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Value choices in life cycle impact assessment of stressors causing human health damage

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SUPPORTING INFORMATION

This is an earlier version of the following article: De Schryver A.M., Van Zelm R., Humbert S., Pfister S., Huijbregts M.A.J. 2011. Value choices in life cycle impact assessment of stressors causing human health damage. *Journal of Industrial Ecology* 15(5): 796-815, , which was published in final form at <http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2011.00371.x/abstract>.

SUMMARY

This supporting information provides a detailed description of and argumentation on the choices and equations that were used to make the model presented in the main text. It contains four tables, which describe (i) the suggested combination of value choices for each human health impact category, (ii) the disability-adjusted life year per incidence case calculated for the different impact categories, (iv) the disability-adjusted life year per degree Celsius increase for climate change, and (v) the percentage damage contribution for substances that contribute to the global damage emissions and water consumption.

Supporting Information S1

Methodology

Value choices

Table S1-1. Suggested combination of value choices on the level of concern (C) and the level of uncertainty (U), applied to the three perspectives for human health. Choices on the level of fate factor, exposure factor, effect factor and damage factor are separated for each impact category (IC).

IC	Step	Value choices	Individualist	Hierarchist	Egalitarian	Not e
All impact categories (generic value choices)	Fate + exposure	The change in concentration due to a change in emission is substance lifetime specific and depends on the time horizon after which the change in concentration is measured (Huijbregts et al., 2005). As temporal vision on life and society is perspective dependent, different timeframes are applied for each perspective (Jager et al., 1997, De Schryver et al., 2009).	20years	100years	Infinite	C
		Future projections on demographical developments, population displacements, changes in GDP, years of schooling and technology changes will alter the sensitivity, size and age composition of the population and thus influence the number of cases (incidence) per emitted substance (Mathers and Loncar, 2006). Future optimistic, baseline and pessimistic scenarios (IPCC, 2000, Murray and Lopez, 1997), can be linked to the individualist, hierarchist and egalitarian perspectives.	Optimistic development	Baseline development	Pessimistic development	U ^a
	Damage	Discounting years of life lost in the future is perspective dependent. Janssen et al. (1995) propose a 0% time discount rate for the egalitarian perspective, a 2% discount for the hierarchist perspective and a 5% discount for the individualist perspective. We follow this vision, except for the hierarchist perspective where a 3% discount rate is chosen, as this is used as default scenario by the World Health Organization (Murray and Lopez, 1996c, WHO, 2008b).	5%	3%	0%	C
		Age weighting allocates a higher importance to a year of life at young age than at old age or infants (Murray and Lopez, 1996c). A higher value for economically more relevant subpopulations corresponds with the individualist perspective, while the group bounded hierarchists and egalitarian perspectives do not differentiate between individuals with different ages (Gold et al., 1996, Murray and Lopez, 1996c).	Yes	No	No	C
		For the impact category particulate matter and ozone formation, part of the damage (chronic diseases) takes place in the future. For other impact categories, the lifetime of the substances is important regarding effects that take place in the future. Future effects are affected by the level of manageability/ adaptation. Better health care system, education and legislation can reduce the disability-adjusted life years (DALYs) per case in the future (Hofstetter, 1998). The type of management is perspective dependent (Thompson et al., 1990, van Asselt et al., 1996).	Adaptive management style	Controlling management style	Comprehensive management style	U ^a
Water scarcity	Fate + exposure	Water availability depends on variability in precipitation. Variability in precipitation gives a certain water stress that depends on the water storage capacities. The correction factor (Corr) for water stress due to variability in precipitation (VF) depends on the level of flow regulation by providing sufficient storage structures (Pfister et al., 2009). According to van Asselt and Rotmans (1996), the individualist perspective coincides with an adaptive management style. Therefore a lower variability factor is suggested. For the hierarchist and egalitarian perspectives the original variability factor, as presented by Pfister et al. (2009), is maintained.	Strong regulated flows: Corr=1 Weak regulated flows: Corr= \sqrt{VF}	Strong regulated flows: Corr= \sqrt{VF} Weak regulated flows: Corr=VF	Strong regulated flows: Corr= \sqrt{VF} Weak regulated flows: Corr=VF	U
	Effect	A food water requirement of 1350m ³ per capita per year is the minimum direct human dietary requirement and is used to derive malnutrition cases per amount of water deprivation (Pfister et al., 2009). Good management can drop the food water requirement to 1000m ³ per person by 2050 (Rockstrom 2006). i.e., 74% of the water requirement and consequently of the expected health effect. This results in 1 case per 1823m ³ per year	0.74 case per 1350m ³ /yr = 1 case per 1823m ³ /yr	1 case per 1350m ³ /yr	1 case per 1350m ³ /yr	U

		water deprived. A water requirement of 1350m ³ per year is applied for the hierarchist and egalitarian perspectives. A good management level, and thus 1 case per 1823m ³ per year is assumed for the individualist perspective.				
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
(Tropospheric) ozone formation	Fate + exposure	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
	Effect	The effect factor is calculated for an average 24h concentration and the daily highest 8h concentration. The average 24h concentration gives a negative total damage from NO _x due to more ozone degradation than formation (Van Zelm et al., 2008). Including or excluding the positive effects of ozone degradation (applying the 24h or 8h scenario) is considered to be a value choice on the level of concern. Positive effects (24h scenario) are only included for the individualist perspective as they consider nature as being stable with assured recovery (Hofstetter, 1998). For the egalitarian and hierarchist perspectives we apply the 8 highest hours of concentration to calculate the effects.	24 hours	8 hours	8 hours	C
		The amount of knowledge about ozone-related morbidity is limited (Vonk and Schouten, 2002, Anderson et al., 2004). Therefore, morbidity from asthma, minor restricted activity days, respiratory hospital admissions and symptom days is only included in the egalitarian perspective (Hofstetter, 1998).	Excluded	Excluded	Included	U
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
Particulate matter	Fate + exposure	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
	Effect	Evidence for effects from primary PM ₁₀ is available (Pope et al., 2009) and therefore included for all perspectives. Evidence concerning human health risks at ambient concentrations of secondary PM from SO ₂ , NO _x and NH ₃ is available (Reiss et al., 2007, USEPA, 2009). However, the level of effect is still being debated (Hofstetter, 1998, Torfs et al., 2007) and therefore excluded for the individualist perspective. Reiss et al. (2007) shows that there are more studies indicating health effects from secondary PM from SO ₂ than from NO _x or NH ₃ . Therefore, in the hierarchist perspective, we decided to include effects from secondary PM from SO ₂ only.	Primary PM ₁₀	Primary PM ₁₀ + secondary PM from SO ₂	Primary PM ₁₀ + secondary PM from SO ₂ , NO _x and NH ₃	U
		<i>The amount of knowledge about asthma, chronic obstructive pulmonary disease, croup in preschool children and ischaemic heart disease is limited. Therefore, these effects are only included in the egalitarian perspective (Hofstetter, 1998).</i>	Excluded	Excluded	Included	U
Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/	
Human toxicity	Fate + exposure	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
		The bioconcentration factor for metals is less than proportional with the environmental concentration (Hendriks et al., 2001). Therefore, oral intake of metals via food (bioaccumulation) is excluded for the individualist perspective, but included for the hierarchist and egalitarian perspectives.	Intake through drinking water, air	Intake through all routes	Intake through all routes	U
	Effect	The International Agency for Research on Cancer evaluates the carcinogenic risk of chemical substances to humans and group substances according to the level of proof on human and animal carcinogenicity (IARC, 2004). According to Hofstetter (1998) the egalitarian perspective is risk adverse and includes all substances with insufficient evidence of carcinogenicity (IARC categories 1, 2A, 2B and 3), the hierarchist perspective reflects a balance between evidence and probability and includes substances with	IARC classification: 1	IARC classification: 1, 2A and 2B	All substances	U

		sufficient evidence (IARC categories 1, 2A and 2B), and the individualist perspective includes substances with strong evidence only (IARC category 1). We follow this vision, except for the egalitarian perspective where all substances with a TD50 are included.				
		The type and level of response for noncarcinogenic effects is uncertain (Huijbregts et al., 2005) and therefore excluded from the individualistic perspectives.	Excluded	Included	Included	U
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
Ionizing radiation	Fate + exposur	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
	Effect	The 'dose and dose-rate effectiveness factor' (DDREF) describes the ratio between the risk increase per Man.Sv observed at high doses and the assted risks at low doses. The DDREF is found to be between 2 and 10. A value of 2 is recognized as being conservative and therefore assumed for the egalitarian perspective (ICRP, 1990). A DDREF factor of 6 is preliminary proposed for the hierarchist perspective and value of 10 for the individualist perspective.	10	6	2	U
		Based on the amount of knowledge not all effects are included in the different perspectives. Bladder, colon, ovary, skin, liver, oesophagus and stomach cancer are possibly or probably connected with ionizing radiation and thus only included in the egalitarian and hierarchist perspectives. For bone surface and remainder cancer no information about the level of proof is available and therefore are only included in the egalitarian perspective. Thyroid, bone marrow, lung and breast cancer are definitely associated to ionizing radiation and thus considered for all perspectives (Frischknecht et al., 2000).	Thyroid, bone marrow, lung and breast cancer	Thyroid, bone marrow, lung, breast, bladder, colon, ovary, skin, liver oesophagus, and stomach cancer	Thyroid, bone marrow, lung, breast, bladder, colon, ovary, skin, liver, oesophagus, stomach, bone surface, and remaining cancer	U
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
(Stratospheric) ozone depletion	Fate + exposure	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
	Effect	Not all effects of ozone have the same level of evidence. Effects of skin cancer (malignant malenoma, basel cell carcinoma and squamous cell carcinoma) solar keratoses and photoaging are certain and can be included for all perspectives. The evidence of increased incidence of cataract, pterygium herpes and sunburn due to increased UV-B radiation is weak (Lucas et al., 2008) and therefore included for the egalitarian perspective only.	Malignant malenoma, basel cell carcinoma, squamous cell carcinoma, solar keratoses and photoaging	Malignant malenoma, basel cell carcinoma, squamous cell carcinoma, solar keratoses and photoaging	Malignant malenoma, basel cell carcinoma, squamous cell carcinoma, solar keratoses, photo aging, cataract, herpes, sunburn and pterygium	U ^b
		<i>The inclusion of positive effects, like vitamin D efficiency is considered a value choice on the level of concern (Jager et al., 1997) and only included for the individualist perspective as they consider nature as being stable with assured recovery (Hofstetter, 1998).</i>	Included	Excluded	Excluded	C
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/

Climate change	Fate + exposure	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/
	Effect	The inclusion of positive effects from ozone depletion substances is a value choice on the level of concern (Jager et al., 1997) and only included for the individualist perspective as they consider nature as being stable with assured recovery (Hofstetter, 1998).	Included	Excluded	Excluded	C
	Damage	Generic value choices only (presented for all ICs at start of the table).	/	/	/	/

Note: The value choices printed in grey italic are not implemented in our characterization factors (CFs). C= value choice on the level of concern; U= value choice on the level of uncertainty; m³/yr = cubic meter per year.

^aValue choice only considered within the CFs of the impact category climate change.

^bOnly the effects of skin cancer and cataract are included in the CFs.

Time horizon

For the impact categories human toxicity, ionizing radiation, stratospheric ozone depletion and climate change, time horizon specific calculations were required. For human toxicity, USES-LCA readily provides fate and exposure results for a 100 year and infinite time horizon Van Zelm et al. (2009). USES-LCA was adapted to calculate fate and exposure factors for a time horizon of 20 years as well. For ionizing radiation, time horizon-specific exposure factors of most radio-active substances were given by IAEA (1985) and Frischknecht et al. (2000). For a limited number of substances, exposure factors for a 20 years time horizon were derived by linear extrapolation between a 10 and 50 years time horizon (emitted to freshwater and marine water: I-129; emitted to air: C-14, I-229, C-137) or by using a 50 years time horizon as first approximation (emitted to freshwater: C-137; emitted to air: H-3; emitted marine water: Am-241, C-14, Cs-137, H3, Ru-106) (see Supporting Information S2). For stratospheric ozone depletion, characterization factors (CFs) were provided for an infinite time horizon only (Hayashi et al., 2006). Fate and exposure factors for the time horizons of 20 years and 100 years were derived by calculating the fraction of exposure via:

$$F_t = 1 - e^{-(t-t_0) \cdot k}$$

where F_t is the fraction of exposure for time horizon t , k the degradation rate of the substance in the atmosphere (year^{-1}) and t_s the time needed for the substance to reach the atmosphere (year). A transport time (t_s) of 3 years was assumed (WMO, 1995). For climate change, the fate and exposure factors were readily available for all three time horizons considered (De Schryver et al., 2009).

Disability-adjusted life years

Each perspective has different visions on age weighting and discount rate, both affecting the disability-adjusted life year (DALY) values. For the individualist perspective, 5% discount rate and age weighting was assumed, presented as [0.05,1], for the hierarchist perspective 3% discount rate and no age weighting was assumed, presented as [0.03,0], and for the egalitarian perspective no age weighting or discounting was assumed, presented as [0,0].

The DALY values were calculated by implementing the necessary information into the world health organization burden of disease template (WHO, 2008a). For the impact categories human toxicity, climate change and ionizing radiation the age specific duration values, incidence rates, age at onset and number of deaths were taken from the report Human Health Statistics 1990 (Murray and Lopez, 1996b), and the disability weights were derived from the Global Burden of Disease 1990 (Murray and Lopez, 1996a). For climate change (De Schryver et al., 2009) the DALYs [0.03,1] of the optimistic 2030 scenario (Mathers and Loncar, 2006) were converted to DALY with 5% discount rate and age weighting. Therefore, the ratio of the DALY [0.03,1] and DALY [0.05,1] for year 1990 per disease and world region was used as scaling factor (Murray and Lopez, 1996a, Murray and Lopez, 1996b). The CFs for ozone depletion (Hayashi et al., 2006) and water scarcity (Pfister et al. 2009) were adapted to the corresponding age weighting

and discount rate by applying the ratio of the required DALY and the original DALY. For the impact categories particulate matter and photochemical ozone formation the age specific population numbers and number of deaths were taken from the Global Burden of Disease 2004 update (WHO, 2008b). Age specific duration times, disability weights and incidence rates were derived from van Zelm et al. (2008). For each impact category the DALYs per incidence case are presented in table S-2. For climate change, the DALYs per degree Celsius increase are presented in table S-3.

Table S1-2. The disability-adjusted life year per incidence case calculated for the different impact categories, following three different perspectives.

	Individualist	Hierarchist	Egalitarian
Impact category	[0.05,1]	[0.03,0]	[0,0]
Water scarcity			
Nutritional deficiencies	1.5E+1	2.0E+1	4.1E+1
Ozone formation			
Acute mortality	8.8E-2	1.3E-1	2.5E-1
Asthma attacks	<i>3.1E-4</i>	<i>2.7E-4</i>	2.7E-4
Minor restricted activity days	<i>1.0E-4</i>	<i>8.5E-5</i>	8.5E-5
Respiratory hospital admissions	<i>1.2E-2</i>	<i>1.1E-2</i>	1.1E-2
Symptom days	<i>1.6E-4</i>	<i>1.3E-4</i>	1.4E-4
ERV for asthma	<i>9.4E-4</i>	<i>8.2E-4</i>	8.2E-4
Particulate matter			
Chronic mortality	3.5E+0	5.2E+0	1.0E+1
Acute respiratory morbidity	3.0E-2	2.6E-2	2.6E-2
Acute cardiovascular morbidity	3.3E-2	2.8E-2	2.8E-2
Human toxicity			
Cancer average	4.8E+0	7.9E+0	1.1E+1
Noncancer average	<i>1.4E+0</i>	1.9E+0	2.7E+0
Ionizing radiation			
Thyroid cancer	4.8E+0	7.9E+	1.1E+1
Bone marrow	5.7E+0	8.4E+0	1.4E+1
Lung cancer	6.8E+0	1.2E+01	1.6E+1
Breast cancer	3.2E+0	5.1E+0	7.6E+0
Bladder cancer	<i>2.1E+0</i>	3.8E+0	5.0E+0
Colon cancer	<i>3.8E+0</i>	6.5E+0	8.8E+0
Ovary cancer	<i>5.5E+0</i>	8.6E+0	1.3E+1
Skin cancer	<i>2.7E+0</i>	4.3E+0	6.3E+0
Liver cancer	<i>9.7E+0</i>	1.5E+1	2.2E+1
Oesophagus cancer	<i>7.5E+0</i>	1.3E+1	1.8E+1
Stomach cancer	<i>5.8E+0</i>	9.9E+0	1.4E+1
Bone surface	<i>4.8E+0</i>	<i>7.9E+0</i>	1.1E+1
Remainder	<i>4.8E+0</i>	<i>7.9E+0</i>	1.1E+1
Hereditary ^a	1.4E+1	2.1E+1	5.7E+1
Ozone depletion			
Melanoma and other skin cancer	2.7E+0	4.3E+0	6.3E+0
Cataract	<i>8.2E-1</i>	<i>1.0E+0</i>	1.1E+0

Note: The figures printed in grey italic are not included for the corresponding perspective. [0.05,1]= 5% discount rate and age weighting; [0.03,0]= 3% discount rate and no age weighting; [0,0]= no age weighting or discounting; ERV= emergency room visits.

^aNo future generation discounting is considered.

Table S1-3. The disability-adjusted life year per degree Celsius increase for climate change (based on expected DALYs for the year 2030), following three different perspectives.

	Individualist	Hierarchist	Egalitarian
Impact category	[0.05,1]	[0.03,0]	[0,0]
Climate change			
Cardiovascular	0.0E+0	2.5E+5	7.6E+5
Diarrhoe	4.8E+5	1.2E+6	4.5E+6
Malnutrition	0.0E+0	3.6E+6	2.0E+7
Malaria	4.1E+5	1.2E+6	4.5E+6
Nat disasters ^a	2.0E+2	-1.3E+5	-5.0E+5

Note: [0.05,1]= 5% discount rate and age weighting; [0.03,0]= 3% discount rate and no age weighting; [0,0]= no age weighting or discounting.
^a The model assumes that protection evolves over time in proportion to projected increases in GDP, this results in negative burdens for the hierarchist and egalitarian perspective.

Results

Characterization factors of water scarcity

For water use CFs were calculated on a country level. This is defined as regionalized impact assessment. Data on annual freshwater availability and water withdrawals were derived from the Watergap2 global model (Alcamo et al., 2003), while data on flow regulation were derived from Pfister et al. (2009). Geographic information system allows data processing on different spatial resolutions (ESRI, 2004) and was used to calculate the new water scarcity index (WSI) per country (see Supporting Information S2). Using the ratios of our calculations on the water requirement, the WSI and the damage factor of Pfister et al. (2009), the CFs from Pfister et al. (2009) were extrapolated for the three perspectives. CFs were calculated for 165 countries and are presented in Supporting Information S2.

Characterization factors of all impact categories

The CFs for each substance and each impact category can be found in Supporting Information S2.

Global damage

The link between inventory data and impact assessment CFs is not always achieved. All carbon containing substances degrade partly to carbon dioxide. For example, over 90% of atmospheric methane degrades to carbon dioxide while the rest is absorbed by micro-organisms in the soil (Badr et al., 1992). In this analysis, no degradation products are included in the inventory dataset or the calculated CFs. For fossil emissions this results in a slight underestimation of the calculated global damage. For biogenic emissions (emissions from the product originally derived from absorbed carbon dioxide from air; such as biogenic methane released by plant products) both the uptake of carbon dioxide as the degradation of the emitted carbon containing substance is excluded, what compensates each other and results in an relative zero effect. The global inventory dataset presents 'methane' emissions as a combination of biogenic and fossil methane. We applied the CF of fossil methane what generates a slight underestimation of the damage.

Table S1-4. Percentage damage contribution (%) of substances that contribute for more than 5% to the global damage of emissions and water consumption of the year 2000.

IC	Country	Water consumption (m ³ /capita)	CFs (DALY/m ³)			Global damage result (% contribution)			
			Individualist	Hierarchist	Egalitarian	Individualist	Hierarchist	Egalitarian	
Water scarcity	India	5.1E+02	9.5E-7	2.0E-6	4.7E-6	59.0	59.8	59.8	
	Pakistan	6.8E+02	9.9E-7	1.9E-6	4.5E-6	11.1	10.6	10.6	
	China	2.4E+02	1.4E-7	2.7E-7	6.5E-7	5.2	4.9	4.9	
	Afganistan	2.0E+03	7.4E-7	1.4E-6	3.4E-6	3.5	3.3	3.3	
	All other countries					21.3	21.4	21.4	
	<i>Total damage for this impact category (in DALY/capita)</i>						<i>1.4E-4</i>	<i>2.8E-4</i>	<i>6.7E-4</i>
	Substance	Emiss. Comp.	Emission (kg/capita)	CFs (DALY/kg or DALY/kBq)			Global damage result (% contribution)		
Ozone formation	Non-methane volatile organic compounds (NMVOC), unspecified	Air	2.7E+1	1.4E-8	2.0E-8	2.0E-7	98.1	55.1	55.1
	Nitrogen oxides	Air	1.9E+1	4.2E-8	2.0E-8	2.0E-7	-210.0 ^a	38.3	38.3
	Sulfur dioxide	Air	2.1E+1	1.1E-9	1.7E-9	1.6E-8	6.2	3.5	3.5
	Remaining substances						0.7	0.3	0.3
	<i>Total damage for this impact category (in DALY/capita)</i>						<i>-3.8E-7</i>	<i>1.0E-6</i>	<i>1.0E-5</i>
Particulate matter	Particulates, < 10 µm	Air	4.8E+	9.2E-5	1.4E-4	2.6E-4	100.0	53.2	34.3
	Sulfur dioxide	Air	2.1E+1	-	2.7E-5	5.1E-5	-	46.8	30.1
	Nitrogen oxides	Air	1.9E+1	-	-	5.7E-5	-	-	30.0
	Ammonia	Air	2.5E+	-	-	8.2E-5	-	-	5.7
	Remaining substances						0.0	0.0	0.0
<i>Total damage for this impact category (in DALY/capita)</i>						<i>4.4E-4</i>	<i>1.2E-3</i>	<i>3.6E-3</i>	
Human toxicity	Benzene	Air	2.4E+0	3.5E-7	8.4E-7	1.1E-6	40.9	3.9	0.5
	Formaldehyde	Air	1.2E-2	4.9E-5	6.7E-5	1.3E-4	27.3	1.5	0.3
	Chromium	Air	2.6E-4	1.3E-3	3.3E-3	1.4E-7	16.4	1.6	0.0
	Dioxins	Air	3.0E-9	5.5E+1	8.6E+1	1.3E+2	8.0	0.5	0.1
	Nickel	Air	5.7E-4	2.2E-4	4.0E-4	6.4E-4	6.0	0.4	0.1
	Mercury	Air	4.9E-5	-	4.2E-1	9.5E-1	-	39.2	8.5
	Chlorine	Water	1.1E-2	-	5.2E-5	7.0E-5	-	14.2	1.8
	Lead	Air	1.5E-3	-	4.8E-3	9.6E-3	-	13.4	2.5
	Arsenic	Air	1.8E-4	4.2E-6	1.5E-2	2.3E-1	0.0	5.3	7.3
	Selenium	Air	1.3E-4	-	1.8E-3	2.2E+0	-	0.5	51.5
	Selenium	Water	1.3E-4	-	2.3E-3	2.8E+0	-	0.1	5.1
	Barium	Soil	5.0E-4	-	5.1E-5	2.5E-2	-	1.2	3.6
	Zinc	Soil	3.3E-3	-	2.0E-6	1.3E-4	-	1.6	2.3
	Lead	Soil	1.5E-3	-	9.2E-7	6.8E-4	0.0	13.4	2.3
	Barium	Air	5.0E-4	-	2.1E-4	2.3E-2	-	0.2	2.1
	Manganese	Water	7.7E-4	-	2.1E-4	5.3E-3	-	0.3	1.9
	Manganese	Air	7.7E-4	-	9.8E-4	1.1E-2	-	0.3	1.5
	Barium	Water	5.0E-4	-	1.3E-4	2.7E-2	-	0.3	1.4
	Arsenic	Soil	1.8E-4	3.0E-8	8.3E-5	1.4E-1	0.0	0.2	1.2
	Cadmium	Air	6.8E-5	2.0E-4	1.9E-2	9.1E-2	0.7	0.2	1.1
	Vanadium	Air	6.0E-4	-	1.1E-3	8.4E-3	-	0.2	0.9
	Remaining substances						0.6	1.7	4.1
	<i>Total damage for this impact category (in DALY/capita)</i>						<i>2.1E-6</i>	<i>1.2E-2</i>	<i>4.9E-5</i>
Ionizing radiation	Cesium-137	Water	3.9E+1	2.4E-8	2.4E-8	2.4E-8	78.9	71.8	19.1
	Carbon-14	Air	9.5E+1	1.6E-9	1.6E-9	1.6E-9	12.9	19.9	59.4
	Cobalt-60	Water	6.2E+	7.0E-9	7.0E-9	7.0E-9	3.6	3.0	0.8
	Cesium-134	Water	1.2E+	2.3E-8	2.3E-8	2.3E-8	2.2	1.9	0.5
	Technetium-99	Water	2.2E+2	2.0E-11	2.0E-11	2.0E-11	0.4	1.3	0.3
	Iodine-129	Water	2.4E+	6.7E-10	6.7E-10	6.7E-10	0.1	0.1	18.1
	Remaining substances						1.9	2.1	1.8
<i>Total damage for this impact category (in DALY/capita)</i>						<i>1.2E-6</i>	<i>3.9E-6</i>	<i>2.8E-5</i>	
Ozone depletion	CFC-12	Air	1.7E-2	4.1E-5	2.6E-4	1.4E-3	25.4	41.5	50.5
	CFC-11	Air	6.6E-3	7.9E-5	3.5E-4	1.3E-3	19.6	22.6	19.4
	HCFC-141b	Air	2.7E-2	1.9E-5	3.6E-5	1.2E-4	19.0	9.3	7.1
	HCFC-22	Air	4.9E-2	7.7E-6	1.6E-5	5.4E-5	14.0	7.6	5.8
	Halon 1211	Air	7.9E-4	4.1E-4	1.0E-3	3.4E-3	12.2	7.7	5.8
	Halon 1301	Air	1.5E-4	8.5E-4	4.6E-3	2.0E-2	4.8	6.7	6.5
	Remaining substances						5.0		5.0
<i>Total damage for this impact category (in DALY/capita)</i>						<i>2.7E-6</i>	<i>1.0E-5</i>	<i>4.6E-5</i>	

Climate change	Carbon dioxide, fossil	Air	4.7E+3	7.4E-9	2.6E-7	1.8E-5	47.7	65.3	92.7
	Methane ^b	Air	4.9E+1	6.2E-7	7.4E-6	5.0E-5	41.7	19.9	2.8
	Dinitrogen monoxide	Air	1.9E+	2.4E-6	8.3E-5	9.6E-4	6.1	8.6	2.0
	HCFC-22	Air	4.9E-2	3.4E-5	5.0E-4	3.4E-3	2.3	1.4	0.2
	Remaining substances						2.2	4.8	2.3
	<i>Total damage for this impact category (in DALY/capita)</i>							<i>7.3E-5</i>	<i>1.8E-3</i>

Note: For water scarcity, the four most contributing countries are presented. Global emissions (in kg or kBq) and water consumption data per capita (in m³) is presented, together with the corresponding characterization factors (CFs in DALY/m³, DALY/kg or DALY/kBq). Emiss. Comp= the compartment of emissions. m³= cubic meter; kg= kilogram; kBq= kilobecquerel.

^aFor the individualist perspective positive effects from nitrogen oxides are included and therefore the CF turns negative. This results in a negative damage for the emission of nitrogen oxides and a total negative damage for ozone formation (-100%).

^bSum of methane from biogenic and fossil origin. We applied the CF of fossil methane, generating therefore a slight underestimation of the damage.

Characterization factors for water consumption and 1239 substances, covering seven human health impact categories, can be found in the Supporting Information S2 (a separate excel document). For each impact category, the new recalculated CFs are presented together with the original CFs (defined as "original CFs"). For human toxicity the original CFs are not presented, as the figures directly derive from the model USES-LCA.

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