Bijlagen -
Handboek Schaduwprijzen

Bijlagen
Delft, maart 2010

Opgesteld door:
S.M. (Sander) de Bruyn
M.H. (Marisa) Korteland
A.Z. (Agnieszka) Markowska
M.D. (Marc) Davidson
F.L. (Femke) de Jong
M. (Mart) Bles
M.N. (Maartje) Sevenster

Colofon

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Annex A Algemene uitgangspunten prijzen

A.1 Prijspeil

De in Annex B en C vermelde preventie- en schadekosten zijn vermeld in het prijspeil van het jaar waarop deze in de literatuur bepaald zijn. Vervolgens zijn deze prijzen omgerekend naar het prijspeil van 2008. Dat hebben we gedaan aan de hand van de Europese Consumentenprijsindex (HICP, Harmonised Index of Consumer Prices).

Deze HICP wordt in alle individuele landen van de Europese Unie opgesteld volgens een standaard methode. Vervolgens kan een HICP voor de Eurozone worden opgesteld. Dit is een gewogen gemiddelde van de prijs indexcijfers van alle lidstaten die de Euro als munteenheid hebben aangenomen. Table 1 toont de HICP-waarden voor de jaren 2001-2008 voor de Eurozone. Deze waarden zijn toegepast op alle Europese data uitgedrukt in Euro's. De trend in de Consumentenprijsindex in Nederland voor 2001-2008 is zeer vergelijkbaar met die van de Eurozone, zodat deze gegevens ook zijn toegepast op Nederland.

Table 1 HICP values (Eurozone)

Year	HICP compared with previous year	Value of Euro relative to 2000 level
2001	0.023	1.023
2002	0.023	1.046
2003	0.021	1.068
2004	0.021	1.091
2005	0.022	1.115
2006	0.022	1.139
2007	0.021	1.164
2008	0.033	1.202

Source: ECB, 2009.

A.2 Discontovoeten

In de literatuur rondom het berekenen van de preventie- en schadekosten worden discontovoeten gebruikt om huidige waarden te bepalen van toekomstige kosten, baten en schades. Voor zover we eigen berekeningen hebben doorgevoerd hebben we gerekend met een discontovoet van 2,5%. Deze discontovoet wordt ook vaak gehanteerd in de literatuur bij de bepaling van sommige preventiekosten. Bij de schadekosten gebruikt de Europese literatuur evenwel een discontovoet van 3%. Dat is van belang omdat de gezondheidsschade niet altijd direct optreedt (zoals bij acute mortaliteit en morbiditeit) maar soms ook met een vertraging van soms wel tientallen jaren. Doordat bij de schadekosten een (iets) hogere discontovoet wordt gebruikt kunnen de schades *lager* uitvallen dan indien gerekend zou worden met een discontovoet van 2,5%.

We hebben in dit project evenwel besloten om geen omrekening te laten plaatsvinden naar een gemeenschappelijke discontovoet van 2,5%. Dit zou namelijk een aanzienlijke investering zijn omdat we in dat geval per ziektegeval de tijdsverdeling tussen dosis en effect zouden moeten

bepalen. De eventuele winst van iets preciezere cijfers zou niet opwegen tegen de investering om deze te achterhalen. Daarbij merken we op dat het verschil in de waarde van schade die zou optreden bij een ziekte tien jaar na emissie gelijk is aan 5%. Met andere woorden: als we de netto contante waarde met een discontovoet van 3% zouden berekenen, zouden we een waarde krijgen die 5% lager is dan als we met 2,5% zouden rekenen. Daarnaast zouden we dan ook een separate correctie moeten maken voor de impacts van leeftijdsopbouw, economische groei en inkomenselasticiteiten voor milieukwaliteit.

A.3 Inkomenselasticiteiten

Door de tijd heen wordt de schade van milieu-impacts hoger. Dit komt omdat bij een groei van het inkomen, milieu hoger wordt gewaardeerd vanwege de positieve inkomenselasticiteit voor de vraag naar milieukwaliteit. In het ExternE-project is een positieve inkomenselasticiteit van 0,85% aangenomen, gebaseerd op een literatuurreview.
Derhalve veronderstelt ExternE een zogeheten upliftfactor van 1,7% op jaarbasis (de combinatie van economische groei van 2% met een inkomens-elasticiteit van 0,85%). Gecombineerd met de discontovoet van 3% betekent dit dat de netto-effectieve discontovoet in het ExternE-project gelijk is aan 1,3% (= 3% - 1,7%). Omdat in elke MKBA een aparte discussie dient plaats te vinden over de inkomenselasticiteiten voor milieukwaliteit en de verwachte economische groei, zouden precieze schaduwprijzen in principe dan ook per MKBA apart moeten worden bepaald, uiteraard in overeenstemming met de economische groeiscenario's die in die MKBA worden gehanteerd.

A.4 Risico-opslag

We hebben geen aparte risico-opslag aan de berekeningen toegevoegd. Er zijn verschillende redenen om met een risico-opslag te werken, afhankelijk van het soort risico. Het is discutabel of er bij milieuschades een risico-opslag zou moeten worden toegekend. Zie voor meer discussie hierover de leidraad MKBA in het milieubeleid (CE, 2007 en RMNO, 2008). In 2009 hebben CPB en PBL gewerkt aan een herziening van het gebruik van risico-opslagen bij milieu-inclusieve MKBAs (zie RWS, 2009). Wij hebben dit niet in onze berekeningen verwerkt. Bij gebruik van onze schaduwprijzen in een MKBA moeten deze derhalve separaat worden gecorrigeerd voor een eventuele risico-opslag. We beseffen dat dit natuurlijk niet optimaal is, maar de hier gepresenteerde schaduwprijzen zijn eerder als kostenkentallen te beschouwen dan als een precieze bepaling van de waarde voor gebruik in een MKBA.

Annex B Preventiekosten

Deze Annex beschrijft de wijze waarop we de preventiekosten hebben bepaald.

B.1 Broeikasgassen

B.1.1 Doel en prognose

In het klimaatverdrag van Kyoto heeft de geïndustrialiseerde wereld zich ten doel gesteld de uitstoot van broeikasgassen in de periode 2008-2012 met 5,2% ten opzichte van 1990 te verminderen. Voor de verschillende landen gelden echter andere doelen. De EU als geheel heeft een reductiedoel geaccepteerd van 8%. Dit doel is binnen de EU vertaald naar een reductiedoel van 6% voor Nederland, oftewel een emissieniveau van 206 Mt CO_2-equivalenten in de periode 2008-2012.

Sinds 2005 is het Europese handelssysteem voor broeikasgassen van kracht dat de emissies van de (zware) industrie en de elektriciteitsproductie reguleert (Directive 2003/87/EC). Vanaf 2012 valt ook de uitstoot van luchtvaart, ten gevolge van vluchten van en naar Europese bestemmingen, onder het systeem.

De internationale gemeenschap is momenteel bezig met de voorbereidingen voor een akkoord over *post*-Kyotodoelen. Vooruitlopend daarop heeft de Europese Commissie recent nieuwe doelen gesteld voor de EU: een 20%-emissiereductie in 2020 ten opzichte van 1990. Indien andere ontwikkelde landen bereid zijn soortgelijke doelen te accepteren, is de EU bereid om een 30%-emissiereductie te accepteren.

In Europees verband heeft Nederland als doel om in 2020 de broeikasgas-emissies te reduceren met 16% ten opzichte van 2005 voor zover de emissies niet worden gereguleerd door het emissiehandelssysteem. De emissiereducties hoeven echter niet noodzakelijk in Nederland plaats te vinden. Gebruik mag worden gemaakt van het *Clean Development Mechanism* (CDM), waarbij emissies worden gereduceerd in ontwikkelingslanden. Deze reducties mogen worden meegeteld voor het behalen van het binnenlandse doel.

Ook het Nederlandse Kabinet heeft in het coalitieakkoord klimaat- en energiedoelen voor 2020 afgesproken. De overheid heeft zich tot doel gesteld om de totale Nederlandse emissie van broeikasgassen te reduceren met 30% ten opzichte van 1990 in 2020, bij voorkeur in Europees verband (*Schoon en Zuinig*). Een reductiedoelstelling van 30% komt overeen met een emissie-plafond van circa 150 miljard kg CO_2-equivalenten in het jaar 2020 (VROM, 2007).

B.1.2 Preventiekosten

De marginale preventiekosten hangen van drie factoren af:

1. De CO_2-handelsprijs binnen het EU ETS.
2. De kosten van het Clean Development Mechanism (CDM).
3. De marginale preventiekosten om binnenlandse emissies te reduceren van niet-EU ETS-sectoren.

Op zich zijn de hoogste kosten te verwachten van de derde categorie. Hoe dan ook, de marginale preventiekosten hangen echter niet enkel af van de marginale preventiekosten om binnenlandse emissies te reduceren van niet-EU

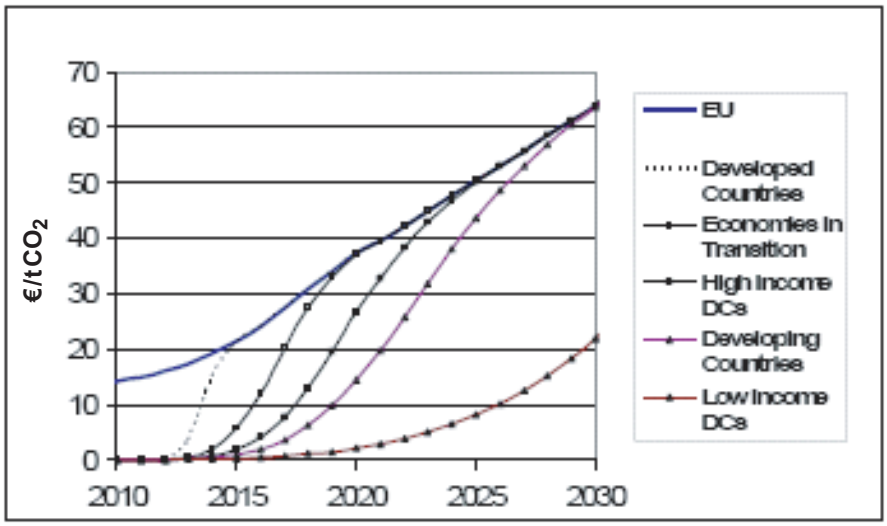
ETS-sectoren, omdat de overheid de keuze heeft meer gebruik te maken van het CDM bij te hoge marginale kosten. De kosten van emissiereducties via het CDM zijn in het algemeen veel lager dan de kosten van binnenlandse emissiereducties. Of de overheid de kosten wel of niet te hoog vindt worden, hangt mede af van de marginale preventiekosten (CO_2-handelsprijs) binnen de EU ETS-sectoren.

In 2007 heeft het ECN in samenwerking met het MNP het Werkprogramma Schoon en Zuinig (VROM, 2007) beoordeeld. Om de afhankelijkheid van het Europese beleid zichtbaar te maken heeft ECN in de beoordeling gewerkt met twee varianten: 'EU hoog' en 'EU laag'. In 'EU hoog' geldt een emissie-reductiedoelstelling van 30% en een CO_2-prijs van 50 €/ton (prijspeil 2007) in 2020. In 'EU laag' geldt een emissiereductiedoelstelling van 20% en een CO_2-prijs van 20 €/ton (prijspeil 2007) in 2020. In de variant 'EU hoog' dient in 2020 in het binnenland 50-67 Mton CO_2 te worden gereduceerd ten opzichte van het referentiescenario, dat wil zeggen *exclusief* emissiereductie in het buitenland middels aankoop van rechten binnen het EU ETS en het CDM. In de variant 'EU laag' is dat in 2020 25-37 Mton CO_2.

Volgens het 'Optiedocument Energie en Emissies 2010/2020' gepubliceerd door ECN en MNP (2006) liggen de marginale preventiekosten bij emissiereducties van 25-37 en 50-67 Mton CO_2 rond de 20 €/ton CO_2 en 50 €/ton CO_2 respectievelijk.

Deze kostenramingen kunnen worden vergeleken met de resultaten van een impact assessment door de Europese Commissie (EC, 2007: 36). Dit document stelt dat de lange termijn stabilisatie van klimaatverandering op 2° C kan worden bereikt tegen preventiekosten die variëren van 15 €/ton CO_2 in 2010 tot 65 €/ton CO_2 in 2030 (Figure 1).

Figure 1 **Koolstofprijs variërend over verschillende regio's en tijd (EC, 2007: 36)**



Mede op basis van deze assessment lijken ons de door ECN en MNP verwachte marginale preventiekosten van 20 €/ton CO_2 en 50 €/ton CO_2 aannemelijk.

Opgemerkt moet worden dat deze waarden gemiddeld lager zijn dan de centrale waarde van 50 €/ton CO_2 (prijspeil 2002), die is beargumenteerd in de update uit 2002 (CE, 2002). Deze waarde werd gebaseerd op het pakket van maatregelen uit de 'Uitvoeringsnota Klimaatverandering', waarin een basis-

pakket en een aanvullend pakket van maatregelen werd voorgesteld waarmee de Kyotodoelstelling kan worden behaald. Bij het kiezen van maatregelen heeft de overheid toen een grens gelegd bij € 68 (*f* 150) per ton CO_2-equivalent (prijspeil 1998). In het licht van de huidige Europese post-Kyoto-doelstellingen, het EU ETS en de invloed van het EU ETS op beleid in sectoren die niet onder het EU ETS vallen, achten wij de eerdere overheids-uitgangspunten en daarmee de eerdere analyse niet meer van toepassing voor toekomstige evaluatie van beleid.

B.1.3 International comparison

The IMPACT handbook (CE, 2008b) provides a summary of the figures obtained in a number of studies that have estimated the external costs of CO_2 emissions. These are reproduced in Table 2.

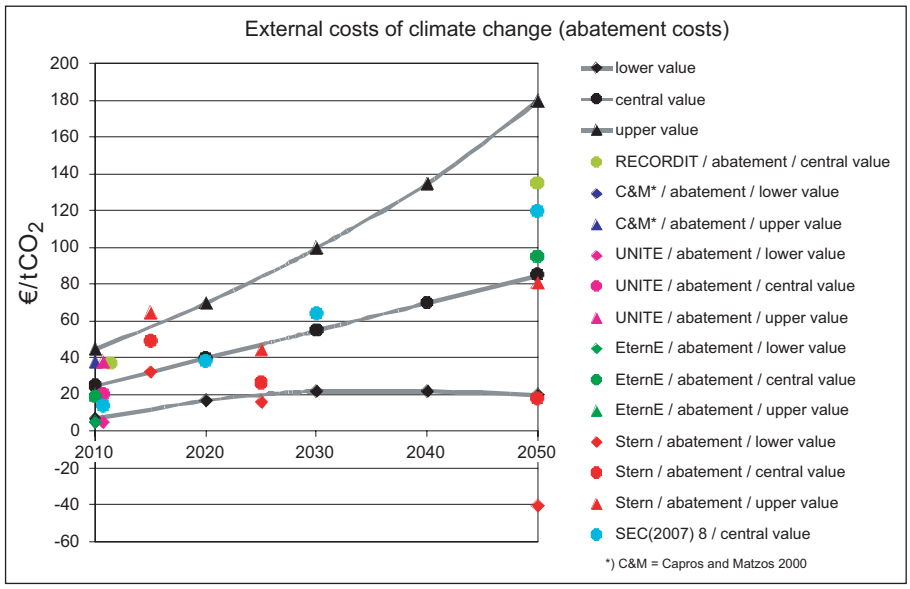
Table 2 **Estimated CO_2 abatement costs (€/tCO_2) cited in various studies**

		Abatement costs (€/tCO_2)			
Source	**Year of application**	**Min**	**Central**	**Max**	**Reference for abatement costs**
RECORDIT, 2000/1	2010 2050		37 135		Kyoto target Long-term IPCC 50% reduction target
Capros and Mantzos, 2000	2010	5		38	Kyoto target: lower value based on trading with countries outside EU, upper value on situation without trading outside EU
UNITE, 2003	2010	5	20	38	Based on Capros and Mantzos, 2000
INFRAS, 2004	2010 2050		20 140		Kyoto target Long-term IPCC 50% reduction target
ExternE, 2005	2010 2050	5	19 95	20	Kyoto target Stabilisation at 2°C temperature rise
Stern, 2006	2015 2025 2050	32 16 -41	49 27 18	65 45 81	Average abatement costs
SEC, (2007)8	2010 2020 2030 2050		14 38 64 120		Stabilisation at 2°C temperature rise Linear extrapolation based on 2020-2030 data

Source: CE, 2008b.

These results can also be depicted graphically (Figure 2).

Figure 2 **Estimated CO_2 abatement costs (€/tCO_2) cited in various studies**



Source: CE, 2008b.

Within the NEEDS project, avoidance costs were assessed according to two scenarios (NEEDS, 2008a):

1. Realistic. In this scenario, the following assumptions are used. Marginal abatement costs are related to Kyoto targets for 2010, 20% reduction in CO_2 emissions in 2020 and subsequently an annual increase in costs with a rate 3% p.a is assumed. Marginal abatement cost curves(MACCs) for the -20% target vary widely and depend very much on which instruments are eligible for use (e.g. permitted 'import' of emission reduction via the Clean Development Mechanism (CDM) or Joint Implementation (JI)). It was consequently assumed that future policy will be defined in such a way that marginal abatement costs will increase by 3% p.a. This result is in line with the recommendations of HEATCO (2006) and Watkiss et al. (2005b) studies. With these MACs, the 2°C target will most likely not be secured. According to the meta-model of Kuik (Kuik et al. 2008), in this scenario we would end up at about 450 ppm CO_2, or roughly 2.8°C warming.
2. Ambitious. In this scenario, values from the meta-analysis model developed by Kuik et al. (2008) in the CASES project were used. If we take 365 ppm to be the goal of the 2°C target, the meta-model yields results of approx. 100 €/tCO_2 for 2025 and 200 €/t for 2050 (in 2000 level of prices). Because of the fact that this value for 2025 is considerably higher than that the values provided in the recent JRC report (2007), it has been proposed to keep on using the value from Kuik et al. (2008) for 2050, but to interpolate exponentially between 2010 and 2050, which brings the values for 2020 closer to the JRC and NEEDS estimates.

These assumptions lead to the values reported in Table 3.

Table 3 **Recommended values of CO_2 abatement costs according to two scenarios (€$_{2008}$ per tCO_2), discounted to year of emission, price level 2008**

Scenario/year of emission	2010	2015	2020	2025	2030	2035	2040	2045	2050
Realistic	25	29	31	35	37	40	54	71	83
Ambitious	25	33	50	55	80	94	119	158	214

Source: Based on CASES, 2008.

It can be noted that the central estimates cited in the IMPACT handbook review (see Table 3) for the period up to 2030 converge with the values proposed in the NEEDS project in the realistic scenario (and are lower than the values estimated for the ambitious scenario, while post-2030 values proposed in IMPACT lie below both trends defined with the two scenarios of NEEDS.

B.1.4 Geselecteerde waarden

Onzekerheid over de preventiekosten van CO_2 reflecteert vooral de vraag welk doel het Nederlandse beleid gaat bepalen voor reductie van CO_2. Indien, na Kopenhagen, EU-breed wordt besloten om -30% te reduceren, valt het EU-doel met het Nederlandse doel samen en zijn de preventiekosten 0,05 €/kg CO_2. Indien de EU vast blijf houden aan -20% en Nederland vast blijft houden aan -30% kunnen de kosten zeer hoog oplopen: de emissies die via EU ETS worden gereguleerd vallen immers min of meer buiten de jurisdictie van Nederland (waar ongeveer 70% van de Nederlandse emissies onder vallen). Hoewel Nederland een strenger emissieplafond mag doorvoeren zal dit tot concurrentienadelen voor de Nederlandse industrie leiden *binnen* de EU, wat op geen draagvlak kan rekenen. Derhalve zal de additionele reductie van 10% (om van -20 naar -30% te gaan) moeten worden gerealiseerd in de overige sectoren, met navenant hogere kosten.

Omdat het voor Nederland weinig zin heeft om uit de pas te lopen met de internationale ontwikkelingen, stellen we daarom voor om de preventiekosten vast te zetten op 0,025 €/kg CO_2. De marges zijn dan 0,02 €/kg CO_2 als ondergrens en 0,05 €/kg CO_2 als bovengrens.

B.2 Aantasting ozonlaag

B.2.1 Doelen

In het ‘Montreal Protocol on Substances that Deplete the Ozone Layer’, waaraan ook Nederland is gebonden, zijn op 16 september 1987 internationale afspraken vastgelegd om de ozonlaag te beschermen. Het protocol heeft als doel alle stoffen die de ozonlaag aantasten te verbieden. Het is sinds 1 januari 1989 van kracht.

De Europese Unie heeft per 1 oktober 2000 het ‘Protocol van Montreal’ uitgewerkt en aangescherpt in EU-Verordening 2037 (gewijzigd in EU-Verordeningen 2038 en 2039) betreffende stoffen die de ozonlaag afbreken. Op basis hiervan mogen in de EU-lidstaten geen CFKs meer worden verkocht en mogen bestaande installaties niet meer met CFKs worden bijgevuld, zelfs al komen deze uit bestaande voorraden.

Het Besluit ozonlaagafbrekende stoffen Wms 2003 (25 augustus 2003) legt de productie, handel en het toepassen van CFKs en halonen aan banden. Het gaat hierbij om de toepassing van CFKs in koel- en airconditioninginstallaties, bij de fabricage van isolatiemateriaal, in oplos- en reinigingsmiddelen en het gebruik van halonen in blusgasapparatuur. Dit besluit heeft het ‘Besluit inzake stoffen die de ozonlaag aantasten 1995’ vervangen.

Sinds 13 augustus 2004 is het Besluit beheer elektrische en elektronische apparatuur van kracht. Het verplicht producenten en importeurs van wit- en bruingoed (TV’s, computers, videorecorders en bijv. föhns) om hun producten in de afvalfase (zodra de consument ze afdankt) verantwoord te verwijderen.

Middels het Besluit verwijdering wit- en bruingoed is het per 1 januari 1999 verboden om te handelen in koel- en vriesapparaten die (h)CFKs bevatten.

Handelaren in gebruikte apparatuur, zoals kringloopbedrijven, mogen sindsdien geen (h)CFK-houdende koel- en vrieskasten meer in- of verkopen. Het handelsverbod betreft zowel de Nederlandse als de internationale handel. Voor het verbod gelden geen uitzonderingen. Geen enkele onderneming kan in aanmerking komen voor een ontheffing. Evenmin is voorzien in een tegemoetkoming in de kosten. Voor consumenten betekent het dat koelkasten die ze inleveren bij een gemeente, kringloopwinkel, reparatiebedrijf of detaillist niet opnieuw mogen worden verkocht. Transacties tussen burgers onderling zijn nog wel toegestaan. Met het handelsverbod wil de overheid voorkomen dat koelkasten en vriesinstallaties worden verscheept naar Afrika en Oost-Europa waar geen capaciteit is om op milieuhygiënische wijze de CFKs te verwijderen.

Per 23 augustus 2002 bestaat een Inzamelingsregeling CFK en halonen voor de milieuvriendelijke inzameling en verwerking van ingezamelde CFKs. Deze regeling is gemaakt op basis van afspraken tussen de overheid (VROM) en de brancheverenigingen van koudetechniek- en luchtbehandelingsbedrijven, NVKL. De regeling biedt eigenaren van koelinstallaties een korting voor het milieuvriendelijk afvoeren van CFKs en halonen. De regeling is gepubliceerd in het Staatsblad (nr. 167, 2 september 2002) en in werking getreden op 4 september 2002.

B.2.2 Preventiekosten

Voor die gevallen dat emissies niet verboden zijn, leiden wij een ruwe indicatie voor de schaduwprijs af uit de kosten van verwerking in de inzamelingsregeling voor oude voorraden CFKs en halonen.

Volgens de inzamelingsregeling brengt de inzamelaar van CFKs en halonen € 5 per kilogram CFK of halon in rekening. Voor gemaakte kosten boven de € 5 per kilogram CFK of halon komt de inzamelaar in aanmerking voor subsidie, tot ten hoogste € 5 per kilogram CFK of halon. De minister kan een verzoek van een inzamelaar tot erkenning afwijzen indien de kosten hoger zijn dan € 10 per kilogram CFK of halon (inclusief BTW).

Naast de inzamelingsregeling voor CFKs/halonen geldt de verwijderingsbijdrage voor wit- en bruingoed zoals vastgesteld in het Besluit verwijdering wit- en bruingoed[1]. Doel van het besluit voor groot witgoed is bestrijding van CFK-emissies en metalen, zoals arseen, koper, kwik, lood en chroom. De verwijderingsbijdrage voor algemeen groot witgoed bedraagt € 5, tegenover een bijdrage van € 17 voor koel- en vriesapparatuur. Het verschil van € 12 per koelkast kan worden toegerekend aan enkel de reductie van CFK-emissies. In het Besluit wordt geschat dat jaarlijks circa 180 ton (H)CFKs wordt teruggewonnen uit 450.000 koelingen, wat neerkomt op circa 0,4 kilogram (H)CFK per koeling. Gecombineerd met de eerdere € 12 per koelkast levert dit een schaduwprijs op voor (H)CFK van 30 €/kg. Het gaat bij de terugwinning van (H)CFKs met name om CFK-11, zodat wij de schaduwprijs op 30 €/kg CFK-11 stellen.

[1] Besluit van 21 april 1998, nr. 97.000.3292, Staatsblad 238, houdende vaststelling van regels voor het na gebruik innemen en verwerken van wit- en bruingoed (Besluit verwijdering wit- en bruingoed).

B.3 Verzuring en fotochemische oxidantvorming

B.3.1 Doelen en prognose

De EU heeft op basis van het Protocol van Gotenburg in 2001 de zogenaamde NEC-richtlijn vastgesteld. NEC staat voor 'national emission ceilings' oftewel nationale emissieplafonds. Het gaat om: zwaveldioxide (SO_2), stikstofoxiden (NO_x), ammoniak (NH_3) en niet-methaan vluchtige stoffen (NMVOS). De nationale emissieplafonds van Nederland voor 2010 voor NO_x, SO_2, NH_3 en NMVOS zijn respectievelijk 260, 50, 128 en 185 kton.

De Europese Commissie zal in 2009 met een voorstel voor nieuwe emissie-plafonds komen, die vanaf 2020 niet meer mogen worden overschreden. De doelstellingen voor 2020 in Table 4 zijn gebaseerd op de laatste stand van discussies over de gewenste ontwikkeling van emissies in de EU en de bijdrage van de individuele lidstaten daarin (zie CE, 2008, zie ook IIASA, 2007; 2008).

Table 4 Doelstellingen en verwachte emissies voor 2020

	NO_x	SO_2	NH_3	NMVOS
NEC-doel 2010	260	50	128	185
Verwacht NEC-doel 2020 (CE, 2008)	186	35	119	143
Emissieplafond voor 2020 volgens ambitie TSAP (GCN, 2008 op basis van IIASA, 2006; 2007)	186-223	35-50	118-123	145-164
Verwachte ontwikkeling van emissies in het *Global Economy* scenario[2] (ECN, 2006)	279	83	147	182
Verwachte ontwikkeling van emissies in het *Global Economy* scenario bij voorgenomen beleid (GCN, 2008)	205,0	51,2	142,8	-

B.3.2 Preventiekosten

Stikstofoxiden (NO_x)

Ten tijde van het schrijven van het Optiedocument (ECN/MNP, 2006) werden zonder beleidswijzigingen emissies verwacht van 279 kton NO_x in 2020. Ten opzichte van het beleidsdoel van 186 kton NO_x in 2020, betekent dit een gat van 93 kton NO_x. De marginale reductiekosten bij deze additionele emissiereductie bedragen volgens het Optiedocument circa 50 €/kg NO_x.

Wij verwachten echter niet dat de daadwerkelijke marginale reductiekosten 50 €/kg NO_x zullen bedragen. Tegen marginale kosten van enkele Euro's per kilo NO_x kan volgens het Optiedocument al circa 70 kton NO_x worden gereduceerd, terwijl ruim 80 kton NO_x kan worden gereduceerd tegen marginale kosten van circa 10 €/kg NO_x. In het verleden is vaker gebleken dat de technische ontwikkelingen op de langere termijn worden onderschat waardoor de reductiekostencurve in de buurt van het beleidsdoel te stijl omhoog schiet. Daarnaast bestaan er synergie-effecten met andere beleidsdoelen (zoals klimaatbeleid) zodat de daadwerkelijke kosten voor NO_x een stuk lager kunnen uitpakken.

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2 *Global Economy* is één van de vier economische scenario's voor Europa tot aan het jaar 2040, die zijn opgesteld door het Centraal Planbureau (CPB, 2003). Zie voor de vertaling van deze scenario's naar emissies: ECN, 2006.

Een betere maat voor de marginale reductiekosten zijn daarom de meest recente inschattingen van de maatregelen die benodigd zijn voor het behalen van de beleidsdoelen. Volgens ECN (2009) kan de actualisatie van het Besluit Emissie Eisen Stookinstallaties B (BEES B) een belangrijke bijdrage leveren aan het realiseren van het NEC-doel voor wat betreft de NO_x-uitstoot. De gemiddelde kosteneffectiviteit is minder dan 5 €/kg NO_x-emissie vermeden maar varieert wel sterk per sector. Voor de industrie, energie en raffinaderijen bedragen de kosten circa 9 €/kg NO_x-emissie vermeden in 2020. Ook het MNP heeft de kosteneffectiviteit van aanvullende maatregelen voor NO_x-emissies in beeld gebracht (MNP, 2007a) en komt tot waarden van netto baten tot rond de 10 €/kg kosten (bijvoorbeeld Euro 6 NO_x-emissie-eisen licht wegverkeer per 1-1-2014). Naast aanscherping van het BEES B, wordt in de rapportage van het planbureau over grootschalige luchtvervuiling in Nederland (MNP, 2008) de 'aanscherping NO_x-emissiehandel van 40 naar 20 g NO_x/GJ in 2020' als belangrijke potentiële maatregel genoemd, met een kosten-effectiviteit van 1 tot 2 €/kg (ECN/MNP, 2006). Tenslotte wordt in de Nederlandse Emissierichtlijn Lucht (NeR) een indicatieve referentiewaarde genoemd van 4,60 €/kg NO_x-emissie voor de kosteneffectiviteit van emissiereducerende maatregelen[3].
Op basis van deze gegevens schatten wij de marginale reductiekosten van het behalen van het NEC-doel in 2020 tussen de 5 en 10 €/kg NO_x. Deze waarde komt overeen met de 7 €/kg NO_x genoemd in de update van 2002 (CE, 2002).

Zwaveldioxiden (SO_2)

Ten tijde van het schrijven van het Optiedocument (ECN/MNP, 2006) werden zonder beleidswijzigingen emissies verwacht in 2020 van 83 kton SO_2. Ten opzichte het beleidsdoel van 35 kton SO_2 in 2020 betekent dit een gat van 48 kton SO_2. De marginale reductiekosten bij deze additionele emissiereductie bedragen volgens het Optiedocument circa 25 €/kg SO_2.

Evenmin als in het geval van NO_x verwachten wij dat de daadwerkelijke marginale reductiekosten 25 €/kg SO_2 zullen bedragen. Tegen enkele Euro's per kilo SO_2 marginale kosten kan volgens het Optiedocument al circa 37 kton SO_2 worden gereduceerd. Na dit punt lopen de marginale reductiekosten snel op. Ook hier verwachten wij dat technologische ontwikkelingen de marginale kosten omlaag zullen brengen.

Volgens ECN (2009) bedraagt de kosteneffectiviteit van maatregelen in de geactualiseerde BEES B 7-8 €/kg SO_2. Het MNP (2007) komt tot waarden van 0,5-3,5 €/kg (Olie- naar gasstook chemische industrie) en een bedrag van 13 €/kg voor 'Verlaging zwavelgehalte rode diesel mobiele werktuigen, binnenvaart en visserij'. De database van het Oostenrijkse International Institute for Applied Systems Analysis (IIASA), dat de onderliggende berekeningen geeft voor de EU voor het vaststellen van de NEC-richtlijnen, geeft voor een van de meest effectieve maatregelen een prijs van circa 5 á 6 €/kg (toepassing *Low sulphur diesel oil - stage 2* (0.045 % S)). Tenslotte wordt in de Nederlandse Emissierichtlijn Lucht (NeR) een indicatieve referentiewaarde genoemd van 2,30 €/kg SO_2-emissie voor de kosten-effectiviteit van emissiereducerende maatregelen[4].

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[3] Nota bene: hoewel deze waarden worden gegeven in de meest recente NeR (SenterNovem, 2009, betreffende paragrafen 2.11 onveranderd sinds december 2006), stammen de waarden uit het midden van de jaren 90.

[4] Zie voetnoot 3.

Op basis van de beschikbare gegevens is ons *expert judgement* dat de marginale reductiekosten van het behalen van het NEC-doel in 2020 tussen de 5 €/kg SO_2 en 10 €/kg SO_2 liggen. Deze waarde is substantieel hoger dan de 2,50 €/kg SO_2 genoemd in de update van 2002 (CE, 2002). Het verschil is met name het resultaat van de substantieel strengere NEC-richtlijn voor 2020.

Ammoniak (NH_3)
Ten tijde van het schrijven van het Optiedocument (ECN/MNP, 2006) werden zonder beleidswijzigingen emissies verwacht in 2020 van 147 kton NH_3. Ten opzichte het beleidsdoel van 119 kton NH_3 in 2020 betekent dit een gat van 28 kton NH_3. De marginale reductiekosten bij deze additionele emissie-reductie bedragen volgens het Optiedocument circa 10 €/kg NH_3.

Opgemerkt dient echter te worden dat een emissiereductie van 22 kton NH_3 kan worden bereikt tegen 4 €/kg NH_3. Ook de analyse van de marginale reductiekostencurve voor NH_3 op basis van de MKBA van de verzuringsplafonds komt tot een waarde van € 3,7 voor een reductie van 21 kton.
De door het MNP onderzochte aanvullende maatregelen voor het behalen van de doelstelling hebben een kosteneffectiviteit van 2 €/kg NH_3 (aanscherping emissiearme aanwending mest op grasland) en 3 €/kg NH_3 (veevoer-aanpassingen bij melkvee).

Op basis van de gegevens komen wij tot marginale reductiekosten van circa 4 €/kg NH_3. Deze waarde is lager dan de 11 €/kg NH_3 genoemd in de update van 2002 (CE, 2002) voor de thema's verzuring en smog samen. Het verschil is met name het resultaat van het minder strenge NEC-richtlijn voor 2020 (119 kton) dan het NMP4-doel 2010 (100 kton).

NMVOS
Ten tijde van het schrijven van het Optiedocument (ECN/MNP, 2006) werden zonder beleidswijzigingen emissies verwacht in 2020 van 182 kton NMVOS. Ten opzichte het beleidsdoel van 143 kton NMVOS in 2020 betekent dit een gat van 39 kton NMVOS. Het optiedocument biedt onvoldoende maatregelen om deze reductie te bewerkstelligen. Circa 12 kton is te reduceren met kosten die oplopen tot circa 8 €/kg NMVOS, terwijl nog eens 16 kton kan worden gereduceerd met maatregelen waarvan geen kosten bekend zijn. In MNP (2007a) wordt de kosteneffectiviteit van de aanvullende maatregelen op circa 5 €/kg NMVOS geschat[5]. Tenslotte wordt in de Nederlandse Emissierichtlijn Lucht (NeR) een indicatieve referentiewaarde genoemd van 4,60 €/kg VOS-emissie voor de kosteneffectiviteit van emissiereducerende maatregelen[6].

Wij schatten de marginale reductiekosten op circa 5 €/kg NMVOS. Deze waarde is substantieel hoger dan de 0,90 €/kg NMVOS genoemd in de update van 2002 (CE, 2002). Het verschil is met name het resultaat van de strengere NEC-richtlijn voor 2020 (143 kton) dan het NMP4-doel 2010 (163 kton).

[5] Op basis van Figuur 3.1, pagina 35: reductie circa 20 kton NMVOS voor circa 100 miljoen Euro.

[6] Zie voetnoot 3.

B.4 Fijn stofvorming

B.4.1 Doelen

Voor de vorming van fijn stof zijn met name de stoffen PM_{10}, $PM_{2,5}$, NO_x en SO_2 van belang. Doelen en preventiekosten met betrekking tot NO_x en SO_2 zijn al bij het thema verzuring besproken.

De nationale beleidsdoelen op het gebied van fijn stof bestaan uit de (Europese) luchtkwaliteitseisen. Sinds 2007 zijn deze normen vastgelegd in nationale wetgeving middels de 'Wet luchtkwaliteit'. Op 11 juni 2008 is er een nieuwe EU-richtlijn (2008/50/EG) van kracht geworden. Bestaande grenswaarden voor PM_{10} en NO_2 blijven daarin ongewijzigd[7], maar lidstaten wordt wel de mogelijkheid geboden om later te voldoen aan deze grenswaarden als zij voldoende inspanning laten zien om de luchtkwaliteit te verbeteren. Daarnaast zijn nieuwe Europese normen geïntroduceerd voor $PM_{2.5}$ (artikel 15.1). Het gaat hierbij om grenswaarden voor de jaargemiddelde concentraties en gemiddelde stedelijke achtergrondconcentraties[8]. Inmiddels heeft de EU Nederland derogatie verleend. Zo is het termijn om de luchtkwaliteitseisen voor PM_{10} verleng tot 2011. Verder is de implementatie van de EU-richtlijn voor $PM_{2,5}$ in Nederlandse wetgeving grotendeels afgerond (PBL, 2009).

Terwijl er dus wel normen gelden voor *concentraties* van fijn stof in de lucht, worden er momenteel geen eisen gesteld aan de *uitstoot* van fijn stof. Onder de huidige NEC-richtlijnen (voor 2010) is er geen emissieplafond vastgesteld. De Europese Commissie heeft wel aangekondigd bij de herziening van de NEC-richtlijn een plafond voor fijn stof op te nemen. Naar verwachting worden er voor fijn stof $PM_{2,5}$ nationale emissieplafonds voor 2020 opgesteld[9] (zie Table 5).

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7 Voor PM_{10} geldt een grenswaarde van 50 µg/m^3 voor het daggemiddelde, die niet vaker dan 35 dagen per kalenderjaar mag worden overschreden. De grenswaarde voor de jaargemiddelde concentratie is 40 µg/m^3.

8 In 2015 dient overal aan de jaarlijks gemiddelde grenswaarde van 25 µg/m^3 te worden voldaan. Daarnaast mag de gemiddelde stedelijke achtergrondconcentratie in Nederland niet meer zijn dan 20 µg/m^3 in 2015. Er ligt een reductiedoelstelling voor $PM_{2,5}$-concentratie van 20% tussen 2010 en 2020.

9 Het herzieningsproces van de NEC-richtlijn heeft wel vertraging opgelopen als gevolg van politieke ontwikkelingen. Zo worden de klimaatonderhandelingen in Kopenhagen afgewacht omdat er een relatie bestaat tussen klimaatbeleid en fijn stofconcentratie in de lucht. CO_2-beleid kan positieve of negatieve neveneffecten hebben op fijn stof, afhankelijk van het type maatregelen dat wordt gestimuleerd.

Table 5 **Doelstellingen en verwachte emissies voor 2020**

	PM_{10}	$PM_{2,5}$
Verwacht NEC-doel 2020 (CE, 2008)	-	16
Emissieplafond voor 2020 volgens ambitie TSAP (GCN, 2008 op basis van IIASA, 2006)		16
Verwachte ontwikkeling van emissies in het *Global Economy*-scenario[10] (ECN, 2004)	47	
Verwachte ontwikkeling van emissies in het *Global Economy*-scenario bij voorgenomen beleid (GCN, 2008)	32,2	13,9

B.4.2 Preventiekosten

Zoals blijkt uit Table 5 is de verwachting dat de totale emissies van $PM_{2,5}$ in 2020 beneden het nationale doel zullen liggen. Ook wat betreft de concentraties fijn stof is het, volgens de meest recente inschatting, waarschijnlijk dat met het voorgenomen overheidsbeleid (grotendeels) wordt voldaan aan de luchtkwaliteitsnormen (PBL, 2009)[11]. De grenswaarden voor $PM_{2,5}$ worden daarbij minder stringent geacht dan de bestaande grenswaarden voor PM_{10}, wat betekent dat als het beleid erin slaagt om vanaf 2011 te voldoen aan de grenswaarde voor PM_{10}, ook automatisch wordt voldaan aan de nieuwe $PM_{2,5}$-grenswaarden per 2015. Overigens bestaan er rondom de concentratie van $PM_{2,5}$ (en dus de beleidsopgave) wel onzekerheden met betrekking tot de emissies, de chemische samenstelling van de deeltjes, de gezondheidseffecten en de metingen (PBL, 2009).

Opgemerkt dient te worden dat het feit dat het nationale doel niet wordt overschreden niet betekent dat lokaal geen luchtkwaliteitseisen (dag-grenswaarden of MTRs) kunnen worden overschreden. Indien dat het geval is, zullen toch emissiereducerende maatregelen moeten worden getroffen. De preventiekostenmethode biedt echter geen handvat voor de aanpak van lokale effecten.

Hoewel vermoedelijk aan de nationale luchtkwaliteitseisen wordt voldaan en het verwachte nationale emissieplafond niet zal worden overschreden, is de daggrenswaarde voor PM_{10} wel beperkend, zoals blijkt bij de realisatie van bouwplannen. Het nationale luchtkwaliteitsbeleid heeft zich daarom gericht op het verbeteren van de luchtkwaliteit, ondermeer door middel van bronmaatregelen zoals het subsidiëren van roetfilters voor dieselvoertuigen en bronmaatregelen bij de landbouw en de industrie. Het Nationaal Samenwerkingsprogramma Luchtkwaliteit (NSL) is een belangrijke pijler in het overheidsbeleid[12]. Daarbinnen werken het Rijk, de provincies en gemeenten samen om de Europese eisen voor luchtkwaliteit te realiseren. Kern van het programma is dat ruimtelijke projecten pas doorgang kunnen vinden wanneer er voldoende reductiemaatregelen tegenover staan. In dat kader is afgesproken dat, naast maatregelen in verkeer en landbouw, de industrie ook

10 *Global Economy* is één van de vier economische scenario's voor Europa tot aan het jaar 2040 die zijn opgesteld door het Centraal Planbureau (CPB, 2003). Zie voor de vertaling van deze scenario's naar emissies: ECN, 2006.

11 PBL (2009) is gebaseerd op de meest recente inzichten. Er is rekening gehouden met de impact van de huidige economische situatie. Eerdere studies schetsten een iets minder positief beeld. In MNP (2007b) wordt bijvoorbeeld de verwachting uitgesproken dat gemiddeld genomen een $PM_{2,5}$-concentratie van 25 of 20 wel gehaald zou kunnen worden, maar dat voor wat betreft de stedelijke achtergrondconcentratie wel aanvullend nationaal beleid nodig zou zijn. De $PM_{2,5}$-doelstellingen zouden stringenter zijn dan die voor PM_{10}.

12 Gegeven de effecten van bronmaatregelen in de sectoren verkeer, industrie en landbouw, wordt via het NSL bepaald welke additionele maatregelen nodig zijn.

een bijdrage gaat leveren aan de emissiereductie[13]. In het Actieplan fijn stof en industrie (VROM, 2008b) staat centraal dat Beste Beschikbare Technieken (BBTs) moeten worden toegepast. Europese overzichten van BBTs, de zogenaamde BBT-referentiedocumenten (BREFs) zijn opgenomen in de Nationale emissierichtlijn (NeR) en dienen als uitgangspunt bij vergunningverlening door het bevoegd gezag[14].

In de nieuwe NeR (SenterNovem, 2009) wordt fijn stof aangeduid als een prioritaire stof. Het bestrijden van de emissie van fijn stof is geregeld via de algemene eisen voor stof. Het gaat om een reductie tot een niveau lager dan 5 mg/Nm^3, uitgezonderd een aantal specifieke productieprocessen. Doekfilters worden vooralsnog beschouwd als de Beste Beschikbare Techniek voor de bestrijding van de emissie van fijn stof (PM_{10} en $PM_{2,5}$).

Tegelijkertijd wordt in de NeR (2009) echter de indicatie gegeven dat maatregelen duurder dan 2,30 €/kg vermeden stof niet verplicht zijn. Deze referentiewaarde is verouderd en niet toegespitst op fijn stof. VROM (2008: 39) merkt op dat 'deze waarde halverwege de jaren 90 is opgesteld en deze de inzichten beschrijft van ruim tien jaar geleden voor stof een periode dat PM_{10} nog niet een onderwerp was'. De kosteneffectiviteit van reductiemaatregelen op het gebied van PM_{10} of $PM_{2,5}$ wordt idealiter dan ook niet vergeleken deze referentiewaarde, die een onderschatting hiervan blijkt te geven. Diverse studies hebben de daadwerkelijk kosten van tal van technische reductieopties in diverse sectoren onderzocht en vinden waardes hoger dan 2,30 €/kg (TNO, 2002; MNP, 2005, 2007; CE, 2008; VROM, 2008b). Uitkomsten vertonen een brede range van circa 10 €/kg tot 275 €/kg.

Om tot een alternatieve inschatting voor de preventiekosten te komen, moet gekeken worden naar de marginale kosten van de duurste maatregelen die moet worden ingezet om de luchtkwaliteitsdoelstellingen te halen. Hier komt meteen een praktisch probleem kijken; er is geen simpele vertaalslag mogelijk tussen marginale wijzigingen in emissies (in kg) en concentraties (in µg/m^3). Dit betekent dat bestaande kosteninschattingen van individuele maatregelen in kg niet als basis kunnen dienen voor de bepaling van preventiekosten omdat ze niet direct te relateren zijn aan het beleidsdoel (concentratie) en de afkapgrens bij het palet aan maatregelen dus lastig te bepalen is, terwijl kosteninschattingen gericht op beleid[15] lastig omgerekend kunnen worden naar preventiekosten in kg.

Wanneer wij pogen tot een ruwe, conservatieve kosteninschatting te komen, gebaseerd op huidige beleidsinitiatieven, komen wij voor PM_{10} op een waarde van 50 €/kg uit. Volgens het Actieplan fijn stof is dit de gemiddelde kosten-effectivitieit van het realiseren van een restemissie van 5 mg/Nm^3 in de industrie, uitgaande van toepassing van doekfilters (de NeRs BBT). Deze techniek is qua emissiereductie gemiddeld genomen gunstiger dan nu reeds genomen maatregelen in het verkeer, waarbij de kosteneffectiviteit veelal tussen de 50 €/kg en 250 €/kg ligt (VROM, 2008b)[16] en vermoedelijk minder gunstig dan maatregelen in de landbouw, waar de overall kosteneffectiviteit

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13 Overigens is in het Actieplan nog niet bepaald om welke industriële sectoren gaat en welke reducties per sector behaald dienen te worden (ECN, 2009).

14 De IPPC-richtlijn (Europese Richtlijn 96/61/EG) verplicht EU-lidstaten om grote milieuvervuilende bedrijven te reguleren middels een integrale vergunning gebaseerd op de beste beschikbare technieken (BBT).

15 Zie bijvoorbeeld MNP (2007a; 2007b) en Arthur D. Little (2008).

16 Zo vindt MNP (2007a) een kosteneffectiviteitcijfer van de Euro 6-emissie-eis voor zwaar wegverkeer van 275 €/kg. In CE (2008), wordt de kosteneffectiviteit van het stimuleren van roetfilters op zo'n 150 tot 210 € geschat.

voor gecombineerde luchtwassers in grote pluimvee- en varkenshouderijen op zo'n € 30-50 per kg wordt geschat (MNP, 2007a; Arthur D. Little, 2008)[17]. Voor $PM_{2,5}$-reductie zijn de kosten per emissiereductie vermoedelijk hoger of gelijk hieraan (zie Arthur D. Little, 2008). Gezien het meest recente inzicht dat de doelen voor PM_{10} stringenter zijn dan die voor $PM_{2,5}$ (PBL, 2009), baseren we ons ook voor $PM_{2,5}$ op de preventiekosten voor PM_{10}.

Tegelijkertijd is er echter een reden om toch vast te houden aan de NeR-waarde van 2,30 €/kg als preventiekostenschatting. Deze waarde is namelijk niet ongeloofwaardig wanneer wij de daggrenswaarden (MTRs) bekijken van voor PM_{10} en NO_x. De MTRs zijn voor beide stoffen gelijk[18], terwijl er goede reden is om aan te nemen dat € 2,30 per vermeden kg NO_x een redelijke waarde is voor het aandeel van NO_x aan het thema humane toxiciteit. Dit wordt hieronder beargumenteerd.

Voor de emissie van NO_x is in paragraaf B.3.2 een schaduwprijs gegeven van tussen de 5 en 10 €/kg NO_x. NO_x draagt echter niet alleen bij aan humane toxiciteit, maar ook aan vermesting, fotochemische oxidantvorming en verzuring. Op basis van de schaduwprijs voor NMVOS en de gelijke equivalentiefactor voor NO_x met betrekking tot het thema fotochemische oxidantvorming schatten wij de bijdrage van NO_x op circa € 5. In het geval van verzuring en vermesting is de bijdrage respectievelijk circa 2 en 3 €. In deze waarden zit de nodige onzekerheid. Op basis van het totaalbedrag voor NO_x van circa 10 €/kg verwachten wij echter niet dat de schaduwprijs voor het thema fijn stofvorming veel hoger kan zijn dan enkele Euro's.

Momenteel kunnen wij op basis van de huidige beschikbare kennis niet de exacte preventiekosten voor PM_{10} en $PM_{2,5}$ bepalen. We zullen uitgaan van 2,30 €/kg, maar in de tabellen met schaduwprijzen wel aangeven dat de huidige kosten van reductiemaatregelen hoger liggen door de waarde van € 50 per kg als indicatie te vermelden. Er zijn wel twee sets met weegfactoren ontwikkeld (set 1a en set 2), om te illustreren dat de waarde voor fijn stof een grote impact heeft op de weegfactoren[19].

B.5 Humane toxiciteit

B.5.1 Doelen en preventiekosten

Aan het thema humane toxiciteit dragen vele verschillende stoffen bij. Voor de uitstoot van toxische stoffen gelden echter geen nationale plafonds. Wel gelden maximale toelaatbare risiconiveaus (MTRs), i.e. concentraties in water en lucht, die niet overschreden mogen worden.

De schaduwprijzenmethode is echter niet direct toepasbaar op lokale effecten. Om bij het ontbreken van nationale doelen voor stoffen zoals zware metalen toch tot schaduwprijzen te komen, leiden wij hier schaduwprijzen af door gevonden waarden voor PM_{10} te relateren aan andere stoffen via de relatieve MTRs. Dat wil zeggen dat een stof waarvan de MTR tien keer lager is dan de MTR voor PM_{10} een tien keer hogere schaduwprijs heeft.

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17 Arthur D. Little (2008) schat de indicatieve kosteneffectiviteit van bestaande oplossingen voor PM_{10}-reductie op enkele uitschieters na oplopend tot circa 40 €/kg.

18 Volgens de karakterisatiefactor uit Recipe draagt NO_x per kg circa de helft bij als PM_{10} zelf.

19 Wanneer met een waarde van 2,30 €/kg wordt gewerkt wordt een groot deel van het effect van SO_2 aan verzuring toegeschreven en heel weinig aan $PM_{2,5}$ (zie paragraaf 6.5).

In tegenstelling tot de andere milieuthema's worden de equivalentiefactoren hier dus niet afgeleid uit ReCiPE. Gezien de uitgangspunten van de preventie-kostenbenadering lijkt het ons meer gepast uit te gaan van de huidige gestelde overheidslimieten, dat wil zeggen de MTRs.

Een correctie is toegepast voor de onderlinge verhouding in verval/afbraak/ halfwaardetijd van de stof (T) en de onderlinge verhouding in de soortelijke massa van lucht (F = 1,273) en water (F = 1) (zie VROM, 1994).

In Table 6 wordt een overzicht gegeven van de schaduwprijzen van de toxische effecten van emissie van de voor dit onderzoek relevante stoffen naar lucht en water. De maximaal toelaatbare concentraties (MTC of grenswaarde) zijn ontleend aan RIVM (2009b).

Table 6 **Schaduwprijzen van toxische effecten van emissies naar lucht en water**

Stof Luchtemissies	MTC (µg per m^3, l)	T	F	Schaduwprijs (€/kg emissie)
CO	10.000	8	1,273	0,01
Benzo(a)pyreen	0,001	8	1,273	92000
Fijn stof (PM_{10})	40	8	1,273	2,30
Dioxines (ng TEQ)	0,000001	8	1,273	92.000.000
As	0,5	8	1,273	184
Cd	0,5	8	1,273	184
Co	0,2	8	1,273	460
Cr	0,0025	8	1,273	36800
Cu	10	8	1,273	9
Hg	0,15	8	1,273	613
Ni	0,25	8	1,273	368
Pb	0,5	8	1,273	184
Zn	100	8	1,273	0,92
Fluoride	0,05	8	1,273	1840
Wateremissies				
As	32	1.000	1	282
Cd	2	1.000	1	4517
Co	3,1	1.000	1	2914
Cr	84	1.000	1	108
Cu	3,8	1.000	1	2377
Hg	1,2	1.000	1	7528
Ni	6,3	1.000	1	1434
Pb	220	1.000	1	41
Zn	40	1.000	1	226
Fluoride	1.500	35	1	0,21

Tenslotte is een vergelijking te maken met de heffingen die van kracht zijn bij de afvoer van stoffen op het oppervlaktewater (Wet verontreiniging oppervlaktewateren). Sinds 1970 is er een verontreinigingsheffing op basis van de Wet verontreiniging oppervlaktewateren (Wvo). Het uitgangspunt van deze heffing is het beginsel dat 'de vervuiler betaalt'. De kosten die gemaakt worden voor het zuiveren van afvalwater worden gefinancierd uit de opbrengsten van de verontreinigingsheffing. Het tarief verschilt per waterschap en varieert tussen de 50 en 70 € per vervuilingseenheid (in 2009). Aangezien de zuiveringskosten per kilo voor de verschillende zware metalen weinig verschillen, zijn ook de bedragen voor de meeste metalen gelijk

(Commissie Integraal Waterbeheer, 1998).[20] Er is daarom nauwelijks een relatie met de toxiciteit, terwijl voor de oude 'zwarte lijst stoffen' arseen, cadmium en kwik een tien maal hogere heffing wordt gegeven. Wij gebruiken de heffingen daarom niet als basis voor de bepaling van schaduwprijzen.

Table 7 **Heffingen voor emissies naar water**

Emissie	Vervuilingseenheden/kg	Heffing in €/kg
Arseen	1	600
Cadmium	1	600
Kwik	1	600
Chroom	0,1	60
koper	0,1	60
lood	0,1	60
Nikkel	0,1	60
Zilver	0,1	60
Zink	0,1	60

B.6 Eutrofiering

De overheid richt haar beleid op een vermindering van de emissies vanuit huishoudens, industrie en landbouw. Voornamelijk de landbouwsector is verantwoordelijk voor vermesting door de productie van mest en het gebruik van kunstmest. Kosten die deze sector dient te maken zijn daarom representatief voor de schaduwprijs voor eutrofiering.

De meststoffenwet regelt het gebruik van mest en mineralen op landbouwbedrijven, onder andere via gebruiksnormen en -voorschriften. Door middel van een aanpassing van de Meststoffenwet per 1 januari 2006 is de Europese Nitraatrichtlijn geïmplementeerd. De gebruiksnormen geven de maximale hoeveelheid aan die vanaf 1 januari 2006 mogen worden gebruikt voor het bemesten van gewassen met stikstof en fosfaat. Voor ieder bedrijf gelden drie soorten gebruiksnormen:

- Een gebruiksnorm voor dierlijke mest uitgedrukt in kilo's stikstof. De norm geeft aan hoeveel dierlijke mest ieder jaar per hectare landbouwgrond mag worden gebruikt.
- Een stikstofgebruiksnorm. Deze geeft aan hoeveel stikstof in totaal per hectare per jaar mag worden gebruikt. Van dierlijke mest en andere organische meststoffen telt daarbij alleen de werkzame stikstof mee. Ook kunstmest telt hierbij mee.
- Een fosfaatgebruiksnorm. Die bepaalt hoeveel fosfaat in totaal per hectare per jaar mag worden gebruikt. Dierlijke mest en andere organische meststoffen en kunstmest tellen hierbij mee.

In de meststoffenwet zijn de heffingen voor veehouders voor overschrijdingen van de verliesnormen voor fosfaat en stikstof vervangen door bestuurlijke boetes voor het overschrijden van de gebruiksnormen:

- 7 €/kg stikstof in overschrijding van de gebruiksnorm dierlijke meststoffen;
- 7 €/kg stikstof boven de totale gebruiksnorm voor stikstof;
- 11 €/kg fosfaat boven de totale gebruiksnorm voor fosfaat;
- 3,50 €/kg overschreden stikstof voor gebruiksnorm stikstof als ook op grond van de gebruiksnorm dierlijke meststoffen wordt beboet;
- 5,50 €/kg overschreden fosfaat voor gebruiksnorm fosfaat als ook op grond van de gebruiksnorm dierlijke meststoffen wordt beboet;

[20] Commissie Integraal Waterbeheer, 1998, Schadelijkheid versus maatstaf, CUWVO.

– 11 €/kg fosfaat en 7 €/kg stikstof waarvan men de afvoer niet kan aantonen.

Op basis van deze heffingen stellen wij de schaduwprijzen voor fosfaat (PO_4) en stilstof (N) op respectievelijk 11 €/kg en 7 €/kg. Deze waarden zijn hoger dan de waarden in de update uit 2002 (CE, 2002) gezien de verhoogde heffingen.

B.7 Finaal afval

Per 1 januari 1996 geldt een verbod op het storten van afval dat kan worden verbrand of gerecycled. Onder recycling wordt ook verstaan het gebruiken van onverwerkbaar niet of nauwelijks toxisch afval als onderlaag bij de aanleg van nieuwe wegen. Na de diverse mogelijke verwerkingsstappen blijft uiteindelijk zogenoemd finaal afval over dat niet verder kan worden verbrand of gerecycled.

In het Landelijk AfvalbeheerPlan (LAP) staat het beleid voor het beheer van alle afvalstoffen waarop de Wet milieubeheer van toepassing is. Het geeft onder meer het beleid voor nuttige toepassing en voor het storten en verbranden van afval. In het recente ontwerp LAP 2009-2012 (VROM, 2008a) zijn de volgende algemene doelstellingen voor het afvalstoffenbeleid gesteld:

– Het beperken van het ontstaan van afvalstoffen. Dit betekent dat de groei van het totale afvalaanbod moet zijn ontkoppeld van de economische groei.
– Het beperken van de milieudruk van de activiteit ‘afvalbeheer’. Dit betekent dat in principe zoveel mogelijk afval nuttig moet worden toegepast, dat alleen afval dat niet nuttig kan worden toegepast mag worden verwijderd en dat alleen het onbrandbaar afval mag worden gestort.
– Het vanuit ketengericht afvalbeleid beperken van de milieudruk van productketens (grondstofwinning, productie, gebruik en afvalbeheer, inclusief hergebruik). Dit betekent onder meer dat voor vermindering van milieudruk in de afvalfase de gehele keten in beschouwing wordt genomen en dat de inzet op vermindering van de milieudruk in de afvalfase niet mag resulteren in afwenteling van milieudruk op andere fases in de keten.

Deze doelstellingen zijn vertaald in kwantitatieve doelstellingen, waaronder:

– Verhogen van de nuttige toepassing van het totaal aan afvalstoffen van 83% in 2006 naar 85% in 2015. Dit kan met name worden bereikt door het stimuleren van afvalscheiding aan de bron en nascheiding van afval-stromen. Hierdoor wordt het eenvoudiger om producthergebruik, materiaalhergebruik en gebruik te bereiken.
– Minstens gelijkhouden van het in 2006 in Nederland reeds behaalde percentage van 95% nuttige toepassing van bouw- en sloopafval, ondanks de verwachte forse toename in de productie van deze afvalstroom in de komende jaren (van 24 Mton in 2006 naar 31 Mton in 2021).
– Minstens gelijkhouden van het in 2006 in Nederland reeds behaalde percentage van 90% nuttige toepassing van industrieel afval, ondanks de verwachte toename in de productie van deze afvalstroom van 16 Mton in 2006 naar 18 Mton in 2021.
– Reduceren van storten van brandbaar restafval van 1,7 Mton in 2007 tot 0 Mton in 2012.

De overheid maakt in haar doelstellingen geen onderscheid tussen de verschillende soorten finaal afval, zoals bijvoorbeeld op grond van de mate van toxiciteit. Om deze reden wordt hier dan ook geen afzonderlijke schaduwprijs gegeven voor de verschillende soorten finaal afval.

B.7.1 Preventiekosten

Eén van de concrete effecten die optreden bij stort van finaal afval is het in beslag nemen van ruimte: de stort*plaats*. Aan dit ruimtegebruik is, in tegenstelling tot andere milieueffecten, een werkelijke marktprijs verbonden. Met behulp van de prijs van ruimte en de beheerskosten voor een stortplaats zou zodoende een prijs voor finaal afval kunnen worden berekend. Op deze wijze wordt echter een te lage waarde gevonden. De maatschappij kent aan een permanent ruimtegebruik voor stort een hogere waarde toe dan aan ruimtegebruik voor andere doeleinden die minder irreversibel zijn. Reden hierachter is dat uit het oogpunt van een duurzame ontwikkeling toekomstige mogelijkheden zo min mogelijk dienen te worden verminderd[21]. Bovendien is aan de stort van afval een moeilijk in te schatten risico van lekkage van toxische stoffen verbonden.
Bovengenoemde overwegingen verklaren waarom door de overheid maatregelen worden genomen om het ontstaan van finaal afval te voorkomen die (veel) duurder zijn dan de kosten die stortplaatsen in rekening brengen.

In het nieuwste ontwerp LAP (VROM, 2008a) is evenals in het vorige LAP (VROM, 2002) opgenomen dat de minimumstandaard voor het bewerken en verwerken van niet-gevaarlijk procesafhankelijk industrieel afval, met uitzondering van de specifieke afvalstromen die in andere sectorplannen worden behandeld, nuttige toepassing is, tenzij nuttige toepassing niet mogelijk is op grond van de aard en samenstelling van de afvalstof of de meerkosten van nuttige toepassing substantieel hoger liggen dan de kosten voor verwijdering van de afvalstof. Onder substantieel wordt verstaan meer dan 150% van het tarief van storten, inclusief de stortbelasting.

Voor het storten van afvalstoffen met een soortelijk gewicht van meer dan 1.100 kilo per m^3 gold in 2008 een laag tarief van € 14,56 per ton en voor afvalstoffen met een lager soortelijk gewicht geldt in 2008 een hoog tarief van € 88,21 per ton. De gemiddelde kosten voor het verbranden van huishoudelijk restafval en daarmee vergelijkbaar bedrijfsrestafval lagen in 2007 rond de € 120 per ton. De kosten voor het storten van afval liggen door de belasting op milieugrondslag op een vergelijkbaar bedrag (VROM, 2008a).

Uit het bovenstaande leiden wij een schaduwprijs af voor industrieel finaal afval van € 180 per ton. Hierbij dient opgemerkt dat voor specifieke, toxische afvalstromen veel hogere bedragen kunnen gelden.

B.8 Geluid

Het geluidsniveau wordt vaak uitgedrukt in dB(A), wat bij benadering een verband heeft met de menselijke waarneming en corrigeert voor de frequentie. In het beleid wordt geluid meestal uitgedrukt in L_{den}, een maat voor het aantal decibellen verspreid over het hele jaar en met een toeslag voor de avond en de nacht. Bij de avond- en de nachtwaarde wordt een straffactor van respectievelijk 5 en 10 dB opgeteld. Daarnaast geldt er een

[21] Ter vergelijking: dat grond een bepaalde prijs heeft impliceert nog niet dat het buitenland voor dat bedrag een stuk grond kan overnemen en aan het eigen grondgebied kan toevoegen.

zogenaamde railbonus (van 5 dB) en een vliegtuigmalus (van 5 dB), omdat veelal spoorgeluid als minder hinderlijk en vliegtuiggeluid als hinderlijker ervaren wordt dan weggeluid.

B.8.1 Beleidskader

Sinds het einde van de jaren 70 vormt de Wet geluidhinder (Wgh) het juridische kader voor het Nederlandse geluidsbeleid. De Wgh bevat een uitgebreid stelsel van bepalingen ter voorkoming en bestrijding van geluidshinder door onder meer industrie, wegverkeer en spoorwegverkeer.
Voor geluidsgevoelige bestemmingen langs wegen geldt in principe een voorkeursgrenswaarde van 48 dB(A), maar hier kan in bepaalde situaties van worden afgeweken. Hogere waarden van 53 dB(A) tot 68 dB(A) kunnen worden vastgesteld. De maximale ontheffingswaarde is de geluidsbelasting die na toestemming van burgemeester en wethouders, gedeputeerde staten of de minister van VROM toelaatbaar is. De situatie mag dan niet meer verslechteren.
De huidige Wet geluidhinder staat onder druk omdat het lawaai door autonome ontwikkeling van het verkeer onbeheerst kan groeien (het 'handhavingsgat'). De huidige regelgeving legt namelijk alleen verplichtingen op om maatregelen af te wegen bij ingrepen op of aan de infrastructuur. Er wordt niet ingegrepen in situaties van verkeersgroei (waarbij de geluidsniveaus dus ook toe kunnen nemen). Daarom worden onder de nieuwe Wet geluidhinder 'geluidsproductieplafonds'[22] geïntroduceerd.

RWS doelmatigheidscriterium

Momenteel hanteert het RWS een doelmatigheidscriterium om te berekenen welke (en welke omvang van) maatregelen financieel doelmatig zijn om overschrijding van de normen te voorkomen.

Hiertoe bevat het doelmatigheidscriterium normbedragen voor maatregelen die vervolgens worden afgezet tegen de geluidsreductie. Wanneer de kosten per dB-woningreductie onder een bepaalde grenswaarde blijven (€ 3.000) is een maatregel doelmatig. Bij bepaling van het aantal dB-woningen wordt ook rekening gehouden met het oorspronkelijke geluidsniveau in de veronderstelling dat een geluidsreductie van 70 naar 69 dB met een grotere verlaging van hinder gepaard gaat dan een verlaging van 51 naar 50 dB. Een 1 dB-reductie bij een geluidsniveau van 70 dB telt daarom voor 2,5 dB, terwijl een 1 dB-reductie bij een geluidsniveau van 51 dB maar voor 1 dB meetelt.

B.9 Preventiekosten voor geluid

Ons voorstel is om de preventiekosten voor geluid af te leiden uit het huidige RWS-doelmatigheidscriterium. Onder de nieuwe Wet geluidhinder zal er één wettelijk (nieuw) doelmatigheidscriterium gelden, maar deze staat nog niet vast.

Uit het bovenstaande leiden wij een (ongewogen) schaduwprijs af van € 3.000 per dB-woning. Het zou echter de voorkeur hebben de schaduwprijs afhankelijk te maken van de mate van overlast en de modaliteit. Bovendien dient de vraag zich aan vanaf welke drempelwaarde deze schaduwprijs geldt.

[22] Deze zijn gelijk aan de huidige geluidsniveaus op referentiepunten langs de weg plus een marge. De toekomstige geluidsniveaus mogen niet hoger zijn dan deze productieplafonds.

Wij raden de volgende drempelwaardes aan[23]:
- 50 dB aan voor wegverkeer;
- 55 dB voor spoorverkeer;
- 45 dB voor vliegverkeer.

De gewogen schaduwprijs voor geluid (€ per dB-woning) is dan gelijk aan:

$$€\ 3.000\ x(1+0,05*\ (L_{den}\ -\ drempelwaarde))$$

De gekozen dB waarde per woning van € 3.000 kan worden geinterpreteerd als een investeringssom: de investeringen die de overheid bereid is te nemen om de overlast boven de drempelwaarde terug te brengen. Uitgaande van een afschrijving voor vaste activa van 25 jaar en een risicovrije rentevoet van 2,5% kan dit worden omgerekend tot een jaarlast van € 162. Uitgaande van een gemiddelde huishoudengrootte van 2,3 personen levert dit een schatting van de preventiekosten van € 70 per dB per jaar.

[23] Gebaseerd op de Miedema & Oudshoorn (2001) geluidshindercurve, waaruit blijkt dat mensen bij eenzelfde geluidsniveau het meest gehinderd worden door vliegtuiggeluid en het minst door spoorweggeluid. Zie ook Nijland & Van Wee (2008) en Dekkers & Van der Straaten (2008).

Annex C Damage cost estimation

C.1 Introduction

This annex provides an extensive account of the methods employed in valuing the damage due to relevant pollutants for the various environmental themes.

C.2 Climate change

Climate change impacts are due mainly to emissions of so-called greenhouse gases, viz. carbon dioxide, (CO_2), nitrous oxide (N_2O) and methane (CH_4). Other substances contributing to global warming include refrigerants (hydrofluorocarbons) and high-altitude aircraft emissions (water vapour, sulphate, soot aerosols and nitrous oxides).

In estimating the damages associated with climate change, several problems are encountered: the impacts concerned are global in nature and not evenly distributed across the planet, and there are uncertainties about the atmospheric lifetime of CO_2. In other words, an additional emission of CO_2 results in impacts occurring far away, both in time and space.

C.2.1 Methodology

Damage cost estimates for climate change have been developed since the early 1990s, mainly through so-called Integrated Assessment Models (IAM). These models combine developments in economic growth with impacts from climate change. The models typically include a cost assessment of direct impacts, but exclude certain indirect effects (termed “socially contingent effects” by Watkiss et al. (2005a), such as the incidence of wars due to climatic stress).

Climate change damages include a broad range of effects related to temperature rise, such as changes in global precipitation, sea level rise, increased risk of extreme events such as drought and severe storms, and in the longer term possibly alteration of ocean currents. These effects may lead to various impacts associated with social costs, which can be summarised as follows (based on Watkiss et al., 2005a):

- Sea level rise may lead to loss of both dry land and wetlands. These impacts can be measured in terms of the costs of protection, which are relatively easy to assess. Another category of costs related to this type of impact is the cost of human migration which depends on various social and political factors (and thus a ‘socially contingent effect’) and is not captured by most valuation models.
- The impact of climate change on energy use will depend on the range and magnitude of temperature changes and is a combination of increase and decrease in demand for heating, whereby falling demand for heating in winter may be offset by rising demand for air conditioning in summer.
- Agricultural impacts are related to changes in cultivated area, in crop types and in yields resulting from changes in temperature and precipitation. In addition to these direct changes, there may be effects related to adaptive abilities and changes in demand and trading patterns, which depend on socio-economic factors.
- There will be impacts on water supplies: in some areas water shortages will be exacerbated by climate change, for example. There is therefore a

potential for increased water scarcity, the costs of which may be very high and highly socially contingent.
- Health effects include decreased cold stress in winter and increased heat stress in summer. To some extent at least, these direct effects will cancel out. Additional impacts include increased incidence of certain parasitic diseases like malaria. Indirect effects on human health include impacts related to changes in food production (especially declining food production in tropical/subtropical countries).
- Ecosystem and biodiversity impacts are the most complex and difficult to evaluate. Potential impacts include an increased risk of extinction of certain vulnerable species. Certain isolated systems like coral reefs are particularly at risk.
- Extreme events such as heat waves, droughts, storms and cyclones may not be linearly dependent on temperature change and the impact of such events is also very hard to assess. Damages will depend on the location and timing of the event and on adaptive responses and are thus also partly socially contingent.
- Major events, including potential catastrophic effects such as loss of the West Antarctic ice sheet, loss of the Greenland ice sheet, methane outbursts, instability or collapse of the Amazon Forest, changes in ocean currents and Indian monsoon transformation, are extremely hard to assess.

These impacts in turn influence the endpoints human health, ecosystems and capital goods. However, they may also result in other social costs, such as migration, which are included in most IAM (e.g. in the FUND model).

Controversial aspects of these models that lead to discrepancies among the results of the various studies include:
- The time horizon adopted (how far into the future are impacts considered?).
- The treatment of risk and uncertainty.
- The underlying emission and economic growth scenarios.
- The discount rate used to account for damages occurring in the (distant) future.
- The dependence of damage valuation on income level (e.g. similar damage suffered by a rich person is assigned a higher monetary value than that suffered by a poorer person).
- Whether or not equity weighting is being used (see Box 1).

Box 1: Equity weighting
Most Integrated Assessment Models assume that the value to be assigned to damages depends on income level, which means the Value of a Statistical Life (VSL) is set proportional to GDP, for example. Equity weighting, by contrast, attaches greater weight to damages occurring in low-income regions than in high-income regions. This corresponds with the theory of declining marginal utility of consumption: the higher an agent's income, the less welfare loss they will suffer from the same absolute loss of income, i.e. the same absolute loss of income causes a greater loss of welfare to the poor than to the rich (based on NEEDS (2007c). See also Chapter 5.

As IAMs do not normally differentiate the damages across the various endpoints as defined in this study, we can only give total estimates for the damage. Moreover, we focus below only on the damage due to CO_2, translating this into damage due to other GHG emissions using equivalence factors at the endpoint level.

C.2.2 Total damage costs for CO_2

Over the last few years the term 'Social Cost of Carbon' (SCC) has been gaining currency and a growing number of studies are concerned with monetary assessment of SCC. This SCC can be interpreted as the total discounted value of future costs and benefits related to emission of one additional unit of CO_2. Tol (2008) provides a meta-analysis of 211 studies on SCC, and arrives at a mean value of $ 23 per tonne of carbon at a 3% discount rate, equivalent to approximately 6.3 $/tCO_2$ (or about 5 €/tCO_2$). The range of estimates reported in Tol's paper is very broad, however: from less than zero to over 2,000 $/tC.[24]

The damage cost approach shows that the external costs of GHG emissions rise over time, as the negative effects of global warming become ever severer as the global temperature rises. As a result, the literature on the damage cost approach generally gives a range of values that can be used in tools like SCBA if a project results in CO_2 emissions for a longer period of time (see Section 5.6).

In the NEEDS and CASES projects[25], damage costs were based on the results of the FUND model (for a model description, see Box 2), as reported in Table 8.

Table 8 **Recommended values of damage costs for CO_2 (Euro$_{2008}$[26] per tCO$_2$), discounted to the year of emission, without equity weighting**

Emissions in decade	2000-09	2010-19	2020-29	2030-39	2040-49	2050-59	2060-69	2070-79	2080-89	2090-99
Damage costs	8	13	16	18	21	33	30	38	48	54

Source: CASES, 2008.

Box 2: The FUND model

FUND is an Integrated Assessment Model (IAM), a computer model of economic growth with a controllable externality of greenhouse warming effects developed by Professor Richard Tol (IVM VU Amsterdam and Economic and Social Research Institute, Dublin). The model distinguishes 16 major regions of the world and runs from 1950 to 2300 in time steps of one year. The period 1950-1990 is used for model calibration, while the period 1990-2000 is based on observations. The climate scenarios for the period 2010-2100 are based on the EMF14 Standardised Scenario, which lies somewhere between the IPCC's IS92a and IS92f scenarios. The model estimates marginal damages from emission of one extra tonne of carbon (and other greenhouse gases). The climate impact module includes the following categories: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources and unmanaged ecosystems. The impacts of climate change are monetised. If people die prematurely due to temperature stress or have to migrate because of sea level rise, these effects are evaluated using approximate valuation factors from literature. For example, the Value of a Statistical Life (VSL) is set at 200 times annual per capita income. The value of

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24 In the literature the (damage or abatement) costs related to carbon dioxide emissions are typically expressed in dollars or Euros per tonne of carbon dioxide (CO_2) or per tonne of carbon (C). Costs per tC translate into costs per tCO$_2$ by dividing by a factor 44/12 = 3.667.

25 NEEDS: New Energy Externalities Developments for Sustainability, European Commission research project implemented during the period 2004-2008, part of the ExternE series; CASES: Cost Assessment for Sustainable Energy Systems, European Commission research project implemented during the period 2006-2008.

26 The original values reported in Euro$_{2000}$ per tonne have been recalculated using HICP indicator (see Annex A.1).

emigration is set at 3 times per capita income, while the value of immigration is 40% of the per capita income in the host region. The monetary value of 4 million USD was taken for loss of one square kilometre of dryland in OECD countries in 1990, and was assumed proportional to GDP per km^2. FUND uses Ramsey-style discounting, which is a combination of the consumption growth rate, risk aversion and the pure rate of time preference (PRTP). PRTP is assumed at three different levels: 0, 1 and 3%. The effective discount rate used even for a specific PRTP varies over time and region, since per capita consumption growth rates vary over time and by region.
(Based on NEEDS (2007c).)

The IMPACT handbook (CE, 2008b) reviews a number of other studies on CO_2 damage costs, the results of which are summarised in Table 9 and Figure 3.

Table 9 Estimated damage costs of climate change according to various studies (€/tCO_2)

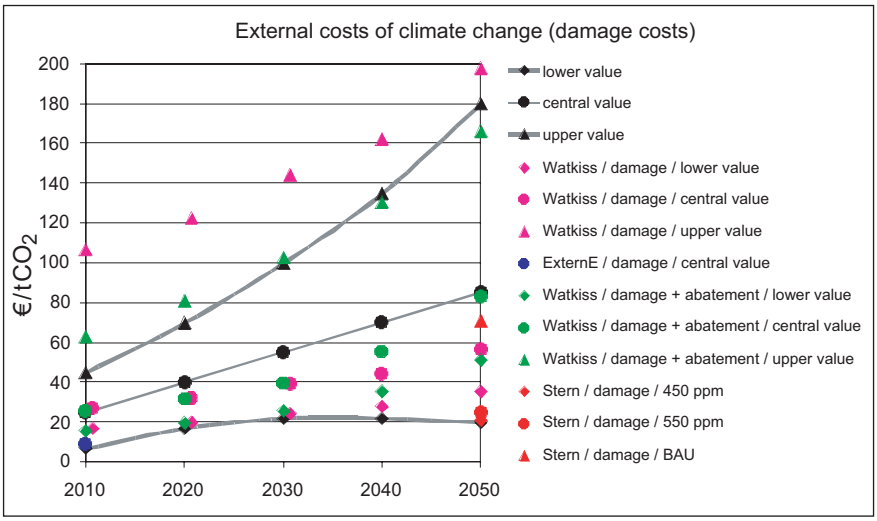
		Damage costs (€/tCO_2)			
Source	Year of application	Min	Central	Max	Comments
ExternE, 2005	2010		9		
Watkiss et al., 2005b	2000	14	22	87	Results based on damage costs only
	2010	17	27	107	
	2020	20	32	138	
	2030	25	39	144	
	2040	28	44	162	
	2050	36	57	198	
Watkiss et al., 2005b	2000	14	22	51	Results based on comparison of damage and abatement costs
	2010	16	26	63	
	2020	20	32	81	
	2030	26	40	103	
	2040	36	55	131	
	2050	51	83	166	
Tol, 2005		-4	11	53	Based on studies with PRTP = 1%
Stern, 2006*	2050		71		Business-as-usual scenario
	2050		25		Stabilisation at 550 ppm
	2050		21		Stabilisation at 450 ppm
DLR, 2006		15	70	280	Based on Downing, 2005

Source: CE, 2008b.

* See Box 3.

It may be noted that the values of damage costs recommended within the NEEDS project converge with the lower bound of the values proposed in Watkiss et al. (2005b).

Figure 3 Estimated damage costs of climate change according to various studies (€/tCO$_2$)



Box 3: The Stern Review

The Stern Review deserves special mention, not for its scientific merits but for its significant political impact. The report, which discusses the effects of climate change and global warming on the world economy, was issued on October 30, 2006 by economist Lord Nicolas Stern of Brentford for the British government. Its main conclusion is that the benefits of strong, early action on climate change considerably outweigh the costs. Stern proposes that one percent of global gross domestic product (GDP) *per annum* should be invested in order to avoid the worst effects of climate change, and that failure to do so could risk global GDP being up to twenty percent lower than it otherwise might be. For modeling damages, the Stern Review uses the PAGE model (one of the Integrated Assessment Models).

The Stern Review has been criticized by many economists. Most critiques relate to modeling details and assumptions, especially the assumed rate of discounting, which is very low compared with most other studies (Stern adopted a pure rate of time preference PRTP of 0.1% while in the NEEDS project, for example, a PRTP of 1% is assumed). The Stern estimates of damages related to GHG emissions are consequently much higher than those reported in most other studies. Tol (2008), for instance, concludes that the Stern Review is an outlier and that its impact estimates are pessimistic even when compared to grey literature and other estimates using low discount rates.

Despite the criticism, the Stern Review remains the most influential and most widely known and discussed report on the economics of climate change to date. Even some of Stern's adversaries admit the Stern review is 'right for the wrong reasons' (e.g. Arrow, 2007; Weitzman, 2007).
(Based on Tol (2008) and Wikipedia.)

C.2.3 Comparison with abatement costs

From comparing the estimates of CO_2 external costs based on the damage and avoidance cost approaches (based on CE, 2008b), the following conclusions can be drawn:

- Estimates based on damage costs tend to be *lower* than those based on abatement costs, certainly in the short term.
- The spread in estimates of short-term external costs among different studies is smaller for avoidance costs than for damage costs.
- The central values calculated in recent studies for long-term (i.e. 2050) damage and avoidance cost all tend to be in the same range: 50–100 €/tCO$_2$. The claim by Stern (2006) that the damage costs are higher

than the avoidance costs, which also appears to be the underlying assumption for the EU strategy aimed at stabilising global warming at 2ºC above pre-industrial levels, can be neither confirmed nor rejected on the basis of these recent estimates.
- Both damage costs and avoidance costs are expected to rise over time.

C.2.4 Conclusion and recommended values

We here adopt the approach followed in the IMPACT study based on a literature review of the various estimates for CO_2. In this approach the abatement costs are used for the time frame up to 2020, with damage costs being used thereafter. The reason for using abatement costs in the short term at least is based on the notion that current environmental policies obviously impose stricter targets than one would expect based on damage costs. The average marginal abatement cost of 25 €/tCO_2 for a 20% reduction is far above the median damage costs based on Tol (2008). The reason is that politicians obviously put a higher value on preserving the climate than economists would advocate. This may be for various reasons, such as omissions in the damage estimates (ignoring indirect effects), a lower time preference on the part of politicians than estimated by economists, moral imperatives such as 'global stewardship', etcetera. As yet, however, policies have only been formulated up to the year 2020. For emissions occurring after that date, IMPACT bases itself on damage costs for estimating longer-term impacts.

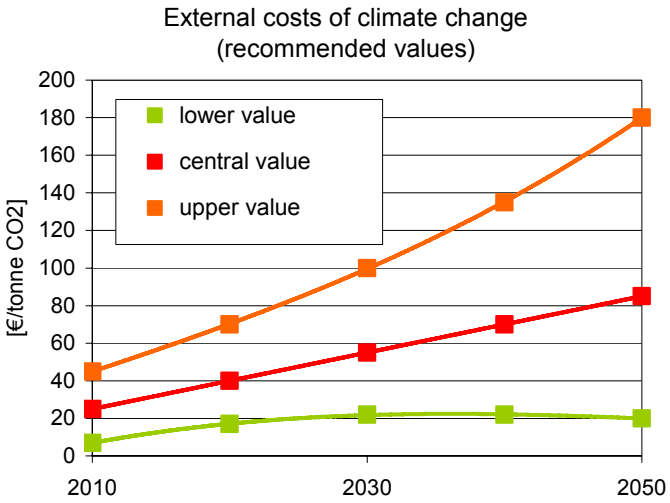
The recommended values for CO_2 shadow prices derived in this way are reported in Table 10 and Figure 4, specified for different years of application.

Table 10 **Recommended values for external costs of climate change (€/tCO_2), expressed as single values for a central estimate and lower and upper values**

	Central values (€/tCO_2)		
Year of application	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Source: CE, 2008b.

Figure 4 **Recommended values for external costs of climate change (€/tCO$_2$), expressed as single values for a central estimate and lower and upper values**



C.3 Acidification, photo-oxidant formation and particulate formation

This section deals with the damages due to acidification, photo-oxidant formation and airborne particulates, established using the Impact Pathway Approach and based largely on estimates from the NEEDS project. Description of the methodology draws extensively on NEEDS (2008a).

C.3.1 Methodology

The group of so-called classical air pollutants includes sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC). NMVOC and NO_x contribute to the formation of tropospheric ozone and ozone is therefore also sometimes referred to as a classical pollutant.

A state-of-the art method for calculating the external costs associated with emissions of classical pollutants is the Impact Pathway Approach developed within the framework of the ExternE[27] series of projects, as described in Chapter 5. The ExternE methodology aims to cover all relevant (i.e. non-negligible) external effects identified via the Impact Pathway Approach.

In this methodology local, Europe-wide and hemispheric modelling were used to simulate environmental quality status and estimate differences between specific cases of pollution and the reference situation. The exposure-response models were compiled and critically reviewed by the ExternE expert groups. Physical impacts were evaluated in monetary terms. For some of the impacts, market prices could be used to evaluate damages. For non-market goods, values were derived using stated and revealed preference methods (cf. Section 5.3).

[27] ExternE (External costs of Energy) is a series of research projects initiated by the European Commission aimed at estimating the socio-environmental damages associated with energy conversion.

With respect to particulate matter (PM), damage cost estimates performed within the NEEDS project are available for PM_{coarse} and $PM_{2.5}$, not for PM_{10}, which comprises both fractions. Based on current emission data for the Netherlands/Europe[28], we have calculated the fractions of $PM_{2.5}$ and PM_{co} in PM_{10}. Subsequently, the price to be assigned to PM_{10} was determined by weighting the prices of PM_{co} and $PM_{2.5}$ with their respective shares in PM_{10} emissions.

C.3.2 Health-related impacts

Health impacts are endpoints which can be modelled using the IPA. Two crucial elements of this approach are definition of concentration-response functions (CRF) and monetary valuation of health impacts.

Within the NEEDS project, a set of CRFs for PM and ozone and corresponding monetary values have been proposed. These functions are the most important and reliable concentration-response functions used in the ExternE series of projects for valuing the health effects associated with emissions of classical pollutants.

It should be noted that according to the recommendations of the NEEDS project experts, human health impacts have only been defined for particulate matter (primary as well as secondary) and ozone.[29] Impacts due to emissions of SO_2, NO_x and NH_3 are factored in after chemical transformation with reactants leading to an increase of concentration of secondary particulate matter (SIA, secondary inorganic aerosols). In the scientific community there is considerable debate on whether SIA has the same toxicity as primary particles, with no consensus yet emerging. In the NEEDS project it was therefore assumed that the damage due to SIA should be the same as for primary particles.

The general approach to estimating the effects of PM (or ozone) on morbidity uses the relative risk found in epidemiological studies, expressed as a percentage change in endpoint per (10) $\mu g/m^3$ PM_{10} (or $PM_{2.5}$) and links this with (i) the background level of the health endpoint in the target population, expressed as new cases per year per unit population, (ii) population size and age, and (iii) the relevant pollution increment, expressed in $\mu g/m^3$. The results are then expressed as extra cases, events or days per year attributed to PM (ExternE, 2005). Within the Ecosense model, uniform breakdown into age groups (Age Group Functions, AGF) and risk groups (Risk Group Functions, RGF) have been assumed for the whole of Europe, based on NEEDS (2007b).

Even though the risk of death due to diseases related to air pollution is lower that the risk of milder effects, reduced life time expectancy (YOLL) has the highest weight in the calculation of the total value of damages related to air pollution (see Table 11).

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28 Depending on the dataset.

29 These toxic impacts cover the bulk of the toxic impacts associated with these pollutants. However, NO_x also has a toxic effect other than through SIA. In this study this is taken into account in Section 4.6, using equivalence factors.

Table 11 Overview of -sponse functions for PM and ozone and corresponding monetary values

Core Endpoints	Pollutant	Risk group (RG)	RGF value	Age Groupe (AG)	AGF value	CRF [1/(µg/m3)]	phys. Impact per person per µg per m3 [1/(µg/m3)]	unit	Monet Val per case or per YOLL [Euro]	External costs per person per µg per m3 [1/(µg/m3)]
primary and SIA < 2.5, i.e. Particle < 2.5µm										
Life expectancy reduction - YOLLchronic	PM2.5	all	1.000	Total	1	6.51E-04	6.51E-04	YOLL	40,000	2.60E+01
netto Restricted activity days (netRADs)	PM2.5	all	1.000	MIX	1	9.59E-03	9.59E-03	days	130	1.25E+00
Work loss days (WLD)	PM2.5	all	1.000	Adults_15_to_64_years	0.672	2.07E-02	1.39E-02	days	295	4.10E+00
Minor restricted activity days (MRAD)	PM2.5	all	1.000	Adults_18_to_64_years	0.64	5.77E-02	3.69E-02	days	38	1.40E+00
primary and SIA < 10, i.e. Particle < 10µm										
Increased mortality risk (infants)	PM10	infants	0.002	Total	0.009	4.00E-03	6.84E-08	cases	3,000,000	2.05E-01
New cases of chronic bronchitis	PM10	all	1.000	Adults_27andAbove	0.7	2.65E-05	1.86E-05	cases	200,000	3.71E+00
Respiratory hospital admissions	PM10	all	1.000	Total	1	7.03E-06	7.03E-06	cases	2,000	1.41E-02
Cardiac hospital admissions	PM10	all	1.000	Total	1	4.34E-06	4.34E-06	cases	2,000	8.68E-03
Medication use / bronchodilator use	PM10	Children meeting PEACE criteria - EU average	0.200	Children_5_to_14	0.112	1.80E-02	4.03E-04	cases	1	4.03E-04
Medication use / bronchodilator use	PM10	asthmatics	0.045	Adults_20andAbove	0.798	9.12E-02	3.27E-03	cases	1	3.27E-03
Lower respiratory symptoms (adult)	PM10	symptomatic_adults	0.300	Adults	0.83	1.30E-01	3.24E-02	days	38	1.23E+00
Lower respiratory symptoms (child)	PM10	all	1.000	Children_5_to_14_years	0.112	1.86E-01	2.08E-02	days	38	7.92E-01
Ozone [µg/m3] - from SOMO35										
Increased mortality risk	SOMO35	Baseline_mortality	0.0099	Total (YOLL = 0.75a/case	1	3.00E-04	2.23E-06	YOLL	60,000	1.34E-01
Respiratory hospital admissions	SOMO35	all	1.000	Elderly_65andAbove	0.158	1.25E-05	1.98E-06	cases	2,000	3.95E-03
MRAD	SOMO35	all	1.000	Adults_18_to_64_years	0.64	1.15E-02	7.36E-03	days	38	2.80E-01
Medication use / bronchodilator use	SOMO35	asthmatics	0.045	Adults_20andAbove	0.798	7.30E-02	2.62E-03	cases	1	2.62E-03
LRS excluding cough	SOMO35	all	1.000	Children_5_to_14_years	0.112	1.60E-02	1.79E-03	days	38	6.81E-02
Cough days	SOMO35	all	1.000	Children_5_to_14_years	0.112	9.30E-02	1.04E-02	days	38	3.96E-01

Abbreviations: Risk Group, RG: group within the general population with a handicap; RGF value: share of RG within the general population; Age group, AG: groups distinguished by different age cohorts; AG value: share of different age cohorts; CRF: concentration-response function; YOLL: Years of Life Lost; RAD: Restricted Activity Days; SIA: Secondary Inorganic Aerosols; SOMO35: sum of ozone means over 35 ppb; WLD: Work Loss Days; MRAD: Minor Restricted Activity Days; LRS: lower respiratory symptoms.
Table constructed for the whole of Europe.
Source: NEEDS (2008a), based on NEEDS (2007b).

Based on the CRFs and monetary valuation (see Chapter 5), a set of values for the external costs per tonne of pollutant has been proposed after modelling a 15% reduction of emissions of each pollutant in different regions using the EcoSense model.[30] The results are available for emissions occurring in 39 European and non-European countries and five marine regions and also include emission-weighted average values for the EU-27. The receptor domain covers the whole of Europe. In addition to modelling the impact of emissions occurring in Europe and adjacent areas, a Northern Hemispheric Model was employed to estimate the external costs of impacts on human health outside Europe caused by emissions of classical pollutants in Europe. These values were derived by applying the same CRF and monetary valuation of impacts as within Europe, regardless of whether the impacts take place in America or Asia, say. In the tables below we first give the values of impacts in Europe and then also the values derived from the Northern Hemispheric Model.

For some substances, different values are given for low height of release, unknown height of release and high height of release. These numbers were estimated using the EcoSense model by using different sets of source-receptor matrices (SRM), using the procedure described below.

[30] http://EcoSenseWeb.ier.uni-stuttgart.de.

The SRM were derived by simulating a 15% emission reduction in each sub-region. This was done in two ways, providing two sets of SRM, viz.:

- For pollutants from all sources, i.e. all SNAP sectors (i.e. including transport, industry, domestic firing systems, but also combustion plants).
- For pollutants (primary particles, SO_2 and NO_x) from SNAP sector 1 (combustion in power plants) only.

Since the first SRM set provides an average value for all emissions, these values have been used for the estimates with unknown height of release. The second SRM set corresponds to releases above 100 m. Further processing of the results allowed €/t values to be derived corresponding to low height of release for primary particulate matter, i.e. below 100 m.

Summarising, if the height of release is unknown, as is often the case in LCA data that includes all a product's life cycle stages, the corresponding values of unknown height of release should be used. If the height of release is approximately known, the values referring to low height of release should be taken for emissions with a release height below 100 m, and the values referring to high height of release should be taken for emissions above 100 m. For emissions from power plants, the results according to high height of release should be used (NEEDS, 2008a).

An Excel tool developed within the NEEDS project permits user-defined assumptions regarding year of emission. The values are provided in two formats: discounted to the year of emission and discounted to the year 2000. In Table 12 and Table 13 we report the estimated external costs associated with the various specific pollutants for emissions in the year 2008, discounted to the year of emission for the EU-27 and the Netherlands, respectively.[31] The original values from the Excel tool, which are given in Euros of 2000, have been adjusted to 2008 prices using the Harmonised Index of Consumer Prices (cf. Annex A).

Table 12 **External costs related to human health per tonne of specific classical air pollutants released in a specific year and discounted to that year ($Euro_{2008}$): EU-27 average**

Pollutant	External cost 2008 at given height of release		
Height of release	**Low**	**Unknown**	**High**
NH_3	13,040.71	13,040.71	13,040.71
NVMOC	802.80	802.80	802.80
NO_X	7,689.11	7,689.11	**5,659.27**[1)]
PMco[32]	**2,026.23**	1,821.93	**673.01**
$PM_{2.5}$	**35,616.50**	33,574.64	**1,6856.42**
SO_2	8,347.69	8,347.69	**7,671.08**

Notes: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: CASES, 2008.

[31] 'Discounted to the year of emission' means that all non-negligible health impacts that may occur in future years due to emission of a given substance are discounted back to the year of emission. With some substances, like PM, the impact lasts for a relatively short time and is assumed to persist for one year, while the impact of other substances, like CO_2 and heavy metals, may prevail for several hundred years.

[32] PMco (PM coarse) is particulate matter with a diameter between 2.5 and 10 µm.

Table 13 **External costs related to human health per tonne of specific classical air pollutants released in a specific year and discounted to that year ($Euro_{2008}$): values for emissions from the Netherlands**

Pollutant	External cost 2008 at given height of release		
	Low	Unknown	High
NH_3	23,110.50	23,110.50	23,110.50
NMVOC	1,670.79	1,670.79	**1,670.79**
NO_X	9,093.71	9,093.71	**7,113.44**
PMco	**3,854.17**	3,842.77	**1,957.73**
$PM_{2.5}$	**65,341.78**	64,535.87	**29,708.46**
SO_2	14,114.75	14,114.75	**10,595.05**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: CASES, 2008.

As can be seen in the tables, the height of release is especially relevant in the case of particulate matter, where impacts for high height of release may be over 50% lower than in the case of unknown or low height of release. Such differences are due to different types of emission characteristic for different heights of release. Transport and domestic firing systems are characterized by a low height of release, where the density of receptors is higher, while high emissions from power plant stacks diffuse over a much greater area, with on average a far lower population density.

Table 14 reports the estimates obtained in the NEEDS project by Northern Hemispheric Modeling (NHM), i.e. for the impacts of pollutants emitted within Europe to other regions. These numbers give only a rough estimate and are the same for emissions occurring anywhere in Europe at any height of release, so in Table 14 in the first column we show general numbers that apply to both the EU-27 and the Netherlands. The two last columns give the total impact on human health from the emissions occurring in the EU-27 and in the Netherlands, after summing the impact within Europe and outside Europe (Table 14 reports only the figures for unknown height of release). As can be seen, for certain pollutants like NH_3 and PPMco, the additional impact associated with non-European receptors is very small, below 1% of the total figure, while for others, especially NMVOC, this additional impact is relatively high, constituting about 20-40% of the total impact value. These differences are due to physical characteristics of the specific substances and, in particular, the likelihood of being transported over long ranges.

Table 14 **Values (€/t of emissions) for Northern Hemispheric Modelling (NHM) and total external costs for human health ($Euro_{2008}$): values for emissions from the EU-27 and the Netherlands**

	Average estimates for NHM	Total EU-27	Total Netherlands
NH_3	3.73	13,044.44	23,114.23
NMVOC	491.66	1,294.46	2,162.45
NO_X	180.15	7,869.26	9,273.86
PMco	2.88	1,824.81	3,845.65
$PM_{2.5}$	216.92	33,791.57	64,752.80
SO_2	382.53	8,730.22	14,496.28

Source: Own calculations based on CASES, 2008.

The values reflecting the impact of classical pollutants on human health change over time because of two factors: 1) an 'uplift factor' related to economic growth, which means that VOLY and other factors forming the basis for valuing the CRF functions for human health are expected to grow in real terms (according to the assumptions made within the NEEDS project, the uplift factor equals 1.7% until 2030 and 0.85 thereafter), and 2) a change in background pollutant emissions, which in the Ecosense model is assumed to occur in the year 2015. For emissions between 2000 and 2014, the model is based on background emissions for 2010, while for later years predicted background emissions for the year 2020 are used (NEEDS, 2008a). The latter factor has a different impact on different values (so no systematic increase or decrease of all estimates can be observed).

C.3.3 Impacts on agricultural crops

Within the NEEDS project, the impacts of air pollution on crops have been divided into impact of SO_2, acidification of agricultural soils due to NH_3, SO_2 and NO_x, impact of ozone and effects of nitrogen deposition (NEEDS, 2008a).

Impact of SO_2

The CRF function for SO_2 assumes that yields will increase with SO_2 concentrations from 0 to 6.8 ppb (part per billion on a molecular level) and decline thereafter. The function is used to quantify changes in crop yield for wheat, barley, potato, sugar beet and oats and is defined as:

$y = 0.74 \cdot [SO_2] - 0.055 \cdot [SO_2]^2$ for $0 < [SO_2] < 13.6$ ppb
$y = -0.69 \cdot [SO_2] + 9.35$ for $[SO_2] > 13.6$ ppb

with y = relative yield change; and
$[SO_2]$ = SO_2 concentration in ppb.

Acidification of agricultural soils

For acidification effects, an upper-bound estimate of the amount of lime required to balance atmospheric acid inputs on agricultural soils across Europe has been estimated. Ideally, the analysis of liming would be restricted to non-calcareous soils, but this refinement has not been introduced given that even the upper-bound estimate of additional liming requirements is small compared with other externalities. The additional lime required is calculated as:

$dL = 50\ kg/meq \cdot A \cdot dDA$

with dL = additional lime requirement in kg/year;
A = agricultural area in ha; and
dDA = annual acid deposition in $meq/m^2/year$.

Impact of ozone

For the assessment of ozone impacts, a linear relationship between yield loss and the AOT 40 value (Accumulated Ozone concentration above a Threshold of 40 ppbV) calculated for the crop growing season (May to June) has been assumed. The relative yield change is then calculated using the following equation together with the sensitivity factors given in Table 15:

$y = 99.7 - Alpha \cdot AOT40crops$

with y = relative yield change; and
Alpha = sensitivity factors.

Table 15 Sensitivity factors for different crop species

Crop species	Sensitivity factor
Rice	0.4
Tobacco	0.5
Sugar beet, potato	0.6
Sunflower	1.2
Wheat	1.7

Fertilisation effects from nitrogen deposition

When it comes to nitrogen there is also a beneficial effect, in the sense that nitrogen is an essential plant nutrient, applied by farmers in large quantities to their crops. Deposition of oxidised nitrogen on agricultural soils is thus beneficial (assuming the dosage of any fertiliser applied by the farmer is not excessive). The reduction in fertiliser requirement is calculated as:

$$dF = 14.0067\ g/mol \cdot A \cdot dDN$$

with dF = reduction in fertiliser requirement in kg/year.
A = agricultural area in km^2. And
dDN = annual nitrogen deposition in meq/m^2/year.

C.3.4 Monetary valuation of crop losses

Crop losses are assessed in monetary terms using the prices of the crops damaged by air pollution. Table 16 summarises the prices per tonne used within the NEEDS project for assessing crop damage due to air pollution.

Table 16 Updated prices of major crops used within the NEEDS project (€/t)

	Updated price per tonne	Source
Sunflower	273	FAOSTAT ($€_{2001}$)
Wheat	137	IFS ($€_{2003}$)
Potato	113	FAOSTAT ($€_{2001}$)
Rice	200	IFS ($€_{2003}$)
Rye	99	FAOSTAT ($€_{2001}$)
Oats	132	FAOSTAT ($€_{2001}$)
Tobacco	2,895	IFS ($€_{2003}$)
Barley	93	IFS ($€_{2003}$)
Sugar beet	64	FAO ($€_{2002}$)

Source: ExternE, 2005.

It should be noted that prices have fluctuated significantly in recent years, with those for major crops like wheat and potato rising until 2008 and subsequently falling. As future crop prices remain uncertain, in this project we have opted to stick to the values used in the NEEDS project.

Average values for the impact of acidification and ozone on agricultural crops due to emissions of NO_x, SO_2, NH_3 and NMVOC generated in 2008 at unknown, low and high height of release based on the results of the NEEDS project are reported below in Table 17 and Table 18. Table 17 gives the values estimated for the EU-27, Table 18 those for the Netherlands. According to the Ecosense calculations, the values for EU-27 are the same for unknown and low height of release thus they are reported in one column.

Table 17 **External costs related to agricultural crop damage per tonne of specific classical air pollutants (Euro$_{2008}$), EU-27 average**

Pollutant	External cost 2008 at given height of release	
	Unknown/low	High
NH_3	-219.93	-219.93
NMVOC	227.14	227.14
NO_X	**394.19**	216.32
SO_2 primary particles	**-32.45**	-22.83
SO_2 secondary particles*	**-15.62**	-9.61

Notes: Values in bold indicate that the values for unknown/low height of release differ from those for high height of release.

* For SO_2 two models have been used, in order to include the impact of both primary and secondary particles. To model sulphate formation a Windrose Trajectory Model (WTM) was used (ExternE, 2005).

Source: CASES, 2008.

Table 18 **External costs related to agricultural crop damage per tonne of specific classical air pollutants (Euro$_{2008}$), values for the emissions from the Netherlands**

Pollutant	External cost 2008 at given height of release		
	Low	Unknown	High
NH_3	- 200.01	- 200.01	- 200.01
NMVOC	461.76	461.76	461.76
NO_X	- 266.69	-266.69	**- 187.48**
SO_2 primary particles	- 41.04	- 41.04	**-69.70**
SO_2 secondary particles	**-70.91**	-72.11	**-74.51**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: CASES, 2008.

Note that in some cases negative values are reported to account for the fact that up to a certain concentration certain substances (specifically, nitrogen and sulphur dioxide) have a beneficial impact: they act as fertilisers. Negative values can thus be interpreted as benefits.

With regard to the development of the values over time, up to the year 2014 the values are the same in constant prices; from 2015 they differ because of the different background concentrations assumed in the Ecosense model from the year 2015 onwards.

C.3.5 Impacts on buildings and capital goods

Air pollutants emitted by the burning of fossil fuels have a serious impact on buildings. The most important pollutants in this category are sulphur and nitrogen compounds, including secondary pollutants and particulates (primarily SO_2, NO_2, O_3 and their reaction products). The effects include loss of mechanical strength, leakage and failure of protective coatings due to the degradation of materials. Within the two-step approach adopted in ExternE, the exposure-response functions link the ambient concentration or deposition of pollutants to the rate of material corrosion, and the rate of corrosion to the time of replacement or maintenance of the material. Performance requirements determine the point in time at which replacement or maintenance is deemed to become necessary. This point is given in terms of critical degradation (ExternE, 2005).

In EcoSenseWeb a CRF has been implemented for the following materials:
- Limestone.
- Sandstone.
- Natural stone, mortar, rendering.
- Zinc and galvanised steel.
- Paint on steel.
- Paint on galvanised steel.
- Carbonate paint.

The monetary values used for evaluating impacts to building materials are based on replacement and repair costs and are reported in Table 19.

Table 19 Monetary values used for the evaluation of impacts to building materials

Materials (maintenance costs per m^2)	Monetary value ($€_{2000}$)
Galvanised steel	Country-specific (17-55)
Limestone	299
Mortar	33
Natural stone	299
Paint	13
Rendering	33
Sandstone	299
Zinc	27

Source: NEEDS, 2008a.

Average values for the impact of NO_x and SO_2 emissions generated at unknown, low and high heights of release in 2008 on buildings and materials are reported below in Table 20 and Table 21. Table 20 gives the values estimated for the EU-27, Table 21 those for the Netherlands.

Table 20 External costs of damage to buildings and materials per tonne of specific classical air pollutants ($Euro_{2008}$), EU-27 average

Pollutant	External cost 2008 at given height of release		
	Low	Unknown	High
NO_x	**84.13**	85.33	85.33
SO_2	**344.92**	311.27	**277.62**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: CASES, 2008.

Table 21 External costs of damage to buildings and materials per tonne of specific classical air pollutants ($Euro_{2008}$), values for the Netherlands

Pollutant	External cost 2008 at given height of release		
	Low	Unknown	High
NO_x	**84.13**	99.75	**98.55**
SO_2	**344.92**	543.21	**592.49**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: CASES, 2008

These values remain unchanged regardless of assumptions about the year of emission.

C.3.6 Impacts on ecosystems

Within ExternE, the environmental impact of air pollution on biodiversity has been estimated for emissions of SO_2, NO_x and NH_3. This impact is associated with acidification and eutrophication of soils. An approach using the measure 'potentially disappeared fraction' (PDF), i.e. biodiversity losses due to acidification and eutrophication, was used (NEEDS, 2008a).

Acidification is caused mainly by emissions of sulphur oxide (SO_x), nitrogen oxides (NO_x) and ammonia (NH_3) and the attendant deposition of acidifying substances like H_2SO_4 as well as a range of sulphates. Eutrophication due to airborne pollutants is due mainly to NO_x and NH_3.

Concentration-response function

For any given land use type, a certain average number of plant species can generally be established. If the soil becomes polluted due to deposition of acifidfying and eutrophying substances, the number of species present and thus biodiversity are reduced. Hence, a delta PDF per deposition can be calculated.

In EcoSense the following information is used to model the loss of biodiversity due to SO_2, NO_x and NH_3 emissions, using the following data:

- Values of PDF per deposition of N and S on natural soils are taken from Ott et al. (2006); see Table 22.
- Depositions per 50 x 50 km^2 grid cell are available from regional dispersion modelling.
- In addition, for each grid cell the share of natural soil is available.
- Finally, a (country-dependent) 'pressure index' is used to account for differences in soil sensitivity.

Table 22 PDF per deposition of N and S on natural soil

Air pollutant	Deposition increase in kg/m^2 * year on natural soil (10 mol/ha)	Average PDF of natural land for the Netherlands	PDF * m^2 * year per kg deposition
Reference Value (Background Level)	--	0.746429	--
SO_x	6.4 * 10-5	0.74654	1.73
NO_x	4.6 * 10-5	0.746867	9.52
NH_3	1.7 * 10-5	0.74687	25.94

Source: NEEDS, 2008a.

Monetary valuation

Within the NEEDS project, the evaluation has been updated according to an average WTP for Europe from Kuik et al. (2008) of 0.47 €/PDF/m^2 (2004 prices) rather than the value of 0.45 €/PDF/m^2 used previously in ExternE, which was based on minimum restoration costs. Since the new value is based on WTP studies, it has been adopted here as more suitable for external cost calculation.

The approach described above is designed to be applicable on a European scale and will not therefore reflect very specific local conditions, e.g. the occurrence of species that are unique to a single location. However, the values proposed may serve as a first approximation.

Table 23 and Table 24 report estimated values of the external costs associated with the impact of the specific pollutants on biodiversity, for emissions generated at unknown/low and high height of release (for this category the values for unknown and low height are the same) occurring in the year 2008, discounted to the year of emission. Table 23 gives the values estimated for the EU-27, Table 24 those for the Netherlands.

Table 23 External costs of impacts on biodiversity loss per tonne of specific classical air pollutants emitted in 2008 (€$_{2008}$), EU-27 average

Pollutant	External cost 2008 at a given height of release	
	Unknown/low	High
NH_3	4,688.22	4,688.22
NMVOC	-97.35	-97.35
NO_X	1,295.54	**1,190.98**
SO_2	253.58	**186.28**

Note: Values in bold indicate that the values for high height of release differ from those for unknown/low height of release.

Source: CASES, 2008.

Table 24 External costs of impacts on biodiversity loss per tonne of specific classical air pollutants emitted in 2008 (€$_{2008}$), values for the Netherlands

Pollutant	External cost 2008 at a given height of release	
	Unknown/low	High
NH_3	4,859.77	4,859.77
NMVOC	-87.30	-87.30
NO_X	1,479.46	**1,442.16**
SO_2	453.18	**1,002.30**

Note: Values in bold indicate that the values for high height of release differ from those for unknown/low height of release.

Source: CASES, 2008.

As can be seen in the tables, the impact of NMVOC (non-methane volatile organic compounds) on biodiversity is on average beneficial, resulting in negative damage values.

Development of the values related to biodiversity loss over time is conditional on the same factors as values for human health impact, i.e. on uplift factor (always positive) and on a change of background emissions assumed in the Ecosense model after the year 2014 (this factor causes an increase of some of the values and a decrease of others).

C.3.7 Impacts not covered in the damage estimates

Classical air pollutants may have two other impacts which are not included in most estimates, nor in this handbook. These are:

- Impacts on cultural heritage.
- Impacts on visibility.

It should be noted that the value of these impacts is probably very small compared to the total estimates of damages due to these pollutants. However, if a SCBA is oriented specifically towards these impacts (or if these impacts are to be deemed large), additional estimates may be provided. Some rough estimation procedures for this purpose are now given.

Cultural heritage

It is worth noting that the NEEDS estimates cited above do not capture any historical or artistic values that can be attached to certain buildings, so that the reported values can be regarded as a lower bound reflecting only use values related to 'regular' buildings and materials. To date, no database exists that could link existing relevant valuation studies with all the historical and artistic objects across Europe. An estimated figure for such values can be derived from empirical studies focusing on specific objects and monuments, or at least on the specific categories of such objects.

Maintenance costs for historical buildings are much more variable than the maintenance costs for 'ordinary' houses. The range of Willingness-to-Pay values for preserving cultural heritage reported in different studies reviewed in ExternE (2005) is very broad: from € 1 to € 86 a year (this range reflects different methodologies, however, and covers both individual and household WTPs).

Rabl (1999) has proposed a method for calculating damage values for cultural heritage, whereby he claims that for a typical case the amenity loss can be assumed to be approximately equal to soiling costs (for a zero discount rate). Hence, the total damage costs can be estimated to be twice the value of the cleaning costs. The key assumptions in this approach are: 1) the amenity loss is restored by renovation (cleaning and repair); 2) people minimise the total cost; and 3) the decision to clean or repair a given object is made by the people suffering the amenity loss. The proposed function relates the soiling damage at receptor location i to the concentration of total suspended matter (TSP):

$$S_i = a * P_i * \Delta TSP$$
$$\text{and } a = b * 2$$

where S_i is annual soiling damage at receptor location i, P_i is the number of people at location I, ΔTSP is a change in annual average concentration of Total Suspended Particles in μg/m^3, a is WTP per person per year to avoid soiling damage of 1 μg/m^3, and b stands for cleaning costs per person per year due to a concentration of 1 μg/m^3 of TSP.

Visibility

Visibility impacts are associated with a reduction in visual range due to the presence of pollutants, especially NO_2, in the atmosphere. In Europe this issue has received relatively little attention, but in the United States there has been a comprehensive study on the topic (ABT, 2000), with the goal of estimating a general relationship between improvement in visibility and the average value placed on such improvements. A plausible relationship was found regarding recreational value in national parks. In addition, a relationship between visibility changes in residential areas and household values for these changes was established. Both relationships were assessed with respect to relative rather than absolute visibility ranges.

Annual values per household for visibility improvements depend very much on location. For example, for a 20% improvement in visibility, values for recreational use were estimated in the range USD11-19 (1999 prices), and values for residential areas in the range of USD24-278 (1997 prices) (ABT, 2000).
Based on this information, it is impossible to relate visibility impacts to a certain dose (e.g. tonne) of specific pollutants. Using values for relative visibility changes based on the US studies in Europe would be inappropriate,

because of major uncertainties in benefit transfer. ExternE (2005) suggests that in the absence of comprehensive European studies on this topic, policy measures with discernible effects on visibility should be assessed in qualitative terms only.

C.3.8 Summarising tables

Table 25 and Table 26 report the total damage costs associated with classical pollutants. In these tables, the values reflecting impacts of specific pollutants emitted in 2008 on human health (including Nothern Hemispheric Modelling, NHM), crops, materials and biodiversity have simply been summed. Table 25 gives the values estimated for the EU-27, Table 26 those for the Netherlands.

Table 25 **Total impact of the specific pollutants (€$_{2008}$ per tonne emission), discounted to year of emission 2008, EU-27 average**

Pollutant	External cost 2008 at a given height of release		
	Low	Unknown	High
NH_3	17,512.73	17,512.73	17,512.73
NMVOC	1,424.25	1,424.25	1,424.25
NO_X	**9,643.11**	9,644.31	**7,332.05**
PPMco	**2,029.12**	1,824.81	**675.89**
$PPM_{2.5}$	**35,833.42**	33,791.57	**17,073.35**
SO_2	9,274.64	9,247.00	**8,485.06**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: Tables in Sections C.3.2-C.3.6, own calculations.

Table 26 **Total impact of the specific pollutants (€$_{2008}$ per tonne emission), discounted to year of emission 2008, values for the Netherlands**

Pollutant	External cost 2008 at a given height of release		
	Low	Unknown	High
NH_3	27,773.99	27,773.99	27,773.99
NMVOC	2,536.91	2,536.91	2,536.91
NO_X	**10,570.76**	10,586.38	**8,646.82**
PPMco	**3,857.05**	3,845.65	**1,960.61**
$PPM_{2.5}$	**65,558.70**	64,752.80	**29,925.38**
SO_2	**15,223.47**	15,379.52	**12,428.16**

Note: Values in bold indicate that the values for low/high height of release differ from those for unknown height of release.

Source: Tables in Sections C.3.2-C.3.6, own calculations.

C.3.9 Emissions from transport

The emissions presented in this handbook are averages for an entire country, viz. the Netherlands, and may not be representative of true damages at the local level, owing to differences in:

a Population density: in densely populated areas damages will obviously be greater than in more sparsely populated areas.

b The pollution source: this is especially relevant for particulate emissions, as transport emissions, emitted at lower ambient levels, will be more harmful than those from point sources higher up.

Within the NEEDS project, no specific values for transport emissions have been estimated. Such estimates have been produced in several other projects, though, for example in the IMPACT handbook (CE, 2008b) based on various HEATCO studies. Here, we reproduce the estimates from the IMPACT study for

human-health effects due to emissions of $PM_{2.5}$; see Table 27 for the estimates for emissions in the Netherlands. The value of € 65,558.70 estimated in the NEEDS project for low height of emission (and transport can be assigned to this category) would be substantially higher if population density and emissions source are taken into account.

Table 27 **Air pollution costs in €/tonne of pollutant for road, rail and waterways (€$_{2008}$ per tonne pollutant) from HEATCO and NEEDS**

Pollutant	$PM_{2.5}$ (exhaust)			PM_{10} (non-exhaust)		
Receptor scope	Urban metropolitan	Urban	Outside built-up areas	Urban metropolitan	Urban	Outside built-up areas
The Netherlands	507,759.83	163,925.30	99,268.55	203,103.93	65,498	39,659.35
Low height of emission (NEEDS)	65,558.70					

* Urban metropolitan: cities with over 0.5 million inhabitants.

** Urban: smaller and medium-sized cities with up to 0.5 million inhabitants.

Source: CE, 2008b.

The figures in Table 27 need some explanation, specifically for comparison with the NEEDS estimates:

- Within the NEEDS project it is assumed that primary and secondary particles are equally harmful per unit mass, irrespective of particle composition. HEATCO treats the various particle fractions and sources as follows: (1) nitrates as equivalent to 0.5 times the toxicity of PM_{10}; (2) sulphates as equivalent to PM_{10} (or 0.6 times $PM_{2.5}$); (3) primary particles from power stations as equivalent to PM_{10}; (4) primary particles from vehicles as equivalent to 1.5 times the toxicity of $PM_{2.5}$.
- Within NEEDS a general dispersion model is used for PM emissions, while HEATCO presents values differentiated by urban and interurban traffic situations.

The values used in NEEDS and HEATCO for VOLY are largely the same, however. Within HEATCO, for acute exposure a value of € 60,500 per year of life lost (YOLL) is taken and for chronic mortality € 40,300, both very similar to the values used in NEEDS (€ 60,000 and € 40,000, respectively).

In addition to the detrimental impact of air pollutants on human health, external costs of transport include congestion, noise and accidents. For estimates of these effects, the reader is referred to the IMPACT handbook and/or source publications cited within the IMPACT handbook.

C.4 Human toxicity

Human toxicity potential (HTP) is an indicator used to compare the relative importance of toxic emissions. The HTP is a characterisation method used to weight emissions, such as those listed in life-cycle inventories and toxic release inventories. HTP is a screening-level risk indicator that accounts for both toxicity and the potential to result in exposure, but this does not generally account for regional differences or variations in population density. Within the HTP indicator, over 300 substances are classified according to the potential damage they can cause.

In Section C.3. we established a shadow price for $PM_{2.5}$. Since the underlying damage under the heading 'human toxicity' relates by definition to human toxic impacts only, one would anticipate being able to use the characterisation factors (in DALY) to establish the potential damages from other pollutants, too. This would yield a relatively simple approach that would, from a methodological point of view, be transparent. However, this choice depends crucially on the reliability of the particular endpoint factors being used. Moreover, since there are several small differences in the background documentation regarding population size, age cohorts and years of reference used in both the estimation for $PM_{2.5}$ and the characterisation factors used in the ReCiPe project, this approach will not yield entirely consistent estimates for HTP. In this handbook we have therefore chosen to add our own estimates for a selected number of additional toxic pollutants, to extend the coverage of our damage estimates. These additional estimates were also developed in the ExternE projects.

C.4.1 Methodology

Within the NEEDS project, damage costs have been established for several toxic pollutants, viz. heavy metals, formaldehyde and dioxins. Country-specific results used in the NEEDS project regarding the inhalation pathway for heavy metals (As, Cd, Cr, Ni, Pb) have been calculated in the ESPREME project (ESPREME, 2007), with country-specific values regarding ingestion being calculated for As, Cd and Pb in the NEEDS project (Fantke, 2008). The Excel tool developed in NEEDS also includes values for mercury, formaldehyde and dioxins based on various studies. These are so-called generic values, expressed directly as 'Euro per tonne'. As these are European averages, they are applicable to all the countries of Europe and any height of release.

The value for Cr-VI is derived from the value for Cr. It is assumed that Cr-VI is the only toxic form of chromium and that this accounts for approx. 20% of environmental chromium. Hence, the monetary value for Cr-VI is around 5 times that for Cr. Consequently, damage costs for either Cr or Cr-VI must be used, and not both.

CRF for inhalation of heavy metals can be found in ESPREME (2007), Spadaro and Rabl (2008) and MethodEx (2006). Country-specific external costs associated with inhalation of heavy metals are included in the EcoSense model.

For As, Cd and Pb there has been a parameterisation of new WATSON model runs including ingestion of food and drinking water due to emissions into air. This is described in Fantke (2008). The CRF functions associated with As, Cd and Pb are summarised in Table 28 and Table 29.

Table 28 **Physical endpoints of human health effects due to ingestion of food, as used in the parameterisation procedure (Fantke 2008)**

Pollutant	Endpoint		Risk Group	Expos. Time	Unit Risk	Severits Measure			Costs per Case
-	Name	Fatality	-	(years)	(risk/kgi$_{ntake}$)	YOLL	YLD	IQ Points	(€/case)
As	Skin cancer	85%	All	70	7.85E-01	5.18	0.16	0	213,520
As	Bladder cancer	85%	All	70	3.91E+00	3.94	0.31	0	169,660
As	Cardiovascular mortality	100%	All	35	2.35E+02	12.80	1.00	0	512,000
As	Still birth (babies)	100%	All	1	2.86E+02	0.00	1.28	0	51,200
Cd	Osteoporosis	100%	All	35	6.26E+02	0.00	0.28	0	11,200
Cd	Renal dysfunction	100%	All	35	3.13E+01	0.00	0.64	0	25,600
Pb	Anaemia	100%	All	1	1.32E+02	0.00	0.64	0	25,600
Pb	IQ points loss (children)	100%	0-1 years	1	1.15E+03	0.00	0.00	1	8,600

Source: Fantke, 2008.

Table 29 **Physical endpoints of human health effects due to ingestion of drinking water, as used in the parameterisation procedure**

Pollutant	Endpoint		Risk Group	Expos. Time	Unit Risk	Severits Measure			Costs per Case
-	Name	Fatality	-	(years)	(risk/kgi$_{ntake}$)	YOLL	YLD	IQ Points	(€/case)
As	Skin cancer	85%	All	70	7.85E-01	5.18	0.16	0	213,520
As	Bladder cancer	85%	All	70	3.91E+00	3.94	0.31	0	169,660
As	Cardiovascular mortality	100%	All	35	2.35E+02	12.80	1.00	0	512,000
As	Still birth (babies)	100%	All	1	2.86E+02	0.00	1.28	0	51,200
Cd	Osteoporosis	100%	All	35	6.26E+02	0.00	0.28	0	11,200
Cd	Renal dysfunction	100%	All	35	3.13E+01	0.00	0.64	0	25,600
Pb	Anaemia	100%	All	1	2.74E+02	0.00	0.64	0	25,600
Pb	IQ points loss (children)	100%	0-1 years	1	1.15E+03	0.00	0.00	1	8,600

Source: Fantke, 2008.

C.4.2 Monetary valuation

The monetary valuation of morbidity and mortality is based on multiplication of the YOLL (years of life lost) and the YLD (years lost due to disability) by the corresponding monetary value of a life year lost, i.e. € 40,000 per VOLY. The monetary valuation of IQ loss is based on Spadaro and Rabl (2008) and is € 8,600 per IQ point.

Table 30 and Table 31 provide a summary of monetary values per tonne of specific pollutants. These are values for the external costs associated with the impact of these pollutants on human health, for emissions occurring in the

year 2008, discounted to the year of emission. It should be noted that these values are relevant only for emissions of the substances to the atmosphere. As indicated in the previous section, however, the impact of some of these substances (As, Cd, Pb) has been evaluated based on models describing ingestion via food and water (i.e. not only via inhalation). Table 30 reports the values estimated for the EU-27, Table 31 those for the Netherlands. These values remain the same regardless of the height of release.

Table 30 **Values of external costs associated with human health impacts per tonne of specific pollutants (€$_{2008}$), EU-27 average**

Pollutant	External cost 2008
Cd	115,149.41
As	728,378.29
Ni	3,164.38
Pb	382,726.15
Hg	11,002,445.72
Cr	18,224.47
Cr-VI*	91,122.34
Formaldehyde	275.06
Dioxin	5,09E+10

* The values for Cr and Cr-VI should be used separately and not both.

Source: CASES, 2008.

Table 31 **Values of external costs associated with human health impacts per tonne of specific pollutants (€$_{2008}$), values for the Netherlands**

Pollutant	External cost 2008
Cd	126,863.64
As	811,080.11
Ni	5,366.44
Pb	407,702.57
Hg	11,002 445,72
Cr	33,461.19
Cr-VI*	167,305.94
Formaldehyde	275.06
Dioxin	5.09E+10

* The values for Cr and Cr-VI should be used separately and not both.

Source: CASES, 2008.

C.5 Eutrophication

Eutrophication is the nutrient enrichment of the aquatic environment (eutrophication of freshwater bodies) or terrestrial environment (eutrophication of soils).

C.5.1 Eutrophication of freshwater bodies

Nutrients that are limiting to the yield of aquatic biomass are phytoplankton (algae), but also duckweed. The growth of algae is governed mainly by the availability of phosphorus and nitrogen. As a result, additional influx of P and N may lead to increased algal growth, causing a chain of adverse ecological effects. The relevant substances include phosphorus and nitrogen compounds emitted to water and soils as well as ammonia (NH_3) and nitrogen oxides (NO_x) emitted to air. In temperate and subtropical regions of Europe, freshwaters

are typically limited by phosphorus, while in marine waters it is usually nitrogen that limits production of algal biomass.
Within the ReCiPe project, CARMEN was used to evaluate the fate factor for aquatic eutrophication due to nutrients emitted in Europe. It is thereby assumed that N is the limiting nutrient in all coastal waters and P in all freshwater bodies. In ReCiPe it is only a damage factor for eutrophication of freshwater due to the phosphorus emissions that is estimated. The resultant figures are reported in Table 32.

Table 32 **Fate factors and eutrophication potentials (EP) for eutrophication of freshwaters**

Emission type	Compartment	Fate factor yr/km^3	EP freshwater
Manure P	Soil	$1.72x10^{-9}$	0.050
Fertiliser P	Soil	$1.83x10^{-9}$	0.053
P from sewage treatment plants	Freshwater	$3.44x10^{-8}$	1

Source: Own calculations based on ReCiPe 2008 (Goedkoop et al., 2009).

Monetary valuation

The potentially disappeared fraction (PDF) per m^3 freshwater has been combined with the average WTP taken from (Kuik et al., 2008). The average WTP for terrestrial ecosystems was estimated at 0.55 €/PDF/m^2. This can be translated to a valuation for freshwater ecosystems by using the terrestrial and freshwater species density from ReCiPe (Goedkoop et al., 2009). This would imply a value of 0.03 €/PDF/m^2 for freshwater ecosystems. The resultant figures are reported in Table 33.

Table 33 **Monetary valuation of eutrophication of freshwaters**

Emission type	Compartment	PDF.yr.m^3/kg	€/kg
Manure P	Soil	2.81	€ 0.09
Fertiliser P	Soil	2.99	€ 0.09
P from sewage treatment plants	Freshwater	56.3	€ 1.78

Source: Goedkoop et al., 2009.

C.5.2 Eutrophication of soils

Within ExternE, the environmental impact of air pollution on biodiversity due to emissions of SO_2, NO_x and NH_3 have been estimated. The impact is related to acidification and eutrophication of soils. An approach using the potentially disappeared fraction (PDF), i.e. biodiversity losses due to acidification and eutrophication is used (NEEDS, 2008a). See also Annex C.3. To divide the impacts of NO_x and NH_3 between soil acidification and eutrophication, we took the approach set out in Annex D.2.

C.6 Ozone depletion

Stratospheric ozone filters the UV-B radiation our of incoming sunlight, thus preventing UV damage at the planet's surface. Ozone is continually formed and destroyed by natural processes that depend on stratospheric chemical conditions and incoming sunlight. In recent decades, however, ozone destruction has increased due to anthropogenic emissions of chlorine- and bromine-containing molecules. These ozone-depleting substances (ODS) act as catalysts in the ozone destruction reaction and as such are preserved and

therefore have the potential to destroy many ozone molecules during their stratospheric residence time. The impacts of UV-B radiation on human health are discussed in Section C.6.2, impacts on nature and capital in Section C.6.3.

C.6.1 Methodology

The best-known group of anthropogenic ODP are probably the chlorofluorocarbons (CFCs), used mainly as aerosol propellants and for refrigeration. Other significant sources include hydrochlorofluorocarbons (HCFCs), halons (brominated chlorofluorocarbons), carbon tetrachloride (CCl_4), methylchloroform (CH_3CCl_3) and methylbromide (CH_3Br). After peaking in the early 1990s, total emissions of ODP had halved by the early 21st century and are expected to return to approximately natural levels by the middle of the century (WMO, 2003).

At the midpoint level, the relative potential of an ODS to destroy stratospheric ozone (Ozone Depleting Potential; ODP) is expressed in kg CFC-11-equivalents per kg ODS (based on WMO, 2003; Goedkoop et al., 2009).

Table 34 Midpoint characterisation factors of several ozone-depleting substances

Ozone Depleting Substance	kg CFC-11-equivalent/kg ODS
CFC-10	0.73
CFC-11	1
CFC-113	1
CFC-114	0.94
CFC-115	0.44
CFC-12	1
CH3CCl3	0.12
Halon 1001	0.38
Halon 1201	1.4
Halon 1202	1.3
Halon 1211	6
Halon 1301	12
Halon 2311	0.14
Halon 2401	0.25
Halon 2402	6
HCFC-123	0.02
HCFC-124	0.02
HCFC-141b	0.12
HCFC-142b	0.07
HCFC-22	0.05
HCFC-225ca	0.02
HCFC-225cb	0.03
CCl_4	0.73
CH_3Br	0.38

Source: Goedkoop et al., 2009.

Since ozone depletion is not part of the NEEDS project, no damage cost estimates were available for each specific ODS. Given that such estimates are also lacking in the literature, we opted to base the human health effect estimates on the ReCiPe (Goedkoop et al., 2009) methodology.[33] Below, we briefly describe the calculation adopted in ReCiPe to obtain human health impact endpoints (in DALY/kg ODS).

In order to calculate the estimated damages, the cumulative ODP of each ODS is first translated into the Effective Equivalent of Stratospheric Chlorine (EESC), which expresses cumulative halogen loading in parts per trillion. The marginal effect of ODS emissions is captured by the fate factor, which expresses the additional chlorine release per kg ODS (ppt/kg CFC-11-eq.) based on the time-integrated effect of the ODS over its stratospheric residence time. The final damage estimate for the environmental theme can then be calculated by multiplying the fate factor by a damage factor, which depends on the specific theme and is described in the appropriate Sections below.

To obtain the shadow price for a specific substance, the endpoints need to be valuated appropriately. In the case of human health effects, these were obtained by using a standard value for a VOLY and multiplying this by the endpoints for each substance. For capital effects, Hayashi et al. (2006) multiplied the endpoint damage for different crops by the estimated producer cost (based on NEEDS, 2008a).

C.6.2 Health-related impacts

UV-B radiation damages biological tissue. In humans, it leads to different kinds of skin cancer (carcinoma) and reduces the opacity of the lens of the eye (cataract). In ReCiPe the endpoint characterisation factors were calculated assuming marginal ODS reductions in 2003 and integrating health impacts until 2044 (when EESC is expected to reach pre-1980 levels and additional marginal emissions will not lead to additional human health loss). Here, we have assumed that marginal emission changes in 2008 result in damages similar to those in 2003. The effect of a change in UV-B radiation on human health was calculated using the AMOUR model (RIVM, 2007) which takes latitude, population density, skin-type distribution, age distribution and altitude into account. The resulting damage factor is expressed in DALY per unit change in EESC (in ppt). These factors can then be translated into characterisation factors in DALYs per tonne CFC-11-equivalent for each group of ODS by multiplication by the fate factor.

Table 35 Endpoint characterisation factor per ODS group

ODS group	Characterisation factor (DALY/t CFC-11-eq.)
CFCs	1.76
CCl_4	3.30
CH_3CCl_3	4.41
Halons	2.64
HCFC	3.65
CH_3Br	4.72

Source: Goedkoop et al., 2009.

[33] Note that, compared with the methodology preferred in the remainder of this report, ReCiPe cost estimates yield lower values, as ReCiPe adheres to a stricter threshold for accepting scientific evidence on which estimates are based.

In order to calculate the endpoint damages per tonne of actual ODS emission (rather than CFC-11-equivalent), the grouped characterisation factors (Table 35) need to be multiplied by the characterisation factor for each specific substance at the midpoint (Table 34). This gives the endpoint characterisation factor in DALYs per emitted kg ODS (Table 36, column 2). Note that these reflect global damages.

Table 36 Endpoint characterisation factors for human health effects and external cost per ODS

Ozone Depleting Substance	Characterisation factor (DALY/kg ODS)	External cost, undiscounted (€$_{2008}$ /kg)	External cost, discount rate 2.5% (€$_{2008}$ /kg)
CFC-10	2.41E-03	132.60	51.87
CFC-11	1.76E-03	96.84	37.88
CFC-113	1.76E-03	96.84	37.88
CFC-114	1.65E-03	91.03	35.61
CFC-115	7.74E-04	42.61	16.67
CFC-12	1.76E-03	96.84	37.88
CH_3CCl_3	5.29E-04	29.12	11.39
Halon 1001	1.00E-03	55.20	21.59
Halon 1201	3.70E-03	203.36	79.55
Halon 1202	3.43E-03	188.83	73.87
Halon 1211	1.58E-02	871.54	340.94
Halon 1301	3.17E-02	1743.08	681.88
Halon 2311	3.70E-04	20.34	7.96
Halon 2401	6.60E-04	36.31	14.21
Halon 2402	1.58E-02	871.54	340.94
HCFC-123	7.30E-05	4.02	1.57
HCFC-124	7.30E-05	4.02	1.57
HCFC-141b	4.38E-04	24.10	9.43
HCFC-142b	2.56E-04	14.06	5.50
HCFC-22	1.83E-04	10.04	3.93
HCFC-225ca	7.30E-05	4.02	1.57
HCFC-225cb	1.10E-04	6.02	2.36
CCl_4	2.41E-03	132.55	51.85
CH_3Br	1.79E-03	98.69	38.61

Source: Goedkoop et al., 2009.

To obtain shadow prices in €/kg, this CF needs to be multiplied by a Value of a Life Year (VOLY). As discussed in Section 5.3, we use a VOLY of € 40,000, corrected for inflation and with an uplift factor to the year 2008. The resulting shadow prices per kg ODS are listed in column 3 of Table 36.

Note, however, that ozone depletion damages are not discounted in ReCiPe. The effects of UV exposure on human health are cumulative, i.e. the incidence of skin cancer cases resulting from increased ozone depletion will increase over time and then decrease again. It may therefore be more appropriate to discount future damages over time. To approximate the distribution of future damages resulting from present-day ozone depletion, we assumed a peak in health damages 40 years after ODS emission (Goedkoop et al., 2009), with half the cases occurring before this peak and half thereafter. The increase from now until the peak, as well as the subsequent decrease were assumed linear, resulting in a triangular distribution of health damages over time. These damages were discounted at 2.5 % and then monetarised using the same VOLY

as for the undiscounted values. The resulting discounted damage costs are reported in column 4 of Table 36.

C.6.3 Nature- and capital-related effects

UV-B radiation also affects non-human biological tissue. Specifically, an increase in radiation associated with ozone depletion will lead to lower Net Primary Production in ecosystems and lower crop yields in agricultural settings. Damages to nature and capital per kg ODS emission have been estimated by Hayashi et al. (2006), who expanded the LIME model to incorporate a damage function for ozone-depleting substances. Similarly to the ReCiPe methodology, a fate factor was determined that translates the ODP of each ODS into EESC and calculates a corresponding increase in UV-B radiation at different latitudes.

For crop damages, the fate factor was then multiplied by a damage factor reflecting crop reduction per unit UV-B increase to yield an endpoint characterisation factor for different ODS (in kg crop yield reduction per kg ODS). Producer cost estimates for specific crops were take from NEEDS (2008a) and multiplied by endpoint characterisation factors to obtain a figure for the external costs per kg ODS.

Similarly, reduced timber yield was calculated by multiplying the fate factor by a damage factor reflecting decreased Net Primary Production per unit UV-B increase. The resulting endpoint characterisation factor was multiplied by producer cost estimates from Japan to obtain external cost per kg ODS.

The external costs reported in Hayashi (2006) were expressed in Yen_{2000}/kg ODS. Here, these values were converted to $Euro_{2000}$ by using the average exchange rate over 2000 (99.3 Yen = 1 Euro), and corrected for inflation and with an uplift factor to the year 2008. The final external cost in €/kg emitted ODS corresponds with our endpoint for agricultural and timber productivity and is reported in Table 37.

Table 37 External costs for social assets per Ozone Depleting Substance

Ozone Depleting Substance	Characterisation factor (DALY/ kg ODS)[34]	External cost, timber (€2008 /kg ODS)	External cost, crops (€2008 /kg ODS)
CFC-10	n.a		
CFC-11		1.14	0.11
CFC-113		1.22	0.12
CFC-114	1.00	1.14	0.11
CFC-115	0.60	0.69	0.06
CFC-12		1.20	0.11
CH_3CCl_3	0.07	0.08	0.01
Halon 1001	n.a		
Halon 1201	n.a		
Halon 1202	n.a		
Halon 1211		2.89	0.27
Halon 1301		16.76	1.58
Halon 2311	n.a		
Halon 2401	n.a		
Halon 2402	5.04	5.76	0.54
HCFC-123		0.00	0.00
HCFC-124		0.02	0.00
HCFC-141b		0.10	0.01
HCFC-142b		0.07	0.01
HCFC-22		0.05	0.00
HCFC-225ca	0.02	0.02	0.00
HCFC-225cb	0.02	0.03	0.00
CCl_4		1.10	0.10
CH_3Br		0.01	0.00

Source: Hayashi et al., 2006.

C.6.4 Discussion

The most important health effect of ozone depletion is an increased incidence of skin cancer. Cancer is regarded as a terrible disease that most people are likely to want to avoid more than any other. Hence they may well cite a higher WTP to avoid living with a cancer than with most other diseases. This premium value for a VOLY for cancer-related diseases was not taken into account here, but may increase the external cost for ODS. Our figures may therefore represent something of an underestimate. On the other hand, human health effects resulting from ODS emissions reflect global damages: the extent and location of ozone depletion are independent of the location of emission. By taking the EU VOLY of € 40,000 independent of the location of the damages, an overestimate of the true damage costs may occur, as WTP for additional life years may be correlated with GDP.

[34] The LIME model estimates do not include capital estimates for each ODS treated in ReCiPe. However, health damage estimates are reported for most substances. Since the underlying fate factor used for health and capital effects is the same, the damage ratio between different substances is the same for capital effects and health effects. Where available, the health damage ratio between a specific substance and CFC-11 was calculated. Subsequently, the CFC-11 endpoint characterisation factor for crop (timber) damages was multiplied by this ratio to obtain external cost estimates for these substances. This calculation was applied to CFC-114, CFC-115, CH3CCl3, Halon 2402, HCFC-225ca and HCFC-225cb.

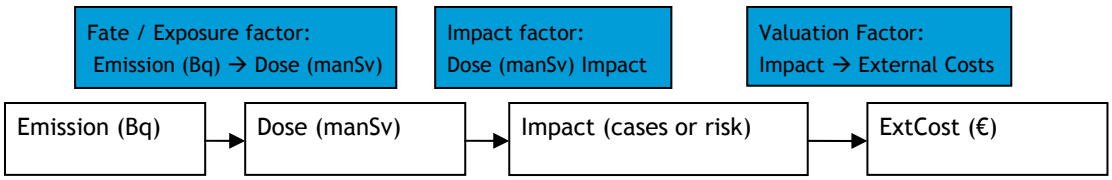
The estimated external costs for health effects exceed those for capital damages by around two orders of magnitude. A similar situation was observed for the group of classical pollutants, where impacts on human health are by far the most costly compared with any other endpoint. This is not that surprising when it is taken into account that valuation of a statistical human life (measured using VSL or VOLY) that is lost due to the impact of a given pollutant is always higher than the valuation of the capital damages caused by the same dose of the pollutant. Within capital damages, the external cost estimates for timber production is about one order of magnitude greater than the combined crop damages. The difference between crops and timber may be explained by the fact that Hayashi et al. used Japanese producer costs to estimate global timber damages. As these costs are likely to be higher in Japan than the average global figure, they may be an overestimate.

Note that increased UV-B radiation may also cause material degradation and ecosystem damage. However, monetary valuations per unit of ODS are not yet available for these environmental themes. Hence, the external costs presented here form an underestimate of the true external costs.

C.7 Ionising radiation

The subatomic particles and electromagnetic waves radiating from certain materials carry enough energy to detach electrons from other atoms or molecules, a process called ionisation. When living tissue is exposed to ionising radiation, it may suffer DNA damage, leading to apoptosis or genetic mutation, which may eventually lead to the development of cancers as well as to heriditary defects passed on to subsequent generations. The amount of ionising radiation resulting from radionuclide emissions is measured in Becquerel (Bq), which expresses the number of nucleus decays per second. In NEEDS (2008a) the following simplified approach has been adopted to calculate the external costs of radionuclide emissions.

Figure 5 **Scheme of assessment of exposure, physical impact and external costs due to release of radionuclides (from Needs 2008)**



C.7.1 Health-related effects

The fate and exposure factors used in NEEDS have been calculated using the methodology set out in UNSCEAR (1993, 2000), whereby radionuclide emissions (in Bq) are related to the 'equivalent radiation dose' at the population level. This equivalent dose is expressed in man-Sievert (manSV), which is calculated by multiplying the amount of absorbed radiation (in J/kg) by a 'quality factor' that depends on radiation type (e.g. photons vs. alpha particles) and a factor that takes into account the exposed part of the body, the duration and level of irradiation. The resulting combined fate and exposure factors in manSv/PetaBequerel (PBq; 10^{15} Becquerel) are listed in Table 38. As can be seen from these data, the human radiation exposure associated with emissions depends on the medium to which the radionuclide was emitted.

Table 38 Endpoint damages to human health caused by radionuclide emissions

Radionuclide	Emitted to	Dose (manSv/PBq)	Fatal cancers (cases/PBq)	Non-fatal cancers (cases/PBq)	Hereditary defects (cases/PBq)
Aerosols, radioactive, unspecified	Air	2,000	100	240	20
Carbon-14	Air	92,270	4,614	11,072	923
Carbon-14	Water	1,000	50	120	10
Cesium-137	Air	7,400	370	888	74
Cesium-137	Water	98	4.90	11.76	0.98
Hydrogen-3, Tritium	Air	4.1	0.21	0.49	0.04
Hydrogen-3, Tritium	Water	0.85	0.04	0,10	0.01
Iodine-129	Air	64,000	3,200	7,680	640
Iodine-131	Air	20,300	1,015	2,436	203
Iodine-131	Water	63,438	3,172	7,613	634
Iodine-133	Air	0	0	0	0
Iodine-133	Water	0	0	0	0
Iodine-135	Air	0	0	0	0
Krypton-85	Air	0.214	0.01	0.03	0.00
Krypton-85	Water	0	0	0	0
Krypton-85m	Air	0	0	0	0
Noble gases, radioactive, unspecified	Air	0.43	0.02	0.05	0.00
Radon-222	Air	2,5	0.13	0.30	0.03
Thorium-230	Air	30,000	1,500	3,600	300
Thorium-230	Water	0	0	0	0
Uranium-234	Air	8,000	400	960	80
Uranium-234	Water	198	9.90	23.75	1.98
Uranium-235	Air	0	0	0	0
Uranium-235	Water	0	0	0	0
Uranium-238	Air	7,000	350	840	70
Uranium-238	Water	1,963	98	236	20
Strontium-90	Water	4.7	0.24	0.56	0.05
Rubidium-106	Water	3.3	0.17	0.40	0.03
Lead-210	Air	1,000	50	120	10
Polonium-210	Air	1,000	50	120	10
Radium-226	Air	600	30	72	6

Source: CASES, 2008.

The health impacts of radiation absorption may manifest themselves in the form of fatal and non-fatal cancers and hereditary defects. It is estimated that each manSv equivalent radiation dose leads to 0.05 cases of fatal cancers, 0.12 cases of non-fatal cancers and 0.01 cases of hereditary defects (see NEEDS, 2008a). For each of these, the expected number of cases per unit emission are shown in Table 38, columns 3–5, for each of the relevant radionuclides.

The valuation of these impacts was based on the number of DALYs per cancer. For fatal cancers, the resulting YOLL (15.95) was multiplied by a VOLY of € 40,000 and the Cost of Illness (COI; € 481,050) was added, summing to € 1.12 million. For non-fatal cancers, the COI of € 481,050 was used. For hereditary effects, a standard value of statistical life (VSL) was taken, summing to € 1.5 million per case.

The external cost per unit emission was calculated by multiplying the disease-specific valuations by the expected number of diseases, shown in Table 38. As described in Annex A, in NEEDS an uplift factor is applied to account for the positive income elasticities of demand (1.7 % until 2030, 0.85% thereafter), and a discount factor of 3% until 2030 and 2% thereafter. Importantly, the radiation emitted by a certain substance changes over time, depending on its half-life. This should be corrected for in the uplift and discount factors, which in NEEDS was only done for Rn-222, H-3 and C-14 (the most prevalent emissions associated with nuclear fuel cycles). The resulting Net Present Values of emissions in the year 2008 are listed in Table 39.

Table 39 External costs of radionuclide emissions

Radionuclide	Emitted to	€$_{2008}$/PBq NPV 2008
Aerosols, radioactive, unspecified	Air	3.54E+08
Carbon-14	Air	1.92E+09
Carbon-14	Water	1.29E+07
Cesium-137	Air	1.31E+09
Cesium-137	Water	1.74E+07
Hydrogen-3, Tritium	Air	7.02E+05
Hydrogen-3, Tritium	Water	1.51E+05
Iodine-129	Air	1.13E+10
Iodine-131	Air	3.59E+09
Iodine-131	Water	1.12E+10
Iodine-133	Air	5.17E+05
Iodine-133	Water	0.00E+00
Iodine-135	Air	0.00E+00
Krypton-85	Air	3.79E+04
Krypton-85	Water	0.00E+00
Krypton-85m	Air	0.00E+00
Noble gases, radioactive, unspecified	Air	7.61E+04
Radon-222	Air	1.99E+04
Thorium-230	Air	5.31E+09
Thorium-230	Water	0.00E+00
Uranium-234	Air	1.42E+09
Uranium-234	Water	3.50E+07
Uranium-235	Air	1.16E+09
Uranium-235	Water	1.27E+08
Uranium-238	Air	1.24E+09
Uranium-238	Water	3.48E+08
Strontium-90	Water	8.32E+05
Rubidium-106	Water	5.84E+05
Lead-210	Air	1.77E+08
Polonium-210	Air	1.77E+08
Radium-226	Air	1.06E+08

Source: Needs, 2008a.

C.7.2 Nature- and capital-related effects

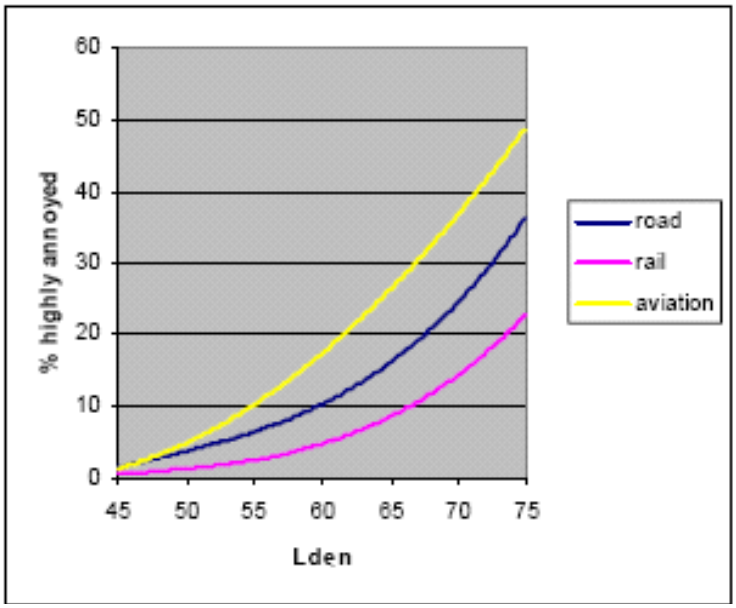
Radiation exposure also affects non-human organisms, and has a detrimental effect on social assets (e.g. it may cause malfunctioning in electronic equipment). No monetary valuation of these effects was available from the literature, and the external costs presented here are therefore an underestimate of the true costs.

C.8 Noise

Noise is often expressed as L_{den} (in dB(A)), a measure of the number of decibels during the year, with a 'penalty' for the evening and night. However, perceptions of noise and noise annoyance depend not only on the sound, but also on such characteristics as its pitch and predictability and personal factors like noise sensitivity and age.

The so-called Miedema curve (see Figure 6) shows that for any given noise level, a higher percentage of people are annoyed by road noise than by rail noise. Noise from aircraft is most annoying.

Figure 6 The Miedema curve for annoyance due to various forms of noise



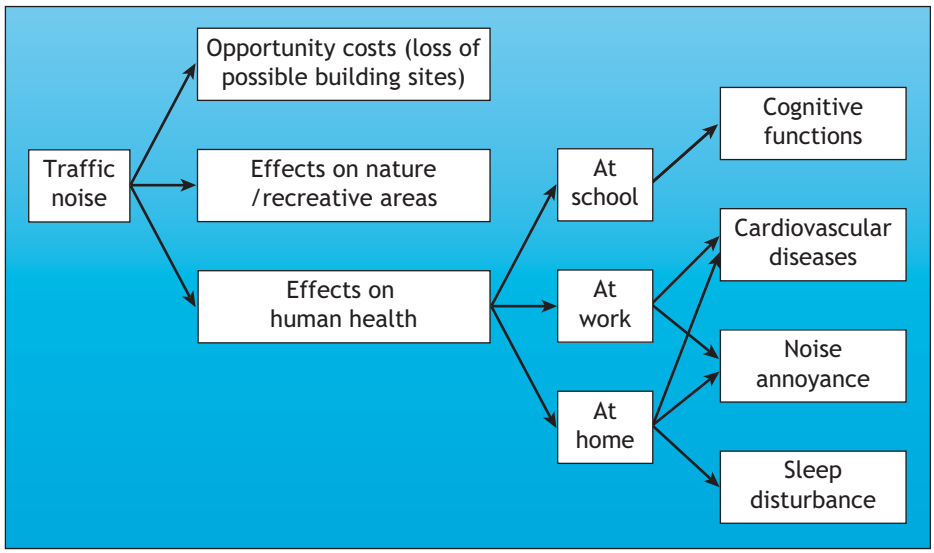
C.8.1 Methodology

As set out in Figure 7 below, the damaging effects of traffic noise are:

- Loss of possible building sites due to government regulations.
- Effects on ecosystems or recreation areas.
- Effects on human health at school, at work or at home.

Most studies only value these last effects, which are also relevant for other types of noise (i.e. due to nearby industrial activities).

Figure 7 Damages associated with traffic noise



The two main impacts of noise on human health are (HEATCO, 2006):
- Annoyance, reflecting the disturbance that individuals experience when exposed to noise.
- Health impacts: mainly stress-related health effects like hypertension and myocardial infarction.

The value of annoyance caused by noise can be estimated using the stated preference (SP) or hedonic pricing (HP) method. In the first of these, people are asked about their behavior in a hypothetical situation; this is therefore a direct way to determine individuals' willingness-to-pay (WTP). In the hedonic pricing method, WTP is determined from analyses of the impact of noise on house prices.

C.8.2 Monetary valuation

The HEATCO project, funded by the EC, analysed the latest research to provide a consistent framework for monetary valuation of transport projects. This included the valuation of environmental issues like noise. The guidelines developed within the HEATCO project take annoyance and health impacts as two independent effects (assuming the health risk is not taken into account in people's perceived noise annoyance). To estimate the value of noise annoyance, stated preference surveys were carried out in five European countries. Benefit transfer was applied to derive national noise annoyance valuations. Quantifiable health costs were added to these values to derive a total value for noise. See Table 40.

Table 40 Values for noise exposure in 2002 PPP € prices (per year per person exposed) for the Netherlands

L_{den} dB(A)	Road	Rail	Aircraft
≥51	10	0	15
≥52	20	0	30
≥53	29	0	46
≥54	39	0	61
≥55	49	0	76
≥56	59	10	91
≥57	69	20	106
≥58	79	29	122
≥59	88	39	137
≥60	98	49	152
≥61	108	59	167
≥62	118	69	183
≥63	128	79	198
≥64	137	88	213
≥65	147	98	228
≥66	157	108	243
≥67	167	118	259
≥68	177	128	274
≥69	186	137	289
≥70	196	147	304
≥71	261	212	374
≥72	277	228	396
≥73	293	244	417
≥74	310	261	439
≥75	326	277	461
≥76	343	294	483
≥77	359	310	505
≥78	375	326	527
≥79	392	343	548
≥80	408	359	570
≥81	425	376	592

Source: HEATCO, 2006.

C.9 Land use

The main impact of land use is damage to ecosystems due to the effects of land occupation and transformation. This section explores the effects of occupation of a certain area of land for a certain period of time.

C.9.1 Methodology

To value ecosystems we adopted the NEEDS approach, which is based on work by NEEDS (2008a). This approach compares the species' abundance of a specific land use (S_i) to the species' abundance of a reference land use (S_{ref}).

Species' abundance is measured as the number of vascular plant species per square meter. The reference land use is a composite of various land uses occurring in the Swiss lowlands.

The NEEDS approach uses the inverse of the relative species' abundance, which is termed the Potentially Disappeared Fraction (PDF):

$$PDF_i = 1 - \frac{S_i}{S_{ref}}$$

For valuing land use, we used the approach developed by Kuik et al. (2008) in the CASES project. In that project, PDF was defined in terms of Ecosystem Damage Potential (EDP). On the basis of 24 studies on ecosystem valuation, the average value per EDP per hectare per year was calculated, yielding a figure of € 4,706 (in 2004 prices). This is the average global value (mainly for Europe and North America) and will therefore not reflect very specific local conditions. However, the value can serve as a first approximation.

In the ReCiPe project (Goedkoop et al., 2009) the average PDF values for different land use types have been estimated based on data from the United Kingdom and Switzerland. These are given in Table 41 for the hierarchist perspective (cf. Annex F).

Table 41 Average PDF values for 18 land use types

Land use type	PDF (per m^2 per year)
Monoculture crops/weeds	1.39
Intensive crops/weeds	1.33
Extensive crops/weeds	1.29
Monoculture fertile grassland	1.13
Intensive fertile grassland	0.92
Extensive fertile grassland	0.69
Monoculture infertile grassland	0.85
Extensive infertile grassland	0.44
Monoculture tall grassland/herb	1.36
Intensive tall grassland/herb	1.05
Extensive tall grassland/herb	0.75
Monoculture broadleaf, mixed forest and woodland	0.63
Extensive broadleaf, mixed and yew LOW woodland	0
Broad-leafed plantation	0.81
Coniferous plantations	0.91
Mixed plantations	1.10
Continuous urban	1.4
Vineyards	0.86

Source: Goedkoop et al. 2009.

C.9.2 Monetary valuation

Multiplying the PDF values cited in Table 41 by the monetary value of € 0.47 per PDF per m^2 per year (derived from the CASES project) yields the figures for external costs reported in Table 42.

Table 42 **External costs for occupation of a certain area of land for different land use types (2004 prices)**

Land use type	External costs (€ per m^2 per year)
Monoculture crops/weeds	€ 0.65
Intensive crops/weeds	€ 0.63
Extensive crops/weeds	€ 0.61
Monoculture fertile grassland	€ 0.53
Intensive fertile grassland	€ 0.43
Extensive fertile grassland	€ 0.32
Monoculture infertile grassland	€ 0.40
Extensive infertile grassland	€ 0.21
Monoculture tall grassland/herb	€ 0.64
Intensive tall grassland/herb	€ 0.49
Extensive tall grassland/herb	€ 0.35
Monoculture broadleaf, mixed forest and woodland	€ 0.30
Extensive broadleaf, mixed and yew LOW woodland	-
Broad-leafed plantation	€ 0.38
Coniferous plantations	€ 0.43
Mixed plantations	€ 0.52
Continuous urban	€ 0.66
Vineyards	€ 0.40

Source: Goedkoop et al., 2009 and Kuik et al., 2008.

C.9.3 Towards weighing factors

To obtain a single figure for valuation of land use, we adopted the average values for Dutch land uses cited in CBS Statline and multiplied them by the external costs; see Table 43.

Table 43 **Average valuation of land use for the Netherlands**

Land use	Percentage in NL	Valuation ($€_{2008}$ per m^2 per year)
Intensive fertile grassland	29%	0.51
Intensive crops	39%	0.74
Continuous urban	15%	0.78
Monoculture broadleaf (mixed forest and woodland)	17%	0.35
Average NL		0.612

Source: CBS, Statline, own calculations.

Annex D Vertaalslag waarderingen per stof naar weging milieuthema's

Zoals uitgelegd in hoofdstuk 6 ontwikkelen we in dit project drie weegsets gebaseerd op de waardering van individuele stoffen:

1. Weegset met preventiekosten gekarakteriseerd op mid-pointniveau.
2. Weegset met economische schadekosten op end-point gekarakteriseerd op mid-pointniveau.
3. Weegset van directe waardering van gezondheids- en biodiversiteitsschade op end-points.

We moeten hierbij met karakterisatiefactoren werken omdat we slechts schaduwprijzen voor een beperkt aantal stoffen hebben. Karakterisatie-factoren geven het relatieve belang aan van een stof voor de bijdrage aan het milieueffect. Als we schaduwprijzen zouden hebben voor alle 1.000 stoffen in een LCA, zouden we niet hoeven te werken met karakterisatiefactoren omdat de individuele schaduwprijzen zelf de karakterisatie zouden weergeven. We zouden dan aan de hand van de schaduwprijzen kunnen bepalen hoe belangrijk stof A ten opzichte van stof B is. Maar als we alleen een schaduwprijs voor stof A hebben, moeten we werken met karakterisatiefactoren.

Bij de translatie van waardering naar weegsets lopen we in de praktijk tegen twee problemen aan:

a Multiple effecten: dat een stof vaak betrekking heeft op meerdere milieuthema's zodat de schaduwprijs van die stof over die thema's verdeeld moet worden.
b Impliciete karakterisatie: dat de schadeschattingen van meerdere stoffen binnen een thema al een impliciete karakterisatie met zich meebrengt die kan afwijken van de mid-pointkarakterisatie die in ReCiPe wordt gegeven. Hoe gaan we met deze verschillen om?

Deze problemen spelen alleen een rol bij de eerste twee weegsets. Voor elk van de twee weegsets hebben we daarbij de best mogelijke methode gekozen om met deze problemen om te gaan. Deze methodes staan hieronder beschreven.

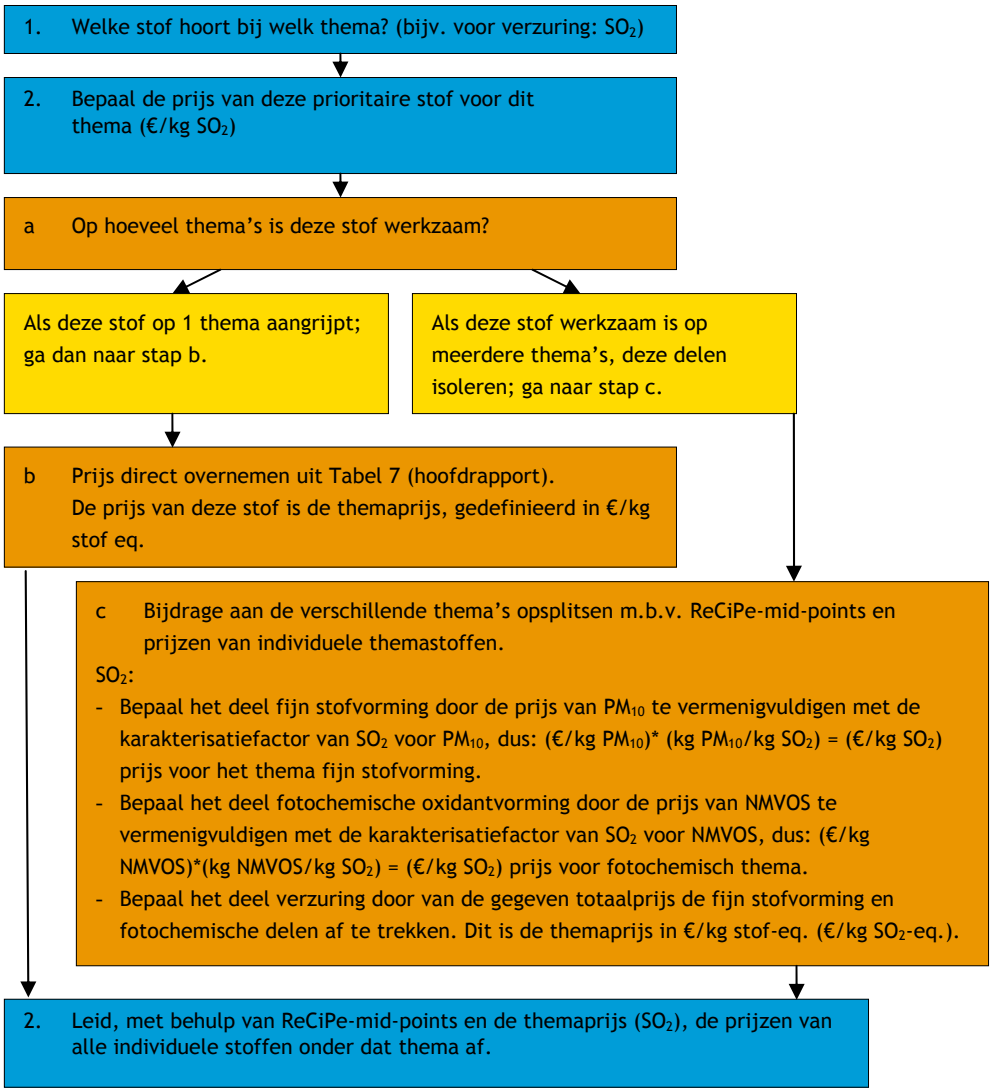
D.1 Preventiekosten

Probleem B (impliciete karakterisatie) is hierbij opgelost door allereerst uit te gaan van een prioritaire stof binnen elk thema. Dat is vaak de stof die als equivalentiefactor wordt gebruikt in de mid-pointkarakterisatiefactoren (bijv. SO_2 voor verzuring). In principe bepaalt deze prioritaire stof de waardering. Wel wordt, achteraf, bekeken of de karakterisatie die op deze manier optreedt in lijn is met de waardering voor de andere stoffen. Dus als we binnen het thema verzuring SO_2 gebruiken om daarmee de waarde voor SO_2-equivalenten weer te geven, dan geeft die waarde van de SO_2-equivalenten ook een impliciete waardering aan NO_x en NH_3 (waarvan de verzurende bijdrage tevens in SO_2-equivalenten is weergegeven bij de ReCiPe-mid-point-karakterisatiefactoren). We hebben hierbij dus achteraf gekeken of de gevonden karakterisatie in lijn lag met de schaduwprijzen die we voor die stoffen hadden ontwikkeld. Dat bleek in alle gevallen redelijk overeen te komen. Zo levert een SO_2-prijs van 5 € per kg een NO_x-waarde op van 9 € per kg. Deze waarde ligt mooi binnen de door overheidsbeleid geïndiceerde bandbreedte van 5-10 € per kg voor NO_x.

Probleem A (multiple milieueffecten) bleek vrij eenvoudig oplosbaar doordat er stoffen zijn die maar op 1 milieueffect een bijdrage hebben (zoals PM_{10} op HTP en NMVOS op smog). Door de waardering voor dit milieueffect te koppelen aan de karakterisatiefactor van een stof die multiple milieueffecten heeft, kunnen die multiple milieueffecten worden onderverdeeld.

Bij beide oplossingen is de impliciete veronderstelling dat de overheid weet heeft van de verhouding van stoffen tot een bepaald milieuthema en derhalve beleid voert voor stoffen niet gericht op reductie van de stof zelf, maar gericht op reductie van het milieueffect.
Figure 8 geeft aan hoe we gewerkt hebben.

Figure 8 **Een schema van de gevolgde aanpak bij preventiekosten**

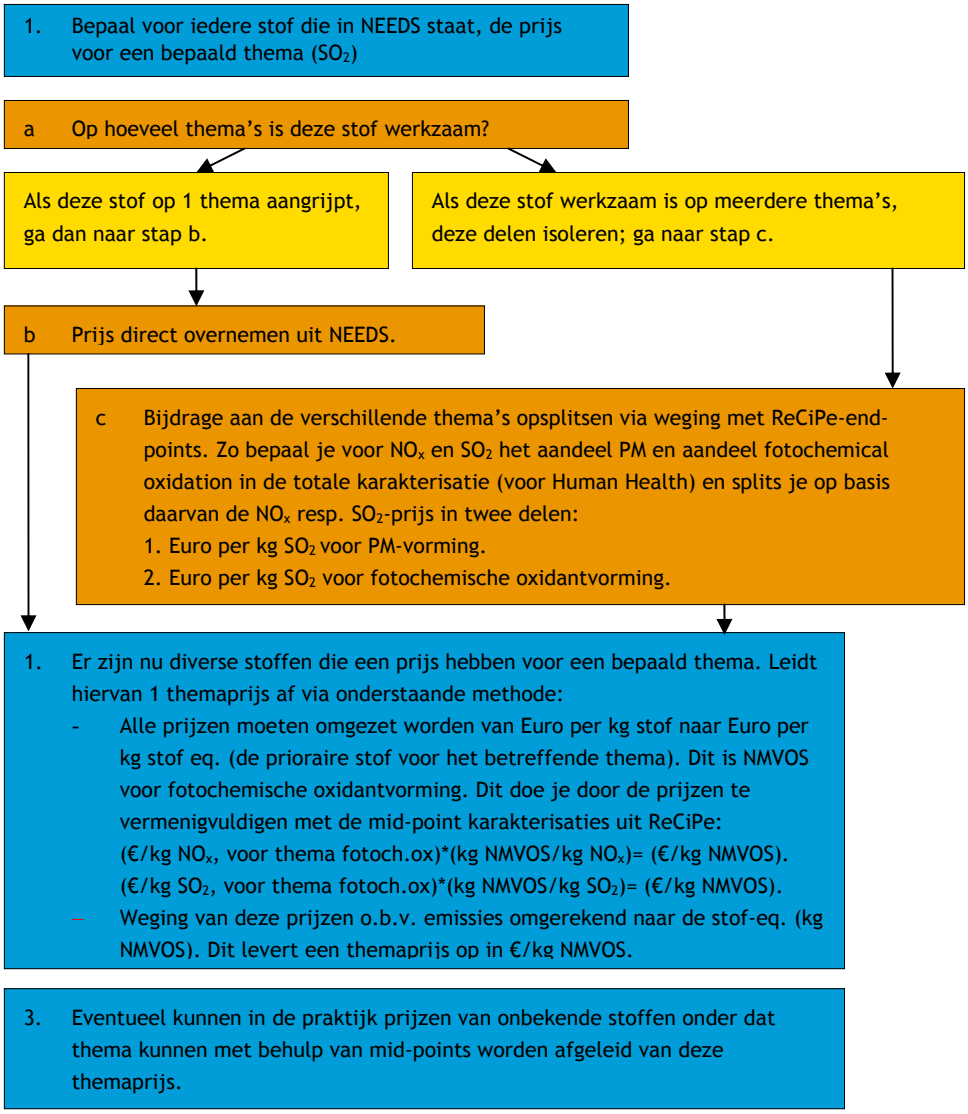


D.2 Economische schadekosten

Probleem B (impliciete karakterisatie) werd hierbij opgelost door een gewogen gemiddelde te nemen van de schades die in Nederland ontstaan. Daartoe hebben we alle schadeschattingen die in Annex C zijn bepaald vermenigvuldigd met hun emissies in Nederland en vervolgens gedeeld door de emissies uitgedrukt in de relevante ReCiPe-mid-pointkarakterisatiefactor.

Voor de oplossing van probleem A (multiple milieueffecten) is hierbij gebruik gemaakt van de ReCiPe-end-points. Deze geven namelijk weer hoeveel de verschillende stoffen, volgens ReCiPe, bijdragen aan de end-points. Met behulp hiervan zijn de bijdrage van de stoffen over de mid-points opgesplitst. Figure 9 geeft onze werkwijze weer.

Figure 9 **Een schema van de gevolgde aanpak bij de bepaling van de economische schadekosten**



NB. De themasplitsingsmethode gebruikt bij preventiekosten kan niet gebruikt worden voor schadekosten omdat je voor dan voor het thema fotochemische oxidantvorming alleen NMVOS prijs uit NEEDS haalt en de prijs van NO_x, SO_2, etc. daar vanaf leidt. Zo ook voor PM-vorming. Maar: als je alle twee de themaprijzen weet waar NO_x werkzaam is (op end-pointniveau HH) en je deze vermenigvuldigt met de mid-pointkarakterisatiefactoren, kom je op een andere totale waarde dan de HH NO_x-prijs uit NEEDS. Beter is om HH-prijs en ecosysteemprijs uit NEEDS te splitsen o.b.v. end-pointkarakterisaties (weging).

We hebben deze methode toegepast onder de volgende veronderstellingen.

Climate change

The total damage costs for climate change (central value) are € 0.0250/kg CO_2-eq. for emissions in the year 2008 (cf. Annex C.1). It should be carefully noted that this figure increases for emissions emitted in later years.

Using ReCiPe endpoint characterisation factors, we split these total damage costs into damage to human health and damage to ecosystems. According to ReCiPe, 1 kg of CO_2 results in a loss of 1.46E-06 DALYs and 7.93E-09 species or 0.57 PDF/m^2.[35] Using the value of a DALY (€ 55,021.46[36]) and a PDF (0.55 €/PDF.m^2[37]), we find that 1 kg of CO_2 results in a damage of € 0.08 to human health and € 0.32 to ecosystems. The total climate change damage costs therefore needs to be subdivided into damage to human health and damage to ecosystems in the proportion of 1 to 4.1.

Acidification and photo-oxidant formation

In this impact category, we use damage costs per pollutant from NEEDS (cf. Annex C.3). As these costs differ for each pollutant, we use the method described in Section 4.5.1 to derive damage costs for each impact category, i.e. for:

- PM formation (PM_{10}-eq.).
- Photo-oxidant formation (NMVOC-eq.). And
- Acidification of soils (SO_2-eq.).

Acidification of soils includes damages caused by NO_x, NH_3 and SO_2 to ecosystems and capital and land. The damages due to NO_x, SO_2, NH_3 and $PM_{2.5}$ under the heading PM formation relate to human health effects. Photo-oxidant formation includes damages caused by NO_x, SO_2 and NMVOC to human health.

Eutrophication of freshwater

In this case we have used endpoint characterisation factors from ReCiPe and valued (aquatic) ecosystems based on the valuation for PDF.m^2 and the terrestrial and freshwater species density. Kuik et al. (2008) valued ecosystems using a value of 0.47 €/PDF.m^2 in 2000 prices (€ 0.55/PDF.m^2 in 2008 prices; see Section 5.3.3). In the ReCiPe project (Goedkoop et al., 2009) terrestrial and freshwater species densities have been estimated as 1.38E-08 per m^2 and 7.89E-10 per m^3, respectively. Using these factors, we arrive at a value of € 0.03 per PDF m^3.

Eutrophication of soils

For this impact category we have used the damage costs from NEEDS (cf. Annex C.3). In NEEDS no distinction is made between damages due to acidification and to eutrophication of soils.
In NEEDS, the impact categories are damages to human health (not relevant here), ecosystems, crops and capital. For ecosystems, we have assumed that NO_x and NH_3 have an impact on both acidification and eutrophication, while SO_2 impacts on acidification only. For capital, we assume that the total impact can be classified under the heading acidification. For crops, we assume that the negative damages due to NO_x and NH_3 (only for the Netherlands, not for

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35 ReCiPe assumes a terrestrial species density of 1.38E-08 per m^2.

36 This is the original value of VOLY from the NEEDS project recalculated with the uplift factor of 1.7% and multiplied by the HICP factor to get the value for 2008.

37 This value has also been recalculated from the original value used in the NEEDS project, in the same way as VOLY (see previous footnote).

Europe) are due to their eutrophication impact, while SO_2 has an acidification impact.
To distinguish the eutrophication and acidification impacts of NO_x and NH_3, we subtracted the acidification impact (using the damage cost of SO_2) from the total damage costs to arrive at the eutrophication impact. To deal with implicit characterisation, the method described in Annex D.2 was applied. Since ReCiPe includes aquatic eutrophication only, we have used the midpoint characterisation factors for marine eutrophication under the assumption that the relative damages of NO_x and NH_3 to marine water and soils are similar.

The damage costs of NMVOC are reported separately, because NMVOC affects ecosystems indirectly.

Human toxicity

Damage costs for each individual pollutant have been adopted from NEEDS (cf. Annex C.4). In NEEDS, the human toxicity of classical pollutants relates solely to air pollution. To arrive at a single damage cost for this impact category, we therefore use the ReCiPe midpoint characterisation factors for human toxicity via this route.

Radiation

Damage costs for each individual radionuclide have been adopted from NEEDS (cf. Annex C.6). To arrive at a single damage cost for this impact category, we have taken an (unweighted) average of the various radionuclides, as we have no data on the relative emission of each. The corresponding figure should therefore be regarded as a proxy. To compare: if we had calculated the shadow price using information from the ReCiPe endpoint factors, the corresponding value would be higher than using the route via NEEDS.

Annex E Valuation methods, benefit transfer and uncertainty

E.1 Introduction

In this annex we first describe the general methods in use for valuing environmental goods (Section E.2), then identify ways to transfers benefit estimates from one country to another (Section E.3) and finally give an assessment of uncertainty (Section E.4).

E.2 Valuation nethods for environmental goods[38]

The methods in use for valuing environmental goods can be divided into three categories:

- Stated preference methods.
- Revealed preference methods.
- Production function approaches.

E.2.1 Stated preference methods

Stated preference approaches are based on surveys in which the respondents give direct answers about their Willingness to Pay (WTP) or Willingness to Accept (WTA) in relation to certain hypothetical changes in environmental quality. By far the most common method in this category is the **Contingent Valuation Method (CVM)**. Although CVM was first developed in the 1960s in the USA, it did not become widely used until the mid-1970s. CVM has been sanctioned for use in the USA in environmental damage claims, while in Europe many government agencies commission its use.

One crucial element of every CVM study is the design of the questionnaire and, in particular, a scenario describing the hypothetical situation of there being a market and consequently a price for the good in question (which is obviously not the case).

Respondents in CVM questionnaire are a random sample of the relevant population; this might be a national sample, for example, a sample of a local population or a sample of visitors to a recreational area.

These questionnaires have several other important design features, including the following:

a People must be given a reason why they might be asked to pay for something that has so far been available free. For example, raising funds might be essential for preserving certain environmentally valuable areas.
b The payment vehicle must be credible and non-controversial. For example, in most countries a tax would be credible but might be controversial if the benefits arising from preserving a certain environmental asset did not accrue to the entire population eligible for such a tax.
c Respondents should be given adequate, unbiased information on the environmental good and its hypothetical market.
d The question about WTP/WTA can be asked in various formats: as an open-ended question, using a payment card, or as a dichotomous choice in which

[38] This section is based on Hanley et al., 2001.

the respondents must accept or reject a given bid price. The average WTP/WTA for the sample can be calculated using a variety of statistical methods, depending on the question format.

e Protest bids should be identified. Protest respondents are those who declare a zero value, not because they do not value the good but because in this way they protest against certain aspects of the survey, e.g. the payment vehicle or the way the questions are posed. Protest bidders are usually separated out before statistical analysis progresses.

f Debriefing questions are a good way to check how well the respondents have understood the scenario and questions.

g The main survey is usually preceded by focus group sessions, which help in designing an appropriate questionnaire.

h The survey may be carried out by mail, telephone or in face-to-face interviews.

The sample average can be aggregated into a population mean/median. During econometric analysis the researchers investigate the relationship between WTP/WTA and various socioeconomic variables such as age and education level.

CVM can be applied in a very wide range of situations, in both a global and local context. It is capable of measuring both use and non-use values, which is a great advantage of all stated preference methods over revealed preference methods. However, CVM has also attracted plenty of criticism. The main points of critique can be summarised as follows:

- The values obtained using CVM are hypothetical; people do not always do what they say they would do. If respondents think they will actually have to pay, they are likely to underestimate their WTP and if they think that their answer is not linked to any actual charges but will influence the environmental change, they are likely to overestimate it. Development of CVM over time has contributed to improvements in questionnaire design, leading to diminishing over- and underestimation of actual WTP.
- In some studies there is a scoping problem, with WTP appearing to be insensitive to the scope of the environmental phenomena. For certain respondents WTP apparently has a symbolic character and reflects a general feeling that environmental goods should be protected rather than a surrogate price for the good described in the scenario. However, Carson (1997) has found that the majority of CVM studies pass tests of scope.
- CVM results are dependent on the information stated in the questionnaire. As many respondents may have never heard of the (e.g.) species described, the researchers, by implementing the survey, are possibly changing the preferences they want to measure.

There are two other stated preference methods in use:

- **Choice experiments/Choice modelling.** According to the characteristics theory of value, the value of a given good is best explained in terms of the characteristics or attributes of that good. For example, the value of a given forest can be broken down into the value of its different attributes, such as the number of plant/animal species in a particular area, or maintenance costs. Identifying the relevant attributes is usually carried out using focus groups. Different bundles of attributes are assembled using statistical methods. The respondents are asked to choose their preferred bundle of attributes, with one of the bundles describing the status quo. By including costs as one of the attributes, it is possible to calculate the marginal WTP in the sample for each attribute and the value of any combination of attributes.

- **Contingent ranking** is similar to choice experiments, with respondents again being presented with bundles of attributes, which they are asked to rank from the most to the least preferred. Using statistical analysis, the economists can then assess marginal WTP for changes in attributes and WTP for a particular bundle of attributes.

E.2.2 Revealed preference methods

In revealed preference (RP) approaches, the value people place on environmental goods is inferred from their behaviour in actual markets for related goods. The most popular methods in this group are the hedonic pricing, hedonic wages and travel cost methods.

- **The hedonic pricing method (HPM)** is based on information from real estate markets. In this method the environmental characteristics of homes are assumed to be important determinants of house prices, along with other factors like location and size. Environmental characteristics can include noise levels, air quality, scenic views and proximity to landfills. In HPM the researchers use regression analysis to estimate the marginal price of environmental attributes, which can be viewed as WTP for the environmental characteristics.
- **The hedonic wages method (HWM)** is based on information from job markets. In this method, the health risk or mortality risk associated with different jobs are assumed to be important determinants of wage. By means of regression analysis the marginal WTP for increased mortality risk can be estimated. This method is particularly useful for deriving the Value of a Statistical Life.
- **The travel Cost Method (TCM)** estimates WTP for outdoor recreation by looking at the expenditures people make to get to the recreational site. These expenditures include time and travel expenses. Typically, people are willing to spend an amount less than or equal to the value of the utility they derive from a recreational trip. In this method, information collected during a survey of visitors to a recreational site is used to create a demand curve for visits (typically, the higher the costs of making a trip, the fewer visits are made per year to the site). From the demand curve the consumer surplus (or changes therein) can be calculated as a measure of the site's value. The most controversial aspects of this method include substitute sites and the value of leisure time. The availability and costs of reaching substitute sites influences the frequency of visiting a given site. This problem can be at least partly resolved by including the costs of trips to these other sites in the travel cost equation or by using random utility models. Valuation of leisure time is difficult, because this depends on the respondent's occupation. For a self-employed person it makes sense to estimate the value of leisure time in terms of hourly earnings foregone, while for someone working on a fixed contract or for a retired person, such an approach would not make sense. Studies reveal, however, that leisure time values are generally positively related to income; commonly used fractions in literature include 33 and 43%.

E.2.3 Production function approaches

In production function approaches, changes in the quality or quantity of an environmental resource are valued by estimating the implications of these changes for outputs and prices of market goods/services, usually in terms of changes in consumer and producer surpluses. This class of methods includes dose-response models (more recently referred to as ecosystem function valuation models) that model the effects of an increase in the concentration of certain pollutants on agricultural crops, forests or fisheries, for example. In production function approaches, monetary values are derived from links to marketed outputs or avoided damage costs or using the replacement cost

approach. One example of the latter would be to value the pollution treatment capacity of a wetland by estimating the costs of providing a human-engineered sewage treatment system of the same capacity.

Ecosystem function valuation approaches are sometimes preferred by ecological economists who criticise the other methods described above as being unreliable. They argue that, wherever possible, different functions of ecosystems should be identified and valued using the production function approach and, if this is not possible, the effects should be described in qualitative terms.

E.3 Value transfer[39]

Damage valuation should ideally be based on high-quality, primary valuation studies. Such studies are not always available, however, which means that researchers and policy-makers in their efforts to provide reliable estimates of environmental damages for a given region/country often have to refer to primary valuation studies carried out for other regions/countries. Such a procedure is referred to as benefit transfer or, more generally, value transfer and covers both time- and space-related adjustments. Value transfer may be regarded as the final step of the Impact Pathway Approach, required in cases where no relevant primary valuation studies exist.

E.3.1 Approaches to value transfer

There are two main approaches to value transfer:

1. Unit value transfer:
   - Simple unit value transfer.
   - Unit value transfer with adjustment for income differences.
2. Function transfer:
   - Value function transfer.
   - Meta-analysis.

Unit value transfer

In the unit value transfer approach, the unit value at the study site is assumed to be representative of the policy site. In option (a), no adjustment for differences in income or other characteristics is made, while in variant (b) there is adjustment for differences in income levels or in the costs of living between the two sites. In the function transfer approach, a value function is either estimated at the study site and transferred to the policy site (a), or estimated from several study sites using meta-analysis (b).

Simple unit transfer is the easiest approach for transferring value estimates from one site to another. This approach assumes that the well-being experienced by an average individual at the study site is the same as that experienced by an average individual at the policy site. Thus, we can directly transfer the value estimate, often expressed as mean willingness-to-pay (WTP) per household per year, from the study site to the policy site.

The obvious problem with this transfer is that individuals at the policy site may not value the environmental benefits or damages the same as the average individual at the study sites. There are two principal reasons for this difference. First, people at the policy site may differ from those at the study site in terms of income, education, religion, ethnic group or other socio-economic characteristics affecting their demand for recreation. Second, even

[39] This section draws extensively on NEEDS (2007a).

if individuals' preferences related to environmental quality at the policy and study sites were the same, the potential for substitution may not be.

The simple unit value transfer approach should not be used for transfer between countries with very different income levels and costs of living. In such cases, *unit transfer with income adjustments* has been applied. The adjusted WTP estimate at the policy site WTP_p can be calculated as:

$$WTP_p = WTP_s \, (Y_p \, / \, Y_s)^{\beta} \qquad (1)$$

where WTP_S is the original WTP estimate from the study site, Y_S and Y_P are the income levels at the study and policy site, respectively, and β is the income elasticity of demand for the environmental good in question. The income elasticity for various environmental goods is typically less than 1 and often in the 0.4-0.85 range[40].

In case there is a lack of data on the income levels of the affected populations at the policy and study sites, Gross Domestic Product (GDP) per capita figures can be used as proxies for income in international value transfers. As using the official exchange rates does not reflect the true purchasing power of currencies, Purchasing Power Parity-adjusted rates should be used.

Even if PPP-adjusted GDP figures can be used to adjust for differences in income and cost of living in different countries, such a procedure will not be able to correct for differences in individual preferences, initial environmental quality, substitute sites and goods, and cultural and institutional conditions between countries (or even within different parts of a country).

Function transfer

Transferring the entire *value function* is conceptually more appealing than merely transferring unit values, because more information is effectively taken into account in the transfer. The value relationship to be transferred from the study site(s) to the policy site can be estimated using either revealed preference (RP) approaches like TC and HP methods or stated preferences (SP) approaches like the CV method and Choice Experiments (CE).[41] For a CV study, the value function can be written as:

$$WTP_{ij} = b_0 + b_1 \, G_j + b_2 \, H_{ij} + e \qquad (2)$$

where WTP_{ij} is the willingness-to-pay of household i at site j, G_j is the set of characteristics of the environmental good at site j, and H_{ij} is the set of characteristics of household i at site j, while b_0, b_1 and b_2 are sets of parameters and e is the random error.

To implement this approach, the analyst would have to find a study in the existing literature with estimates of the constant b_0 and the sets of parameters b_1 and b_2. It would then be necessary to collect data on the two groups of independent variables, G and H, at the policy site, insert them in Equation 2, and calculate the households´ WTP at the policy site.

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[40] Within the NEEDS project, an income elasticity of 0.85 has been used in the uplift factor for temporal adjustment of values due to economic growth.

Note that formally, β this is the income elasticity of WTP, not of demand, and that there is no simple relationship between the two measures.

[41] These methods were described earlier in this Annex (E.2).

The main problem with the value function approach arises because of exclusion of relevant variables in the WTP (or bid) function estimated in a single study. When the estimation is based on observations from a single study on one or a small number of recreational sites or a particular change in environmental quality, a lack of variation in some of the independent variables usually prohibits inclusion of these variables.

Instead of transferring the value function from one selected valuation study, results from several valuation studies could be combined in a *meta-analysis* to estimate one common value function. Meta-analysis has been used to synthesize research findings and improve the quality of literature reviews of valuation studies in order to arrive at adjusted unit values. In a meta-analysis, several original studies are analysed as a group, with the result from each study being treated as a single observation in a regression analysis. If multiple results from each study are used, various meta-regression specifications can be used to account for such panel effects.

The meta-analysis enables evaluation of the influence of a wider range in characteristics of the environmental good, the features of the samples used in each analysis (including characteristics of the population affected by the change in environmental quality) and the modelling assumptions. The resulting regression equations explaining variations in unit values can then be used together with data collected on the independent variables in the model describing the policy site to construct an adjusted unit value.

E.3.2 Steps in transferring value estimates

The following steps can be distinguished in the process of transferring value estimates from study site(s) to a policy (or project) site:

1. **Determining the transfer unit**
2. For *mortality*, the unit values would be in terms of the value of prevented fatalities (referred to also as Value of a Statistical Life, VSL) or the value of life years lost (Value of a Life Year, VOLY).
3. For *morbidity*, it would typically be value per symptom-day (described in detail for different illnesses) for acute symptoms, and value per case for chronic diseases.
4. For certain *ecosystem services*, unit costs can be used, e.g. market prices for fish, or unit cost per tonne of carbon. Within the NEEDS project an aggregate measure of ecosystem losses (Potentially Disappearing Fraction, PDF) has been used and evaluated.
5. For *recreational use*, consumer surplus per activity day (i.e. per visitor per day) can be used, multiplied by an estimated change in the number of activity days (or visits) at the policy site.

1. Spatial transfer

If the policy site is considered to approximate the study sites well in all respects, *unit value transfer* can be used. If there are several equally suitable study sites to transfer from, they should all be evaluated and the transferred values calculated from a value range.

For unit transfers between countries, differences in currency, income and cost of living between countries can be corrected for by using Purchasing Power Parity (PPP),corrected exchange rates or ratio of income per capita at PPP (often approximated with GDP at PPP). Using only PPP-adjusted exchange rates would mean assuming zero income elasticity (this approach would assume the same valuation of resources across countries, regardless of income differences between them), while using GDP at PPP ratio as an adjustment

factor would imply assuming a unitary income elasticity (so that if GDP at PPP is two times higher in country B than in country A, WTP for environmental improvements would be doubled as well). As empirical evidence shows that income elasticity of WTP for environment-related values is less than 1 but not equal to zero, neither of these approaches would be correct. In the approach adopted throughout this handbook, in which we propose valuation of damages based on the concept of opportunity costs rather than absolute (intrinsic) value, it would be more appropriate to use GDP at PPP ratio combined with income elasticity, according to Equation (1) above. The income elasticity factor should be based on recommendations from literature devoted to the specific topic in question. Skipping the elasticity factor would mean assuming an income elasticity equal to 1, which might cause overestimation.

Unit value transfer, especially with adjustment for income level, can be recommended as the simplest and most transparent way of transfer both within and between countries. This transfer method has in general also been found to be just as reliable as the more complex procedures of value function transfers and meta-analysis (NEEDS, 2007a).

2. Temporal adjustment

The value estimate should be adjusted from the time of data collection to current currency using the Consumer Price Index (CPI) for the policy site country. This adjustment allows the impact of inflation to be factored out. In transferring values from a study site to another country, these values should first be converted to local currency in the year of data collection using PPP (Purchase Power Parity) corrected exchange rates in the year of data collection, and the local CPI then used to update to current currency values.

In addition, for valuation studies performed several years earlier, it may be recommended to adjust the values using an uplift factor, to correct for the increase in WTP due to growth of average income in real terms.

E.3.3 Uncertainty and transfer errors

There are two main sources of uncertainty and errors in value transfer:

- Errors associated with estimation of the unit value/value function at the study site.
- Errors associated with transferring the study site value(s) to the policy site.

The first type of error can be minimised by choosing the primary studies which use the best, state-of-the-art methodology. The second type of error arises through transferral of the primary estimates, both in space and in time. The results of validity tests of different value transfer procedures for different types of environmental goods have shown that individual transfer errors in spatial value transfer vary from a few percent to several hundred percent (NEEDS, 2007a). However, average transfer errors, for both national and international value transfer, seem to be about ± 20-40%. In many cases this would be an acceptable transfer error. However, sensitivity analysis should be performed to see if this interval for the estimated values would influence the outcome of the CBA or policy recommendations.

E.4 Uncertainty[42]

The methodology for assessing uncertainty of the NEEDS estimates of damage costs is based on lognormal distributions and geometric standard deviations (i.e. multiplicative confidence intervals). This choice is related to the fact that damage cost values according to the Impact Assessment Method used within the NEEDS project are a product of several factors, such as increase in concentration of a given pollutant, slope of the CRF, density of the receptors and a monetary estimate of a given endpoint.

The lognormal distribution of a variable z (here representing damage costs) is obtained by assuming that the logarithm of z has a normal distribution. Invoking the central limit theorem for the product z, one can say that the lognormal distribution is the 'natural' distribution for multiplicative processes, in the same way that the Gaussian distribution is 'natural' for additive processes. Although the lognormal distribution becomes exact only in the limit of infinitely many factors, in practice it can serve as a good approximation even for a few factors, provided the distributions with the largest spread are not too far from lognormal (NEEDS, 2008b).

For many environmental impacts the lognormal model for the result is quite relevant because the impact is a product of factors and the distributions of the individual factors are not too far from lognormality. For most situations of interest here one can assume independence of the distributions (e.g. for atmospheric dispersion, CRFs and monetary values), and thus one finds that the geometric standard deviation σ_{gz} of the product z is given by:

$$[\ln(\sigma_{gz})]^2 = [\ln(\sigma_{gx1})]^2 + [\ln(\sigma_{gx2})]^2 + \ldots + [\ln(\sigma_{gxn})]^2 \qquad (3)$$

For a lognormal distribution, the geometric mean μ_g is equal to the median. If a quantity with a lognormal distribution has a geometric mean μ_g and a geometric standard deviation σ_g, the probability is approximately 68% that the true value will lie within the interval (μ_g/σ_g, $\mu_g\sigma_g$,) and 95% that it will be in the interval (μ_g/σ_g^2, $\mu_g\sigma_g^2$).

Below, we report the approximate confidence intervals for damage values calculated within the NEEDS project in three categories: classical pollutants, GHGs and trace pollutants.

1. Classical pollutants

Rabl and Spadaro (1999) have examined the uncertainties of each step of the impact pathway analysis for classical pollutants to estimate the uncertainties associated with the various components of the calculation. Table 44 reports their assumptions for the component uncertainties and the results for the damage costs for mortality. Because mortality accounts for over two-thirds of the damage costs of many pollutants, the uncertainty associated with this endpoint can be viewed as a good estimate for that associated with the sum total of impacts.

[42] This description is based on NEEDS (2008b).

Table 44 Uncertainty of damage cost estimates per kg of pollutant for mortality

	Log-normal?	σ_{gi} PM	*ln* $(\sigma_{gi})^2$	σ_{gi} SO_2 via sulphates	*ln*$(\sigma_{gi})^2$	σ_{gi} NO_x via nitrates	*ln*$(\sigma_{gi})^2$
Exposure calculation							
Dispersion	*yes*	1.5	*0.164*	1.7	*0.282*	1.7	*0.282*
Chemical transformation	*yes*	1	*0*	1.2	*0.033*	1.4	*0.113*
Background emissions	*no*	1	*0*	1.05	*0.002*	1.15	*0.02*
Total σ_g for exposure		1.5	*0.16*	1.76	*0.32*	1.9	*0.41*
ERF							
Relative risk	*no*	1.5	*0.164*	1.5	*0.164*	1.5	*0.164*
Toxicity of PM components	*?*	1.5	*0.164*	2	*0.48*	2	*0.48*
YOLL, given relative risk	*no?*	1.3	*0.069*	1.3	*0.069*	1.3	*0.069*
Total σ_g for ERF		1.88	*0.4*	2.33	*0.71*	2.33	*0.71*
Monetary valuation							
Value of YOLL (VOLY)	*yes*	2	*0.48*	2	*0.48*	2	*0.48*
Total σ_g		**2.78**	***1.04***	**3.42**	***1.51***	**3.55**	***1.61***

Source: NEEDS, 2008b.

Table 44 shows sample calculations of geometric standard deviation σ_g. The relative contributions of the σ_{gi} to the total can be seen in the column $\ln(\sigma_{gi})^2$.

NEEDS (2008b) report to three significant figures only, to bring out the differences between these pollutants and the larger uncertainties of the secondary pollutants. But in view of the subjective and rather uncertain assumptions made, the authors believe it is best to simply sum the results by saying that **the geometric standard deviation of these damage costs equals approximately 3**. This means that for classical pollutants, the true values lie, with a 68% probability, within an interval between the central value divided by three and the central value multiplied by three.

2. GHGs

For GHGs, the analysis of uncertainty is based on Tol (2005), who reviews a large number of damage cost analyses. He gathered over 100 estimates for the marginal damage costs to form a probability density function. The function proves to be strongly right-skewed, with a median of 3.8 \$/tCO_2, a mean of 25.4 \$/tCO_2 and a 95% confidence level of 95 \$/tCO_2. The distribution is not exactly lognormal since it extends to negative costs; these results were excluded because the authors do not believe the average worldwide impact could be beneficial. NEEDS (2008b) conclude that, if negative costs are excluded, the distribution is not too different from a lognormal with its tail of high estimates of low probability. They therefore consider it reasonable to estimate the geometric standard deviation of greenhouse gas damage costs by assuming that the ratio of the 95% level and the median equals σ_g^2, implying that

$$\sigma_g = \sqrt{95/3.8} = 5$$ for the damage costs of CO_2, CH_4 and N_2O.

Thus, we can conclude that for GHG estimates based on Tol (2005), approximately 68% of estimates falls within an interval between the central value divided by five and the central value multiplied by five. For the mean estimate from Tol (2005) of $ 25.4 this would imply the following 68% confidence interval: (5, 127).

3. Trace pollutants

Using the same assumption about lognormality of damage distribution, NEEDS (2008b) calculate geometric means for the trace pollutants. The results are shown in Table 45.

Table 45 **Summary of geometric standard deviations σ_g for the damage costs**

Pollutant	σ_g
As, Cd, Cr-VI, Hg, Ni, Pb	4
Dioxins	5

Uncertainty related to transfer to other regions

NEEDS (2008b) have also examined the uncertainties associated with the transfer of the individual components of the damage costs calculation (emissions, atmospheric modeling, dose-response functions and monetary valuation) to regions other than the EU. The results are expressed in terms of geometric standard deviations and listed in Table 46. To obtain the total uncertainty for a given region, the figures relevant to that region need to be combined with the geometric standard deviations of the damage costs for the EU-15

Table 46 **Geometric standard deviations associated with the transfer of components of the damage cost calculation**

Component of calculation	σ_g
Transfer of technologies	
CO_2 emissions with CCS	1.3
Other emissions	[a]
Atmospheric modelling	
If no data for effective deposition velocity v_{dep}	1.5
If no data for stack height	2
If no data for local population or no data for wind	3
Background concentrations for sulphate and nitrate formation	1.2
Background concentrations for O_3 formation due to NO_x	2
Background concentrations for O_3 formation due to VOC	1.3
Modelling of ingestion dose	
Toxic metals	2
Exposure-Response Functions	
PM, NO_x, SO_2, toxic metals	2
Monetary values, non-market goods	
WTP for goods other than health	2
WTP for health	
$(GDP/cap)/(GDP/cap)_{ref} = 0.5$	1.3
$(GDP/cap)/(GDP/cap)_{ref} = 0.2$	1.7
$(GDP/cap)/(GDP/cap)_{ref} = 0.1$	2.1

[a] Depends on site.

For example, if the transfer is to a region where no data for the effective deposition velocity v_{dep} are available, where the health system and individual sensitivities are very different from the EU-15, and where the PPP-adjusted GDP/capita is 1/5 that of the EU-15, the data in Table 47 indicate that the total uncertainty for the damage cost of PM_{10} can be expressed as $\sigma_g = 4.3$, which is much larger than the $\sigma_g = 3$ in the EU-15. The calculations are based on Equation 1, earlier in the text.

Table 47 Example of estimation of uncertainty with transfers

Example for PM_{10}	σ_g	$\log(\sigma_g)^2$
In EU-15	3	1.21
No v_{dep} data	1.5	0.16
CRF	2	0.48
WTP in region with $(GDP/cap)/(GDP/cap)_{ref} = 0.2$	1.7	0.28
Total	4.3	2.13

As can be seen in the table, the total uncertainty for the damage cost of PM_{10} in the region is $\sigma_g = 4.3$, much greater than the $\sigma_g = 3$ in the EU-15. If local population data are lacking, the uncertainty will increase to $\sigma_g = 5$.

NEEDS (2008b) note that many if not most policy applications of ExternE concern choices where the detailed location of the installations is not known in advance; in such cases one needs typical values for a country rather than site-specific results.

The authors conclude that the estimation of uncertainties is difficult and replete with uncertainties of its own; it necessarily involves subjective judgment, and various readers might well come up with different assessments of the component uncertainties. However, the authors of the report believe that unless all the component uncertainties are systematically over- or underestimated, there will be compensation of errors: some may be higher, some lower, but overall, the sum in Equation 1 is not likely to change much.

Annex F Modelling in ReCiPe

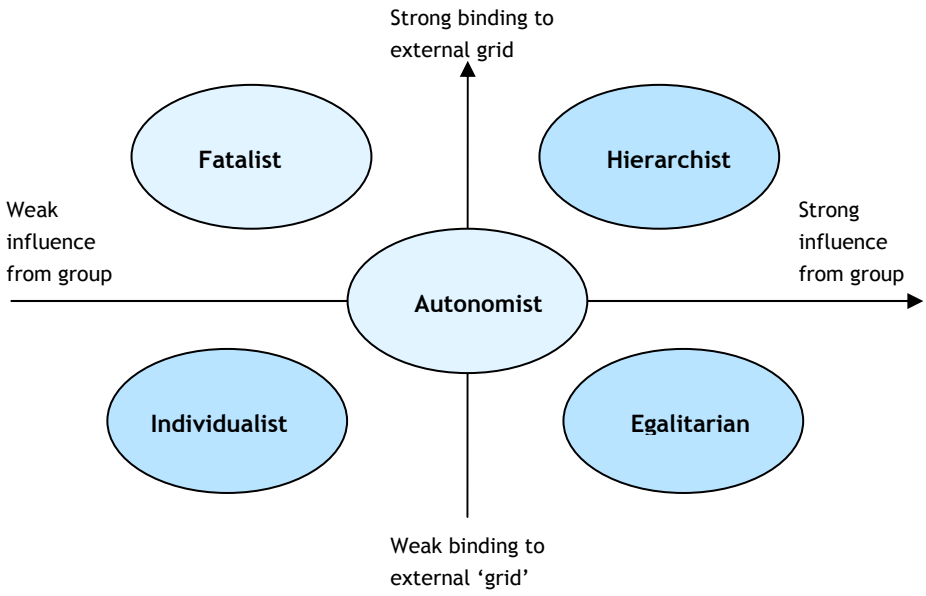
F.1 Introduction

The characterisation models used in the ReCiPe project are subject to uncertainty, since the modelled relationships reflect currently incomplete and uncertain knowledge of environmental mechanisms. Just as in Eco-indicator 99, it was therefore decided to group different sources of uncertainty and choices into a limited number of perspectives, according to the 'Cultural Theory' elaborated by Thompson, et al. (1990).

F.2 Concept of the Cultural Theory

Thompson et al. distinguishes five basic value systems by looking at the strength of the relations people have with their group and the degree to which an individual's life is circumscribed by externally imposed prescriptions (their so-called 'grid'); see Figure 10.

Figure 10 The five basic value systems according to Thompson et al.



The most important characteristics of these five 'archetypes' are:

1. Individualists lack strong links with either their group or their grid. They hold that all environmental limits are provisional and subject to negotiation.
2. Egalitarians have a strong link to the group, but a weak link to their grid. Relations between group members are often ambiguous and conflicts readily occur.
3. Hierarchists have strong links to both group and grid, both controlling others and being controlled by them. This hierarchy creates a high degree of stability in the group.
4. Fatalists have a strong link with the grid, but not with the group. These people act individually and are usually controlled by others.

5. Autonomists are a relatively small group that escapes the manipulative forces of both groups and grids.

The last two archetypes cannot be used, because fatalists are guided by what others say and autonomists think completely independently.

F.3 The three perspectives

In ReCiPe the three perspectives can be summarised as follows:
1. Individualist. In this scenario only proven cause-effect relations are included and the short-term perspective is used. For human health issues age-weighting is applied. There is technological optimism with regard to human adaptation.
2. Hierarchist. Included in this scenario are facts backed up by scientific and political bodies. The hierarchical attitude is common in the scientific community and among policy-makers.
3. Egalitarian. This scenario uses the precautionary principle and the very long-term perspective.

F.4 Overview of choices for the perspectives (in ReCiPe)

Table 48 Overview of choices for environmental mechanisms (from pollutants to midpoint impact category)

Impact category	Individualist	Hierarchist	Egalitarian
Climate change	20-yr time-horizon	100 yr time-horizon	500 yr time-horizon
Terrestrial acidification	20-yr time-horizon	100 yr time-horizon	500 yr-time-horizon
Human toxicity	100-yr time-horizon Organics: all exposure routes Metals: drinking water and air only Only carcinogenic chemicals with TD_{50} classified as 1, 2A, 2B by IARC	Infinite time-horizon All exposure routes for all chemicals All carcinogenic chemicals with reported TD_{50}	Infinite time-horizon All exposure routes for all chemicals All carcinogenic chemicals with reported TD_{50}
Terrestrial ecotoxicity	100-yr time-horizon	Infinite time-horizon	Infinite time-horizon
Freshwater ecotoxicity	100-yr time-horizon	Infinite time-horizon	Infinite time-horizon
Marine ecotoxicity	100-yr time-horizon Sea + ocean for organics and non-essential metals. For essential metals only the sea compartment is included, i.e. excluding oceanic compartments.	Infinite time-horizon Sea + ocean for all chemicals	Infinite time-horizon Sea + ocean for all chemicals
Ionising radiation	100-yr time horizon	100,000-yr time-horizon	100,000-yr time-horizon

Source: Goedkoop et al., 2009.

Table 49 Overview of choices for environmental mechanisms (from midpoint to endpoint impact category)

Impact category	Individualist	Hierarchist	Egalitarian
Climate Change	Full adaptation; no cardiovascular risks; no malnutrition; low-range RR for natural disasters.	Mean adaptation; mean relative risk for all mechanisms; no diarrhea if GDP>6000 $/yr.	No adaptation; high cardiovascular risks; high risk for disasters; high risk for malnutrition.
Climate Change	Dispersal of species assumed.	Dispersal of species assumed.	No dispersal of species assumed.
Terrestrial acidification	20 yr time-horizon.	100 yr time-horizon.	500 yr time-horizon.
Land occupation	Positive effects of land expansion are considered.	Fragmentation problem considered.	No positive effects of land expansion considered.
Land transformation	Max. restoration time is 100 yr.	Mean restoration times.	Maximum restoration times.
Fossil fuel depletion	Time horizon: 2030.	For coal, time-horizon: 2030; for all other fossil fuels: 2030-2080.	For coal, time-horizon: 2030; for all other fossil fuels: 2030-2080.

Source: Goedkoop et al., 2009.

Annex G Comparing NEEDS with RECIPE

G.1 Introductie

Het werk dat in dit rapport is gepresenteerd, bouwt in belangrijke mate op voorgaande studies. Twee studies waarop dit rapport steunt, zijn ReCiPe (Goedkoop et al., 2009) en NEEDS (2008). In deze paragraaf zullen de belangrijkste verschillen tussen deze twee methodes kort worden toegelicht.

G.1.1 Schade definitie

Bij het definiëren van de schade op end-pointniveau nemen ReCiPe en NEEDS een iets ander uitgangspunt. In ReCiPe wordt het effect van emissies op drie impactthema's berekend: menselijke gezondheid, kwaliteit van ecosystemen, en beschikbaarheid van grondstoffen. De impact op deze thema's wordt voor iedere emissie uitgedrukt in dezelfde eenheden: respectievelijk DALYs, aantal verloren soorten per jaar en Dollar per jaar. Door het gebruik van dezelfde eenheden, kunnen de impacts van verschillende emissies op één van deze thema's dus op 'end-pointniveau' met elkaar vergeleken worden.

In NEEDS worden weliswaar vergelijkbare impactthema's gebruikt (menselijke gezondheid, verlies van biodiversiteit, landbouwgewassen en materiële schade), maar wordt geen gebruik gemaakt van gestandaardiseerde 'end-points'. Zo worden bijv. voor het thema 'menselijke gezondheid' niet alle effecten vertaald naar DALYs, maar wordt ook specifieker gekeken naar bijv. verlaging van IQ (bij loodvergiftiging), of het ontstaan van erfelijke defecten (bij ioniserende radiatie). Vervolgens worden deze schades gevalueerd door bijv. Willingness-to-Pay te bepalen om een bepaalde schade te voorkomen, of de economische schade die optreedt door verminderd functioneren of het behandelen van een ziekte. Door het gebruik van verschillende 'end-points', zijn de emissieschades in principe pas met elkaar vergelijkbaar na monetarisatie.

G.1.2 Geografische dekking

Er zijn ook belangrijke verschillen tussen ReCiPe en NEEDS op het verschil van geografische dekking. Het uitgangspunt van NEEDS is om effecten op regionaal, Europees niveau te bepalen, en gebruikt het EcoSense-model om tot schattingen van schadekosten te komen voor 'classical pollutants' voor individuele Europese landen en de EU als geheel. Deze schadeschattingen gemodelleerd met EcoSense zijn in principe uit te breiden naar direct omliggende regio's, zoals Noord-Afrika. Indien de bepaling van regionale effecten niet mogelijk is op basis van de beschikbare gegevens, wordt teruggegrepen op berekeningen op globaal niveau. Dit is bijv. het geval bij de bepaling van schadekosten die gepaard gaan met ioniserende radiatie. NEEDS maakt gebruik van ruimtelijk gedifferentieerde databases (gridcel van 50 x 50 km) van bevolkingsdichtheid, achtergrondconcentraties en klimatologische omstandigheden in Europa die de relatie tussen emissies en fysieke impacts bepalen.

In ReCiPe wordt in eerste instantie juist verzocht om *globale* schadekosten te berekenen (Goedkoop et al., 2009, p. 5). Dit is bijvoorbeeld het geval bij broeikasgassen en ozonafbrekende substanties, waarvan de schade die optreedt onafhankelijk is van de locatie van de emissie. Schadekosten van emissies waarvan het effect afhankelijk is van lokale of regionale omstandigheden, worden op regionaal niveau berekend. Voorbeelden van zulke regionale omstandigheden die deze effecten beïnvloeden zijn weersomstandigheden,

achtergrondconcentraties, hygiënische factoren en bevolkingsdichtheid. Deze factoren spelen een rol bij bijv. verzuring, eutrofiëring, fotochemische ozonvorming en toxiciteit, waardoor de schade daarvan op regionaal niveau is berekend. Deze regionale berekeningen zijn in eerste instantie toepasbaar op Europese landen, maar kunnen in principe ook gebruikt worden voor overige hoogontwikkelde landen in een gematigd klimaat. In ReCiPe worden gemiddelde waarden gebruikt voor bevolkingsdidchtheid, achtergrond-concentraties en klimatologische omstandigheden voor Europa voor klassieke emissies.

G.1.3 Tijdschalen en verdiscontering

Een belangrijk verschil is nog dat de tijdschalen in ReCiPe afhankelijk zijn gemaakt van de gekozen visie. De effecten worden in ReCiPe *niet* verdisconteerd. Met andere woorden: een emissie van CO_2 uu levert tot de gekozen tijdspanne (zie Annex F) effecten op DALY en PDF op. In de NEEDS-schattingen worden die effecten *wel* verdisconteerd. Dit verklaart de aanzienlijke verschillen in schadewaardering op ReCiPe-end-points en de resultaten uit de *Integrated Assessment Models* die worden gebruikt bij klimaatverandering.

G.1.4 Epidemiologische drempels

Zowel ReCiPe als NEEDS heeft een bepaalde drempel voor het wel of niet meenemen van studies in de schadebepalingen. In ReCiPe wordt bijv. het impactthema ‘menselijke omgeving’ niet meegenomen, omdat de auteurs de onzekerheid in de studies over dit onderwerp te groot vinden. Verder zijn in ReCiPe verschillen in de betrouwbaarheid van data meegenomen in de drie verschillende perspectieven: individualistisch, hiërarchisch en egalitair. Van deze perspectieven is de eerste de strengste en neemt alleen maar studies mee waarin impacts onomstotelijk zijn vastgesteld. Het egalitaire perspectief is het minst streng en komt in feite overeen met het voorzorgsprincipe; onderbouwde aanwijzingen van schade-impacts zijn genoeg om ze mee te nemen. Het hiërarchische perspectief zit hier tussenin. Verder verschillen deze perspectieven in het beschouwde tijdsvenster. Het egalitaire perspectief neemt effecten mee die verder in de toekomst plaatsvinden, waar het individualistische perspectief vooral naar effecten op de huidige generatie kijkt.

In NEEDS wordt weliswaar een afweging gemaakt op basis van de kwaliteit en beschikbaarheid van studies, maar dit leidt tot een algemene beslissing tot wel of niet meenemen van de studie. Er wordt geen onderscheid gemaakt tussen verschillende perspectieven, zoals bij ReCiPe het geval is. Op basis van het feit dat er bij NEEDS wel een selectie wordt gemaakt van de impacts (bij loodvergiftiging worden bijv. effecten als anemie, nierdysfunctie en hoge bloeddruk niet meegenomen), maar dat deze niet zo streng lijken als bij het individualistische perspectief in ReCiPe (bijv. het wel meenemen van materiële schade als impactthema), kan grofweg gesteld worden dat de aanpak van NEEDS overeenkomt met het hiërarchische perspectief in ReCiPe.

Annex H Physical impact indicators

H.1 Introduction

In this study we use a total of five indicators for physical impacts: YOLL, YLD, DALY, PDF and QALY, as described in this annex.

H.1.1 YOLL

One of the physical impacts of environmental pollution is premature death in a given population. Ozone, smog, toxic substances and ionising radiation all result in premature death. The years of life lost (YOLL[43]) is a widely accepted indicator for this purpose, originating from health sciences.

YOLL correspond to the number of deaths multiplied by the standard life expectancy at the age at which death occurs. For a given cause, age and sex the following basic formula applies: YOLL = N x L, where N is the number of deaths and L the standard life expectancy at age of death in years. The standard life expectancy used to calculate YOLL at each age is the same for deaths in all regions of the world. All non-health characteristics such as race, socio-economic status and occupation are excluded from consideration.

In the original variant, non-uniform age weights were applied, with less weight being given to years lived at younger and older ages[44]. Age weighting reflects the social value of each year lost, and ranges from 0 at birth, peaking to 1.5 at age 25 and gradually declining thereafter (Murray, 1994). In addition, 3% time discounting is used. In recent publications, no age weights are applied.[45]

In the ExternE project estimates of YOLL-impacts have been defined for various substances (see Section 2.3.5).

H.1.2 YLD

One commonly used indicator of morbidity is the years lost due to disability (YLD) for incident cases of the health condition. To estimate the YLD for a particular cause in a particular time period, the number of incident cases in that period is multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The disability weight depends on changes in economic productivity levels due to the illness (level of loss of functioning). The basic formula for YLD is: YLD = I x DW x L, where I is the number of incident cases, DW the disability weight (based on the judgment of a panel of experts) and L the average duration of the case until remission or death (in years). Disability weights are uniform for everyone living a year in a specified health state.

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43 Also abbreviated to YLL.

44 See e.g. Lopez and Murray (1998).

45 Uniform age weights have been used in e.g. World Bank (2006b) and World Bank (2006a).

H.1.3 DALY

The DALY is a health gap measure that extends the concept of potential years of life lost due to premature death to include equivalent years of healthy life lost by virtue of individuals being in states of poor health or disability (Murray, 1996).

DALYs for a disease are the sum of the years of life lost due to premature mortality (YOLL) in the population and the years lost due to disability (YLD) for incident cases of the health condition. One DALY represents the loss of one year of equivalent full health (WHO, 2008).

In short, DALY can be defined as years of life lost plus years lost to disability: DALY = YOLL + YLD.

Box 4: Example of DALY calculations
With uniform age weights, death in infancy corresponds to 30 DALYs, and death at age 20 to around 28 DALYs. Thus, a disease burden of 3,000 DALYs in a population would be the equivalent of around 100 infant deaths or to approximately 5,000 persons living one year with blindness (DW 0.6) (GBD, 2006).

The DALY methodology has its roots in the QALY framework, developed in the 1970s (see Section H.1.5). In the 1980s the World Bank initiated a review of priorities for controlling specific diseases. The review generated findings about the comparative cost-effectiveness of interventions for most diseases important in developing countries, with the purpose of informing decision-makers in the health sectors of these countries. This process resulted in the publication of the first edition of Disease Control Priorities in Developing Countries (DCP1). This publication included an initial assessment of health status for low- and middle-income countries as measured by deaths from specific causes.

In 1992, the World Bank commissioned the so-called initial global burden of disease (GBD) study to provide a comprehensive assessment of the disease burden in 1990. The estimates, combined with analyses of the cost-effectiveness of interventions, were used during preparation of the World Development Report 1993 (World Bank, 1993).

Over the last decade the World Health Organization (WHO) has undertaken a new assessment of the global burden of disease for 2000-2002. It has also invested in improving the conceptual, methodological and empirical basis of burden of disease assessments. A comprehensive and updated version of these assessments is included in the WHO's 2006 publication (GBD, 2006). Global burden of disease statistics, including DALYs, YOLL, projections of mortality, etc., are accessible on the WHO's web pages (WHO, 2008).

Many countries and health development agencies have adopted the GBD approach as the standard for health accounting and for guiding determination of health research priorities, including Australia, India, Mexico, South Africa, Turkey and the United States, as well as the WHO itself (GBD, 2008).

Burden of disease and injury indicators (including DALYs) have been calculated for a set of major risk factors. One of the categories of risk factors is 'environmental risks', which include unsafe water, sanitation and hygiene, urban air pollution and indoor smoke from household use of solid fuels. Calculations do not cover any estimates related to specific pollutants.

H.1.4 PDFs

An indicator of biodiversity loss has been developed that is referred to as the Potentially Disappeared Fraction of selected species (PDF). For a given land use type, a certain number of vascular plant species is defined. If the land use type changes from one with a higher number of different species to one with fewer species, the number of species (biodiversity) is reduced. Hence, a 'delta PDF' can be calculated.

The PDF indicator was proposed in Eco-indicator 1999 for the assessment of acidification and eutrophication impacts. PDF measures the percentage of plants that is likely to disappear as a result of converting land use type. By extension, it can be assumed that the damage to plants and lower organisms is also representative of the damage to populations of higher animals (Eco-idicator, 2000).

Within the NEEDS project the PDF approach has been used for assessing acidification and eutrophication impacts on ecosystems. To be able to compare and evaluate specific land-use types, the species number of a set of land use types has been standardised for 1 m^2. This absolute species number is transformed into a relative number using the regional species richness of the Swiss Lowlands as a reference. Hence, the PDF values can be interpreted as the relative decline in biodiversity caused by a land use change from Swiss Lowland use to the respective land use category. For example, conversion of land from a Swiss Lowland state to conventional arable land would imply that 74% of all species would potentially disappear (NEEDS, 2006).

In the Ecosense model used within the NEEDS project for modelling and valuation of different impacts of pollution, the values of PDF per deposition are taken from a study by Ott et al. (2006), based on the damage model Natuurplanner. From the regional dispersion modelling, depositions per grid cell are available. For each 50 x 50 km^2 grid cell, the share of natural soil is available. Finally, a 'pressure index' (country-dependent) is applied which indicates the sensitivity of the soil (RIVM, 2000). This information has been used in EcoSense to model the loss of biodiversity due to SO_2, NO_x and NH_3 emissions.

This approach is designed to be applicable on a European scale. Consequently, it may not reflect specific local conditions, e.g. the occurrence of locally endangered species at a particular location. It can be used to make first approximations and, with the inclusion of this impact category, the importance of biodiversity and the Willingness-To-Pay to avoid its loss is demonstrated.

In the present project, PDF has been evaluated in monetary terms; see Section 5.3.3.

H.1.5 QALY

The indicator quality-adjusted life-year (QALY) takes into account the pain and suffering associated with disease and illness. One QALY is defined as 1 year in perfect health or its equivalent (Mauskopf and Morales, 2000). A health status index converts the concepts of health into quantifiable measures of an individual's perception of the impact of their health status on their general sense of well-being. Health states are classified based on the degree of restriction of mobility, social interaction, physical activity, pain or other symptoms a person may experience. The first classification of this kind was developed in Bush et al. (1972) based on a survey of 867 subjects in California. A more recent set of health states is the health utility index (HUI), for which

utility weights have been estimated.[46]
In addition to health utility weights, to make due allowance for the estimated duration of each health state, the following assumptions need to be made in order to calculate QALYs lost as a result of illness (Mauskopf and Morales, 2000):

1. Age at onset (e.g. 30 years).
2. Remaining life expectancy (e.g. 46 years).
3. Quality of life in the absence of the illness (e.g. 1).
4. Discount rate (e.g. 3%).
5. Number of different functional states (e.g. hospital days, bed days, house days).
6. Morbidity for those dying from acute conditions.
7. Pattern of utility loss for chronic conditions (e.g. constant utility loss).
8. Life expectancy loss for chronic conditions (e.g. no life expectancy loss).

While QALYs are in principle universal, it is also possible to calculate with country-specific utility weights obtained in national samples. QALYs are not dependent on any socio-economic characteristics such as age or income.

QALYs have been used in health sector Cost-Effectiveness Analysis (CEA) for three decades (Sassi, 2006). They are most frequently used to assess the improvement in quality-adjusted life expectancy deriving from a specific health intervention relative to a situation in which either no intervention or a standard alternative intervention is provided. Thus, the health effects of certain interventions like vaccinations or preventing given products from reaching the consumer can be measured in QALYs. This approach is used, for example, by the American Food and Drug Administration (FDA) to evaluate programmes designed to improve health conditions.

Indicators like QALY and DALY are sometimes criticised on ethical grounds. Because of their design and how they are used in practice, one might draw the conclusion that disabled people are less entitled to scarce health resources for interventions that would extend their lives than people in normal health. This is in contrast with the basic principles of WHO (which, *nota bene*, endorses the DALY approach) (Arnesen and Nord, 1999).

Box 5: DALYs and QALYs
DALYs and QALYs are complementary concepts. QALYs are years of healthy life lived; DALYs are years of healthy life lost. To reflect the different burdens associated with different health states, QALYs use 'utility' weights, while DALYs use 'disability weights'. In a simplified example, if the utility of deafness is 0.67, the disability weight of deafness is 1-0.67 = 0.33. Disregarding age weighting and discounting, and assuming a life expectancy of 80 years, a deaf man living for 50 years represents 0.67 x 50 = 33.4 QALYs gained and 0.33 x 50 + 30 x 1 = 46.6 DALYs lost (based on (Arnessen, 1999)).

[46] Utility weights used in QALY calculation differ from disability weights used in DALY calculations in several respects. Disability weights refer to loss of functioning caused by a disease, while utility weights reflect the level of quality of life enjoyed in particular health states. The two types of weights are derived using different elicitation techniques and different groups of subjects. DALY calculations tend to be based on a universal set of standard weights based on expert valuations, while QALY calculations often rely on preference-based quality-of-life measures elicited from general population samples or groups of patients (Sassi, 2006).

Although QALYs and DALYs stem from the same broad conceptual framework, they are not interchangeable, as they are based partly on different assumptions and methodologies. Understanding the systemic differences between the two measures is important for enabling policy-makers to make sound judgements about the outcomes of specific health interventions (Sassi, 2006).

Annex I Houdbaarheid data

I.1 Inleiding

Het voorliggende rapport biedt een momentopname bij de waardering en weging van emissies en milieueffecten. Het rapport geeft onder andere een update van eerdere resultaten uit 2002 (CE, 2002). De schaduwprijzen die in de vorige studie waren bepaald op basis van de preventiekosten dienden in de eerste plaats te worden geüpdate omdat de beleidsdoelen waarop de schaduwprijzen waren gebaseerd inmiddels zijn achterhaald door nieuwe doelen. Ook de resultaten uit de voorliggende studie zullen te zijner tijd opnieuw tegen het licht moeten worden gehouden. In deze Annex bespreken we op welke momenten een update aan de orde is (zie ook paragraaf 7.2).

I.2 Nieuwe beleidsdoelen

In de preventiekostenmethode wordt de schaduwprijs voor een aantal emissies bepaald door het snijpunt van de marginale reductiekostencurve en het beleidsdoel dat veelal wordt weergegeven als een verticale lijn. Wanneer beleidsdoelen significant wijzigen dienen ook de schaduwprijzen opnieuw te worden bepaald. Wanneer bijvoorbeeld een nieuw internationaal klimaatakkoord leidt tot strengere doelen en bijvoorbeeld een verlaging van het emissieplafond binnen het Europese handelssysteem voor emissierechten, dan stijgt ook de schaduwprijs voor CO_2.

I.3 Nieuwe reductiekostencurves en economische ontwikkeling

Naast het beleidsdoel is de andere bepalende factor in de preventiekosten-methode de marginale reductiekostencurve. Deze curve kan wijzigen door nieuwe inzichten, veranderingen in emissies ten gevolge van veranderende economische activiteiten en technologische ontwikkelingen. Technieken voor emissiereductie worden immers met de tijd goedkoper. Dit wil zeggen dat wanneer voldoende informatie voorhanden is voor nieuwe marginale reductie-kostencurves ook de schaduwprijzen geüpdate dienen te worden. Te denken valt aan het moment van verschijnen van een nieuw Optiedocument door ECN en PBL. Tenslotte, indien de economische neergang sinds halverwege 2008 geen conjuncturele neergang is maar een structureel karakter krijgt, zullen de beleidsdoelen tegen lagere kosten worden gerealiseerd.

I.4 Nieuwe onderliggende methoden en waarden schadewaardering

Bij de schadekosten liggen de waardes meer vast omdat de onderliggende variabelen (zoals dosis-responsefuncties, verspreiding van vervuiling en waardering van end-points) door de tijd heen weinig veranderen. Bij schade-kosten is het wetenschapsgebied echter nog volop in ontwikkeling. Nieuwe studies of een nieuwe aanpak, kunnen derhalve nieuwe inzichten opleveren. Dit speelt vooral een rol rondom (a) het gebruik van de discontovoet voor het berekenen van impacts die ver in de tijd heen liggen (en dan met name rondom het gebruik van optiewaardering); (b) waardering van een mensen-leven in de context van milieuvervuiling; (c) waardering van optiewaardes en ‘bequest values’ als onderdeel van de milieuwaardering. Daarnaast zullen de thema’s, waarbij waardering nu nog niet via de impact-pathway-benadering

zijn bepaald (zoals vermesting), in de toekomst mogelijkerwijs ook via die route worden bepaald.

Annex J Totale lijst met weegfactoren

Op basis van de weegfactoren van weegset 1 en 2 en de ReCiPe-mid-point-karakterisatiefactoren is een uitgebreide lijst met schade- en preventie-schattingen gemaakt. Deze lijsten zijn in deze laatste Annex te vinden.

J.1 Lijst met schadekosten

Table 50, Table 51 en Table 52 geven de schadekosten van meer dan 400 stoffen. Er zijn drie categorieën onderscheiden: lucht, bodem en water, om aan te geven op welk(e) compartiment(en) de verontreinigende stof in kwestie een impact heeft.

Schadekosten voor emissies naar lucht zijn bepaald met behulp van de weegfactoren van weegset 2 uit het rapport (zie ook hoofdstuk 6) en de ReCiPe-mid-point-karakterisatiefactoren. Voor sommige stoffen zoals SO_2 is rechtstreeks de waardering uit NEEDS overgenomen.

De schadekosten voor de categorieën grond en water zijn bepaald met behulp van directe waardering van ReCiPe end-pointkarakterisatiefactoren (de methode van weegset 3). Voor deze compartimenten konden wij niet de waardering uit NEEDS overnemen, omdat NEEDS uitgaat van emissies naar lucht. Omdat directe waardering van ReCiPe-end-pointkarakterisatiefactoren een minder betrouwbare methode is dan methode 2 (met NEEDS-schade-kosten), zijn deze schadeschattingen bij benadering.

Bij de lijst met schadekosten is de veronderstelling er een lineaire relatie is tussen de bijdrage van de individuele stoffen aan het thema (zoals verzuring) en de achterliggende schade.

Table 50 Schadekosten voor emissies naar lucht (verkregen via methode 2 met NEEDS-schadekosten)

Stof	Euro per kg
1,4-Dioxane	8,67E-03
1-Butanol	6,12E-01
1-Butene	1,06E+00
1-Butene, 2-methyl-	7,58E-01
1-Butene, 3-methyl-	6,59E-01
1-Hexene	8,62E-01
1-Pentene	9,62E-01
1-Propanol	5,52E-01
1-Propanol, 3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, HFE-7100	7,43E+00
2-Acetylaminofluorene	2,15E+00
2-Benzothiazolethiol	5,90E-03
2-Butanol	3,94E-01
2-Butanone, 3,3-dimethyl-	3,18E-01
2-Butanone, 3-methyl-	3,58E-01
2-Butenal	3,49E-01
2-Butene (cis)	1,13E+00
2-Butene (trans)	1,11E+00
2-Hexanone	5,63E-01
2-Hexene (cis)	1,05E+00

Stof	Euro per kg
2-Hexene (trans)	1,05E+00
2-Methyl pentane	4,13E-01
2-Methyl-1-propanol	3,54E-01
2-Methyl-2-butene	8,27E-01
2-Pentanone	5,40E-01
2-Pentene (cis)	1,10E+00
2-Pentene (trans)	1,10E+00
2-Propanol	1,85E-01
3-Hexanone	5,89E-01
3-Methyl-1-butanol	4,26E-01
3-Pentanol	5,89E-01
4-Methyl-2-pentanone	4,83E-01
Acetaldehyde	7,31E-01
Acetamide	1,30E-02
Acetic acid	9,56E-02
Acetic acid, methyl ester	5,81E-02
Acetic acid, propyl ester	2,77E-01
Acetone	9,57E-02
Acetonitrile	9,72E-03
Acetophenone	5,90E-03
Acrolein	1,27E+02
Acrylamide	8,03E+00
Acrylic acid	7,66E+00
Actinides, radioactive, unspecified	1,07E-01
Alcohol, diacetone	3,02E-01
Aldehydes, unspecified	2,26E+00
Allyl chloride	2,08E-01
Ammonia	2,78E+01
Aniline	7,99E-02
Aniline, p-chloro-, hydrochloride	7,29E-01
Anthracene	7,35E-03
Antimony	1,38E+02
Arsenic	8,11E+02
Barium	1,39E+01
Benzaldehyde	-7,42E-02
Benzenamine, 2-methoxy-5-nitro-	6,01E-02
Benzene	2,43E-01
Benzene, (epoxyethyl)-	4,66E-02
Benzene, 1,2,3-trimethyl-	1,25E+00
Benzene, 1,2,4-trichloro-	1,34E-01
Benzene, 1,2,4-trimethyl-	1,26E+00
Benzene, 1,2-dichloro-	2,41E-02
Benzene, 1,3,5-trimethyl-	1,36E+00
Benzene, 1,3-dinitro-	8,59E+00
Benzene, 1,4-dichloro-	2,06E-02
Benzene, 1-propyl-	6,24E-01
Benzene, 3,5-dimethylethyl-	1,30E+00
Benzene, ethyl-	7,18E-01
Benzene, hexachloro-	1,19E+01
Benzene, pentachloro-	3,05E+00
Benzidine	1,98E+00
Benzidine, 3,3'-dichloro-	1,24E+00
Benzo(a)pyrene	1,10E+00
Benzotrichloride	1,31E+01

Stof	Euro per kg
Benzyl chloride	8,38E-02
Beryllium	7,33E+03
Biphenyl, 4-amino-	7,45E-01
Bis(2-chloro-1-methylethyl)ether	1,45E-01
Bis(2-chloroethyl)ether	4,23E-01
Bromoform	2,62E-01
Butadiene	9,42E-01
Butadiene, hexachloro-	3,63E-01
Butanal	7,81E-01
Butane	3,47E-01
Butane, 1,1,1,3,3-pentafluoro-, HFC-365mfc	1,99E+01
Butane, 2,2-dimethyl-	2,37E-01
Butane, 2,3-dimethyl-	5,33E-01
Butane, nonafluoroethoxy, HFE-569sf2	1,48E+00
Butane, perfluoro-	2,22E+02
Butane, perfluorocyclo-, PFC-318	2,58E+02
Butanol, 2-methyl-1-	4,81E-01
Butanol, 2-methyl-2-	2,24E-01
Butanol, 3-methyl-2-	4,00E-01
Butene, 1,4-dichloro-2- (trans)	1,77E+00
Butyl acetate	2,65E-01
C.I. disperse yellow 3	1,67E-02
Cadmium	1,27E+02
Caprolactam	1,45E-02
Carbamic acid, ethyl ester	2,21E-02
Carbon dioxide	2,50E-02
Carbon dioxide, fossil	2,50E-02
Carbon dioxide, land transformation	2,50E-02
Carbon disulfide	9,80E-01
Carbon monoxide, biogenic	2,66E-02
Carbon monoxide, fossil	2,66E-02
Carbon-14	4,25E-01
Catechol	8,55E-03
Cesium-134	2,40E-02
Cesium-137	2,71E-02
Chlorendic acid	1,62E-01
Chlorine	4,31E+00
Chloroform	1,44E+00
Chloromethyl methyl ether	5,00E-01
Chromium	3,35E+01
Chromium VI	1,67E+02
Cobalt	8,90E+01
Cobalt-58	8,51E-04
Cobalt-60	3,34E-02
Copper	3,41E-01
Cumene	4,95E-01
Cyanide	1,74E+00
Cyclohexane	2,86E-01
Cyclohexanol	5,10E-01
Cyclohexanone	2,94E-01
Cyclohexene, 4-vinyl-	1,43E-02
Cyclohexylamine	2,93E-02
Cyclopentadiene, hexachloro-	3,08E+01
Decabromodiphenyl oxide	1,69E+01

Stof	Euro per kg
Decane	3,78E-01
Diethyl ether	4,38E-01
Diethyl ketone	4,07E-01
Diglycidyl resorcinol ether	1,27E-01
Dihydrosafrole	8,63E-03
Diisopropyl ether	3,92E-01
Dimethyl carbonate	2,46E-02
Dimethyl ether	2,11E-01
Dimethylcarbamyl chloride	4,46E+00
Dinitrogen monoxide	7,45E+00
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	5,09E+07
Dipropylthiocarbamic acid S-ethyl ester	2,83E-01
Dodecane	3,51E-01
Epichlorohydrin	2,64E+00
Ethane	1,21E-01
Ethane, 1,1,1,2-tetrachloro-	2,27E-01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	3,58E+01
Ethane, 1,1,1,2-tetrafluoro-2-bromo-, Halon 2401	9,78E+00
Ethane, 1,1,1-trichloro-, HCFC-140	3,66E+00
Ethane, 1,1,1-trifluoro-, HFC-143a	1,12E+02
Ethane, 1,1,1-trifluoro-2,2-chlorobromo-, Halon 2311	5,48E+00
Ethane, 1,1,2,2-tetrachloro-	1,74E-01
Ethane, 1,1,2,2-tetrafluoro-, HFC-134	2,75E+01
Ethane, 1,1,2-trichloro-	8,70E+00
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1,93E+02
Ethane, 1,1,2-trifluoro-, HFC-143	8,83E+00
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	2,28E+01
Ethane, 1,1-difluoro-, HFC-152a	3,10E+00
Ethane, 1,2-dibromo-	3,03E+00
Ethane, 1,2-dibromotetrafluoro-, Halon 2402	2,76E+02
Ethane, 1,2-dichloro-	6,75E-01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2,87E+02
Ethane, 1,2-difluoro-, HFC-152	1,33E+00
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	6,05E+01
Ethane, 1-chloro-2,2,2-trifluoro-(difluoromethoxy)-, HCFE-235da2	8,75E+00
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	2,72E+00
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	1,60E+01
Ethane, 2-chloro-1,1,1-trifluoro-, HCFC-133a	3,12E-01
Ethane, chloro-	4,93E-03
Ethane, chloropentafluoro-, CFC-115	2,02E+02
Ethane, fluoro-, HFC-161	3,00E-01
Ethane, hexafluoro-, HFC-116	3,05E+02
Ethane, pentachloro-	2,31E-01
Ethane, pentafluoro-, HFC-125	8,75E+01
Ethanol	3,93E-01
Ethanol, 2-butoxy-	4,76E-01

Stof	Euro per kg
Ethanol, 2-methoxy-	3,02E-01
Ethene	9,85E-01
Ethene, chloro-	3,18E-01
Ethene, dichloro- (cis)	4,40E-01
Ethene, dichloro- (trans)	3,86E-01
Ethene, tetrachloro-	1,61E+00
Ethene, trichloro-	3,24E-01
Ether, 1,1,1-trifluoromethyl methyl-, HFE-143a	1,89E+01
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcc3	1,44E+01
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcf2	9,35E+00
Ether, 1,1,2,2-Tetrafluoroethyl methyl-, HFE-254cb2	8,98E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356mec3	2,53E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcc3	2,75E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf2	6,63E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf3	1,26E+01
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236ea2	2,47E+01
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236fa	1,22E+01
Ether, 2,2,3,3,3-Pentafluoropropyl methyl-, HFE-365mcf3	2,75E-01
Ether, di(difluoromethyl), HFE-134	1,58E+02
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245cb2	1,77E+01
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa1	7,15E+00
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa2	1,65E+01
Ether, ethyl 1,1,2,2-tetrafluoroethyl-, HFE-374pc2	1,39E+01
Ether, pentafluoromethyl-, HFE-125	3,73E+02
Ethyl acetate	2,06E-01
Ethyl acrylate	1,69E-02
Ethylene glycol	3,67E-01
Ethylene glycol monoethyl ether	3,80E-01
Ethylene oxide	2,08E-01
Ethyne	8,39E-02
Fertiliser, nitrogen	9,12E-01
Fluoranthene	3,90E-02
Formaldehyde	2,75E-01
Formic acid	3,15E-02
Heptane	4,86E-01
Hexane	5,02E-01
Hexane, 2-methyl-	4,04E-01
Hexane, 3-methyl-	3,58E-01
Hexane, perfluoro-	2,33E+02
HFE-227EA	3,85E+01

Stof	Euro per kg
HFE-236ca12 (HG-10)	7,00E+01
HFE-263fb2	2,75E-01
HFE-329mcc2	2,30E+01
HFE-338mcf2	1,38E+01
HFE-338pcc13 (HG-01)	3,75E+01
HFE-347pcf2	1,45E+01
HFE-43-10pccc124 (H-Galden1040x)	4,68E+01
Hydrazine, methyl-	1,10E-01
Hydrocarbons, aliphatic, alkanes, cyclic	2,78E-01
Hydrocarbons, aromatic	2,59E-01
Hydrocarbons, chlorinated	1,65E+00
Hydrogen fluoride	5,49E+00
Hydrogen-3, Tritium	2,89E-05
Hydroquinone	5,86E-02
Iodine-129	1,88E+00
Iodine-131	3,04E-04
Iodine-133	1,88E-05
Isobutane	3,02E-01
Isobutene	6,18E-01
Isobutyraldehyde	5,06E-01
Isopentane	3,99E-01
Isoprene	1,07E+00
Isopropyl acetate	2,07E-01
Krypton-85	2,82E-07
Lead	4,08E+02
Lead-210	3,04E-03
Maleic anhydride	8,38E-02
Manganese	6,61E+01
manure N	9,87E-01
m-Cresol	1,93E-02
Mercury	1,10E+04
Methacrylic acid, methyl ester	1,56E-01
Methane	6,25E-01
Methane, biogenic	6,31E-01
Methane, bromo-, Halon 1001	8,79E+01
Methane, bromochlorodifluoro-, Halon 1211	3,91E+02
Methane, bromodifluoro-, Halon 1201	6,49E+01
Methane, bromotrifluoro-, Halon 1301	6,48E+02
Methane, chlorodifluoro-, HCFC-22	4,92E+01
Methane, chlorofluoro-, HCFC-31	3,80E-01
Methane, chlorotrifluoro-, CFC-13	3,60E+02
Methane, dibromo-	3,85E-02
Methane, dibromodifluoro-, Halon 1202	5,09E+01
Methane, dichloro-, HCC-30	7,63E-01
Methane, dichlorodifluoro-, CFC-12	3,24E+02
Methane, dichlorofluoro-, HCFC-21	3,78E+00
Methane, difluoro-, HFC-32	1,69E+01
Methane, dimethoxy-	1,61E-01
Methane, fluoro-, HFC-41	2,30E+00
Methane, fossil	6,31E-01
Methane, iodotrifluoro-	1,00E-02
Methane, monochloro-, R-40	1,23E+00
Methane, tetrachloro-, CFC-10	1,88E+02
Methane, tetrafluoro-, CFC-14	1,85E+02

Stof	Euro per kg
Methane, trichlorofluoro-, CFC-11	1,59E+02
Methane, trifluoro-, HFC-23	3,70E+02
Methanol	1,43E-01
Methyl ethyl ketone	3,67E-01
Methyl formate	2,66E-02
Molybdenum	3,18E+01
Molybdenum trioxide	1,84E+00
m-Phenylenediamine	6,71E-02
m-Xylene	1,09E+00
Naphthalene	1,69E-01
Nickel	5,37E+00
Nitrate	1,60E+00
Nitrilotriacetic acid	5,92E-04
Nitrobenzene	2,58E+00
Nitrogen fluoride	4,30E+02
Nitrogen oxides	1,06E+01
Nitroglycerin	1,44E-02
N-Methylolacrylamide	1,12E-01
NMVOC, non-methane volatile organic compounds, unspecified origin	2,54E+00
N-Nitrosodiethylamine	1,31E+02
N-Nitrosodiphenylamine	1,34E-02
N-Nitrosodipropylamine	6,98E+01
N-Nitrosopiperidine	3,20E-01
Noble gases, radioactive, unspecified	2,63E-10
Nonane	4,07E-01
o-Cresol	2,44E-02
Octane	4,46E-01
o-Phenylenediamine dihydrochloride	2,46E-03
o-Toluidine hydrochloride	1,50E-02
o-Xylene	1,04E+00
PAH, polycyclic aromatic hydrocarbons	4,23E-01
Particulates	6,48E+01
p-Cresidine	4,75E-03
Pentanal	7,52E-01
Pentane	3,89E-01
Pentane, 2,3-dihydroperfluoro-, HFC-4310mee	4,10E+01
Pentane, 3-methyl-	4,71E-01
Pentane, perfluoro-	2,29E+02
PFC-9-1-18	1,88E+02
PFPMIE	2,58E+02
Phenol	1,91E-02
Phenol, 2,4,5-trichloro-	5,20E-02
Phenol, 2,4,6-trichloro-	1,59E-02
Phenol, 2,4-dichloro-	7,33E+00
Phenol, 2,4-dimethyl-	5,68E-02
Phenol, 2,4-dinitro-	1,35E+00
Phenol, pentachloro-	8,98E-01
Phosphorus	3,88E+02
Phthalate, dimethyl tere-	4,83E-02
Plutonium-238	1,34E-01
Plutonium-alpha	1,67E-01
Polonium-210	3,04E-03

Stof	Euro per kg
Polychlorinated biphenyls	7,45E-01
Propanal	7,87E-01
Propane	1,73E-01
Propane sultone	1,06E+00
Propane, 1,1,1,2,2,3-hexafluoro-, HFC-236cb	3,35E+01
Propane, 1,1,1,2,3,3,3-heptafluoro-, HFC-227ea	8,05E+01
Propane, 1,1,1,2,3,3-hexafluoro-, HFC-236ea	3,43E+01
Propane, 1,1,1,3,3,3-hexafluoro-, HCFC-236fa	2,45E+02
Propane, 1,1,2,2,3-pentafluoro-, HFC-245ca	1,73E+01
Propane, 1,1,3,3-tetrafluoro-, HFC-245fa	2,58E+01
Propane, 1,2-dibromo-3-chloro-	2,21E+01
Propane, 1,2-dichloro-	5,51E+00
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	1,60E+01
Propane, 2,2-dimethyl-	1,70E-01
Propane, 2-nitro-	1,69E-01
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	3,83E+00
Propane, perfluoro-	2,21E+02
Propargyl alcohol	4,02E-01
Propene	1,11E+00
Propene, 1,3-dichloro-	2,50E+01
Propene, 1-chloro-1-	7,70E-01
Propionic acid	1,47E-01
Propylene glycol	4,50E-01
Propylene glycol methyl ether	3,50E-01
Propylene glycol t-butyl ether	4,56E-01
Propylene oxide	8,75E-01
p-Xylene	9,96E-01
Pyrene	6,94E-02
Pyridine	2,19E+00
Radium-226	1,82E-03
Radon-222	4,85E-05
Safrole	2,31E-03
s-Butyl acetate	2,71E-01
Selenium	1,69E+02
Silver	8,01E+02
Sodium azide	6,50E-01
Styrene	2,05E-01
Sulfur dioxide	1,54E+01
Sulfur hexafluoride	5,70E+02
Sulfur oxides	1,10E+01
Sulphur, trifluoromethyl pentafluoride	4,43E+02
t-Butyl acetate	5,22E-02
t-Butyl alcohol	1,04E-01
t-Butyl ethyl ether	2,40E-01
t-Butyl methyl ether	1,79E-01
Thallium	1,16E+02
Thioacetamide	1,68E-01
Thiourea	1,39E-02
Thorium-230	9,10E-02
Tin	1,05E+00
Toluene	6,46E-01

Stof	Euro per kg
Toluene diisocyanate	2,68E+02
Toluene, 2,4,6-trinitro-	1,02E+01
Toluene, 2,4-diamine	3,26E-01
Toluene, 2,4-dinitro-	2,97E+00
Toluene, 2,6-dinitro-	3,03E+01
Toluene, 2-chloro-	1,47E-01
Toluene, 2-ethyl-	8,86E-01
Toluene, 3,5-diethyl-	1,28E+00
Toluene, 3-ethyl-	1,00E+00
Toluene, 4-ethyl-	8,92E-01
Toluene, dinitro-	5,76E-01
Triethyl amine	1,63E-02
Undecane	3,78E-01
Uranium	1,64E-02
Uranium alpha	1,64E-02
Uranium-234	1,94E-01
Uranium-235	4,25E-02
Uranium-238	1,64E-02
Vanadium	7,14E+01
Vinyl acetate	7,04E-02
Xenon-133	2,85E-07
Xylene	2,13E-02
Zinc	1,02E+01

Table 51 **Schadekosten voor emissies naar grond (verkregen via methode 3, directe waardering van ReCiPe-end-point-karakterisatiefactoren)**

Stof	Euro per kg
2,4,5-T	3,40E+00
2,4-D	3,40E+00
Abamectin	1,06E+02
Acephate	4,66E+00
Acifluorfen	1,84E-02
Aclonifen	5,54E+00
Aldicarb	1,20E+03
Aldoxycarb	1,78E+02
Alpha-cypermethrin	1,98E+02
Aluminum phosphide	1,87E+03
Ametryn	1,01E+02
Amitraz	9,07E-01
Anthracene	3,26E+01
Antimony	3,32E+01
Arsenic	1,16E+01
Asulam	1,91E-01
Atrazine	1,78E+02
Azadirachtin	8,25E+01
Azinphos-methyl	2,36E+02
Barium	9,89E+00
Bendiocarb	2,86E+02
Benomyl	5,86E-01
Bentazone	2,45E+00
Beryllium	7,39E+02
Bifenox	8,04E-01
Bifenthrin	2,01E+02

Stof	Euro per kg
Bitertanol	1,05E+00
Botran	1,53E+01
Bromacil	2,44E+00
Bromine	3,31E+02
Bromoxynil	1,88E+01
Bromuconazole	4,38E+01
Buprofezin	2,34E-01
Butylate	1,90E-01
Cadmium	1,13E+02
Captan	9,37E-01
Carbaryl	1,09E+01
Carbendazim	5,82E+01
Carbetamide	3,15E+00
Carbofuran	2,56E+02
Carboxin	8,10E+00
Chlorfenvinphos	1,48E+02
Chloridazon	2,45E+00
Chlorimuron-ethyl	3,77E-03
Chlormequat	2,92E-02
Chlormequat chloride	7,36E-02
Chloropicrin	7,00E+02
Chlorothalonil	1,51E-01
Chlorotoluron	6,44E+00
Chlorpropham	8,91E-02
Chlorpyrifos	5,03E-01
Chlorsulfuron	2,34E-02
Chromium	5,40E-06
Chromium VI	3,17E-03
Clofentezine	6,71E-02
Clopyralid	9,40E+00
Cloquintocet-mexyl	4,64E-02
Cobalt	1,44E-20
Copper	4,24E-03
Cyanazine	5,83E-02
Cycloate	4,84E-01
Cycloxydim	3,53E-02
Cyfluthrin	1,26E-01
Cymoxanil	6,52E-02
Cypermethrin	5,29E+01
Cyromazine	5,24E+00
Daminozide	1,44E-03
DDAC	8,12E-01
Deltamethrin	6,71E-03
Desmedipham	3,24E-01
Desmetryn	1,19E+01
Diazinon	1,93E+00
Dicamba	2,09E-02
Dichlobenil	4,88E+00
Dichlorvos	2,40E-01
Dicofol	6,05E-01
Difenoconazole	5,16E+00
Difenzoquat	1,60E-02
Diflubenzuron	1,70E-02
Diflufenican	1,32E-02

Stof	Euro per kg
Dimethipin	1,95E-01
Dimethoate	4,02E-02
Dimethomorph	2,62E+00
Dinoseb	5,61E+00
Dinoterb	2,43E+01
Diphenamid	8,36E-03
Dipropylthiocarbamic acid S-ethyl ester	3,42E-02
Diquat dibromide	1,69E+00
Disodium acid methane arsenate	4,28E+00
Disulfoton	7,87E-01
Dithianon	4,45E-02
Diuron	7,26E-02
DNOC	1,38E+01
Dodine	1,77E-03
Endosulfan	5,89E-02
Endothall	1,74E-03
Epoxiconazole	1,74E+01
Esfenvalerate	3,09E+03
Ethephon	1,90E-01
Ethion	1,53E-01
Ethofumesate	2,16E+00
Ethoprop	4,29E+01
Etridiazole	5,44E+00
Fenamiphos	3,38E-01
Fenarimol	6,11E-01
Fenbuconazole	7,81E-02
Fenbutatin oxide	1,72E+01
Fenitrothion	1,22E-01
Fenpiclonil	9,60E+00
Fenpropathrin	2,84E-02
Fenpropimorph	7,26E-01
Fentin acetate	6,44E-01
Fentin hydroxide	4,07E-01
Fenvalerate	7,92E-02
Ferbam	1,67E+00
fertilizer P	9,40E-02
Fluazifop-P-butyl	8,92E-01
Fluazinam	5,32E+02
Fluometuron	9,41E-03
Fluorochloridone	4,36E+00
Flusilazole	2,31E-01
Flutolanil	5,61E-03
Folpet	5,20E-02
Fomesafen	1,92E-01
Fonofos	2,02E-01
Fosetyl-aluminium	1,45E-03
Fuberidazole	1,16E+01
Glufosinate ammonium	1,83E-01
Glyphosate	2,84E-05
Heptenophos	5,16E+00
Hexaconazole	3,44E-01
Hexazinone	7,15E-03
Hexythiazox	2,83E-02
Hymexazol	5,40E+00

Stof	Euro per kg
Imazalil	2,40E-02
Imazaquin	1,02E-03
Ioxynil	8,28E+00
Iprodion	1,60E-03
Isofenphos	7,10E-01
Isoproturon	1,34E+02
Isoxaben	1,90E-02
Kresoxim-methyl	1,35E-02
Lactofen	1,87E+00
Lambda-cyhalothrin	6,04E+01
Lead	1,16E-01
Lindane	3,92E+00
Linuron	4,50E-01
Malathion	3,22E-04
Maleic hydrazide	5,20E-03
Mancozeb	3,22E-05
Maneb	1,56E-03
Manganese	7,32E-02
manure P	8,88E-02
MCPA	1,47E-01
MCPB	5,07E-03
m-Cresol	2,09E-03
Mecoprop	1,40E+00
Mecoprop-P	5,00E-02
Mepiquat chloride	1,09E-02
Mercury	3,55E+02
Metalaxil	3,41E-02
Metamitron	1,14E+00
Metam-sodium	1,25E+03
Metazachlor	7,24E+00
Methabenzthiazuron	1,18E+01
Methamidophos	2,96E-01
Methidathion	9,02E-02
Methiocarb	1,09E-01
Methomyl	2,96E-01
Methoxychlor	1,18E-02
Metiram	1,57E-01
Metobromuron	1,99E+01
Metolachlor	2,69E-02
Metribuzin	2,77E-02
Metsulfuron-methyl	2,61E-03
Mevinfos	1,25E-02
Molinate	3,28E-01
Molybdenum	1,79E+00
Monolinuron	2,36E+01
Monosodium acid methanearsonate	5,08E+00
Myclobutanil	1,00E-02
Naled	6,88E-01
Napropamide	5,61E-03
Nickel	4,69E-02
Nicosulfuron	7,60E+00
Norflurazon	1,09E-02
Orbencarb	2,36E+00
Oryzalin	1,17E-02

Stof	Euro per kg
Oxadixyl	1,88E+00
Oxamyl	1,06E-02
Oxydemeton-methyl	1,64E+01
Oxydiazon	4,27E-01
Oxyfluorfen	1,85E+00
Oxytetracycline	2,15E+02
Paclobutrazol	1,39E-02
Parathion	4,48E-02
Parathion, methyl	3,21E-01
Pendimethalin	4,07E-02
Phenmedipham	3,64E-05
Phorate	1,50E-01
Phosmet	1,33E-02
Phosphorus	6,72E+02
Picloram	1,96E-02
Pirimicarb	3,20E+00
Pirimiphos methyl	1,03E-01
Prochloraz	2,14E-01
Procymidone	1,74E-02
Profenofos	1,14E-01
Prometryn	1,50E-02
Pronamide	8,20E-02
Propachlor	7,59E-03
Propamocarb	1,50E-02
Propamocarb HCl	1,90E+00
Propanil	1,74E-02
Propaquizafop	2,90E+00
Propargite	4,06E-02
Propene, 1,3-dichloro-	1,27E+00
Propham	1,25E-03
Propiconazole	1,05E-01
Propoxur	6,88E-02
Prosulfocarb	9,48E-01
Pyrazophos	2,05E-01
Pyridaben	2,19E+01
Pyridate	1,70E-02
Pyriproxyfen	5,83E-03
Quinmerac	3,34E-01
Quizalofop ethyl ester	1,14E-01
Resmethrin	2,38E-02
Rimsulfuron	3,06E+01
Rotenone	2,61E-01
Selenium	2,93E+02
Sethoxydim	4,30E-03
Silver	4,10E+01
Simazine	4,77E-01
Starane	6,04E-02
Sulprofos	5,24E-02
Tebufenozide	3,75E-02
Tebuthiuron	1,05E-02
Teflubenzuron	6,71E-01
Terbacil	2,02E-02
Terbufos	1,93E+01
Terbuthylazin	1,32E+01

Stof	Euro per kg
Terbutryn	1,69E+00
Thallium	6,49E+00
Thiabendazole	1,59E-02
Thidiazuron	2,72E+01
Thifensulfuron-methyl	6,60E-02
Thiobencarb	1,45E-01
Thiodicarb	5,05E-02
Thiophanat-methyl	3,11E-03
Thiram	2,67E-02
Tin	7,65E-04
Tolclophos-methyl	1,39E-01
Tralomethrin	4,97E-01
Triadimefon	4,86E-02
Triadimenol	1,42E-02
Tri-allate	1,05E-01
Triasulfuron	1,69E-01
Triazofos	1,29E+01
Trichlorfon	6,22E-03
Triclopyr	7,40E+00
Trifluralin	3,25E-01
Triforine	2,22E-01
Urea	1,31E-01
Vanadium	1,67E+00
Vinclozolin	1,04E-01
Zinc	2,55E-01
Zineb	5,43E-03

Table 52 **Schadekosten voor emissies naar water (verkregen via methode 3, directe waardering van ReCiPe-end-pointkarakterisatiefactoren)**

Stof	Euro per kg
1,4-Dioxane	6,57E-03
1-Butanol	1,02E-03
1-Octanol	9,02E-03
2-Benzothiazolethiol	4,44E-01
2-Butanol	1,36E-04
2-Butenal	6,28E-02
2-Ethoxyethyl acetate	3,38E-03
2-Propanol	5,54E-05
Acenaphthene	7,96E-02
Acetamide	1,49E-03
Acetic acid	2,08E-03
Acetone	4,22E-04
Acetonitrile	3,34E-03
Acetophenone	6,15E-03
Acrylamide	1,88E-01
Acrylic acid	1,79E-03
Acrylonitrile	2,26E-01
Allyl chloride	3,00E-02
Allylamine	1,10E-02
Aniline	4,43E-02
Aniline, p-chloro-, hydrochloride	1,02E-01
Anthracene	1,30E-01
Antimony	2,22E+01

Stof	Euro per kg
Antimony-124	2,53E-02
Arsenic, ion	5,62E+02
Barium	1,56E+01
Benzaldehyde	1,20E-02
Benzenamine, 2-methoxy-5-nitro-	1,73E-02
Benzenamine, 4-methyl-	2,59E-01
Benzene	1,63E-02
Benzene, 1,2,4-trichloro-	3,19E-01
Benzene, 1,2,4-trimethyl-	3,32E-02
Benzene, 1,2-dichloro-	6,94E-02
Benzene, 1,2-dinitro-	3,97E+00
Benzene, 1,3,5-trimethyl-	1,03E-02
Benzene, 1,3-dichloro-	2,58E-02
Benzene, 1,3-dinitro-	2,44E+00
Benzene, 1,4-dichloro-	8,00E-02
Benzene, 1,4-dinitro-	8,14E-01
Benzene, chloro-	5,81E-02
Benzene, ethyl-	7,84E-03
Benzidine, 3,3'-dimethyl-	5,57E-01
Benzyl chloride	5,07E-02
Beryllium	1,45E+01
Bis(2-chloro-1-methylethyl)ether	4,65E-02
Bis(2-chloroethyl)ether	3,27E-02
Bis(chloromethyl)ether	3,50E+02
Bromate	2,54E-01
Bromine	4,04E+00
C.I. direct blue 218	4,55E-04
C.I. disperse yellow 3	6,05E-02
Cadmium, ion	4,96E+00
Caprolactam	6,33E-04
Carbamic acid, butyl-, 3-iodo-2-propynyl ester	1,65E+00
Carbamic acid, ethyl ester	2,31E-03
Carboxylic acids, unspecified	1,37E-03
Catechol	5,04E-02
Cesium-134	4,44E+00
Cesium-137	5,16E+00
Chlorine	9,00E+00
Chloroacetic acid	5,40E-02
Chloroform	7,77E-01
Chromium VI	4,03E-02
Chromium, ion	2,84E-02
Cobalt	1,04E+00
Cobalt-58	1,26E-03
Cobalt-60	1,36E+00
Cumene	1,31E-02
Cumene hydroperoxide	1,09E-01
Cupferron	9,35E-02
Cyanide	7,54E-01
Cyclohexane	2,56E-03
Cyclohexanol	4,68E-04
Cyclohexene, 4-vinyl-	6,99E-02
Cyclohexylamine	1,86E-02
Decabromodiphenyl oxide	5,61E-05

Stof	Euro per kg
Dibenzofuran	1,24E-01
Dicyclopentadiene	2,02E-02
Diethanolamine	1,17E-03
Dimethylamine	1,40E-03
Dipropylthiocarbamic acid S-ethyl ester	1,16E-01
EDTA	1,44E-03
Ethane, 1,1,1-trichloro-, HCFC-140	1,25E-02
Ethane, 1,1,2,2-tetrachloro-	1,46E-01
Ethane, 1,2-dibromo-	2,50E+00
Ethane, 1,2-dichloro-	6,67E-01
Ethane, chloro-	3,65E-03
Ethane, hexachloro-	4,58E+01
Ethanol, 2-butoxy-	3,38E-03
Ethanol, 2-methoxy-	5,96E-03
Ethene, 1,2-dichloro-	1,87E-03
Ethene, chloro-	1,80E-01
Ethene, dichloro- (trans)	1,83E-01
Ethene, tetrachloro-	1,88E+00
Ethene, trichloro-	7,12E-03
Ethyl acrylate	3,60E-02
Ethylene diamine	2,26E-03
Ethylene glycol	2,95E-04
Ethylene oxide	7,68E-02
Fluoranthene	3,98E+00
Formaldehyde	2,14E-01
Formic acid	8,00E-04
Glyoxal	2,00E-03
Hydrazine	1,62E+00
Hydrocarbons, aromatic	9,22E-01
Hydrogen-3, Tritium	1,40E-05
Hydroquinone	4,20E-02
Iodine-129	3,09E+00
Iodine-131	1,55E-02
Lead	8,43E+00
Maleic anhydride	3,81E-07
Manganese	2,66E+01
Manganese-54	9,84E-03
m-Cresol	3,35E-02
Mercury	9,58E+02
Methacrylic acid, methyl ester	9,76E-03
Methane, dichloro-, HCC-30	3,87E+00
Methane, tetrachloro-, CFC-10	7,74E+02
Methanol	3,43E-04
Methyl acrylate	1,53E-02
Methyl ethyl ketone	2,42E-04
Molybdenum	4,89E+01
Molybdenum trioxide	4,26E-01
m-Phenylenediamine	2,01E-02
m-Xylene	1,35E-02
Naphthalene	1,22E-01
Nickel, ion	3,37E+00
Nitrilotriacetic acid	9,05E-04
Nitrobenzene	7,62E-01
Nitroglycerin	5,59E-02

Stof	Euro per kg
N-Methylolacrylamide	1,57E-02
N-Nitrosodiphenylamine	2,01E-01
o-Cresol	1,10E-02
o-Phenylenediamine	2,39E-02
o-Toluidine	2,51E-03
o-Xylene	1,45E-02
PAH, polycyclic aromatic hydrocarbons	1,29E-01
p-Cresidine	9,13E-03
p-Cresol	1,70E-03
Phenanthrene	1,47E-01
Phenol	2,27E-03
Phenol, 2,4,5-trichloro-	1,01E-01
Phenol, 2,4,6-trichloro-	3,63E-02
Phenol, 2,4-dichloro-	3,40E-02
Phenol, 2,4-dimethyl-	4,67E-02
Phenol, 2,4-dinitro-	2,83E-01
Phenol, 2-nitro-	1,12E-01
Phenol, 4-nitro-	7,62E-03
Phosphate	1,80E+00
Phosphorus	1,44E+01
Phthalate, butyl-benzyl-	1,14E-01
Phthalate, dibutyl-	3,78E-01
Phthalate, dimethyl-	3,71E-03
Phthalate, dioctyl-	2,64E-01
p-Nitroaniline	5,79E-02
Polychlorinated biphenyls	4,73E+00
p-Phenylenediamine	1,94E-02
Propane, 1,2-dichloro-	4,54E+00
Propane, 2-nitro-	7,76E-02
Propene, 1,3-dichloro-	3,99E-01
Propylene oxide	1,82E-01
Pyrene	5,39E-01
Pyridine	6,31E-02
Radium-226	3,98E-03
Selenium	4,02E+02
Silver, ion	3,11E+01
Silver-110	1,55E-02
Sodium azide	6,62E-02
Sodium dimethyldithiocarbamate	1,16E+00
Sodium formate	2,28E-04
Styrene	2,65E-02
Sulfuric acid, dimethyl ester	7,32E-04
t-Butyl alcohol	2,25E-02
t-Butyl methyl ether	2,38E-03
Thallium	7,69E+01
Thiourea	5,31E-02
Tin, ion	3,42E-02
Toluene	6,19E-03
Toluene diisocyanate	4,72E+02
Toluene, 2,4,6-trinitro-	2,19E-03
Toluene, 2,4-diisocyanate	1,85E-03
Toluene, 2,4-dinitro-	4,52E-02
Toluene, 2,6-dinitro-	1,05E-01
Toluene, 2-chloro-	7,43E-02



Stof	Euro per kg
Toluene, dinitro-	2,07E-01
Tribufos	7,41E+01
Tributyltin compounds	2,78E+02
Tributyltin oxide	2,78E+02
Triethyl amine	5,13E-04
Triethylene glycol	8,72E-06
Uranium alpha	7,04E-02
Uranium-234	7,48E-02
Uranium-235	7,04E-02
Uranium-238	7,04E-02
Vanadium, ion	1,70E+01
Vinyl acetate	1,19E-02
Xylene	7,20E-03
Zinc, ion	1,61E+00

J.2 Lijst met preventiekosten

Table 53, Table 54 en Table 55 geven de preventiekosten van meer dan 400 stoffen. De preventiekosten zijn bepaald met behulp van de weegfactoren van weegset 1 uit het rapport (zie ook hoofdstuk 6) en de ReCiPe-mid-point-karakterisatiefactoren. Als in de laatste kolom een uitroepteken bij een bepaalde stof staat, dan geeft dat aan dat de stof op meerdere milieuthema's effect heeft. De tabellen zijn onderverdeeld in drie categorieën: lucht, grond en water, om aan te geven op welk(e) compartiment(en) de verontreinigende stof in kwestie een impact heeft.
De lijst met preventiekosten dient vooral gebruikt te worden voor weging. Deze preventiekosten zijn dus niet gelijk aan de kosten van technische maatregelen om de uitstoot van een bepaalde stof te reduceren. Indien ze toch gebruikt worden voor waardering dient men te beseffen dat dit gebeurt onder de volgende veronderstelling: de aanname dat het overheidsbeleid economisch efficiënt en conform de milieukundige equivalentie tussen stoffen wordt vormgegeven (zie de behandeling in paragraaf 4.3.3). Omdat dit zeker niet het geval is, dient er voorzichtig te worden omgesprongen bij het gebruik van deze impliciete preventiekosten als waardering.

Table 53 Preventiekosten voor emissies naar lucht

	€/kg
1,4-Dioxane	9.66E-01
1-Butanol	5.25E+00
1-Butene	9.10E+00
1-Butene, 2-methyl-	6.50E+00
1-Butene, 3-methyl-	5.65E+00
1-Hexene	7.40E+00
1-Pentene	8.25E+00
1-Propanol	4.74E+00
1-Propanol, 3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, HFE-7100	7.43E+00
2-Acetylaminofluorene	2.39E+02
2-Benzothiazolethiol	6.58E-01
2-Butanol	3.38E+00
2-Butanone, 3,3-dimethyl-	2.73E+00
2-Butanone, 3-methyl-	3.08E+00
2-Butenal	3.89E+01
2-Butene (cis)	9.70E+00

	€/kg
2-Butene (trans)	9.55E+00
2-Hexanone	4.83E+00
2-Hexene (cis)	9.05E+00
2-Hexene (trans)	9.05E+00
2-Methyl pentane	3.55E+00
2-Methyl-1-propanol	3.04E+00
2-Methyl-2-butene	7.10E+00
2-Pentanone	4.63E+00
2-Pentene (cis)	9.45E+00
2-Pentene (trans)	9.45E+00
2-Propanol	1.59E+00
3-Hexanone	5.05E+00
3-Methyl-1-butanol	3.66E+00
3-Pentanol	5.05E+00
4-Methyl-2-pentanone	4.14E+00
Acetaldehyde	1.67E+01
Acetamide	1.45E+00
Acetic acid	8.20E-01
Acetic acid, methyl ester	4.99E-01
Acetic acid, propyl ester	2.38E+00
Acetone	1.14E+00
Acetonitrile	1.08E+00
Acetophenone	6.58E-01
Acrolein	1.42E+04
Acrylamide	8.95E+02
Acrylic acid	8.53E+02
Actinides, radioactive, unspecified	0.00E+00
Alcohol, diacetone	2.60E+00
Aldehydes, unspecified	1.96E+02
Allyl chloride	2.32E+01
Ammonia	1.16E+01
Aniline	8.90E+00
Aniline, p-chloro-, hydrochloride	8.12E+01
Anthracene	8.19E-01
Antimony	1.54E+04
Arsenic	1.13E+05
Barium	1.55E+03
Benzaldehyde	1.02E+00
Benzenamine, 2-methoxy-5-nitro-	6.69E+00
Benzene	4.97E+00
Benzene, (epoxyethyl)-	5.20E+00
Benzene, 1,2,3-trimethyl-	1.07E+01
Benzene, 1,2,4-trichloro-	1.49E+01
Benzene, 1,2,4-trimethyl-	1.08E+01
Benzene, 1,2-dichloro-	2.69E+00
Benzene, 1,3,5-trimethyl-	1.17E+01
Benzene, 1,3-dinitro-	9.57E+02
Benzene, 1,4-dichloro-	2.30E+00
Benzene, 1-propyl-	5.35E+00
Benzene, 3,5-dimethylethyl-	1.12E+01
Benzene, ethyl-	6.34E+00
Benzene, hexachloro-	1.32E+03
Benzene, pentachloro-	3.40E+02
Benzidine	2.21E+02

	€/kg
Benzidine, 3,3'-dichloro-	1.38E+02
Benzo(a)pyrene	1.23E+02
Benzotrichloride	1.46E+03
Benzyl chloride	9.34E+00
Beryllium	8.17E+05
Biphenyl, 4-amino-	8.30E+01
Bis(2-chloro-1-methylethyl)ether	1.61E+01
Bis(2-chloroethyl)ether	4.72E+01
Bromoform	2.92E+01
Butadiene	1.87E+01
Butadiene, hexachloro-	4.05E+01
Butanal	6.70E+00
Butane	2.98E+00
Butane, 1,1,1,3,3-pentafluoro-, HFC-365mfc	1.99E+01
Butane, 2,2-dimethyl-	2.04E+00
Butane, 2,3-dimethyl-	4.57E+00
Butane, nonafluoroethoxy, HFE-569sf2	1.48E+00
Butane, perfluoro-	2.22E+02
Butane, perfluorocyclo-, PFC-318	2.58E+02
Butanol, 2-methyl-1-	4.13E+00
Butanol, 2-methyl-2-	1.93E+00
Butanol, 3-methyl-2-	3.43E+00
Butene, 1,4-dichloro-2- (trans)	1.98E+02
Butyl acetate	2.27E+00
C.I. disperse yellow 3	1.87E+00
Cadmium	8.00E+04
Caprolactam	1.62E+00
Carbamic acid, ethyl ester	2.46E+00
Carbon dioxide	2.50E-02
Carbon dioxide, fossil	2.50E-02
Carbon dioxide, land transformation	2.50E-02
Carbon disulfide	1.09E+02
Carbon monoxide, biogenic	2.28E-01
Carbon monoxide, fossil	2.28E-01
Carbon-14	0.00E+00
Catechol	9.52E-01
Cesium-134	0.00E+00
Cesium-137	0.00E+00
Chlorendic acid	1.80E+01
Chlorine	4.81E+02
Chloroform	7.25E+01
Chloromethyl methyl ether	5.57E+01
Chromium	7.13E-01
Chromium VI	1.27E+04
Cobalt	9.91E+03
Cobalt-58	0.00E+00
Cobalt-60	0.00E+00
Copper	3.80E+01
Cumene	4.47E+00
Cyanide	1.63E+01
Cyclohexane	2.45E+00
Cyclohexanol	4.38E+00
Cyclohexanone	2.53E+00
Cyclohexene, 4-vinyl-	1.60E+00

	€/kg
Cyclohexylamine	3.27E+00
Cyclopentadiene, hexachloro-	3.43E+03
Decabromodiphenyl oxide	1.88E+03
Decane	3.25E+00
Diethyl ether	3.76E+00
Diethyl ketone	3.50E+00
Diglycidyl resorcinol ether	1.41E+01
Dihydrosafrole	9.61E-01
Diisopropyl ether	3.36E+00
Dimethyl carbonate	2.11E-01
Dimethyl ether	1.62E+00
Dimethylcarbamyl chloride	4.97E+02
Dinitrogen monoxide	7.45E+00
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	2.24E+08
Dipropylthiocarbamic acid S-ethyl ester	3.15E+01
Dodecane	3.02E+00
Epichlorohydrin	2.94E+02
Ethane	1.04E+00
Ethane, 1,1,1,2-tetrachloro-	2.53E+01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	3.61E+01
Ethane, 1,1,1,2-tetrafluoro-2-bromo-, Halon 2401	7.50E+00
Ethane, 1,1,1-trichloro-, HCFC-140	3.73E+00
Ethane, 1,1,1-trifluoro-, HFC-143a	1.12E+02
Ethane, 1,1,1-trifluoro-2,2-chlorobromo-, Halon 2311	4.20E+00
Ethane, 1,1,2,2-tetrachloro-	1.94E+01
Ethane, 1,1,2,2-tetrafluoro-, HFC-134	2.75E+01
Ethane, 1,1,2-trichloro-	4.50E+02
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1.91E+02
Ethane, 1,1,2-trifluoro-, HFC-143	8.83E+00
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	2.37E+01
Ethane, 1,1-difluoro-, HFC-152a	3.13E+00
Ethane, 1,2-dibromo-	3.38E+02
Ethane, 1,2-dibromotetrafluoro-, Halon 2402	2.21E+02
Ethane, 1,2-dichloro-	7.52E+01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2.78E+02
Ethane, 1,2-difluoro-, HFC-152	1.33E+00
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	5.99E+01
Ethane, 1-chloro-2,2,2-trifluoro-(difluoromethoxy)-, HCFE-235da2	8.75E+00
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	3.39E+00
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	1.58E+01
Ethane, 2-chloro-1,1,1-trifluoro-, HCFC-133a	3.47E+01
Ethane, chloro-	5.50E-01
Ethane, chloropentafluoro-, CFC-115	1.97E+02
Ethane, fluoro-, HFC-161	3.00E-01
Ethane, hexafluoro-, HFC-116	3.05E+02
Ethane, pentachloro-	2.58E+01
Ethane, pentafluoro-, HFC-125	8.75E+01
Ethanol	3.40E+00
Ethanol, 2-butoxy-	4.08E+00
Ethanol, 2-methoxy-	2.60E+00
Ethene	8.45E+00
Ethene, chloro-	3.54E+01
Ethene, dichloro- (cis)	3.78E+00

	€/kg
Ethene, dichloro- (trans)	3.31E+00
Ethene, tetrachloro-	1.76E+02
Ethene, trichloro-	3.16E+00
Ether, 1,1,1-trifluoromethyl methyl-, HFE-143a	1.89E+01
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcc3	1.44E+01
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcf2	9.35E+00
Ether, 1,1,2,2-Tetrafluoroethyl methyl-, HFE-254cb2	8.98E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356mec3	2.53E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcc3	2.75E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf2	6.63E+00
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf3	1.26E+01
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236ea2	2.47E+01
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236fa	1.22E+01
Ether, 2,2,3,3,3-Pentafluoropropyl methyl-, HFE-365mcf3	2.75E-01
Ether, di(difluoromethyl), HFE-134	1.58E+02
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245cb2	1.77E+01
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa1	7.15E+00
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa2	1.65E+01
Ether, ethyl 1,1,2,2-tetrafluoroethyl-, HFE-374pc2	1.39E+01
Ether, pentafluoromethyl-, HFE-125	3.73E+02
Ethyl acetate	1.77E+00
Ethyl acrylate	1.88E+00
Ethylene glycol	3.15E+00
Ethylene glycol monoethyl ether	3.26E+00
Ethylene oxide	2.32E+01
Ethyne	7.20E-01
Fertiliser, nitrogen	5.11E-01
Fluoranthene	4.35E+00
Formaldehyde	2.67E+02
Formic acid	2.71E-01
Heptane	4.17E+00
Hexane	7.11E+00
Hexane, 2-methyl-	3.47E+00
Hexane, 3-methyl-	3.08E+00
Hexane, perfluoro-	2.33E+02
HFE-227EA	3.85E+01
HFE-236ca12 (HG-10)	7.00E+01
HFE-263fb2	2.75E-01
HFE-329mcc2	2.30E+01
HFE-338mcf2	1.38E+01
HFE-338pcc13 (HG-01)	3.75E+01
HFE-347pcf2	1.45E+01
HFE-43-10pccc124 (H-Galden1040x)	4.68E+01
Hydrazine, methyl-	1.23E+01
Hydrocarbons, aliphatic, alkanes, cyclic	2.40E+00
Hydrocarbons, aromatic	5.04E+00
Hydrocarbons, chlorinated	1.20E+02
Hydrogen fluoride	6.12E+02
Hydrogen-3, Tritium	0.00E+00
Hydroquinone	6.53E+00
Iodine-129	0.00E+00
Iodine-131	0.00E+00

	€/kg
Iodine-133	0.00E+00
Isobutane	2.60E+00
Isobutene	5.30E+00
Isobutyraldehyde	4.34E+00
Isopentane	3.42E+00
Isoprene	9.20E+00
Isopropyl acetate	1.78E+00
Krypton-85	0.00E+00
Lead	3.54E+04
Lead-210	0.00E+00
Maleic anhydride	9.34E+00
Manganese	7.36E+03
manure N	5.53E-01
m-Cresol	2.15E+00
Mercury	1.18E+06
Methacrylic acid, methyl ester	1.74E+01
Methane	6.25E-01
Methane, biogenic	6.76E-01
Methane, bromo-, Halon 1001	8.13E+03
Methane, bromochlorodifluoro-, Halon 1211	2.27E+02
Methane, bromodifluoro-, Halon 1201	5.21E+01
Methane, bromotrifluoro-, Halon 1301	5.39E+02
Methane, chlorodifluoro-, HCFC-22	4.69E+01
Methane, chlorofluoro-, HCFC-31	4.23E+01
Methane, chlorotrifluoro-, CFC-13	3.60E+02
Methane, dibromo-	3.85E-02
Methane, dibromodifluoro-, Halon 1202	3.90E+01
Methane, dichloro-, HCC-30	5.42E+01
Methane, dichlorodifluoro-, CFC-12	1.62E+03
Methane, dichlorofluoro-, HCFC-21	3.78E+00
Methane, difluoro-, HFC-32	1.69E+01
Methane, dimethoxy-	1.39E+00
Methane, fluoro-, HFC-41	2.30E+00
Methane, fossil	6.76E-01
Methane, iodotrifluoro-	1.00E-02
Methane, monochloro-, R-40	1.36E+01
Methane, tetrachloro-, CFC-10	1.39E+04
Methane, tetrafluoro-, CFC-14	1.85E+02
Methane, trichlorofluoro-, CFC-11	3.02E+02
Methane, trifluoro-, HFC-23	3.70E+02
Methanol	1.75E+00
Methyl ethyl ketone	3.15E+00
Methyl formate	2.28E-01
Molybdenum	3.54E+03
Molybdenum trioxide	2.05E+02
m-Phenylenediamine	7.48E+00
m-Xylene	9.35E+00
Naphthalene	1.88E+01
Nickel	1.01E+03
Nitrate	8.96E-01
Nitrilotriacetic acid	6.60E-02
Nitrobenzene	2.88E+02
Nitrogen fluoride	4.30E+02
Nitrogen oxides	8.72E+00

	€/kg
Nitroglycerin	1.60E+00
N-Methylolacrylamide	1.24E+01
NMVOC, non-methane volatile organic compounds, unspecified origin	5.00E+00
N-Nitrosodiethylamine	1.46E+04
N-Nitrosodiphenylamine	1.50E+00
N-Nitrosodipropylamine	7.77E+03
N-Nitrosopiperidine	3.57E+01
Noble gases, radioactive, unspecified	0.00E+00
Nonane	3.50E+00
o-Cresol	2.71E+00
Octane	3.83E+00
o-Phenylenediamine dihydrochloride	2.74E-01
o-Toluidine hydrochloride	1.67E+00
o-Xylene	8.90E+00
PAH, polycyclic aromatic hydrocarbons	4.72E+01
Particulates, < 10 um	2.30E+00
Particulates, < 10 um (mobile)	2.30E+00
Particulates, < 10 um (stationary)	2.30E+00
Particulates, < 2.5 um	2.30E+00
Particulates, > 2.5 um, and < 10um	2.30E+00
p-Cresidine	5.29E-01
Pentanal	6.45E+00
Pentane	3.34E+00
Pentane, 2,3-dihydroperfluoro-, HFC-4310mee	4.10E+01
Pentane, 3-methyl-	4.05E+00
Pentane, perfluoro-	2.29E+02
PFC-9-1-18	1.88E+02
PFPMIE	2.58E+02
Phenol	2.13E+00
Phenol, 2,4,5-trichloro-	5.80E+00
Phenol, 2,4,6-trichloro-	1.77E+00
Phenol, 2,4-dichloro-	8.17E+02
Phenol, 2,4-dimethyl-	6.33E+00
Phenol, 2,4-dinitro-	1.50E+02
Phenol, pentachloro-	1.00E+02
Phosphorus	4.32E+04
Phthalate, dimethyl tere-	5.38E+00
Plutonium-238	0.00E+00
Plutonium-alpha	0.00E+00
Polonium-210	0.00E+00
Polychlorinated biphenyls	8.30E+01
Propanal	6.75E+00
Propane	1.49E+00
Propane sultone	1.18E+02
Propane, 1,1,1,2,2,3-hexafluoro-, HFC-236cb	3.35E+01
Propane, 1,1,1,2,3,3,3-heptafluoro-, HFC-227ea	8.05E+01
Propane, 1,1,1,2,3,3-hexafluoro-, HFC-236ea	3.43E+01
Propane, 1,1,1,3,3,3-hexafluoro-, HCFC-236fa	2.45E+02
Propane, 1,1,2,2,3-pentafluoro-, HFC-245ca	1.73E+01
Propane, 1,1,3,3-tetrafluoro-, HFC-245fa	2.58E+01
Propane, 1,2-dibromo-3-chloro-	2.46E+03
Propane, 1,2-dichloro-	6.14E+02
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	1.58E+01

	€/kg
Propane, 2,2-dimethyl-	1.46E+00
Propane, 2-nitro-	1.89E+01
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	3.65E+00
Propane, perfluoro-	2.21E+02
Propargyl alcohol	4.49E+01
Propene	9.50E+00
Propene, 1,3-dichloro-	2.78E+03
Propene, 1-chloro-1-	8.58E+01
Propionic acid	1.27E+00
Propylene glycol	3.86E+00
Propylene glycol methyl ether	3.00E+00
Propylene glycol t-butyl ether	3.91E+00
Propylene oxide	9.75E+01
p-Xylene	8.55E+00
Pyrene	7.73E+00
Pyridine	2.44E+02
Radium-226	0.00E+00
Radon-222	0.00E+00
Safrole	2.58E-01
s-Butyl acetate	2.33E+00
Selenium	1.88E+04
Silver	8.92E+04
Sodium azide	7.25E+01
Styrene	8.47E+00
Sulfur dioxide	5.00E+00
Sulfur hexafluoride	5.70E+02
Sulfur oxides	5.00E+00
Sulphur, trifluoromethyl pentafluoride	4.43E+02
t-Butyl acetate	4.48E-01
t-Butyl alcohol	8.95E-01
t-Butyl ethyl ether	2.06E+00
t-Butyl methyl ether	2.19E+00
Thallium	1.29E+04
Thioacetamide	1.87E+01
Thiourea	1.55E+00
Thorium-230	0.00E+00
Tin	1.17E+02
Toluene	7.29E+00
Toluene diisocyanate	2.99E+04
Toluene, 2,4,6-trinitro-	1.14E+03
Toluene, 2,4-diamine	3.63E+01
Toluene, 2,4-dinitro-	3.31E+02
Toluene, 2,6-dinitro-	3.38E+03
Toluene, 2-chloro-	1.64E+01
Toluene, 2-ethyl-	7.60E+00
Toluene, 3,5-diethyl-	1.10E+01
Toluene, 3-ethyl-	8.60E+00
Toluene, 4-ethyl-	7.65E+00
Toluene, dinitro-	6.42E+01
Triethyl amine	1.81E+00
Undecane	3.25E+00
Uranium	0.00E+00
Uranium alpha	0.00E+00
Uranium-234	0.00E+00

	€/kg
Uranium-235	0.00E+00
Uranium-238	0.00E+00
Vanadium	7.96E+03
Vinyl acetate	7.84E+00
Xenon-133	0.00E+00
Xylene	2.37E+00
Zinc	1.13E+03

Table 54 Preventiekosten voor emissies naar grond

	€/kg
2,4,5-T	3.93E+00
2,4-D	8.81E-01
Abamectin	1.03E+02
Acephate	2.17E+02
Acifluorfen	1.10E+00
Aldicarb	6.07E+02
Alpha-cypermethrin	3.89E+00
Aluminum phosphide	7.73E+01
Amitraz	1.13E+01
Anthracene	1.15E-01
Antimony	6.97E+02
Arsenic	6.26E+02
Asulam	6.83E-03
Atrazine	5.18E+00
Azinphos-methyl	1.65E+00
Barium	3.80E+02
Bendiocarb	7.75E+00
Benomyl	2.83E-03
Bentazone	5.75E+00
Beryllium	7.43E+01
Bifenthrin	1.11E+01
Bitertanol	2.16E+00
Botran	2.74E+00
Bromoxynil	1.07E+00
Buprofezin	1.12E+01
Butylate	3.98E-01
Cadmium	1.27E+03
Captan	1.67E-03
Carbaryl	6.88E-01
Carbendazim	5.84E-01
Carbofuran	2.71E+01
Carboxin	3.93E-01
Chlorfenvinphos	7.38E+02
Chlorimuron-ethyl	2.25E-01
Chlormequat	1.75E+00
Chlorothalonil	8.99E+00
Chlorpropham	5.31E+00
Chlorpyrifos	3.01E+01
Chlorsulfuron	1.40E+00
Chromium	3.22E-04
Chromium VI	1.90E-01
Clofentezine	4.03E+00
Cobalt	8.63E-19

	€/kg
Copper	2.53E-01
Cyanazine	3.47E+00
Cyfluthrin	7.52E+00
Cypermethrin	3.15E+03
Cyromazine	3.13E+02
Daminozide	8.60E-02
Deltamethrin	4.00E-01
Diazinon	1.15E+02
Dicamba	1.25E+00
Dichlorvos	1.44E+01
Dicofol	3.61E+01
Difenzoquat	9.52E-01
Diflubenzuron	1.01E+00
Dimethipin	1.16E+01
Dimethoate	2.39E+00
Dinoseb	3.34E+02
Diphenamid	5.01E-01
Dipropylthiocarbamic acid S-ethyl ester	2.04E+00
Diquat dibromide	1.01E+02
Disulfoton	4.69E+01
Dithianon	2.67E+00
Diuron	4.32E+00
Dodine	1.06E-01
Endosulfan	3.52E+00
Endothall	1.04E-01
Ethephon	1.13E+01
Ethion	9.15E+00
Ethoprop	2.55E+03
Fenamiphos	2.02E+01
Fenarimol	3.63E+01
Fenbuconazole	4.67E+00
Fenbutatin oxide	1.03E+03
Fenitrothion	7.27E+00
Fenpropathrin	1.70E+00
Fenpropimorph	4.35E+01
Fentin acetate	3.86E+01
Fentin hydroxide	2.44E+01
Fenvalerate	4.72E+00
Ferbam	9.94E+01
Fertiliser, nitrogen	5.11E-01
fertilizer P	5.77E-01
Fluometuron	5.61E-01
Flusilazole	1.38E+01
Flutolanil	3.36E-01
Folpet	3.11E+00
Fomesafen	1.15E+01
Fonofos	1.21E+01
Fosetyl-aluminium	8.65E-02
Glufosinate ammonium	1.09E+01
Glyphosate	1.70E-03
Hexaconazole	2.05E+01
Hexazinone	4.26E-01
Hexythiazox	1.69E+00
Imazalil	1.44E+00

	€/kg
Imazaquin	6.10E-02
Iprodion	9.52E-02
Isofenphos	4.26E+01
Isoxaben	1.14E+00
Kresoxim-methyl	8.05E-01
Lactofen	1.12E+02
Lead	6.90E+00
Lindane	2.35E+02
Linuron	2.69E+01
Malathion	1.92E-02
Maleic hydrazide	3.11E-01
Mancozeb	1.93E-03
Maneb	9.29E-02
Manganese	4.37E+00
manure N	5.53E-01
manure P	5.45E-01
MCPA	8.79E+00
MCPB	3.04E-01
m-Cresol	1.25E-01
Mepiquat chloride	6.51E-01
Mercury	2.12E+04
Metalaxil	2.04E+00
Methamidophos	1.77E+01
Methidathion	5.38E+00
Methiocarb	6.51E+00
Methomyl	1.77E+01
Methoxychlor	7.06E-01
Metiram	9.41E+00
Metolachlor	1.60E+00
Metribuzin	1.65E+00
Metsulfuron-methyl	1.56E-01
Mevinfos	7.48E-01
Molinate	1.96E+01
Molybdenum	1.07E+02
Myclobutanil	5.98E-01
Naled	4.12E+01
Napropamide	3.36E-01
Nickel	2.81E+00
Norflurazon	6.49E-01
Oryzalin	7.02E-01
Oxamyl	6.33E-01
Oxydiazon	2.55E+01
Oxyfluorfen	1.11E+02
Paclobutrazol	8.28E-01
Parathion	2.67E+00
Parathion, methyl	1.91E+01
Pendimethalin	2.44E+00
Phenmedipham	2.17E-03
Phorate	8.95E+00
Phosmet	7.94E-01
Picloram	1.17E+00
Pirimiphos methyl	6.16E+00
Prochloraz	1.28E+01
Procymidone	1.04E+00

	€/kg
Profenofos	6.81E+00
Prometryn	8.99E-01
Pronamide	4.88E+00
Propachlor	4.53E-01
Propamocarb	8.95E-01
Propanil	1.04E+00
Propargite	2.42E+00
Propene, 1,3-dichloro-	7.59E+01
Propham	7.50E-02
Propiconazole	6.28E+00
Propoxur	4.09E+00
Pyrazophos	1.22E+01
Pyriproxyfen	3.47E-01
Quizalofop ethyl ester	6.79E+00
Resmethrin	1.42E+00
Rotenone	1.56E+01
Selenium	1.75E+04
Sethoxydim	2.58E-01
Silver	2.46E+03
Simazine	2.85E+01
Tebufenozide	2.24E+00
Tebuthiuron	6.26E-01
Teflubenzuron	4.03E+01
Terbacil	1.21E+00
Terbufos	1.15E+03
Terbutryn	1.01E+02
Thallium	3.89E+02
Thiabendazole	9.50E-01
Thifensulfuron-methyl	3.96E+00
Thiobencarb	8.67E+00
Thiodicarb	3.01E+00
Thiophanat-methyl	1.86E-01
Thiram	1.60E+00
Tin	4.58E-02
Tolclophos-methyl	8.33E+00
Tralomethrin	2.97E+01
Triadimefon	2.90E+00
Triadimenol	8.49E-01
Tri-allate	6.23E+00
Triasulfuron	1.01E+01
Triazofos	7.71E+02
Trichlorfon	3.73E-01
Trifluralin	1.94E+01
Triforine	1.32E+01
Vanadium	9.96E+01
Vinclozolin	6.21E+00
Zinc	1.52E+01
Zineb	3.24E-01

Table 55 Preventiekosten voor emissies naar water

	€/kg
1,4-Dioxane	3.43E-01
1-Butanol	4.05E-02
2-Benzothiazolethiol	3.15E-01
2-Butenal	3.06E+00
Acenaphthene	1.96E-01
Acetamide	8.76E-02
Acetone	2.01E-02
Acetonitrile	1.10E-01
Acetophenone	3.77E-02
Acrylamide	1.12E+01
Acrylic acid	3.34E-02
Acrylonitrile	1.21E+01
Allyl chloride	1.35E+00
Ammonium. ion	7.00E+00
Aniline	1.48E+00
Aniline. p-chloro-. hydrochloride	6.12E+00
Anthracene	7.73E-03
Antimony	1.29E+03
Antimony-124	0.00E+00
Arsenic. ion	3.36E+04
Barium	9.27E+02
Benzaldehyde	5.82E-02
Benzenamine. 2-methoxy-5-nitro-	1.04E+00
Benzene	8.26E-01
Benzene. 1.2.4-trichloro-	1.05E+01
Benzene. 1.2-dichloro-	1.28E+00
Benzene. 1.3-dinitro-	6.62E+01
Benzene. 1.4-dichloro-	1.37E+00
Benzene. chloro-	1.80E+00
Benzene. ethyl-	5.04E-02
Benzyl chloride	1.09E+00
Beryllium	4.90E+01
Bis(2-chloro-1-methylethyl)ether	2.78E+00
Bis(2-chloroethyl)ether	1.85E+00
Bis(chloromethyl)ether	2.09E+04
Bromate	1.47E+01
C.I. direct blue 218	2.71E-02
C.I. disperse yellow 3	3.61E+00
Cadmium. ion	2.78E+02
Caprolactam	3.11E-02
Carbamic acid. ethyl ester	1.27E-01
Carboxylic acids. unspecified	1.91E-02
Catechol	1.67E-01
Cesium-134	0.00E+00
Cesium-137	0.00E+00
Chlorine	3.91E+02
Chloroform	4.58E+01
Chromium VI	7.08E-01
Chromium. ion	1.21E-03
Cobalt	4.30E-19
Cobalt-58	0.00E+00
Cobalt-60	0.00E+00
Cumene	6.42E-02

	€/kg
Cupferron	5.59E+00
Cyanide	8.64E+00
Cyclohexane	4.76E-02
Cyclohexene. 4-vinyl-	4.16E+00
Cyclohexylamine	2.78E-01
Decabromodiphenyl oxide	3.34E-03
Dipropylthiocarbamic acid S-ethyl ester	4.90E+00
Ethane. 1.1.2.2-tetrachloro-	6.35E+00
Ethane. 1.2-dibromo-	1.47E+02
Ethane. 1.2-dichloro-	3.93E+01
Ethane. chloro-	2.18E-01
Ethane. hexachloro-	2.71E+03
Ethanol. 2-butoxy-	1.82E-01
Ethanol. 2-methoxy-	3.57E-01
Ethene. chloro-	1.07E+01
Ethene. dichloro- (trans)	1.09E+01
Ethene. tetrachloro-	1.09E+02
Ethene. trichloro-	1.26E-01
Ethyl acrylate	1.15E-01
Ethylene glycol	1.58E-02
Ethylene oxide	4.28E+00
Fluoranthene	8.60E+00
Formaldehyde	1.23E+01
Hydrazine	2.85E+01
Hydrocarbons. aromatic	3.36E+01
Hydrogen-3. Tritium	0.00E+00
Hydroquinone	2.48E-02
Iodine-129	0.00E+00
Iodine-131	0.00E+00
Lead	5.01E+02
Maleic anhydride	1.52E-05
Manganese	1.58E+03
Manganese-54	0.00E+00
m-Cresol	2.05E-01
Mercury	5.68E+04
Methacrylic acid. methyl ester	5.45E-01
Methane. dichloro-. HCC-30	2.64E+01
Methane. tetrachloro-. CFC-10	1.33E+04
Methanol	1.24E-02
Methyl ethyl ketone	6.30E-03
Molybdenum	2.92E+03
Molybdenum trioxide	2.55E+01
m-Phenylenediamine	1.20E+00
Naphthalene	4.76E+00
Nickel. ion	1.57E+01
Nitrate	7.14E+00
Nitrilotriacetic acid	4.32E-03
Nitrite	6.90E+00
Nitrobenzene	4.12E+01
Nitrogen	7.00E+00
Nitrogen. organic bound	7.00E+00
Nitroglycerin	2.03E-01
N-Methylolacrylamide	9.34E-01
N-Nitrosodiphenylamine	4.85E+00

	€/kg
o-Cresol	9.34E-02
PAH. polycyclic aromatic hydrocarbons	4.55E+00
p-Cresidine	5.43E-01
Phenol	2.60E-02
Phenol. 2.4.5-trichloro-	8.99E-01
Phenol. 2.4.6-trichloro-	3.47E-01
Phenol. 2.4-dichloro-	1.92E+00
Phenol. 2.4-dimethyl-	1.11E+00
Phenol. 2.4-dinitro-	5.84E+00
Phosphate	1.10E+01
Phosphorus	1.09E+01
Phthalate. butyl-benzyl-	6.65E-02
Phthalate. dibutyl-	4.30E-01
Phthalate. dioctyl-	1.52E+01
Polychlorinated biphenyls	2.55E+02
Propane. 1.2-dichloro-	2.71E+02
Propane. 2-nitro-	4.62E+00
Propene. 1.3-dichloro-	2.32E+01
Propylene oxide	1.05E+01
Pyrene	3.98E-01
Pyridine	3.61E+00
Radium-226	0.00E+00
Selenium	2.39E+04
Silver. ion	1.11E+03
Silver-110	0.00E+00
Sodium azide	8.69E-01
Styrene	9.11E-01
t-Butyl alcohol	1.27E+00
t-Butyl methyl ether	1.22E-01
Thallium	4.46E+03
Thiourea	1.60E-01
Tin. ion	2.85E-01
Toluene	1.61E-01
Toluene diisocyanate	2.81E+04
Toluene. 2.4.6-trinitro-	9.38E-02
Toluene. 2.4-dinitro-	1.26E+00
Toluene. 2.6-dinitro-	6.19E+00
Toluene. 2-chloro-	3.91E+00
Toluene. dinitro-	1.24E+01
Tribufos	4.32E+03
Tributyltin compounds	7.94E+02
Uranium alpha	0.00E+00
Uranium-234	0.00E+00
Uranium-235	0.00E+00
Uranium-238	0.00E+00
Vanadium. ion	8.37E+02
Xylene	1.73E-01
Zinc. ion	8.19E+01