	-12.7	5.2	0	0
78	Ericaceae	Vaccinium vitis-idaea	0.55	1.3	-15.9	38.1	0	0
79	Euphorbiaceae	Euphorbia amygdaloides	0.60	-14.0	-27.0	-2.6	$1.7\cdot10^{-1}$	$-1.1\cdot10^{-3}$
80	Euphorbiaceae	Euphorbia dulcis	0.40	-3.4	-6.2	-0.3	0	$3.0\cdot10^{-4}$
81	Euphorbiaceae	Mercurialis perennis	0.40	-43.4	-54.3	-35.1	1.1	$-6.5\cdot10^{-3}$
82	Fagaceae	Castanea sativa	0.45	-3.5	-4.5	0.0	0	0
83	Fagaceae	Fagus sylvatica	0.30	-0.7	-4.1	2.8	0	0
84	Fagaceae	Quercus cerris	0.30	-2.9	-5.7	1.6	0	0
85	Fagaceae	Quercus ilex	0.25	-7.7	-17.3	4.9	0	0
86	Fagaceae	Quercus petraea	0.30	-2.7	-7.1	1.7	0	$-4.7\cdot10^{-4}$
87	Fagaceae	Quercus robur	0.45	-3.8	-8.6	1.1	0	0
88	Fagaceae	Quercus rubra	0.40	-2.5	-6.8	1.9	0	0
89	Fagaceae	Quercus sp.	0.15	-2.8	-7.6	-1.6	0	0
90	Gentianaceae	Gentiana asclepiadea	0.15	-6.0	-18.7	-1.7	0	0
91	Geraniaceae	Geranium robertianum	0.40	-5.7	-8.7	-2.6	$2.1\cdot10^{-1}$	$-1.5\cdot10^{-3}$
92	Geraniaceae	Geranium sylvaticum	0.30	-20.9	-40.7	-1.4	0	0
93	Gramineae	Agrostis canina	0.25	0.2	-3.5	10.4	0	0
94	Gramineae	Agrostis capillaris	0.40	-0.9	-2.3	0.5	0	0
95	Gramineae	Anthoxanthum odoratum	0.20	2.0	-3.2	7.4	0	0
96	Gramineae	Brachypodium sylvaticum	0.45	-9.8	-16.6	-3.2	$1.7\cdot10^{-1}$	$-1.2\cdot10^{-3}$
97	Gramineae	Calamagrostis arundinacea	0.55	-7.0	-29.5	-0.5	0	0
98	Gramineae	Calamagrostis epigejos	0.35	-7.8	-16.9	0.8	0	$-4.9\cdot10^{-4}$
99	Gramineae	Calamagrostis varia	0.35	-5.1	-6.1	-2.5	0	$3.2\cdot10^{-4}$
100	Gramineae	Calamagrostis villosa	0.50	-6.4	-14.8	1.8	0	0
101	Gramineae	Dactylis glomerata	0.45	-2.3	-5.3	1.9	0	0
102	Gramineae	Deschampsia cespitosa	0.55	-5.7	-12.4	0.8	$3.1\cdot10^{-2}$	0
103	Gramineae	Deschampsia flexuosa	0.50	-1.9	-6.4	2.5	0	0
104	Gramineae	Festuca altissima	0.30	-23.9	-51.2	4.0	0	$-2.3\cdot10^{-4}$
105	Gramineae	Festuca heterophylla	0.60	-1.4	-4.6	1.8	0	0
106	Gramineae	Festuca ovina	0.55	-6.3	-17.7	5.3	0	0
107	Gramineae	Festuca rubra	0.40	0.3	-3.8	4.4	0	0
108	Gramineae	Holcus lanatus	0.20	-5.7	-10.7	-0.8	0	0
109	Gramineae	Hordelymus europaeus	0.02	-981.3	-1766.9	-189.0	$1.6\cdot10^{1}$	$-1.2\cdot10^{-1}$
110	Gramineae	Melica uniflora	0.45	0.4	-7.9	7.6	0	0
111	Gramineae	Milium effusum	0.45	-3.5	-7.8	0.8	0	0
112	Gramineae	Molinia caerulea	0.45	-14.3	-74.4	10.1	$-1.0\cdot10^{-1}$	0
113	Gramineae	Poa nemoralis	0.30	0.2	-6.9	6.7	0	0
114	Gramineae	Poa trivialis	0.25	-2.9	-4.5	1.4	0	0
115	Guttiferae	Hypericum androsaemum	0.00	-7719.7	-22908.4	7152.2	0	0
116	Guttiferae	Hypericum montanum	0.25	-3.7	-4.7	-1.0	0	0
117	Guttiferae	Hypericum perfoliatum	0.65	-32.2	-56.4	-7.6	0	0
118	Guttiferae	Hypericum perforatum	0.30	-5.0	-7.8	-2.2	$1.5\cdot10^{-2}$	0
119	Guttiferae	Hypericum pulchrum	0.40	-6.5	-19.6	-1.1	0	0
120	Hypnaceae	Hypnum cupressiforme	0.55	-1.7	-8.2	9.9	0	0
121	Juncaceae	Juncus effusus	0.05	-3.1	-3.1	-1.7	0	0
122	Juncaceae	Luzula forsteri	0.65	-7.5	-20.7	6.0	0	0
123	Juncaceae	Luzula luzulina	0.45	-4.2	-12.2	0.6	0	0

#	Family	Species	P_{crit}[4]	a_s median	a_s 2.5th pc	a_s 97.5th pc	b_s	c_s
124	Juncaceae	Luzula luzuloides	0.45	-1.8	-5.2	0.7	0	0
125	Juncaceae	Luzula multiflora	0.40	0.8	-3.1	2.1	0	0
126	Juncaceae	Luzula nivea	0.40	-3.4	-15.2	9.5	0	0
127	Juncaceae	Luzula pilosa	0.70	1.0	-2.6	4.7	0	0
128	Juncaceae	Luzula sylvatica	0.25	-4.5	-14.4	-1.1	0	0
129	Labiatae	Ajuga reptans	0.60	-1.4	-3.7	1.0	0	$2.2 \cdot 10^{-4}$
130	Labiatae	Clinopodium vulgare	0.35	-2.3	-4.6	1.6	0	0
131	Labiatae	Galeopsis pubescens	0.15	-2.3	-4.0	2.6	0	0
132	Labiatae	Galeopsis speciosa	0.30	-16.6	-32.5	-0.8	0	0
133	Labiatae	Galeopsis tetrahit	0.35	-3.9	-7.1	-0.7	0	0
134	Labiatae	Glechoma hederacea	0.30	-8.1	-13.4	-2.8	$2.3 \cdot 10^{-2}$	0
135	Labiatae	Lamiastrum galeobdolon	0.45	-4.2	-8.8	0.4	$2.1 \cdot 10^{-2}$	0
136	Labiatae	Melittis melissophyllum	0.45	-1.7	-6.4	4.6	0	0
137	Labiatae	Prunella vulgaris	0.50	-3.2	-5.0	1.7	$3.8 \cdot 10^{-2}$	0
138	Labiatae	Salvia glutinosa	0.20	-6.9	-10.4	-3.5	$4.7 \cdot 10^{-2}$	0
139	Labiatae	Stachys officinalis	0.30	-3.2	-6.8	0.5	0	0
140	Labiatae	Stachys sylvatica	0.40	-4.0	-4.9	-1.8	0	$3.3 \cdot 10^{-4}$
141	Labiatae	Teucrium scorodonia	0.65	-11.0	-93.7	6.4	0	0
142	Leguminosae	Cytisus scoparius	0.40	-3.0	-7.3	0.7	0	0
143	Leguminosae	Genista tinctoria	0.15	-3.4	-5.7	0.3	0	0
144	Leguminosae	Lathyrus montanus	0.40	-7.2	-8.8	-3.7	$2.0 \cdot 10^{-1}$	$-1.6 \cdot 10^{-3}$
145	Leguminosae	Lathyrus vernus	0.35	-34.0	-62.2	-5.4	$8.6 \cdot 10^{-2}$	0
146	Leguminosae	Vicia cracca	0.30	-5.1	-5.1	-5.1	0	$3.4 \cdot 10^{-4}$
147	Leguminosae	Vicia sepium	0.40	-23.3	-34.8	-11.8	$2.9 \cdot 10^{-1}$	$-1.7 \cdot 10^{-3}$
148	Liliaceae	Lilium martagon	0.35	-3.1	-8.3	2.7	0	0
149	Liliaceae	Maianthemum bifolium	0.40	-3.0	-16.8	2.2	$1.6 \cdot 10^{-2}$	0
150	Liliaceae	Paris quadrifolia	0.40	-0.6	-7.9	5.9	0	$3.2 \cdot 10^{-4}$
151	Liliaceae	Polygonatum multiflorum	0.45	-1.7	-3.3	-0.1	0	0
152	Liliaceae	Polygonatum verticillatum	0.45	-22.3	-44.8	0.6	0	$4.8 \cdot 10^{-4}$
153	Liliaceae	Ruscus aculeatus	0.40	-3.2	-7.4	2.7	0	0
154	Lycopodiaceae	Diphasiastrum complanatum	0.20	-5.2	-9.4	-1.0	0	0
155	Lycopodiaceae	Huperzia selago	0.50	-3.8	-10.1	2.4	0	0
156	Lycopodiaceae	Lycopodium annotinum	0.65	-11.1	-22.8	0.6	0	0
157	Oleaceae	Fraxinus excelsior	0.45	-5.3	-17.1	-0.4	0	0
158	Oleaceae	Fraxinus ornus	0.00	-302.5	-647.4	122.2	0	0
159	Onagraceae	Circaea alpina	0.35	-10.0	-20.8	0.9	0	0
160	Onagraceae	Circaea lutetiana	0.35	-5.4	-18.9	6.8	$3.4 \cdot 10^{-2}$	0
161	Onagraceae	Epilobium montanum	0.35	-4.5	-9.1	-0.2	$2.6 \cdot 10^{-2}$	0
162	Orchidaceae	Dactylorhiza maculata	0.25	-5.1	-5.1	-5.1	0	$3.2 \cdot 10^{-4}$
163	Orchidaceae	Epipactis helleborine	0.50	-3.5	-15.6	2.5	0	0
164	Orchidaceae	Goodyera repens	0.20	-4.7	-8.0	-1.3	0	0
165	Orchidaceae	Listera cordata	0.30	-1.5	-9.4	8.8	0	0
166	Orchidaceae	Neottia nidus-avis	0.35	-4.4	-5.3	-1.8	0	$2.8 \cdot 10^{-4}$
167	Orchidaceae	Platanthera bifolia	0.30	-5.1	-5.1	-5.1	0	$3.5 \cdot 10^{-4}$
168	Oxalidaceae	Oxalis acetosella	0.45	-6.3	-15.6	2.3	$5.5 \cdot 10^{-2}$	0
169	Pinaceae	Abies alba	0.60	-11.4	-23.5	0.7	0	0
170	Pinaceae	Picea abies	0.45	-6.0	-37.2	4.3	$-1.8 \cdot 10^{-2}$	0
171	Pinaceae	Pinus sylvestris	0.65	-6.9	-21.3	6.9	$-6.0 \cdot 10^{-2}$	0
172	Pinaceae	Pseudotsuga menziesii	0.35	-2.5	-4.7	-0.3	0	0
173	Polygonaceae	Rumex acetosella	0.35	-20.7	-38.5	-2.8	0	0
174	Polypodiaceae	Polypodium vulgare	0.20	-3.8	-16.8	9.1	0	0
175	Primulaceae	Cyclamen hederifolium	0.45	-4.8	-21.0	14.5	0	0
176	Primulaceae	Lysimachia nemorum	0.30	-6.5	-15.9	2.6	0	0
177	Primulaceae	Primula elatior	0.30	-5.7	-6.6	-3.6	$4.4 \cdot 10^{-2}$	0
178	Primulaceae	Trientalis europaea	0.55	-0.5	-25.7	25.2	0	0
179	Pyrolaceae	Orthilia secunda	0.20	-3.9	-8.8	1.0	0	0
180	Ranunculaceae	Actaea spicata	0.35	-4.9	-9.4	-0.3	0	$3.2 \cdot 10^{-4}$
181	Ranunculaceae	Anemone nemorosa	0.50	-1.7	-7.3	2.0	0	0

#	*Family*	*Species*	P_{crit}[4]	a_s median	a_s 2.5th pc	a_s 97.5th pc	b_s	c_s
182	Ranunculaceae	Helleborus foetidus	0.15	-2.9	-6.9	2.4	0	0
183	Ranunculaceae	Hepatica nobilis	0.30	-1.9	-10.3	-0.5	0	0
184	Ranunculaceae	Ranunculus ficaria	0.30	3.4	-4.5	11.2	0	0
185	Ranunculaceae	Ranunculus lanuginosus	0.30	-9.6	-21.9	2.7	0	0
186	Ranunculaceae	Ranunculus repens	0.40	-11.4	-20.7	-2.0	$4.5 \cdot 10^{-2}$	0
187	Rhamnaceae	Frangula alnus	0.40	-3.2	-6.4	-0.1	0	0
188	Rosaceae	Crataegus monogyna	0.50	-2.6	-7.7	0.3	0	0
189	Rosaceae	Fragaria vesca	0.50	-4.4	-4.4	-4.4	$1.1 \cdot 10^{-1}$	$-6.6 \cdot 10^{-4}$
190	Rosaceae	Geum urbanum	0.45	-4.4	-4.4	-4.4	0	$3.4 \cdot 10^{-4}$
191	Rosaceae	Malus sylvestris	0.20	-3.0	-5.1	0.4	0	0
192	Rosaceae	Potentilla erecta	0.20	-1.4	-2.6	2.2	0	0
193	Rosaceae	Potentilla sterilis	0.15	-5.5	-5.5	-5.5	$3.6 \cdot 10^{-2}$	0
194	Rosaceae	Prunus avium	0.40	-15.6	-32.8	2.2	0	0
195	Rosaceae	Prunus serotina	0.55	-11.6	-26.6	3.3	$-1.6 \cdot 10^{-1}$	0
196	Rosaceae	Prunus spinosa	0.70	-2.9	-6.1	1.3	0	0
197	Rosaceae	Pyrus communis	0.15	-2.6	-4.4	2.5	0	0
198	Rosaceae	Rosa arvensis	0.30	-4.3	-14.4	1.1	0	0
199	Rosaceae	Rosa pendulina	0.02	-227.3	-709.4	32.9	0	$1.0 \cdot 10^{-2}$
200	Rosaceae	Rubus caesius	0.25	0.9	-3.6	7.2	0	0
201	Rosaceae	Rubus fruticosus	0.10	-3.5	-5.4	-1.6	0	0
202	Rosaceae	Rubus hirtus	0.45	-7.9	-21.8	2.6	0	0
203	Rosaceae	Rubus idaeus	0.35	0.8	-11.8	7.2	0	0
204	Rosaceae	Rubus sp.	0.70	-6.9	-17.5	3.0	0	0
205	Rosaceae	Rubus ulmifolius	0.40	-5.1	-12.3	2.6	0	0
206	Rosaceae	Sorbus aria	0.65	-3.3	-11.8	5.7	0	0
207	Rosaceae	Sorbus aucuparia	0.45	-4.2	-12.8	2.6	0	0
208	Rosaceae	Sorbus domestica	0.35	0.4	-15.8	20.0	$-1.5 \cdot 10^{-1}$	0
209	Rosaceae	Sorbus torminalis	0.35	-5.4	-11.5	3.2	0	0
210	Rubiaceae	Cruciata glabra	0.25	-2.4	-7.9	3.3	0	0
211	Rubiaceae	Galium aparine	0.30	-3.4	-5.3	2.1	$3.3 \cdot 10^{-2}$	0
212	Rubiaceae	Galium boreale	0.35	-3.4	-5.1	-0.5	0	0
213	Rubiaceae	Galium mollugo	0.25	-7.2	-13.2	-1.3	0	0
214	Rubiaceae	Galium odoratum	0.50	-1.9	-8.9	2.4	0	0
215	Rubiaceae	Galium rotundifolium	0.30	-1.8	-6.7	-0.7	0	0
216	Rubiaceae	Galium saxatile	0.55	-3.2	-8.9	2.5	$-1.6 \cdot 10^{-1}$	0
217	Salicaceae	Populus tremula	0.25	-3.5	-7.3	0.7	0	0
218	Saxifragaceae	Chrysosplenium alternifolium	0.50	-15.7	-35.5	3.9	0	0
219	Scrophulariaceae	Digitalis lutea	0.30	-4.1	-8.7	2.2	0	0
220	Scrophulariaceae	Digitalis purpurea	0.30	-1.4	-6.7	-0.7	0	0
221	Scrophulariaceae	Melampyrum pratense	0.45	0.5	-6.8	11.3	$-3.4 \cdot 10^{-2}$	0
222	Scrophulariaceae	Melampyrum sylvaticum	0.40	-9.2	-38.3	0.7	0	0
223	Scrophulariaceae	Scrophularia nodosa	0.35	-1.5	-3.7	2.2	0	$1.9 \cdot 10^{-4}$
224	Scrophulariaceae	Veronica chamaedrys	0.50	-3.9	-3.9	-3.9	$3.4 \cdot 10^{-2}$	0
225	Scrophulariaceae	Veronica montana	0.35	-7.0	-16.4	2.7	$3.6 \cdot 10^{-2}$	0
226	Scrophulariaceae	Veronica officinalis	0.50	-1.0	-3.3	0.8	0	0
227	Solanaceae	Solanum dulcamara	0.15	-3.3	-5.5	2.9	0	$3.3 \cdot 10^{-4}$
228	Thelypteridaceae	Phegopteris connectilis	0.50	-7.7	-17.8	2.3	0	0
229	Thuidiaceae	Thuidium tamariscinum	0.50	-1.9	-8.6	10.1	0	0
230	Thymelaeaceae	Daphne laureola	0.35	-25.1	-81.6	38.8	0	$-2.2 \cdot 10^{-3}$
231	Thymelaeaceae	Daphne mezereum	0.45	-8.4	-15.4	-1.3	$6.5 \cdot 10^{-2}$	0
232	Umbelliferae	Aegopodium podagraria	0.35	-2.3	-7.5	2.7	$4.3 \cdot 10^{-2}$	0
233	Umbelliferae	Angelica sylvestris	0.15	-5.2	-5.2	-5.2	$3.2 \cdot 10^{-2}$	0
234	Umbelliferae	Sanicula europaea	0.55	-6.2	-12.4	-1.6	$7.2 \cdot 10^{-2}$	0
235	Urticaceae	Urtica dioica	0.60	-6.0	-15.4	-2.2	$2.7 \cdot 10^{-2}$	0
236	Violaceae	Viola alba	0.35	-2.0	-6.9	4.6	0	0
237	Violaceae	Viola canina	0.10	-2.4	-6.9	3.4	0	0
238	Violaceae	Viola reichenbachiana	0.70	-7.0	-12.2	-2.0	$1.2 \cdot 10^{-1}$	$-7.9 \cdot 10^{-4}$

#	*Family*	*Species*	P_{crit}[4]	a_s			b_s	c_s
				median	*2.5th pc*	*97.5th pc*		
239	Violaceae	Viola riviniana	0.55	-3.2	-3.2	-3.2	$3.2 \cdot 10^{-2}$	0
240	Violaceae	Viola sp.	0.10	-5.8	-5.8	-5.8	$3.6 \cdot 10^{-2}$	0
241	Woodsiaceae	Athyrium filix-femina	0.55	-4.0	-11.3	0.9	0	0
242	Woodsiaceae	Gymnocarpium dryopteris	0.65	-23.9	-82.7	4.9	0	0

Table 2: 242 plant species involved in the effect factor calculations and their critical probability of occurrence (P_{crit}), a_s, b_s, c_s needed to calculate the Potentially Disappeared Fraction of plant species (PDF).

References:

(4) De Vries, W.; Reinds, G. J.; Van Dobben, H.; De Zwart, D.; Aamlid, D.; Neville, P.; Posch, M.; Auée, J.; Voogd, J. C. H.; Velet, E. M. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report 2002; EC, UN/ECE: Brussels, Geneva, 2002.

IV. EUTROPHICATION

E. REDFIELD RATIO BASED CONVERSION FACTORS (LAST COLUMN)

Redfield ratio (Redfield et al., 1993) refers to the typical composition of aquatic phytoplankton (C106H263O110N16P).

Nitrogen	*g N/g nutrient*	*g NO_3^-/g nutrient*	*g PO_4^{3-}/g nutrient*
NO_3^-	0.23	1	0.09577
NO_2^-, NO_2, NO_x	0.30	1.35	0.1291
N_2O	0.64	2.82	0.2699
NO	0.47	2.07	0.1979
NH_3	0.82	3.65	0.3493
CN^-	0.54	2.38	0.2284
N	1	4.43	0.4241

Table.1: N containing nutrients in surface waters.

Phosphorous	**g P/g nutrient**	**g PO_4^{3-}/g nutrient**	**g NO_3^-/g nutrient**
PO_4^{3-}	0.33	1	10.44
$P_2O_7^{2-}$	0.35	1.09	11.40
P	1	3.06	32.00

Table.2: P containing nutrients in surface waters.

F. CONVERSION FACTORS FOR INVENTORY DATA THAT REFER TO LOADING THE TECHNOSPHERE (AGRICULTURAL TOPSOIL AND WASTEWATER TREATMENT), ACCORDING TO EDIP 2003 (POTTING AND HAUSCHILD, 2005)

Traditionally in LCA, the topsoil and wastewater treatment plants are considered the technosphere. Inventory data usually refer to nutrient application in agriculture (prior to uptake by plants) and sometimes to discharge of nutrients to the sewer system (prior to elimination processes by wastewater treatment). This means loading of the technosphere. The ReCiPe method takes this into account if the topsoil in Europe is concerned, by means of the the GIS-based model (CARMEN) on which it relies. For other continents, however, inventory data that relate loading the topsoil have to be converted into net emission, i.e. the amount that is available to eutrophy the aquatic environment. The factors in table 3 can be used to obtain net emission data for aquatic eutrophication.

	Nitrogen			***Phosphorus***
	Grassland <100 kg N/ha	*Grassland >100 kg N/ha*	*Arable & Natural land*	*All land types*
Sand	0	0.15	0.25	0.1
Loam	0	0.10	0.18	0.1
Clay	0	0.05	0.10	0.1
Peat	0	0.01	0.05	0.1

Table.3: Factors that relate nutrient application on various agricultural soil types to net emission, i.e., that part that is available for drainage and runoff (Potting and Hauschild, 2005).

For emission of nitrogen and phosphorus by the civil population, the ReCiPe method is based on net emission. The reason is that most often the discharge from STPs is characterized in detail. As a consequence the emission of N and P at the outlet (effluent) of an STP, thus after purification, is known per inhabitant. If only emission data exist with respect to raw sewage, conversion factors in Table 4 may be applied.

Wastewater treatment process	*Nitrogen*	*Phosphorus*
Untreated	1	1
Mechanical treatment (primary sedimentation)	0.73	0.6
Mechanical + biological treatment	0.37	0.37
Mechanical + chemical treatment	0.43	0.17
Mechanical + biological + chemical treatment	0.23	0.15
Mechanical + biological treatment + denitrification	0.16	0.13
Mechanical + chemical treatment + denitrification	0.14	0.08

Table.4: Factors (g/g) for multiplication if inventory data refer to wastewater before wastewater treatment.

G. ALTERNATIVE SCENARIOS OF N SUPPLY TO AGRICULTURAL FIELDS

Gross supply of manure and fertilizer

Gross supply refers to the amount that the farmer has available just at the moment of application. A certain fraction of the nitrogen in manure or fertilizer will volatilize as NH_3 and will be transported to terrestrial and marine environments. The model calculations with CARMEN and EUTREND are conducted for the default settings that 21 % of the nitrogen in manure and 7 % in fertilizer will not reach the soil at the intended location.

The compute fate factors for scenarios that deviate from this default setting, it is necessary to resolve the overall fate factors into soil and air constituents.

Emission compartment specific fate factors for gross N supply

Emission compartment specific fate factors for nitrogen due to gross manure and fertilizer supply are summarized in Table 5. These soil or air specific fate factors are independent on the percentage of nitrogen that volatilizes. Note that the overall fate factor for gross N supply, FF (manure/fertilizer, N, all) are exclusively applicable to default volatilization percentages and are unequal to the sum of the respective emission compartment specific fate factors. It should be noted that although the latter are independent on the percentage volatilization, they are only applicable to the total N supply, multiplied by the fraction released to air, respectively by the fraction enters the soil, to obtain the impact scores (IS). Only for the default volatilization settings the impact score IS (N, all), which is the product of the FF(N, all) and the total N supply, is equal to the sum of IS (N, air) and IS (N, soil).

Example: the IS (with respect to seawater) for 1 tn/yr of manure N is equal to FF (manure N, all) multiplied by 1 tn/yr yielding 5.69•10-6 yr/km3. In turn, this is equal to 0.21 (tn/yr) X 1.09•10-5 yr/km3 + 0.79 (tn/yr) X 4.31•10-6 tn/km3.

Fate factor	*Seawater*	*Freshwater*	*Remarks*
FF (manure N, soil)	$4.31 \cdot 10^{-6}$	$2.12 \cdot 10^{-5}$	independent of % volatilization
FF (fertilizer N, soil)	$4.80 \cdot 10^{-6}$	$3.20 \cdot 10^{-5}$	independent of % volatilization
FF (manure N, air)	$1.09 \cdot 10^{-5}$	$2.55 \cdot 10^{-5}$	independent of % volatilization
FF (fertilizer N, air)	$1.07 \cdot 10^{-5}$	$2.60 \cdot 10^{-5}$	independent of % volatilization
FF (manure N, all)	$5.69 \cdot 10^{-6}$	$2.21 \cdot 10^{-5}$	only for default % volatilization
FF (fertilizer N, all)	$5.21 \cdot 10^{-6}$	$3.16 \cdot 10^{-5}$	only for default % volatilization

Table 5: Emission compartment resolved and overall fate factors (all in yr/km3) for the default scenario of N supply.

Varying volatilization percentages

Emission compartment specific fate factors for nitrogen due to gross manure or fertilizer are independent of the percentage N volatilization. However, they require the emission to each compartment. In other words, both the total amount of N supply and the volatilization percentage should be available to compute two impact scores: one for the fraction that reaches the surface water (either sea or freshwater) exclusively via soil and one for the fraction that initially travels through the air before it contributes to aquatic eutrophication.

Some LCA practitioners, however, prefer to deal with only one impact score. Nevertheless, a volatilization percentage should be available for either manure (am) or fertilizer (af) which can be used to formulate overall fate factors as given in Table 6. Note that if a manure injection technique allows volatilization to reduce to 7 % the overall fate factor (for example for seawater it would be (4.77•10-6 yr/km3) is unequal to the default fertilizer application with also 7 % (5.21•10-6 yr/km3). The conclusion could be drawn that such an application of manure would be 10 % less eutrophying for coastal seas.

Seawater eutrophication potentials for agricultural N supply with varying volatilization rates, can be computed by means of Table 7.

Fate factor	***Seawater (midpoints)***	***Freshwater***
FF (manure N, all)	$(1-a_m)\cdot 4.31\cdot 10^{-6} + a_m\cdot 1.09\cdot 10^{-5}$	$(1-a_m)\cdot 2.12\cdot 10^{-6} + a_m\cdot 2.55\cdot 10^{-5}$
FF (fertilizer N, all)	$(1-a_f)\cdot 4.80\cdot 10^{-6} + a_f\cdot 1.07\cdot 10^{-5}$	$(1-a_f)\cdot 3.20\cdot 10^{-6} + a_f\cdot 2.60\cdot 10^{-5}$

Table.6: Composite fate factors (all in yr/km3) for N supply if volatilization of N deviates from the default scenario; a_m and a_f are volatilization fractions for manure and fertilizer, respectively.

Emission	***EP seawater***
manure N → soil, air	$(1-a_m)\cdot 0.060 + a_m\cdot 0.152$
fertilizer N → soil, air	$(1-a_f)\cdot 0.067 + a_f\cdot 0.149$

Table.7: Seawater eutrophication potentials (EP) for N supply for varying volatilization rates.

Net emission of manure and fertilizer for varying volatilization percentages

Table 8 is only valid for the scenario of N supply with default volatilization rates. The net/gross factors for varying volatilization fractions (am for manure and a_f for fertilizer) are given in Table 7. It should be emphasized that these net/gross factors are solely applicable to the overall gross fate factor given by Table 6.

Intervention	***Emission***	***Net/Gross ratio***
manure N	soil + air	$1/((1-a_m)\cdot(1-0.912))$
fertilizer N	soil + air	$1/((1-a_f)\cdot(1-0.875))$
manure N	soil	1/(1-0.912) = 11.42
fertilizer N	soil	1/(1-0.875) = 7.97
manure N	air	N/A
fertilizer N	air	N/A

Table.8: Net/gross correction factors for FF(N, soil) in Table 5 and FF(N, all) in Table 6 if only net emission data are available.

The factor $(1-a_m)$ in Table 8 represents the elimination fraction due to volatilization of NH_3 during manure supply. 0.912 is the fraction of nitrogen in manure that is removed from the topsoil due to various processes such as uptake by plants and binding to soil particles (0.875 is the removal fraction of fertilizer N). Note that if the a_m equals default value of 0.21, the net gross factor becomes 14.46 as in Table 8.

Example

A new manure injection method is used to supply nutrients to arable land. Approximately 7 % of the nitrogen volatilizes during the whole cycle of application. From the mineral bookkeeping information system the following is known: 50 tn N per year will leave the topsoil due to run-of and leaching processes. This amount will be available to eutrophy surface waters in Europe.

Step 1

Although gross supply rates of N is not part of the inventory, yet the gross composite fate factor is calculated with the formulae in Table 6. With am = 7, for seawater this will yield: (1.00-0.07)•4.31•10-6 + (0.07)•1.09•10-5 = 4.77•10-6 yr/km3. Although the analysis has not completed yet, already the conclusion can be drawn that if the supply of manure can be managed is such a way that volatilization to air has been reduced to the level of fertilizer supply (7 %), the gross fate factor is approximately 10% lower than for fertilizer supply: 5.21•10-6 yr/km3 (see Table 8). This is entirely attributed to a higher elimination of N in topsoil in the calculation routines of CARMEN.

Step 2
The net/gross ratio has to be evaluated from Table 8. With am = 7, the net/gross ratio for manure is equal to 1/((1-0.07)•(1-0.845)) = 12.22

Step 3
The net composite fate factor for manure injection causing 7 % nitrogen volatilization is: 4.77•10-6 yr/km3 • 12.22 = 5.83•10-5 yr/km3
The midpoint impact score is: 50 (tn nitrogen/yr) X 5.83•10-5 (yr/km3) = 0.0029 tn N/km3 = 0.0029 µg N/L seawater

H. EXPOSURE FACTORS

As in seawater only nitrogen is considered the limiting nutrient, characterization factors with respect to phosphorus are cancelled. In freshwater phosphorus is considered the limiting nutrient and here the characterization factors for N are ignored. The bold printed fate factors in Table 5 are multiplied with the Redfield numbers of Table 3, yielding a set of exposure factors for relevant water systems (Table 2). These exposure factors could be used as midpoint characterisation factors. In ReCiPe, however, such a choice would imply that there is not a direct link to the characterization factor at the endpoint level. Therefore, the (bold) fate factors in Table 9 are the midpoints.

Intervention	***Emission***	***Dimension***	***Exposure factor***	***Water system***
manure P	soil	(tn algae/tn P))·(yr/km^3)	$3.74 \cdot 10^{-4}$	freshwater
fertilizer P	soil	(tn algae/tn P))·(yr/km^3)	$2.94 \cdot 10^{-4}$	freshwater
manure N	soil + air	(tn algae/tn N))·(yr/km^3)	$8.99 \cdot 10^{-5}$	seawater
fertilizer N	soil + air	(tn algae/tn N))·(yr/km^3)	$8.23 \cdot 10^{-5}$	seawater
P from STP	freshwater	(tn algae/tn P))·(yr/km^3)	$3.94 \cdot 10^{-2}$	freshwater
N from STP	freshwater	(tn algae/tn N))·(yr/km^3)	$1.13 \cdot 10^{-3}$	seawater
emission NH_3	air	(tn algae/tn NH_3))·(yr/km^3)	$1.04 \cdot 10^{-4}$	seawater
emission NO_2	air	(tn algae/tn NO_2))·(yr/km^3)	$4.41 \cdot 10^{-5}$	seawater

Table.9: Exposure factors for aquatic eutrophication.

I. CHARACTERISTICS OF EUROPEAN FRESHWATER SYSTEMS IN CARMEN

Nr	*River name*	*Area catchment*	*Vol.*	*Nr*	*River name*	*Area catchment*	*Vol.*
		km^2	km^3			km^2	km^3
1	N.Iceland	$5.47 \cdot 10^4$	12.1	53	Seine	$7.99 \cdot 10^4$	10.4
2	S. Iceland	$4.09 \cdot 10^4$	5.1	54	Rhone	$9.84 \cdot 10^4$	12.9
3	Klar	$1.17 \cdot 10^5$	44.3	55	Charente	$1.99 \cdot 10^4$	0.9
4	N.Kola	$1.15 \cdot 10^5$	7.9	56	Garonne	$9.21 \cdot 10^4$	1.5
5	Cardigan	$3.69 \cdot 10^3$	2.7	57	Adour	$1.81 \cdot 10^4$	0.2
6	Kalix	$2.98 \cdot 10^5$	5.1	58	Aude	$1.06 \cdot 10^4$	0.6
7	Kandalaks	$1.72 \cdot 10^5$	6.3	59	Var	$1.12 \cdot 10^4$	2.3
8	Dvina	$4.43 \cdot 10^5$	2.0	60	Nervion	$2.37 \cdot 10^4$	3.9
9	Pecora	$5.07 \cdot 10^5$	14.8	61	Galicia	$3.41 \cdot 10^4$	3.8
10	Sogne	$4.23 \cdot 10^4$	19.9	62	Douro	$9.79 \cdot 10^4$	12.8
11	Setesdal	$3.89 \cdot 10^4$	3.8	63	Mondego	$1.08 \cdot 10^4$	0.6
12	Tyri	$1.85 \cdot 10^4$	0.1	64	Tajo	$8.36 \cdot 10^4$	1.3
13	Oslo	$4.22 \cdot 10^4$	1.2	65	Sado	$1.34 \cdot 10^4$	2.0
14	Gota	$6.77 \cdot 10^4$	2.4	66	Guadiana	$6.80 \cdot 10^4$	0.0
15	Angerman	$1.39 \cdot 10^5$	1.5	67	Guadalqivir	$6.54 \cdot 10^4$	1.3
16	Logan	$9.00 \cdot 10^4$	11.7	68	Andarax	$1.75 \cdot 10^4$	3.5
17	Kumo	$8.27 \cdot 10^4$	2.5	69	Segura	$1.60 \cdot 10^4$	1.5
18	Neva	$3.96 \cdot 10^5$	8.9	70	Jucar	$4.44 \cdot 10^4$	1.9
19	Volga	$1.45 \cdot 10^6$	189.1	71	Balearic	$3.63 \cdot 10^3$	3.4
20	Lorne	$1.99 \cdot 10^4$	12.2	72	Ebro	$8.93 \cdot 10^4$	11.7
21	Moray	$2.26 \cdot 10^4$	6.7	73	Llobregat	$1.38 \cdot 10^4$	2.4
22	Forth	$2.93 \cdot 10^4$	3.2	74	Arno	$2.30 \cdot 10^4$	2.9
23	Konge	$2.11 \cdot 10^4$	6.4	75	Adiatic	$4.14 \cdot 10^4$	5.0
24	Belt	$2.12 \cdot 10^4$	11.3	76	Tevere	$2.26 \cdot 10^4$	1.4
25	Venta	$5.24 \cdot 10^4$	2.4	77	Gaete	$1.37 \cdot 10^4$	0.5
26	Daugava	$1.08 \cdot 10^5$	1.0	78	Lipari	$1.49 \cdot 10^4$	4.1
27	Neman	$7.75 \cdot 10^4$	1.3	79	Agri	$2.80 \cdot 10^4$	5.1
28	Shannon	$4.92 \cdot 10^4$	11.0	80	Simeto	$1.88 \cdot 10^4$	4.1
29	Staney	$1.41 \cdot 10^4$	3.0	81	W.Corse	$4.08 \cdot 10^3$	2.3
30	Lee	$1.59 \cdot 10^4$	1.2	82	E.Corse	$3.58 \cdot 10^3$	0.7
31	Lake District	$2.30 \cdot 10^4$	2.7	83	W.Sardinia	$1.64 \cdot 10^4$	3.7
32	Humber	$4.42 \cdot 10^4$	1.6	84	E.Sardinia	$6.28 \cdot 10^3$	1.6
33	Severn	$3.19 \cdot 10^4$	3.3	85	Cetina	$3.01 \cdot 10^4$	9.4
34	Thames	$2.07 \cdot 10^4$	1.1	86	Drin	$6.45 \cdot 10^4$	9.1
35	Avon	$1.77 \cdot 10^4$	4.1	87	Acheloos	$1.10 \cdot 10^5$	15.9
36	Weser	$6.27 \cdot 10^4$	1.0	88	Maritsa	$5.75 \cdot 10^4$	2.9
37	Elbe	$1.49 \cdot 10^5$	19.4	89	Istrandca	$2.23 \cdot 10^4$	1.9
38	Mecklenburg	$1.75 \cdot 10^4$	4.0	90	Sakarya	$2.82 \cdot 10^5$	2.0
39	Oder	$1.28 \cdot 10^5$	16.7	91	S.Marmara	$2.34 \cdot 10^4$	1.5
40	Vistula	$2.26 \cdot 10^5$	2.7	92	Gedis	$4.58 \cdot 10^4$	1.4
41	Dnjepr	$6.52 \cdot 10^5$	5.0	93	Menderes	$4.76 \cdot 10^4$	1.4
42	Don	$4.90 \cdot 10^5$	64.0	94	Crete	$1.64 \cdot 10^4$	10.5
43	Lower Rhine	$2.84 \cdot 10^4$	2.4	95	Po	$7.24 \cdot 10^4$	9.5
44	Middle Rhine	$1.16 \cdot 10^5$	15.1	96	Adige	$4.22 \cdot 10^4$	2.2
45	Upper Rhine	$4.16 \cdot 10^4$	5.4	97	Upper Danube	$1.17 \cdot 10^5$	15.3
46	Manche	$1.59 \cdot 10^4$	1.8	98	Middle Danube	$3.72 \cdot 10^5$	48.6
47	Scheldt	$2.34 \cdot 10^4$	1.5	99	Lower Danube	$3.03 \cdot 10^5$	39.6
48	Meuse	$3.43 \cdot 10^4$	4.5	100	Dniestr	$9.92 \cdot 10^4$	1.5
49	Caspian	$3.77 \cdot 10^5$	19.4	101	Don	$9.87 \cdot 10^4$	4.3
50	Aulne	$2.62 \cdot 10^4$	4.3				
51	Vilaine	$1.24 \cdot 10^4$	0.7	**Total**		$\mathbf{1.01 \cdot 10^7}$	**8840**
52	Loire	$1.18 \cdot 10^5$	15.4				

Table 10:

J. CHARACTERISTICS OF EUROPEAN COASTAL SEAS IN CARMEN

Nr	*Name coastal sea*	*Surface (km^2)*	*Volume (km^3)*
1	Irish sea (eastern part)	22,186.6	750
2	St George's Channel	14,612.7	1,000
3	Irish sea (western part)	11,159.5	800
4	Celtic sea	118,997	20,000
5	English Channel (western part)	51,874.6	3,200
6	English Channel (eastern part)	32,952.9	1,300
7	Golf of Biscay	236,140	330,000
8	Atlentic ocean (around Scotland)	199,719	13,000
9	North sea / Norwegian sea	217,092	56,000
10	North sea (northern part)	216,049	14,000
11	North sea (southern part)	126,874	5,000
12	Skagerrak	29,499.4	7,237
13	Kattegat	16,130.3	515
14	Øresund/Great and Small Bealt	37,857.8	1,000
15	Caltic sea (west from Gotland)	71,002.8	3,800
16	Caltic sea (below 15)	0	770
17	Caltic sea (east from Gotland)	143396	7,000
18	Caltic sea (below 17)	0	1,500
19	Gulf of Riga	15,555.1	400
20	Gulf of Finland	26,473.6	1,100
21	Gulf of Bothnia (southern part)	67,678.2	4,900
22	Gulf of Bothnia (northern part)	43,807.3	1,500
23	Norwegian sea	324,194	100,000
24	Venice bay	32,498.1	1,700
25	Adriatic sea (northern part)	44,188.2	4,600
26	Adriatic sea (southern part)	54,416.7	16,000
27	Eegean sea (western part)	39,067.8	6,700
28	Black sea (northern part)	120,583	7,000
29	Sea of Azov	47,980	1,200
30	Black sea (middle part)	134,003	22,000
31	Black sea (south/eastern part)	154,651	23,000
32	Marmara sea	13,794	1,700
33	Eegean sea (eastern part)	43,932.4	12,000
34	Sea of Creta	116,554	63,000
35	Ballearic Basin (northern part)	73,772.9	72,000
36	Gulf of Lion / Ligurian sea	123,938	230,000
37	Algero Provencal basin	48,171.8	120,000
38	Tyrrhonian basin (northern part)	95,668.8	87,000
39	Tyrrhonian basin (southern part)	129,740	270,000
40	Ballearic basin (southern part)	29,673.9	14,000
41	Back sea (deep water)	0	420,000
Total		**3,325,885**	**1,946,672**

Table 11:

K. COUNTRIES IN EUROPE AS EMISSION REGIONS CONSIDERED IN CARMEN

Nr	***Country***
1	Bulgaria
2	Czechia & Slovakia
3	Hungary
4	Poland
5	Romania
6	Russia
7	Yugoslavia
8	Byelorussia
9	Baltic countries
10	Moldavia
11	Ukraine
12	the Netherlands
13	West Germany
14	France
15	Italy
16	Spain
17	Sweden
18	United Kingdom
19	Iceland
20	Norway
21	Finland
22	Ireland
23	Denmark
24	Belgium & Luxembourg
25	East Germany
26	Switzerland
27	Austria
28	Portugal
29	Greece
30	Turkey
31	Caucasus
32	Albania

Table 12:

V. *LAND USE: DATA SOURCES*

Three data sources are used:

- A British study from M.J. Crawley and Harral, J.E., 2001. Scale dependence in plant biodiversity. Science, volume 291, p 264-268. This study is used to calculate the z-factor for six different land use types.
- A recently published study 'Countryside Survey 2000: Survey of Broad Habitats and Landscape features'. This study contains British data, in particularly about arable land use types and linear features and these will be used to complete the data of Kollner.
- The data of Kollner, containing c-factors for plenty of Swiss land use types. Unfortunately, the data of arable land use types is unclear and will not be used.

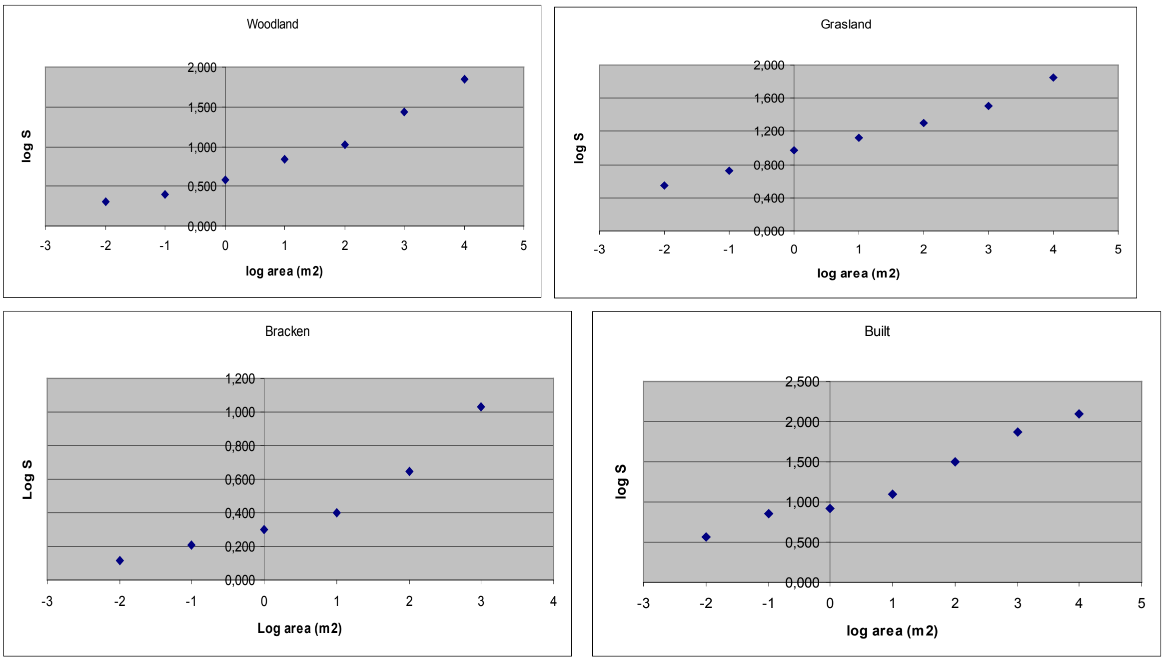
The British study of Crawley and Harral is used as a source for the z-factors. Land use types not analysed in Crawley received the z factor of Köllner. The c-values of the land use types are derived from data of Köllner and the Countryside Survey 2000. To avoid data pollution due to different data sources, an extrapolation is performed. This is done by setting the land use types 'bread-leafed forest/woodland' of the two sources at the same level. Taking the difference between the land use types into account, all other land use types are adjusted. By this method, different area locations could be distinguished, data for different types of forest and agriculture could be generated and finally a list of 28 different land use types is produced.

L. BRITISH STUDY OF CRAWLEY

In the study of Crawley and Harral, data on species diversity for six different land use types and 11 spatial scales, from 0,01 to 10^8 squares, in Great Britain were collected and analysed. They observed the scale and land use type dependency of the species-area relationship, with specific attention at factor z. Two main conclusions could be drawn:

Z is dependent of the size of the area (see figure 1)
Z is dependent of the land use type

The spatial scale dependency of z can be presented as a parabolic function. For very small and very large areas, z is relatively small, while mid-size areas (10^5-$10^{12}m^2$) has a higher z.



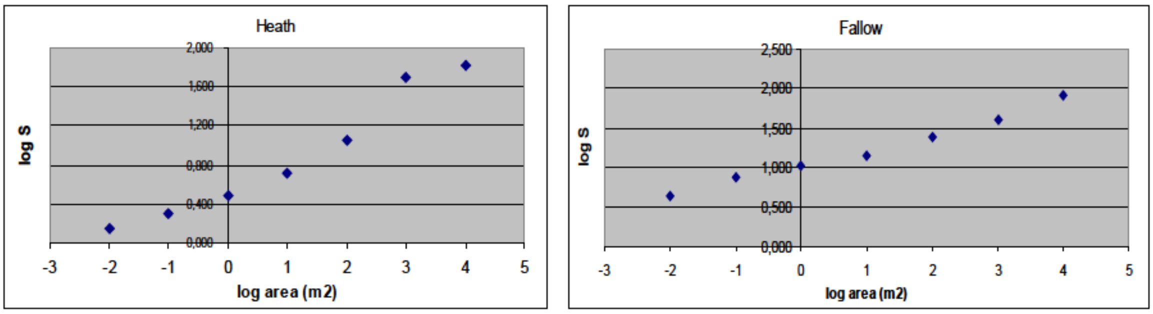


Figure 1: Habitat differences in area species relationships, for six different land use types.

Because, in LCI, the size of the area occupied or used is not known, only one characterisation factor per land use type can be produced. The scale dependency of z is examined in the main report1.

M. THE COUNTRYSIDE SURVEY

The Countryside Survey 2000 (CS2000) is a major audit of the British countryside carried out in 1998-1999. It has both detailed field observations and satellite imagery which has provided a complete land cover census for Great Britain and Northern Ireland. Data of North Ireland will be excluded in this report. The field survey covers both terrestrial and freshwater habitats. It also aims to report on the extent and condition of important landscape features such as hedges and verges.

In this survey, detailed field observations have been made in a random sample of 1 km grid squares across Great Britain. They were selected randomly within the various sample strata. Altogether, 569 sample squares were visited; 366 were in England and Wales. Collection of data such as habitat types, hedgerows and plant species complements powerful satellite imagery. Many of the sample squares visited during the CS2000 field survey also had information recorded within them in the earlier countryside surveys of 1978, 1984, and 1990. Of the 569 squares that were surveyed in 1998/9, 60 were 'new'.

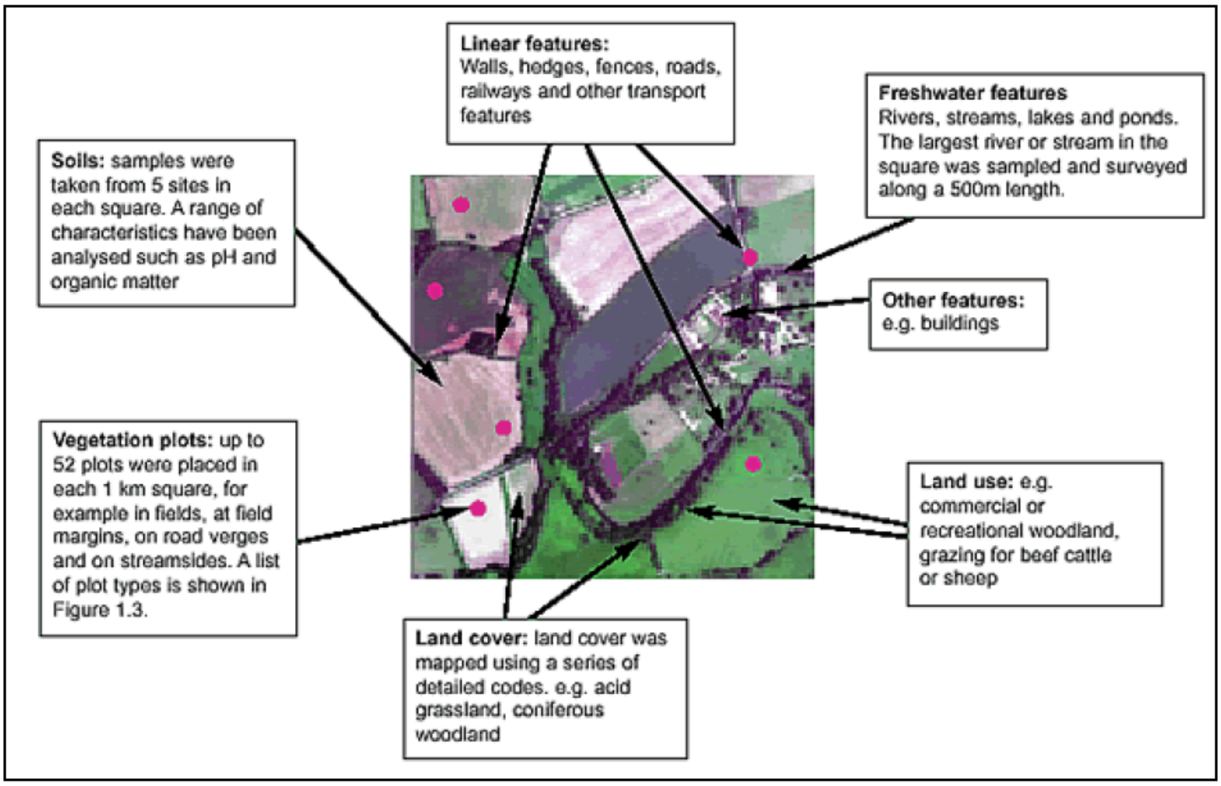


Figure 2: Data gathered from a CS2000 sample square

Code letter	*Plot type*	*Plot Size*	*Maximum no. per km²*	*First surveyed*
X	Fields and other main land cover parcels	14 x 14 m	5	1978
R	Road verges	1 x 10 m	2	1978
V	Additional road verges	1 x 10 m	3	1990
S	Stream and riverside	1 x 10 m	2	1978
W	Additional stream and riverside	1 x 10 m	3	1990
B	Field boundaries	1 x 10 m	5	1990
H	Hedgerows	1 x 10 m	2	1978
Y	Targeted habitat plots	2 x 2 m	5	1990
A	Arable field margins	1 x 100 m	5	1998
D	Woody species only in hedges	1 x 30 m	10	1998
U	Unenclosed Broad Habitats	2 x 2 m	10	1998

Table 1: List of vegetation plot types.

Based on the species composition, each plot type is allocated to a specific aggregated class. Underneath follows a table with the different types of aggregate classes used in this project.

Aggregate Class Code	*Description*
Heath/bog	Ericaceous vegetation of wet or dry ground most extensive in upland areas of Britain. Includes raised and blanket bog vegetation.
Fertile grasslands	Improved and semi-improved grasslands very common across Britain. Usually with a long history of high macro-nutrient inputs and cut more than once a year for silage.
Tall grassland and herb	Most typical of road verges and infrequently disturbed patches of herbaceous vegetation. Includes 'old field' communities of spontaneous, fallow grassland. Usually dominated by tussockforming perennial grasses and tall herbs.
Crops/. weeds	Communities of cultivated and disturbed ground. Includes land under arable cultivation
Moorland grass and mosaics	Extensive, graminaceous upland vegetation, usually with a long history of sheep grazing.
Upland wooded	Includes upland semi-natural broadleaved woodland and scrub plus conifer plantation. Also includes established stands of Bracken (Pteridium aquilinum).
Lowland wooded	Tree and shrub dominated vegetation of hedges, woodland and scrub in lowland Britain.
Infertile Grasslands	Unimproved and semi-improved communities in wet or dry and basic to moderately acidic vegetation. Lowland, species-rich mesotrophic grassland is represented here.

Table 2: Descriptions of the eight aggregate classes of the countryside vegetation system:

How to handle this data?

Using the z values of Crawley, the size of each plot and an area size of $1m^2$, for each plot type and aggregated class c is calculated. The calculated c-factor will finally be extrapolated, using the conforming c-factor of Crawley. This, in order to avoid data pollution, due to different data sources. The results of the extrapolation can be find in table 3.

Aggregated class	*Plot Type*	*Total plots*	*Z used*	*c (CF-1m2)*
Crops/Weeds	A	423	0,21	4,6
Crops/Weeds	B	57	0,21	6,2
Crops/Weeds	RV	52	0,21	6,5
Crops/Weeds	X	465	0,21	2,0
Fertile Grassland	A	73	0,207	6,2
Fertile Grassland	B	462	0,207	7,9
Fertile Grassland	RV	1311	0,207	8,8
Fertile Grassland	SW	215	0,207	10,2
Fertile Grassland	X	445	0,207	3,7
Infertile Grassland	B	725	0,207	10,5
Infertile Grassland	H	88	0,207	11,4
Infertile Grassland	RV	932	0,207	11,8
Infertile Grassland	SW	790	0,207	12,7
Infertile Grassland	X	458	0,207	7,1
Tall Grassland/Herb	A	525	0,207	4,7
Tall Grassland/Herb	B	1316	0,207	7,2
Tall Grassland/Herb	RV	1373	0,207	8,9
Tall Grassland/Herb	H	373	0,207	8,7
Tall Grassland/Herb	X	36	0,207	4,8
Tall Grassland/Herb	X	89	0,207	0,9
Moorland Grass/Mosaic	B	143	0,298	7,6
Moorland Grass/Mosaic	RV	245	0,298	8,6
Moorland Grass/Mosaic	SW	1117	0,298	10,3
Moorland Grass/Mosaic	X	366	0,298	4,4
Heat and bog	B	32	0,298	5,5
Heat and bog	RV	27	0,298	2,9
Heat and bog	SW	416	0,298	7,8
Heat and bog	x	479	0,298	2,9
Rivers and streams	All Classes	2339	0,21	9,90
Broadleaf, mixed and yew LOW woodland	X	70	0,256	3,1
Broadleaf, mixed and yew LOW woodland	RV	15	0,256	7,6
Broadleaf, mixed and yew LOW woodland	SW	102	0,256	5,8
Broadleaf, mixed and yew LOW woodland	B	41	0,256	5,2
Broadleaf, mixed and yew UPLAND woodland	X	60	0,256	3,9
Broadleaf, mixed and yew UPLAND woodland	RV	18	0,256	9,6
Broadleaf, mixed and yew UPLAND woodland	SW	124	0,256	8,2
Broadleaf, mixed and yew UPLAND woodland	B	25	0,256	5,9
Conifer LOW woodland	X	12	0,256	2,8
Conifer UP woodland	X	92	0,256	2,0
Conifer UP woodland	RV	15	0,256	6,1
Conifer UP woodland	SW	41	0,256	6,9

Table 3: Calculated c factors for the plot types of the CS2000, using the z-factors of Crawley.

The main advantages of using this data is the transparency of the data and the differentiation to different plot types. While the disadvantage is the lack of interesting land use types, especially urban areas and fallows.

N. KÖLLNER

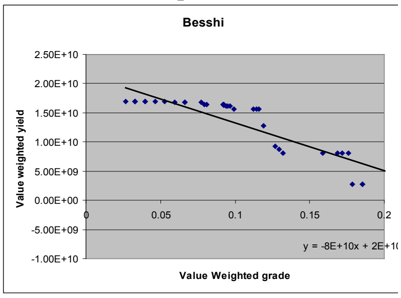
The work of Thomas Kollner (2004) is a follow up on an earlier work (1999) used to develop Eco-indicator 99. It introduces some different, improved approaches and data for more land use types.
In total 5581 sample plots were used to produce the data, but little background information is given or known.

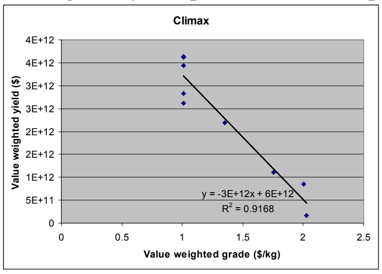
His work is especially written to improve LCA methodologies and contains a classification of land cover types according to Corine. For each land use type the main species number, Standard error, minimum and maximum values is available. The amount of plots available for each land use type reaches from a minimum of 2 plots until a maximum of 1312 plots.

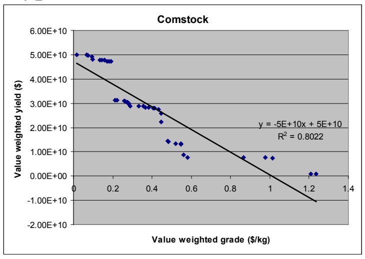
The main advantage of using this data is the interesting land use types included in his research. The disadvantages are the non-transparency of the data concerning borders and sometimes the small number of plots used.

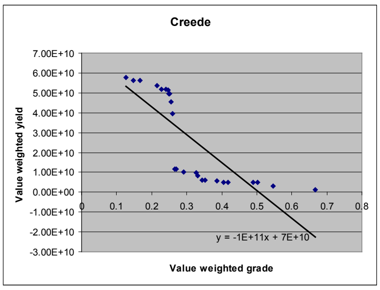
VI. MINERAL RESOURCE DEPLETION

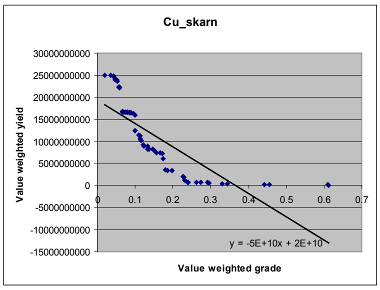
The table below provides an overview of all grade/yield prots for each deposit type.

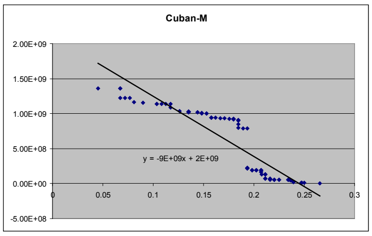


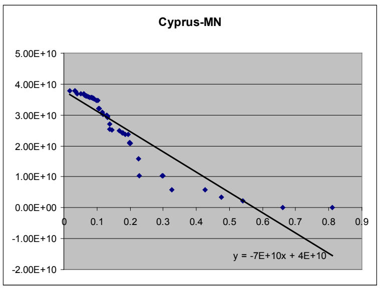


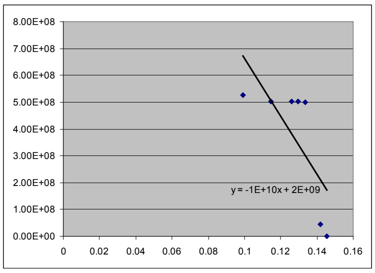


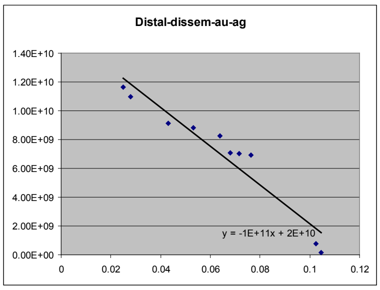


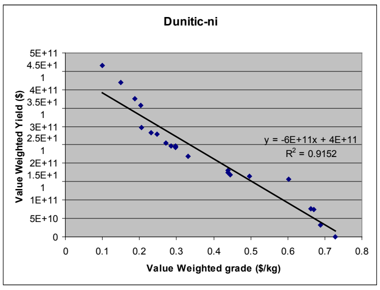


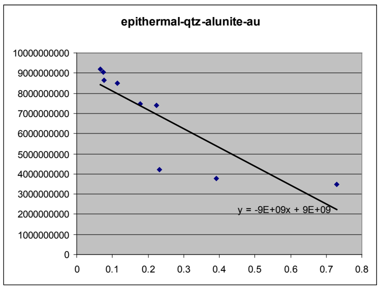


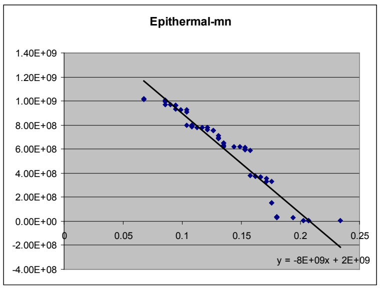


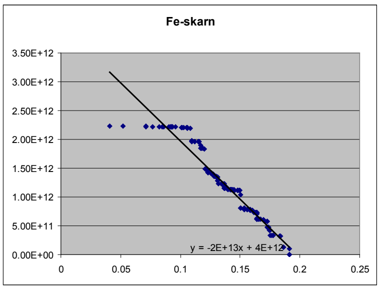


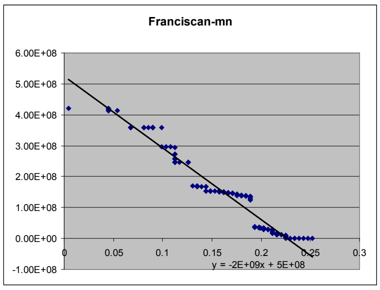


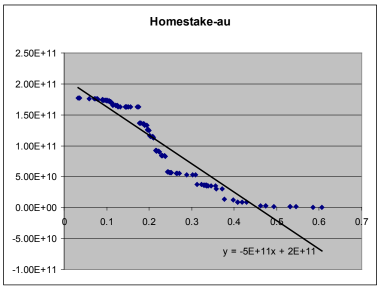


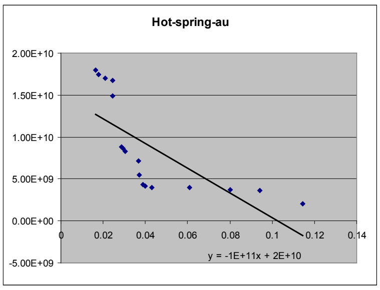


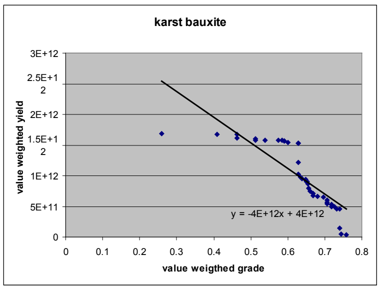


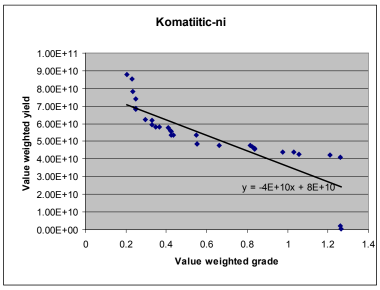


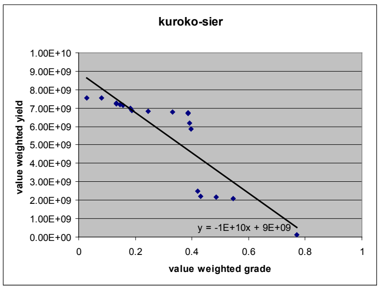








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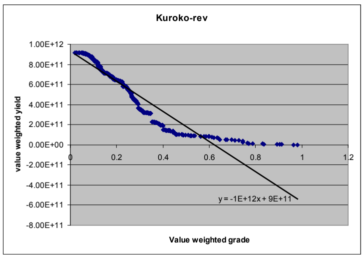
Kuroko-rev
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Value weighted grade
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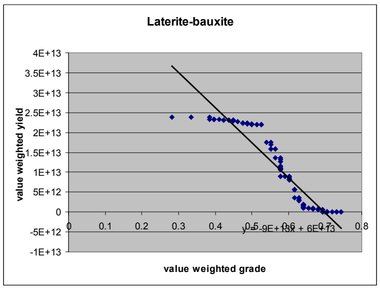
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value weighted grade
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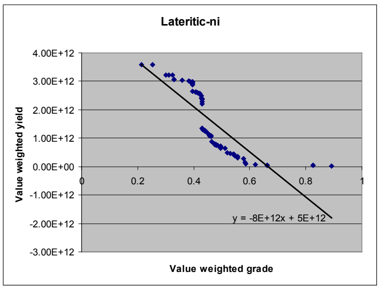
Lateritic-ni
Value weighted yield
Value weighted grade
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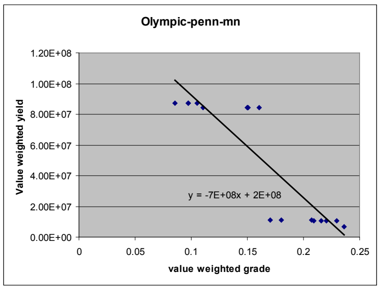
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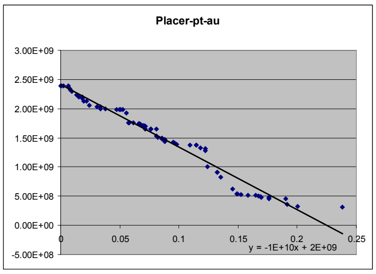
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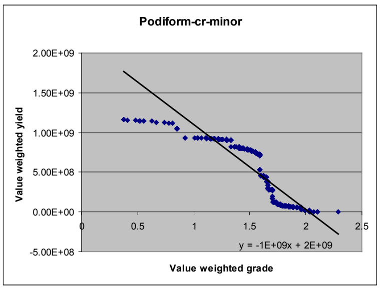
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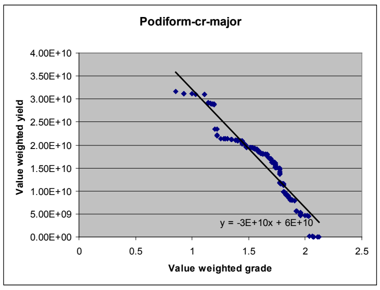
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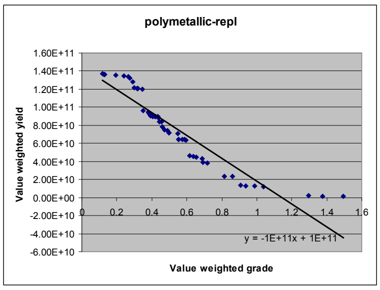
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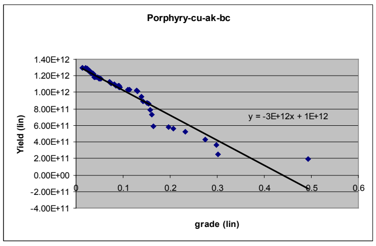
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Yield (lin)
grade (lin)
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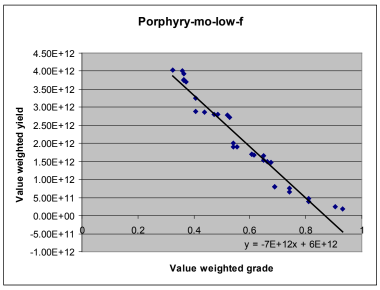
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Value weighted grade
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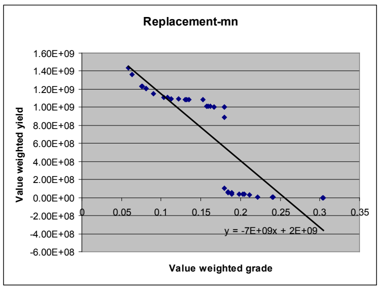
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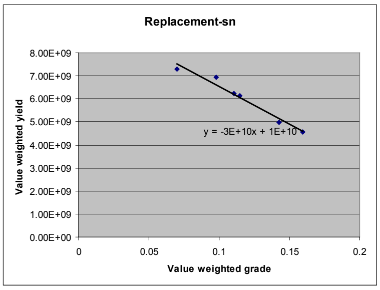
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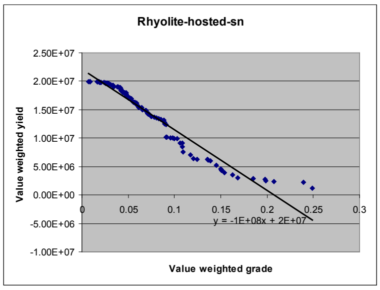
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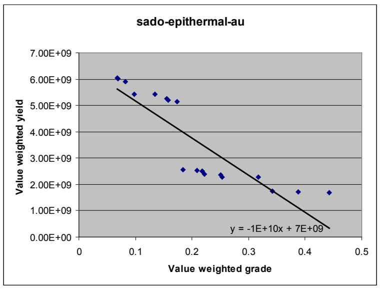
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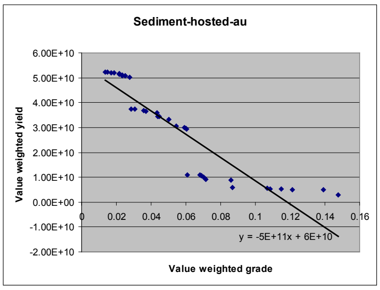
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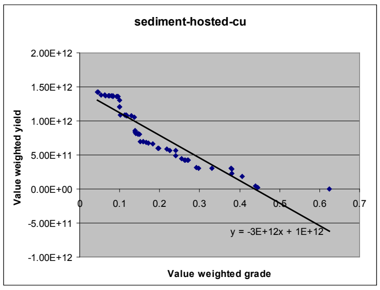
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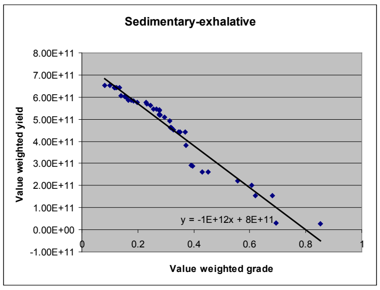
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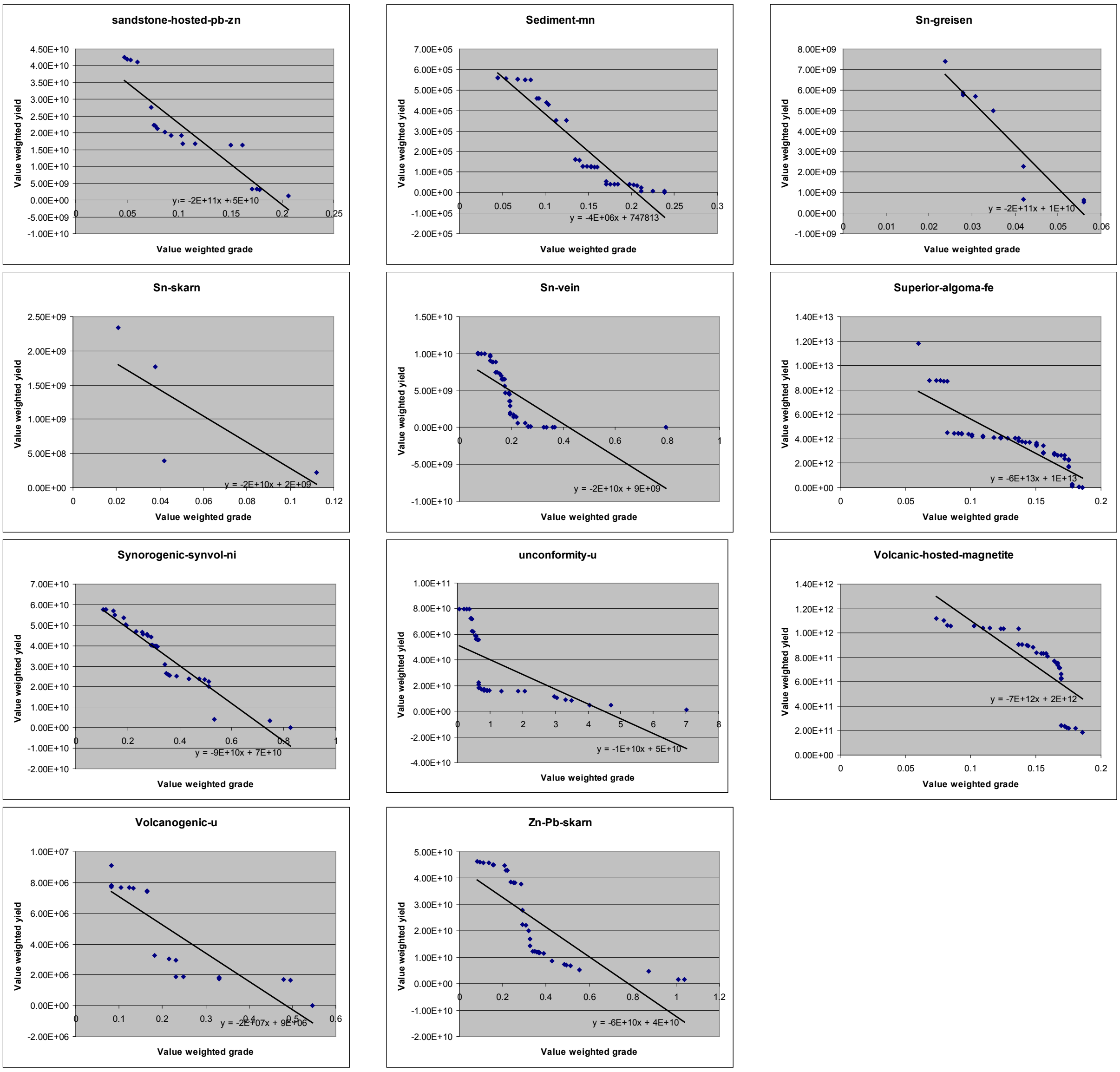


Figure 1: Overview of the grade-yield extrapolations per deposit

VII. FOSSIL RESOURCES

O. DIFFERENT VIEWS AND DATA ON THE AVAILABILITY OF FOSSIL FUEL RESERVES

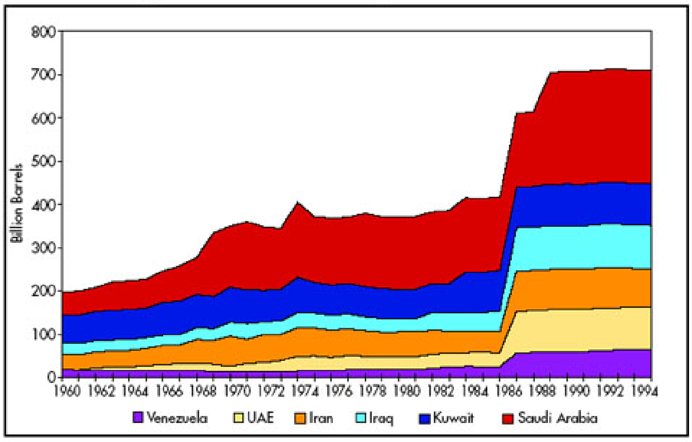
The spectrum of views on the availability of conventional oil ranges from the Peak-oil movement (www.aspo.org or peak-oil.com) to international organisations like the International Energy Agency (IEA), or commercial organisations like the Cambridge Energy Research Agency (CERA). Below, we briefly discuss the backgrounds of the peak oil scenario and CERA.

Peak oil scenario

The Peak Oil movement consists of concerned geologists and others that want to warn the world that we are near the moment the oil production in the world will peak, and steadily decline over the coming two centuries. The idea that the oil supply will peak is based on the theory of Hubert, who has correctly predicted the peak in oil production in the US. According to this theory, oil regions produce their peak capacity when the extracted amount of oil is about half the total stock. After this moment oil production will slow down. All conventional oil producing regions except the OPEC have by now passed peak production for conventional (liquid) oil. Other arguments from the Peak Oil movement are based on the fundamental unreliability of data on reserves, like:

- There are fundamental problems in estimating the size of a newly discovered oil field. Geologists always start with very conservative estimates, and correct these as production progresses, but these estimates are influenced by policy interests
- Oil companies usually underreport their proven reserves, as they prefer to show shareholders a steady or steadily growing reserve. They rather start with a conservative estimate and make a correction each year. They are certainly very careful not to over report, as this is punished very heavily by shareholders if discovered[2].
- The quota OPEC countries may produce are directly linked to their proven reserves. When this rule was made, the world oil resources doubled, as almost all countries decided to be less conservative and on average, double the estimates. Some countries report identical resource estimates for over 30 years, which can not be correct; see also additional information.

Figure 7.4: **OPEC Official (proved) Oil Reserves**



Source: *BP Statistical Review of World Energy,* 1997.

Figure 1: Illustration of the unreliability of oil statistic: in 1986 the OPEC rules changed. Export quota were based on the proven reserves; these reserves doubled suddenly

A strong argument of the Peak Oil movement is that de discovery rate of conventional oil has fallen below 20 Gb (Gigabarrel[3]) over the past decades, while the annual consumption is steadily climbing to about 70 Gb per year, so mankind is indeed running out of conventional oil resources.

In contrast with the Peak Oil movement we have organisations like the IEA (International Energy Agency), and many oil companies that stress there is nothing to worry about in the near future, and that the peak is at least 30 years away; not because the Hubbert theory is wrong, but because we are far from having used up half of all the conventional oil reserves. Another criticism is that there are still huge amounts of unconventional resources, like tar sands, and that since the oil prices have reached a significant higher level, there are big investments in the exploitation.

[2] As happened to Shell; the result was a very significant decrease of share price

[3] I barrel, or 1 bbl= 158.9873 liter

The data provided by the peak oil scenario advocates is generally difficult to interpret. Most experts in this group seem to quote fellow peak oil experts, but often there are very few hard facts. For instance an often quoted article by Cleveland (1984) in Science magazine states that the Energy Return on Investment (EROI) is decreasing quickly, from a typical value of hundred in the sixties till below seventy. This would mean the increased cost for energy is indeed rising fast. The problem with this reference is that it is over 20 years old, and it is limited to the situation in the USA, where conditions are very different from the rest of the world as the oil production has peaked a long time ago, resulting in a high EROI. The remaining resources are relatively difficult to extract. On many websites and discussion forums, see for instance http://www.energycrisis.com these figures are presented as if they are valid for the entire oil production.

The peak oil movement does not really present a scenario like the CERA does. It merely disputes the assumptions in the CERA report, and simply points out that there will be a big oil crunch, with prices sky rocketing. It is difficult to translate this type of prediction into a increased energy cost concept, as if one assumes the non conventional supplies will not enter the market, there is no surplus production capacity, only a scarcity that will skyrocket the prices. We found a number of sources that give some indications on the possible price effects:

- The House of Representatives energy subcommittee met Wednesday morning, December 7, 2005 On the subject of Peak Oil some leading experts were present. The chairman of ASPO (association for the prediction of Peak Oil gave a testimony that did not result in concrete numbers but Dr. Robert l. Hirsch, senior energy program advisor of SAIC (www.saic.com) gave a testimony in which he stated that a 4% shortage in supply could easily result in an oil price of 160 dollar per barrel. This assumption comes from the Shockwave report http://www.secureenergy.org/
- Koppelaar 2005 from the Dutch Peak oil foundation describes the consequences of the peak oil in terms of expected prices, but these do not differ from other sources such as the IEA; in fact this source is also quoted.

The vagueness of this scenario makes it impossible to use it, even though it would be a very interesting scenario for the egalitarian perspective.

CERA outlook

The Cambridge Energy Research Agency is a commercial company that produces detailed and very authoritative assessments of energy supply issues. It has very good links to oil companies. In the 2005 outlook they claim to have made a very detailed analysis of the production capacity and resource availability in all larger oil wells. They also claim to have analysed the investment plans of all major companies in the oil industry sector. Their conclusion is that there is no need to worry and that at reasonable price levels, the supply will be adequate till at least 2020. The figure below shows their key findings: the production of crude (liquid) oil rises slightly from 60 to 70 million barrels per day, the main growth comes from unconventional oils like:

- Condensates (a by-product of natural gas)
- Natural gas Liquids (a by- product of natural gas)
- Extra Heavy oil (oil sands etc., especially in Canada (Alberta) and Venezuela (Orinoko)
- Ultra deep water

By 2020 these resources should contribute 34% to the liquid fuel production. It is interesting to see that they do not take bio fuels in consideration as an important option. Another important assumption is that the current production level of conventional oil is stable over the years. Especially this assumption is heavily criticised by the peak oil movement.

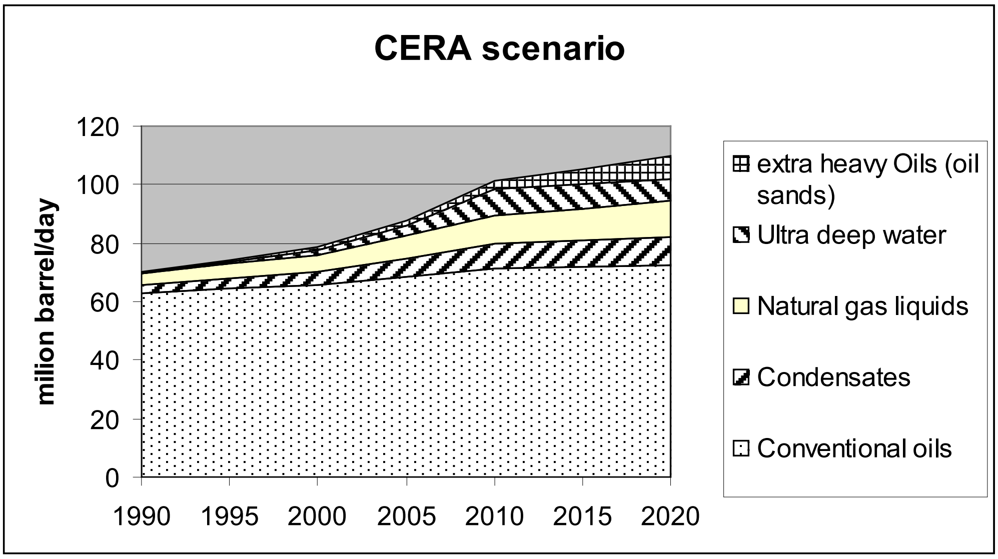


Figure 2: Reconstructed model scenario on the contribution of different conventional and unconventional oils to the total oil production. Essentially the CERA scenario assumes a stable supply of conventional oil, mainly from the OPEC Middle East region.

(Million barrels a day)	*1990*	*2000*	*2005*	*2010*	*2020*
Conventional oils	63,1	65,6	68,6	71,4	72,3
Condensates	2,3	4,4	6,3	8,5	10
Natural gas liquids	4,4	6,1	7,7	9,6	12
Ultra deep water	0	1,6	3,5	9	7,5
extra heavy Oils (oil sands)	0,2	0,9	1,8	3	7,8
Total	70	78,6	87,9	101,5	109,6

Table 1:

This scenario can be used to base a surplus energy value on, when we can calculate how much additional energy is needed in the non conventional sources

Description of conventional oil reserves

About 1000 Gb of oil has been extracted till now. The OPEC and the rest of the world have about 1100 Gb of proven reserves, then there are 650 Gb that are expected to be found (based on the investments and historic success rates).

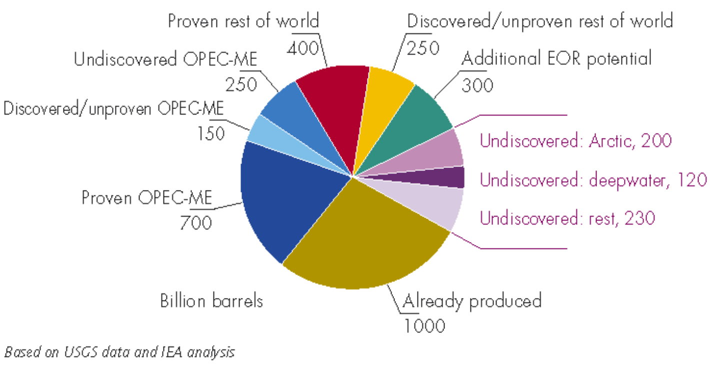


Figure 3:

An interesting category is the EOR, the Extended Oil Recovery; this is oil still available in abandoned wells, that can be extracted uses a variety of technologies, such as:

- Injection of water, CO2, Polymers (with surfactant properties) and other surfactants
- Injecting heat

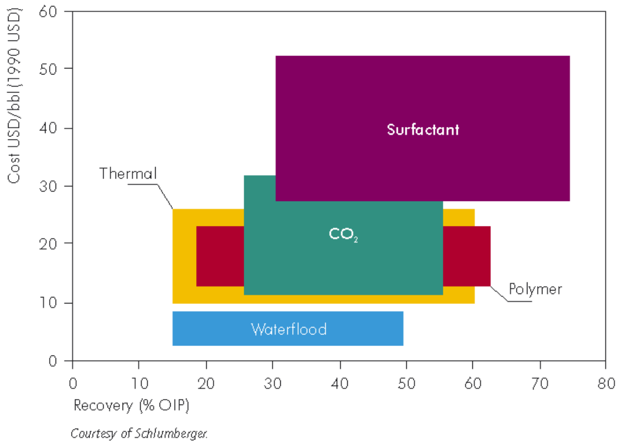


Figure 4:

The last category of conventional oils is the oil found in deep waters. There is a very significant increase in investments in this area. This type of reserves could contribute another 550 Gb. But the price and the energy investments are high

All in all present sources such as the IEA estimate that are still 3000 Gb of conventional oil reserves, while another 1000 Gb of conventional oil reserves has been extracted.

Description of unconventional oil reserves

Unconventional oils are a group of fossil fuels that need additional processes to get the properties of oil. Important groups are briefly described below

Tarsands, or Minable Butumen

Minable bitumen; these are sands that can be recovered by digging them up from the surface, sometimes some overburden needs to be removed. Well known locations are in Canada (Alberta) and Venezuela (Orinoco). They need to be "upgraded", to turn them in "syncrude or synthetic Oil, either by mixing them with lighter oil or increasing the hydrogen to carbon ratio. This is done either by Cooking (removing carbon) or Hydro cracking (adding Hydrogen).

A relatively new technique is the Steam Assisted Gravity Drainage or SAGD process, used for bitumen that are to far below the surface to be mined with mechanical means. In this process the sand is not "mined" but large amounts of steam are injected into the sand. This process requires huge amounts of natural gas, and by 2015, the production rate will become constrained due to lack of available natural gas.

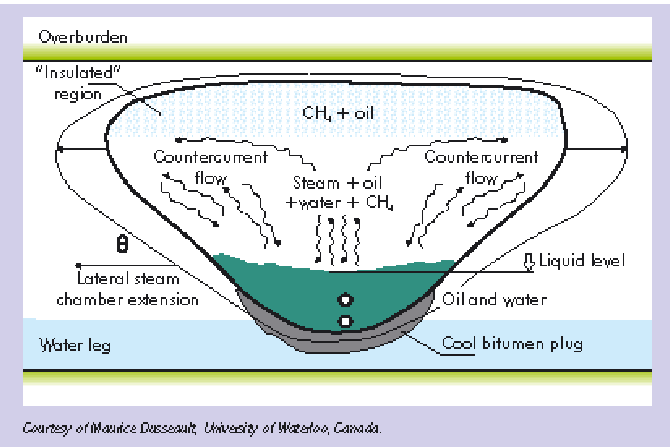


Figure 5:

There are now three major efforts to develop more efficient technologies, mostly based on technologies used to extract the EOR reserves from old oil fields, but it is unclear if they will become successful:

- In situ combustion. By adding air, some of the bitumen can burn and thus avoid the use of natural gas as an external source. The major hurdle is the difficulty to control the process.

- Microbiological, using the ability of some microbes to decompose the heavy components into lighter fractions that can be pumped out.
- Use of lighter hydrocarbons as a solvent. The most promising attempt seems to be the re-injection of some of the lighter fraction obtained from the upgrading process, while using the heavier fraction as an energy resource for producing the steam for the SAGD process. A first example is the Longlake operation that will use 70.000 barrels per day, without using natural gas.

The IEA finds it difficult to assess whether these technologies will prove to be successful, in spite of the heavy investments. Apart from technical problems there is a chance that fluctuations in the oil-price can scare off future investments. This makes it quite difficult to predict how big the share of tar sands in the oil production will become once the supply of natural gas puts limits on the extraction, still the IEA maintains that with a stable Oil price of 20 to 40 dollar per barrel, the tar sands can become a very significant source of supply for many decades.

Oil shale

Oil shale is a mixture between deposits such as marl with a high fraction of organic materials. These are often available in a stable form, called Kerogen. This Kerogen can be extracted if heated to 500 degrees, and the resulting shale oil can be used directly. As shales have a low permeability the rock has to be crushed before the extraction can taken place.
Shales can sometimes be mined in an open pit process. Such processes cause very large environmental problems as there are very large amounts of waste. In situ techniques, like these are developed for tar sands are possible, but have not proven to be successful yet. Such in situ techniques would in principle create much lower impacts, apart from a very high energy use. IEA estimates that 30% of the energy extracted has to be used for operating such in situ processes.
So although according to most estimates there are about 1000 Gb of oil equivalents that can potentially be recovered, the contribution to the oil supply will not be very high in the next few decades. IEA estimates that some shale projects can be operated at 25 dollar per barrel, but there are also many situations where the price would be as high as 75 dollar per barrel, especially if the CO2 emissions will need to be mitigated.

Unconventional gas

Although there is no sharp definition, unconventional gas relates to types of gas that used to be neglected, but are now developed, especially in the USA. The most important types are “coal bed methane” and “tight gas”. They represent very large resources, about 1500 Gb Oil equivalents. In the USA they already supply 25% of the natural gas.

Coal bed methane

Methane in coal mines have been seen as an important cause of accidents rather than a fuel. This methane used to be vented, but more and more it is captured, not because it is a resource, but because of the climate forcing properties of methane.
Coal bed methane production can especially be interesting in coal deposits that are too deep, or that are considered to be of poor quality. In some cases methane can be extracted by simply drilling and installing a pipe through which the methane is released by its own pressure. Often there are problems, as coal beds have a low permeability, and contain a lot of water, that blocks the release of the methane, as methane is bounded to the coal. In the latter case very large amounts of water need to be pumped.
Technology development is not very high to date, the current sources (10% of the US gas production) is achieved through trial and error, and using relatively simple solutions. A very interesting development is the injection of CO2 in these coal beds, as CO2 releases the methane that is bound to the coal, as CO2 itself has a stronger bounding force. IEA states that the technology is still at it infancy, and the first experiments give mixed results.

Tight gas

Tight gas comes from deposits that are highly impermeable, and till recently they were not seen as a exploitable deposits. Some new techniques (Hydro cracking) create cracks throughout such deposits along which the gas can escape. Another technique involves the drilling of many small wells, each giving a slow release of the gas. It is unclear how much gas can be retrieved, although the US gets already about 15% of its gas supply form such deposits, and also in Russia significant amounts come from these types of resources.

Methane Hydrates

Methane hydrates are crystal-like solids formed when methane is mixed with water at low temperature and moderate pressure. More generally, these solids are referred to as "clathrates". Methane hydrates can be found on the seabed or in permafrost Arctic regions, when the temperature and pressure are within the "hydrate existence domain".
The potential of this resource is enormous, but estimates vary widely. It is thought that the amount of methane in these hydrates is larger than 10^{15} to 10^{19} m^3 gas, or 2 to 20,000 times the amount of natural gas. Several experiments to recover this types of resources are ongoing, but the economic feasibility is far from being proven. EIA does not expect a significant production amount before 2030.

Coal and gas to liquits

Although transforming solid or gaseous fuels to liquid does not add to the availability of fossil resources, this development of this technology can have big impacts on the other non conventional sources, as according to the EIA, it is a potential competitor to some of these unconventional resources. It is expected that this process can be used to produce oil at a price between 30 to 60 dollar to barrel.
Current Gas to Liquids (GTL) technology uses variants of the Fischer-Tropsch (FT) process, originally developed in Germany and used extensively in South Africa to produce gasoline from coal. The energy efficiency of this process is low, about 70% of the energy in the resource ends up in the liquid product; the rest is dissipated as heat. Depending on the location, some of this heat can be used in other processes.
An alternative pathway is to produce methanol from methane (a well established industrial process), and DME from methanol (a recent but well developed process). DME can be used as an alternative to liquid petroleum gas (LPG, i.e. butane and propane), or even as an alternative to diesel (www.aboutdme.org).
One of the consequences of this development is that coal and gas can be come substitutes in case the supply of oil would become restricted