Combining life cycle inventory results with planetary boundaries: The Planetary Boundary Allowance impact assessment method Update PBA'06

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Zürich, April 2016

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Significant digits Figures in this report often feature several digits. This is not to imply that all the shown digits are really significant or that the data displayed is very precise. Showing several digits helps to minimise the avoidable accumulation of rounding mistakes along the chain of calculations performed here, and in possible future studies referring to this data.

Suggested citation: Doka G (2016) Combining life cycle inventory results with planetary boundaries: The Planetary Boundary Allowance impact assessment method Update PBA'06. Gabor Doka, Doka Life Cycle Assessments, Zurich, Switzerland. April 2016. Available at http://www.doka.ch/DokaPBA06Method.pdf

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1.1 Introduction

Rockström et al. 2009 have proposed several planetary boundaries defining a safe operating space for humans on the planet. In the first PBA report (Doka 2015) these planetary boundaries were translated into units common in environmental Life Cycle Assessment (LCA). The result is a Life Cycle Impact Assessment (LCIA) method, which can be used to check if the life cycle burdens of a particular lifestyle or personal consumption pattern fits into the available planetary capacities. While other available "sustainability checks" often have weakly justified ad hoc targets or focus on only a few environmental effects[1], the PBA method is founded on explicit planetary capacities for eight different impact categories.

1.2 General outline

Name: The LCIA method described here is called PBA'06. PBA stands for *planetary boundary allowance*. The suffix 06 stands for a generic mid-2000 date, derived from the periods Rockström et al. provide figures for the current state of the considered systems. The first PBA version was called PBA'05. This present update is called PBA'06.

Per-capita limits: In a first preparatory step, eight different planetary boundaries are converted into per-capita-allowances, i.e. the equitable annual allowance of environmental burden for each human is calculated. A human population of 10 thousand million is assumed, which is a coarse estimate of a peak value expected to be reached during this century. I.e. considering the lag times of technology, society and politics the allowance is formulated based on the requirements of the *future,* instead of a present-day allowance (based on 7.3 billion humans) which would require continuous adjustments depending on how the human population is growing.

The units of burden: The different LCIA characterisation factors which express the burden of exchanges on planetary systems are derived in detail below. The unit of the characterisation factors is given *as a fraction of the per-capita-allowance for each of the eight implemented planetary boundary*. A value of one PBA is the full annual per-capita allowance for that boundary. For instance, CO_2 has a characterisation factor of 0.000869 PBA_{CC}/kg CO_2. An emission of 100 kg CO_2 then results in 0.0869 PBA_{CC}, which for instance means that such an emission claims 8.69% of a person's annual allowance for the planetary boundary for Climate Change.

No regionalisation: Only coarse distinction of emissions are available in current LCA data, e.g. emissions in urban air vs. rural air, or emissions to surface water vs. marine water. Current LCIA methods do not provide geographical distinctions, like for instance an emission in Swiss midlands vs. an emission in the Zhejiang Province, China. Therefore it is customary and accepted procedure in LCA to assess pollutants regardless of exact geographic location using generic effect factors representing typical average burden potentials. While a geographical distinction of characterisation factors is certainly desirable and something to work towards in the future, presently the PBA'06 provides no regionalisation and provides only *generic global characterisation factors*. Regionalised characterisation factors would presently not represent any increase in result precision, as the applied life cycle inventory data is not regionalised either.

Multi-dimensional results: All characterisation factors are given in PBA per unit of an environmental exchange. The PBA for different boundaries are calculated for different physical units like kg CO_2-equivalents or m^3 water consumption. But a value of 1 PBA represents always the per-capita annual allowance for each of the heeded boundaries. This is similar to the Ecological Footprint method, where a value of 1 planet means for instance that consumption exceeds the planetary capacities. But in the PBA method not only *one* boundary is observed, but *eight* different "flavours" of planetary

[1] I am particularly thinking here of the 2000-Watt-society (Novatlantis 1998), the Ecological Footprint method (Wackernagel & Rees 1996), and the 1-ton-CO_2 target (Boulouchos et al. 2008).

capacities or boundaries are calculated. This can be used as a multi-dimensional ecological sustainability check, which heeds many more pollutants and exchanges than the ecological footprint does[2].

Subscripts can be used to distinguish the allowances for different boundaries as shown in the following table, e.g. PBA_{CC} for climate change.

Planetary Boundary	Unit for the Planetary Boundary Allowances	
Climate change	**PBA_{CC}**	CC for "Climate Change"
Ocean acidification	n.a. [1] PBA_{AC}	AC for "Acidification"
Stratospheric ozone depletion	**PBA_{OD}**	OD for "Ozone Depletion"
Atmospheric aerosol loading	**PBA_{PM}**	PM for "Particulate Matter"
Nitrogen cycle	**PBA_{N}**	N for "Nitrogen"
Phosphorus cycle	**PBA_{P}**	P for "Phosphorus"
Global freshwater use	**PBA_{FW}**	FW for "Freshwater"
Land occupation	**PBA_{LO}**	LO for "Land Occupation"
Loss of biodiversity	**PBA_{BD}**	BD for "Biodiversity"
Chemical pollution	n.a. [1] PBA_{TX}	TX for "Toxicity"

1 Not operationalised in PBA'06.

1.3 Optional full aggregation

The eight different PBA values can in theory be added together to result in a single score for environmental damage. A single score might be easier to communicate, since one value instead of eight are displayed. It is suggested that such an aggregated result is referenced not with the unit PBA, but with the unit APBA for *aggregated planetary boundary allowance*. Also the LCIA method name shall in this case be adapted to APBA'06. The reason for this is that with full aggregation certain consequences are ensuing:

a) For an aggregated PBA, the value of 1 has no special significance anymore. For the *unaggreagated* PBA scores a value of 1 means that the personal allowance for that boundary is reached. Several values below 1 (meaning all personal allowances are not exceeded) can add up to a sum of over 1[3].

b) Adding up all eight individual PBA values implies that all planetary boundaries are of *equal importance*. PBAs can measure exceedance of acceptable planetary burden targets, and each target must not be exceeded for being sustainable, but there is no weighting between the different targets. For instance reaching the boundary of atmospheric aerosol loading is equally important than reaching the boundary of biodiversity loss.

c) Full aggregation means that compensations between burdens on Earth Systems become a mathematical possibility, although such compensations make not sense for the real world planetary systems involved. For example, a comparison between two lifestyle options A and B might result in both options having an ABPA of 4, but option A might have all PBA values at 0.5 and options B might have one value at 2 and all others at 0.286. So while option A does not violate any boundaries, option B has an exceedance of one Earth System boundary. Therefore B is clearly less desirable, although both lifestyles A and B have identical APBA scores.

These caveats mean that APBA values can *not be used for sustainability checks anymore*. Only the unaggreagated PBA values can be used for sustainability checks. But APBA can well be used for the

2 The Ecological Footprint method only heeds emissions of CO_2 (no other greenhouse gases) and various land occupations.

3 Also dividing the sum by 8 does not restore the significance of a boundary allowance. For instance a sum from eight PBAs, where one boundary is exceeded (and therefore representing an unsustainable consumption), like (1.2 +0.1 +0.1 +0.1 +0.1 +0.1 +0.1 +0.1) /8 = 1.9 /8 = 0.2375, results in a value below 1 after division by 8, but that does not mean that consumption pattern is sustainable. Division by eight to obtain APBA values is not allowed.

more traditional goals of product LCA of pointing out relatively less burdening options (comparative LCA) or identifying relevant burden contributions in one single product (dominance analysis).

1.4 Method overview

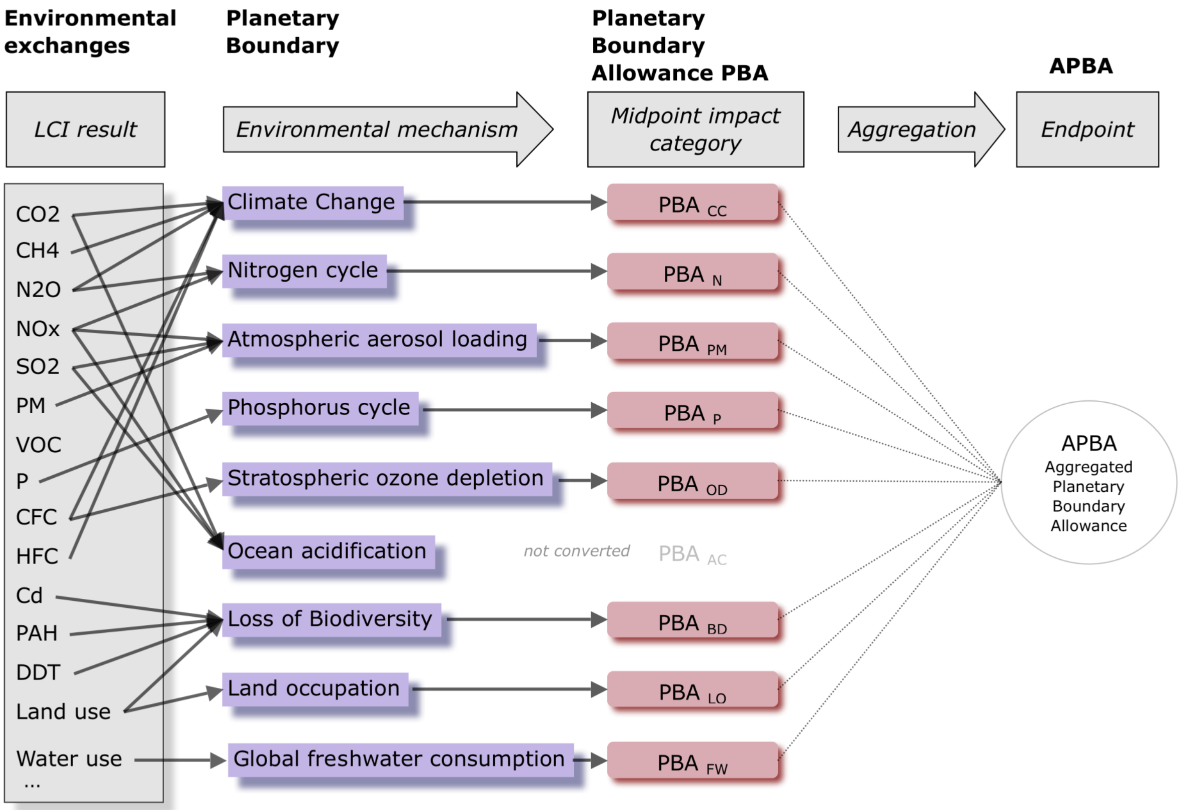

Fig. 1.1 A simplified outline of the PBA'06 method, including the optional full aggregation to APBA (aggregated planetary boundary allowance)

Planetary System Damage	**Boundaries set in Steffen et al. 2015**	**Operationalisation in PBA'06 for Life Cycle Inventory data**	**Per-Capita Allowance in PBA'06**
Climate Change	• ≤ 305 ppm CO_2 in atmosphere and • ≤ 1 W/m^2 warming power surplus	Warming power surplus converted to GWP for various greenhouse gas emissions	1150.75 kg CO_2-Eq per capita and year
Loss of biodiversity	• ≤ 10 extinctions per million species.yr (E/MSY) and • ≤ 1 E/MSY aspirational target and • ≥ 90% Biodiversity Intacness Index BII (new)	10% Biodiversity Intacness Index BII loss converted to relative reversible species loss from various emissions	0.0000195 species.yr per capita and year
Nitrogen cycle	• ≤ 62 Mt N /yr fixation	Nitrogen-containing emissions to air, water, soil	6.2 kg N emitted per capita and year
Phosphorus cycle	• ≤ 11 Mt P /yr emitted to ocean and • ≤ 6.2 Mt P mined + applied to erodible soils	Emissions of phosphorus and PO_4 to oceans directly, and indirect effects via characterisation approach for non-marine emissions	1.1 kg P emitted per capita and year
Stratospheric ozone depletion	• ≥ 276 Dobson Units stratospheric ozone concentration	14 Dobson Unit loss converted to ODP-weighted emissions of various ozone-depleting gasses	0.04094 kg ODP-Eq per capita and year
Ocean acidification	≤ 20% reduction aragonite saturation	not operationalised	–
Global freshwater use	• ≤ 4000 km3 / yr blue water use • Maximal monthly withdrawal in basin per flow-regime	Evaporative blue water consumption from water emissions to air	400'000 litre water per capita and year
Land occupation	• ≥ 75% original forest cover (global average) • Regional distinctions	Non-forest land occupations counted as forest loss	8510 m^2 non-forest land occupation per capita and year
Atmospheric aerosol loading	• ≤ 0.25 Atmospheric Optical Depth AOD on Indian Subcontinent • ≤ 10% warming Aerosols in total AOD	AOD converted to particle formation of air emissions (climate effect, not human health related)	Various particle generating emissions (SO_2, NH_3, NO_2, NMVOC, PM) derived from $2.22 \cdot 10^{-12}$ AOD.yr per capita and year
Chemical pollution	Undefined, renamed to "Introduction of novel entities" (includes GMO, nanomaterials, unknown effects)	not operationalised	–

1.5 Climate Change

Rockström et al. present a twofold boundary value: one for CO_2 concentration in the atmosphere and one for total man-made thermal forcing. In order to be able to assess various greenhouse gases, and not only CO_2 alone, the second boundary of + 1 W/m^2 is used here.

For 10 billion inhabitants the per-capita-allowance is therefore $+ 1 \cdot 10^{-10}$ W/m^2.

Climate Change impact categories in LCA are usually available in GWP-weighted sums (GWP= Global Warming Potential), the so called CO_2-equivalents. The so called *absolute* GWP is the denominator in GWP calculations. For a 100 year time horizon the absolute GWP of CO_2 is given as 8.69E-14 (W.yr)/(m^2.kg CO_2) (Forster et al. 2007:211). The physical unit of (W.yr)/m^2 results, because the absolute GWP is the integrated area under the W/m^2 versus year chart. Therefore an LCIA result derived from GWP_{100yr} in kg CO_2-equivalents can be converted to absolute radiative forcing values by multiplying with 8.69E-14 (W.yr)/(m^2.kg GWP_{100yr} CO_2-eq).

The per-capita-allowance of $+ 1 \cdot 10^{-10}$ W/m^2.cap corresponds therefore to an annual allowance of 1150.75 kg CO_2eq per capita[4]. Present global average annual per-capita emissions are 6560 kg CO_2eq [5], or a factor 5.7 larger.

1.6 Loss of Biodiversity (new boundary)

Steffen at al. 2015 maintain the previous biodiversity planetary boundary of 10 extinctions per year and per million existing species (E/MSY) already set in Rockström et al. 2009. Additionally, Steffen et al. introduce a second kind of biodiversity boundary based on the concept of *Biodiversity Intactness Index* (BII). This metric ranges from 100% to 0% and measures relative damages to species richness due to human activities. This metric is similar to the concept of potentially disappeared fraction of species (PDF), which measures a relative and reversible species loss. PDF has been used in various LCIA methods, like Eco-indicator'99. [6]

In the previous PBA'05 method (Doka 2015) the initial boundary on *extinction* was linked with the absolute *reversible* species loss as used in the LCIA method ReCiPe'08 (Goedkoop et al. 2013). A tentative reduction factor of 20 was employed, along with a working hypothesis that *irreversible* and *reversible* species losses are directly proportional. With the Biodiversity Intactness Index BII Steffen et al. introduced a metric that is very close to metrics already measuring biodiversity loss in various LCIA methods. Since now both boundaries can be linked to the reversible species losses expressed as PDF, the question arises, which of the two planetary boundaries should be heeded – the irreversible extinctions or the relative and reversible species losses. In the precautionary vein of the planetary boundary publications, the *more severe boundary* should be heeded in order to avoid critical planetary system shifts. It is shown below that the BII boundary results in a reduction factor of approximately 29 and is therefore the more severe boundary (and/or that the tentative reduction factor of 20 for the extinction boundary in PBA'05 was too low). Therefore, in PBA'06 the planetary boundary based on Biodiversity Intactness Index will be used.

Steffen et al. set the planetary boundary for Biodiversity Intactness Index at 90%. This is an *average* value and can comprise areas and biomes with high intactness, like forests, and areas with low intactness, like built-up land. The BII metric is an area-wide aggregate of species richness. A BII of 100% would mean that an area under investigation features all the species that are expected to occur on an *undisturbed* area. The planetary boundary means of 90% that the critical species richness shall be 90% of the undisturbed species richness – as the global area-wide average value. The BII metric is

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4 From $1 \cdot 10^{-10}$ W/m^2 divided by 8.69E-14 (W.yr)/(m^2.kg GWP_{100yr} CO_2-eq) = 1150.75 kg GWP_{100yr} CO_2-eq/ yr

5 45'913.5 Mt CO_2-eq in 2011 (http://cait2.wri.org) from 7 billion people.

6 Some other additions are made in Steffen at al. 2015: While the planetary boundary is still set at 10 E/MSY, they note that as an "aspirational goal" a value of 1 E/MSY should be kept in mind. Also they make clear that using the unit of species extinctions is an interim variable, and that a measure of true genetic diversity would be desirable, but is impractical due to low data availability.

of the nature "more is better". To arrive at a "less is better" metric, the same orientation as the metrics of the other planetary boundaries, the planetary boundary is reformulated into 10% intactness *loss*. A value of 10% BII loss does not mean that 10% of all species are extinct. It means that human activity on the planet has reduced species richness by an area-weighted average of 10%, but all species can or could still exist on the planet.

The ReCiPe-Method calculates the total effect of the world's anthropogenic emissions in the year 2000 on reversible extinctions to be 5'614'580 species.yr/yr [7]. This value includes various effects of eutrophication and acidification, land uses, and ecotoxic chemicals, including their temporally delayed effects. The ReCiPe authors calculate this value using the concept of potentially disappeared fraction of species (PDF) which measures *relative* biodiversity losses in an ecotope – much like BII – but then convert these relative losses in to *absolute* species losses by multiplying with planetary species densities (Goedkoop et al. 2013:9). The ReCiPe authors use a planetary species richness of 1.95 million known species.[8] A global intactness loss of 10% would mean that a biodiversity loss of 195'000 species.yr/yr is the planetary boundary. The per-capita allowance for 10 billion inhabitants is then 0.0000195 species.yr/yr per capita. ReCiPe features characterisation factors to calculate species losses for a broad range of emissions and also land occupations and transformations with the unit species.yr which can be used to calculate characterisation factors of PBA'06 for the biodiversity loss boundary.

The ReCiPe-Method calculates the total effect of the World's anthropogenic emissions on reversible extinctions (including delayed effects) at 5'614'580 species.yr/yr, or a factor 28.79 over the planetary boundary[9].

1.7 Nitrogen cycle (new boundary)

Steffen et al increased the planetary for nitrogen flow to 62 Mt N, from the original 35 Mt N in Rockström et al (Mt = million metric tons). Therefore this boundary is becoming less severe compared to PBA'05.

Rockström et al. suggest the planetary boundary to be human's rate of nitrogen fixation as "a giant valve that controls a massive flow of new reactive N into the Earth System". The authors include leguminous crops, fossil-fuel combustion and biomass burning in their calculation of human-driven nitrogen conversion, not only industrial fixation of atmospheric nitrogen (Haber-Bosch synthesis). It is therefore clear that the actually damaging nitrogen flow is not humanity's uptake or fixation as such, but the *emissions* of reactive nitrogen. This provides a simple link to LCI results. Emissions of ammonia, nitrate, nitrogen oxides are counted as reactive nitrogen[10]. Rockström et al. exclude nitrous oxide (N_2O) which is relatively unreactive, having an average atmospheric lifetime of 120 years. Nitrous oxide emissions are however heeded in other planetary boundaries allowances (Climate Change and Ozone depletion).

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7 For the Hierarchist archetype in ReCiPe. Species.yr is the unit of reversible damages (one single species reversibly disappeared over one year), the denominator yr results from using annual emission rates for the year 2000. So the reversible damage includes a temporal duration. The cited figure of over 5 million species.yr annually might appear large, but keep in mind that it includes also effects of the current emissions in the future.

8 As the sum of 1.6 mio terrestrial species, 0.1 mio freshwater species, and 0.25 mio marine species (Goedkoop et al. 2013:9). These are the known and described species. The authors note themselves that the true number of species might be much higher, e.g. 18 million, but base their assessment on described species. Therefore this number is used here to consistently convert between *relative* species losses (BII) and the *absolute* species losses (in species.yr) used in ReCiPe.

9 The current damage value seems to imply a *loss of species richness* of 287.9% (=10% · 28.79), which seems a mathematical impossibility: How can more than 100% of the species richness be lost? The answer is that LCA has *integration of effects over time*. In simple terms: it is possible that an emission *today* will cause damages for decades to come. If an emission causes a reversible species decrease of 1%, but this effect lasts for 200 years, a temporal integration will result in 200% loss, or 2 PDF.yr. Please note that reversible biodiversity losses include a time unit, e.g 'species.yr' or 'PDF.yr'.

10 A range of other emissions, which appear in the ecoinvent database, are also included based on their nitrogen content: ammonium carbonate, tetramethyl ammonium hydroxide, organic bound nitrogen.

To assign the planetary boundaries to LCI results, only one assumption is made here that said amount of fixed nitrogen ultimately will be emitted as reactive nitrogen. This means that the planetary boundary of 62 Mt fixed nitrogen annually given by Steffen et al. corresponds to an identical emission of reactive nitrogen.

Rockström et al. emphasize that nitrogen flow and phosphor flow are two parts of one single planetary boundary called "geochemical flows". Obviously the two key nutrients N and P are interrelated in their damaging effects (mainly eutrophication). However, since LCI results offer separate emission figures for either and the authors have also provided two separate and completely independent planetary boundaries for N and P flows, they can be implemented as *two* separate boundaries for the purposes of the PBA method.

With the restrictions explained above, the planetary boundary of 62 Mt nitrogen per year is identical to the planetary allowance of emission of reactive nitrogen, excluding nitrous oxide. The per-capita allowance for 10 billion inhabitants is then 6.2 kg nitrogen emissions per year.

1.8 Phosphorus cycle

Rockström et al. propose the planetary boundary to be 11 Mt P emitted into oceans annually. Since the LCI database ecoinvent distinguishes emissions into marine water from emissions in freshwater, a straightforward assessment of emissions of phosphorus into oceans is possible.

The per-capita-allowance is 1.1 kilograms of phosphorus into oceans annually. An emission of 1 kg phosphorus into ocean has therefore a PBA_P of 0.9090 (=1/1.1). Marine emissions of phosphorus and phosphate PO_4 can be heeded directly, with phosphate converted into phosphorus equivalents (32.6% P in PO_4). Ecoinvent also features the ill-defined *"solids"* (suspended and dissolved) as marine emissions. These emissions are partially counted as phosphorus using an average phosphorus concentration in solids of 0.066 w-% derived from average Earth crust concentrations.

In addition to direct marine emissions, using a characterisation approach also non-marine emissions of phosphorus can be included. The effect of phosphorus emissions on *marine ecotoxcicty* from the ReCiPe method is used here (Goedkoop et al. 2013). Since this impact category discerns the effects on marine biota only, it expresses the phosphorus arriving in the ocean according to the LCIA fate model employed in ReCiPe (USES-LCA 2.0.). By relating the characterisation factors of non-marine phosphorus emissions to a direct marine phosphorus emission, the fraction of phosphorus arriving in the ocean can be calculated. For instance an emission of 1 kg P on soil leads to 0.337 kg P arriving in the ocean, therefore receiving 33.7% of the characterisation of a direct marine P emission. Please note that these percentages or transfer factors are purely biogeophysical factors and contain no information on phosphorus toxicity anymore.

Tab. 1.1 Characterisation approach for non-marine phosphorus emissions

Phosphorus emission media	**Marine ecotoxicity characterisation factor ReCiPe** species.yr/kg emission	**Effect relative to direct emission P in ocean** = fraction in ocean	**PBA characterisation factor** PBA_P/ kg emission
ocean water (salt)	3.35875E-09	= 100%	0.9090
surface water (fresh)	1.18142E-09	35.2%	0.31977
soil	1.13087E-09	33.7%	0.3081
air	1.79472E-09	53.4%	0.4857

Rockström et al. emphasize that nitrogen flow and phosphor flow are two parts of one single planetary boundary called "geochemical flows". Here the phosphor-to-ocean-boundary is treated like an independent boundary. See also text on nitrogen cycle above.

2015 Addition: Steffen at al. 2015 introduce an additional boundary for the phosphorus cycle of 6.2 Mt P applied from inorganic, mined fertilizers to erodible soils. Steffens supplementary information suggests that all cropland is considered to be erodible soil. With the present LCI data this boundary cannot be operationalised, as flow data for *inorganic* phosphorus to *soil* is not recorded. In LCI results, emissions of phosphorus are not differentiated according to inorganic or organic sources, for example in manure[11]. Furthermore agricultural production inventories in ecoinvent are not featuring the gross mass of fertilizer phosphorus spread on fields/soil, but the *net loss* to groundwater. Phosphorus emissions to groundwater are not unique to agricultural processes and also occur in various landfilling processes. So groundwater emissions to groundwater in LCI results cannot be back-calculated to phosphor applied to agricultural soil.

Errata: In the previous PBA'05 (Doka 2015, version of July 2015) a calculation error lead to PBA_P characterisation factors which were a factor 1000 too large (per-capita-allowance was mistakenly 1.1 *grams* of P into oceans). With the corrected per-capita allowance a characterisation factor results which is a factor 1000 lower.

1.9 Stratospheric ozone depletion

Rockström et al. propose the planetary boundary to be a global average stratospheric ozone concentration of 276 Dobson units. Unlike many other boundaries, this is a *minimal desirable* value, while other boundaries represent a *maximal tolerable* value. With a pre-industrial level of 290 DU as specified by the authors, the boundary corresponds to a target of 14 Dobson units ozone *loss*. 14 Dobson units ozone loss is then the maximal permissible damage to the ozone layer. With the change from a boundary for ozone concentration to a limit for ozone loss, a metric is established that has the same orientation as the other boundary metrics for system damages, i.e. less is better.

Ozone depletion impact categories in LCA are usually available in sums weighted with the Ozone Depletion Potential (=ODP). Each ozone-depleting substance (=ODS) has an individual ODP weight, which represents its ability to destroy stratospheric ozone. ODP values are always relative to the reference substance, CFC-11.[12] So ODP-weighted emission sums are given in CFC-11-equivalents.

Similar in structure to the GWP, the ODP sums give a *relative* measure of ozone destruction – relative to CFC-11 – while the planetary boundary relates to an *absolute* loss of ozone in Dobson units (one Dobson unit is $2.69 \cdot 10^{16}$ ozone molecules per square centimetre).

Originally, the calculations of ODPs by the WMO were based on the absolute ozone destruction potential of CFC-11 in the denominator. Current ODP calculations however are based on the chlorine release relative to the chlorine release of CFC-11, and I lack the expertise to convert this information to an absolute ozone loss.

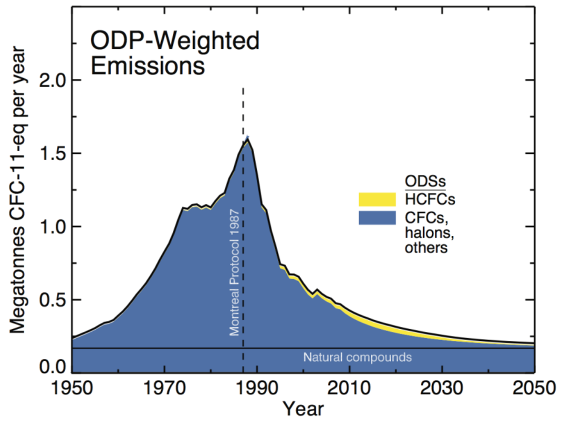
Instead an alternative approach is used here to convert the *relative* ODP metric into a value for *absolute* ozone loss. The time series for 1950-2050 of annual emissions of ODP-weighted emissions is available from (WMO 2010). ODS emissions are expected to return to pre-industrial levels by 2050. The total amount of anthropogenic ODS emissions can be estimated to be 40.85 Megatonnes ODP-equivalents (not per year, but as a total sum integrated over time, distributed over the period ~1940 until 2050). The ODP emission timeline is shown in Fig. 1.1.

On the other hand the expected effects of ODS on the ozone layer are summarised in (Newman et al. 2009). In Figure 2 of that publication the global average stratospheric ozone destruction in Dobson units over the period of 1960-2100 is given. The expected damage to the ozone layer is shown in Fig.

[11] Cattle feed might contain additions of inorganic phosphor minerals. And the topic might further be complicated by the recent development of *recycled phosphorus fertilizer* gained from the ash of the incineration of wastewater treatment sludge. This would be an *inorganic* fertilizer, but not from normal mines. Steffen's supplementary information suggests that damaging types of phosphorus are those that come from formerly inert sources, like common mines, but not manure, since this is largely already reactive phosphorus present in the area. So a sludge ash fertilizer would probably not be counted as damaging to planetary boundaries, since this too comes largely from already reactive phosphorus.

[12] Also known as Freon-11, Trichloro-fluoro-methane, CCl_3F.

1.2. From that it can be estimated that the total cumulated damage to the ozone layer from anthropogenic ODS emissions – i.e. integrated over time – will be -1'397.1 DU.year [13].



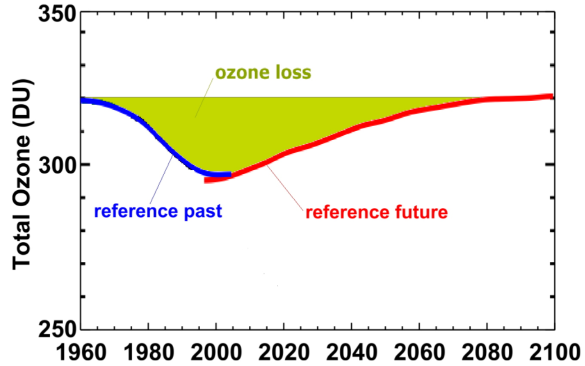


Fig. 1.1 Ozone-depleting substances emissions 1950 - 2050, adapted from (WMO 2010)

Fig. 1.2 Average global ozone concentration 1960 - 2100, adapted from (Newman et al. 2009) [1]

1 I noted that (Newman et al. 2009) seem to imply an undisturbed global average for total ozone of 320 DU pre-1960, while Rockström et al. cite an undisturbed, pre-industrial value of 290 DU (from Chipperfield et al. 2006). I did not try to reconcile this, but assumed that the expressed *absolute loss* of ozone in DU is compatible.

Both data items – the total ODS release and the total DU loss – cover the whole temporal development from onset to total remediation. This then allows to calculate the average absolute ozone loss per ODP emission. The absolute ozone depleting effect of ODS is 34.197 DU.year per Megaton ODP (calculated from 1'397.1 DU.year / 40.85 Mt ODP).

The permissible ozone loss is 14 Dobson units and therefore the global *annual* allowance of ozone damage is 14 DU.year. With the absolute ozone depleting effect of ODS derived above the permissible ozone loss corresponds to an annual emission of ODS of 0.409 Mt ODP per year (calculated from 14 DU.yr / 34.197 DU.yr/Mt ODP). With 10 billion inhabitants the per-capita allowance is therefore 0.04094 kg ODP-Eq per year.

Seeing that emissions CFCs are declining, the human pressure on the ozone layer is being dominated by other substances, for example nitrous oxide (N_2O). It is a gas with a long atmospheric lifetime and has also climate change effects (GWP_{100a} is 298 CO_2-Eq). It is destroyed in the upper atmosphere, where it releases NO radicals which catalytically destroy ozone in a similar manner as chlorine and bromine radicals. An ODP factor for N_2O of 0.017 R11-Eq has been published in (WMO 2010b). For comparison, this value is of similar magnitude as that of many partially chlorinated HCFCs which are included in the Montreal protocol, like HCFC-31, HCFC-121, HCFC-122 etc. It is suggested here that this factor – respectively a characterisation factor of 0.41525 PBA_{OD}/kg N_2O [14]– shall be applied to emissions of nitrous oxide.

1.10 Ocean acidification

Rockström et al. propose the planetary boundary for ocean acidification to be a global mean saturation state of aragonite in surface seawater 2.75 omega units. An omega value over 1 signifies an

[13] The unit of (Dobson unit * year) results from the ozone loss (DU) over time (years), i.e. the integral of the DU vs. time chart, which is the green area in Fig. 1.2.

[14] The value of 0.017 ODP/kg N_2O divided by the annual allowance for ozone depletion of 0.04094 ODP-Eq/year results in 0.41525 PBA_{OD}/kg N_2O

oversaturation with aragonite, while at a value below 1 the water is undersaturated with aragonite, prompting dissolution of solid aragonite, i.e. dissolution of shells and skeletal structures of marine biota.

As a direct link to LCA, data of some acidifying emissions (e.g. ammonia NH_4) to ocean water are usually listed in LC inventories. The main driver of ocean acidification is however dissolution of atmospheric CO_2 [15]. This would require a fate model connecting CO_2 air emissions from LCI to changes in global mean aragonite saturation in surface seawater. Such data could not be found.

According to the sources used by the authors (Table 1 in Guinotte & Fabry 2008), the planetary boundary of 2.75 omega units would correspond to an atmospheric CO_2 concentration of 395 ppm. Rockström et al. already set a boundary for atmospheric CO_2 regarding Climate Change at 350 ppm. Therefore the Ocean Acidification boundary will not be exceeded by adhering to the Climate Change boundary[16]. Steffen at al. 2015 confirm this understanding: *"This boundary would not be transgressed if the climate-change boundary of 350 ppm CO_2 were to be respected."* This however ignores other acidifying oceanic emissions, e.g. acid rain into seawater, which are deemed minor.

An explicit calculation of ocean acidification allowance would be preferable to avoid burden shifting, but it currently appears that by heeding the Climate Change allowance, the ocean acidification boundary will not be exceeded.

Ocean-acidifying emissions are heeded in the PBA'06 method with regard to *other* effects they have: NH_3, NO_x and SO_2 in aerosol dimming; NH_3, NO_x also in nitrogen flow; CO_2 in climate change. These emissions therefore do not go unnoticed in the PBA'06 method, though it can be said that the lack of an inclusion of their ocean-acidifying effects underestimates their full damage potential within an LCIA method.

1.11 Global freshwater consumption

Steffen et al. maintain the planetary boundary for annual blue water consumption to be 4000 km^3 or $4 \cdot 10^{15}$ litres. With 10 billion inhabitants the annual per-capita allowance is 400'000 litre or 400 m^3. Blue water consumption consists of surface water (lakes, rivers, groundwater) which is subsequently either *evaporated* into air, or *incorporated* into traded goods[17].

Steffen et al. complement the global boundary for blue water (consumptive use) with limits for withdrawals[18] from rivers. These limits are distinguished temporally for high-, intermediate-, and low-flow months and are to be applied on a basin-wide geographical scale. As LCI data currently lacks both sufficient temporal and geographical resolution, only the global boundary value can be heeded in PBA'06.

The ecoinvent database v3 has emissions of water into air, which can be counted as the *evaporative* blue water consumption[19]. The *"incorporative"* water consumption, i.e. water contained in products is

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15 *"On a global scale, the alterations in surface water chemistry from anthropogenic nitrogen and sulfur deposition are a few percent of the acidification [...] due to the oceanic uptake of anthropogenic CO_2."* (Doney et al. 2007)

16 In this study, the Climate Change boundary is heeded with the second boundary of $+1 W/m^2$. Rockström et al. note that the two boundaries for Climate Change "correspond roughly to the same estimated degree of climate change" (page 10 of supplemental material to Rockström et al. 2009). The $+1 W/m^2$ boundary will therefore undercut the 395 ppm CO_2 boundary implied by the ocean acidification boundary.

17 Blue water merely used and returned within the same watershed is not blue water *consumption*, but blue water *withdrawal*. Polluted water can be expressed with a *grey water footprint*. Rainwater and soil moisture evaporated or incorporated into traded goods, especially in agriculture or forestry, is called *green water consumption*. Steffen et al. only heed blue water consumption for the global boundary.

18 Steffen et al. use the word 'withdrawal' which would include also water returned into the same basin (but maybe in a polluted and/or thermically changed state).

19 Inventoried processes in ecoinvent v3 can only have blue water sources as water input. Green water (soil moisture, precipitation) is not inventoried as a water input. Water outputs in ecoinvent processes are: (A) water emission to air →

not directly available in ecoinvent inventory result data, but can be estimated to be of minor importance, i.e. the water evaporated in the process is usually the dominant blue water consumption. Heeding also the "incorporative" water use would be preferable.

In ecoinvent, water emissions to air are inventoried per cubic-metre (m^3) and in four subcategories[20]. All these four exchanges are summed up without weighting, to calculate the consumptive pressure on blue water resources.

While the formulated water boundary excludes a valuation of grey water, pollutants emitted to fresh water will be heeded in other boundaries, i.e. nitrogen cycle, and loss of biodiversity.

1.12 Land occupation (new boundary)

Steffen et al. formulate a global planetary boundary for *remaining forest cover*. The motivation is to capture the climate regulating effects of forested areas on the ice-free land surface. The planetary boundary globally is set at remaining forest area 75%. More specific goals are set for 3 different biomes: tropical, temperate, and boreal, which presently cannot operationalised with ecoinvent LCI data. The global planetary boundary represents of 47.9 million km^2 forest cover. The remaining forest cover in 2010 was 61.9% or 39.5 million km^2, and must therefore be deemed unsustainable.

The forest cover area is a *minimal* boundary, i.e. more forest area is better. To be in the same vein as the other boundaries, which are of the type "less is better", the forest area boundary is reformulated here to a "non-forest area boundary".

The total ice-free land surface on the planet is 133 million km^2. [21] The planetary boundary for forest cover implies that *maximally* 85.1 million km^2 of the land surface shall be *non-forest* areas (= 133 – 47.9). With this reformulated boundary all non-forest land occupations will be counted as contributing damages. These can be built-up lands, traffic areas, residential areas, cropland, pastures, meadows, orchards, plantations, industrial areas, landfills etc. With 10 billion inhabitants the annual per-capita allowance is 8510 m^2.year non-forest land occupation[22].

The total amount of non-forest, ice-free land areas in 2010 was 93.5 million km^2 (=133 – 39.5). The current reduction factor for this boundary is therefore 1.1 (= 93.5/85.1), which means the boundary is slightly overshot.

A "natural background" of non-forest areas is not excluded from this accounting. Anthropogenic land uses can include also fallows, steppe, deserts, e.g. for traffic areas, mining sites, landfills. Potentially any kind of land surface can become subject to human activities and therefore can turn up in Life Cycle inventory data of land use. Excluded for the PBA'06 assessment are only ice surfaces and natural sea surfaces, which are also excluded in the boundary setting by Steffen.

An exclusive assessment of land uses which are only occurring on areas which could potentially also be forest areas would require that the process inventory data distinguishes such land uses, for instance *'built-up land on potential forest area'* versus *'built-up land on area without forest potential'*. Such distinctions are presently not available in LCI data, but could become feasible in the future with

(evaporation), (B) water emission to surface water (return), (C) wastewater output to technosphere, (D) incorporation in product (water content property of product). Outputs A and D should be counted as blue water consumption. Output D is not available in LCI result lists provided by ecoinvent and extensive programming would be required to obtain these figures. Water evaporated in treatment of wastewater (C) is included in linked processes of wastewater treatment. Emissions of water to air represent therefore the evaporative blue water use.

20 The four subcategories are "non-urban air or from high stacks", "urban air close to ground", "lower stratosphere + upper troposphere", "unspecified".

21 Globally 1995 million hectares are converted to cropland, which is 15% of the ice-free land surface (given in Supplementary Material p.19 of Rockström et al. 2009). Therefore 19.95 mio km^2 / 15% = 133 mio km^2 .

22 Land *occupation* has the physical unit (area.time), e.g. (m^2.year) i.e. includes a time dimension, while land *transformation* (from one land use type to another) has the physical unit of an area, e.g. m^2.

geographically resolved, regionalised data. Then also the 3 different biome targets by Steffen could be operationalised.[23]

In Europe the large majority of land uses are on potentially forested areas (Potapov et al. 2009). Notable exceptions to this are Iceland, Norway and Romania, see Fig. 1.3. So for most land uses occurring in Europe the potential forest area is indeed close to the total land area, and therefore most land uses indeed are preventing forest areas. So the deviation made by not discriminating for land uses on areas without forest potential in LCI is small for European direct land uses.

In PBA'05 only *cropland* (without pastures and meadows) was assessed as a relevant land use, based on the conceptions in Rockström et al. 2009. In PBA'06 a large range of different land uses is assessed, which from an LCA perspective is desirable to avoid burden shifting due to assessment gaps.

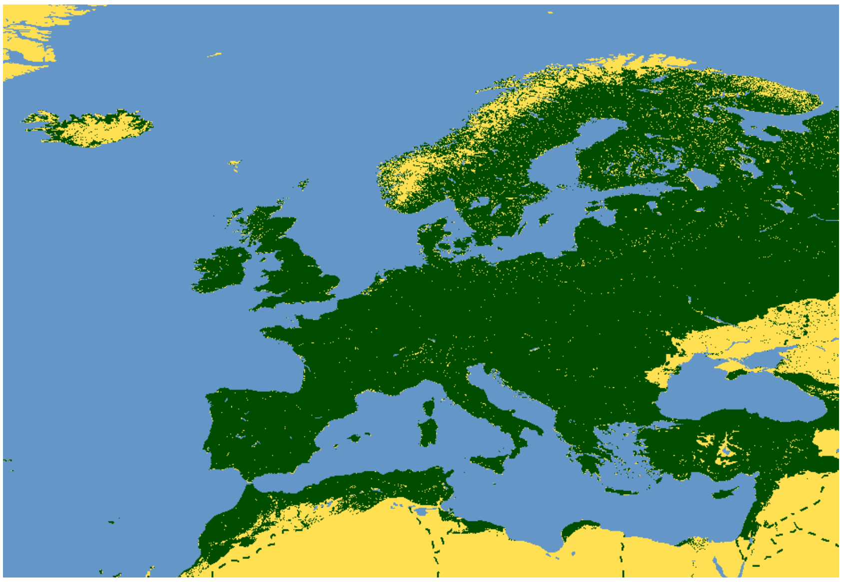

Fig. 1.3 Original forest cover in Europe 8000 years ago in green; non-forest areas in yellow. Adapted from (Potapov et al. 2009).

1.13 Atmospheric aerosol loading (new boundary)

Steffen et al. 2015 have quantified this planetary boundary, while a quantification was missing in the previous Rockström et al. 2009. They mention two main reasons to consider aerosols as a planetary problem: (a) their influence on the climate system, (b) their adverse effects on human health. Steffen et al. focus on the climate effect on regional circulation patterns.

Aerosols (natural and man-made) can lead to decreases of incident solar radiation ("dimming") and can affect climate patterns. Steffen et al. use the regional example of monsoon patterns in South Asia and the danger of substantially drier monsoon periods caused by dimming effects of aerosols. They use the metric of Aerosol Optical Depth (AOD) and derive a boundary of AOD = 0.25. More on the AOD metric below.

Steffen et al. also set a boundary of the share of *warming* AOD to be less than 10% of the total AOD. Warming aerosols convert incident solar radiation into heat. Examples are black carbon (e.g. soot) or

[23] A coarse control of the relevance of this inclusion can be tried here: barren lands like tundras and deserts might reasonably be excluded from being counted, because they can usually not support a potential forest and also because human activities, especially farming, are predominantly on other original land types. With this assumption, the relevant land base shrinks from 133 million km^2 to about 124 million km^2. The planetary boundary for non-forest areas in this case becomes 76 million km^2 (= 124 – 47.9). The reduction factor then becomes 1.23 (= 93.5/76), instead of the 1.1 derived above. On a global level therefore the inclusion of barren lands in the land base for non-forest areas will not influence the results to a large degree.

hematite in mineral dust, while for instance sulfate aerosols have a cooling effect by scattering light. Life Cycle Inventory data usually features simply particulate matter, e.g. $PM_{2.5}$, as primary particle emissions, and these metrics are for instance used for the particle emissions of a diesel engine and a gravel quarry alike[24]. Warming aerosols like black carbon are usually not discriminated in LCI data. For this reason the second boundary of maximally 10% warming AOD in total AOD can presently not be operationalised in the PBA method.

Approximation: Setting planetary boundaries from a regional example

Steffen derived one *regional* boundary for South Asia and not a *planetary* boundary. And preferably we would want a regionalised impact model and also regionalised process inventories (LCI). Presently, the common LCA databases have neither. As remarked at the beginning of this report the characterisation factors derived here have no regional differentiation for this reason. Regionally resolved LCA results have been long on the wish list of many LCA professionals and while frameworks for them are emerging, the data handling requirements are considerable. For a long time the LCA community had to work with the limited methods that *were* available. For instance although LCA can include emissions and burdens from all over the world, frequently used impact assessment methods usually are, still, from regions much smaller: for instance for Europe, USA, or Switzerland, depending on the method. So in view of the accepted practice – out of necessity – of applying models for much smaller regions for emissions worldwide, I feel bold enough to devise a procedure to apply Steffen's results derived for South Asia on world emissions. This procedure is detailed in the following sections. Maybe there is some fairness in the fact that after decades of LCA results, also of Asian processes, being based on damage models of the Occident, this time South Asia gets to be the exemplary case to set the generic example. I emphasize again: proper regional damage models for all the world would be preferable, and I will gladly use them as soon as they become feasible. In the meantime I use this approximation as a placeholder, which gives us at least *some* indication of the aerosol damage of the analysed systems. The alternative would be to have *no results* for aerosol damage, i.e. being fully blind towards the danger of aerosol dimming, while waiting for perfect information.

For sustainability checks on lifestyles the effects of aerosol loading will usually not be decisive and therefore the approximation made here will be uncritical for sustainability checks. In a study applying the PBA'06 method on individual consumption patterns the most critical and therefore limiting boundaries were the global warming boundary (for current lifestyles in Switzerland) and the biodiversity boundary (for future lifestyles) (Doka 2016).

Aerosol Optical Depth AOD as a metric

The optical depth is a measure of how well a material hinders transmission of incident light. A large optical depth means a lot of radiation is either scattered back or absorbed. For Aerosol Optical Depth the material in question is the atmosphere and the AOD is a measure of how well light is held up the atmosphere ("dimming"). AOD has no physical unit. An AOD value of zero means no light energy is held up; 0.5 means that roughly 40% is held up; and at 1 roughly 63% is held up.

AODs are usually not given for the whole solar radiation energy, but for a particular light wavelength. The AODs used by Steffen at al. are based on absorption of light with a wavelength of 550 nm – corresponding to light of a blue-green hue in the spectrum of visible light, near the energy maximum of the solar spectrum.

The anthropogenic part of aerosol dimming

Steffen et al. set the aerosol boundary for South Asia at an AOD value of 0.25, and give the current state for South Asia as 0.3. These values include a natural background of aerosols e.g. from volatilised salt from sea spray, desert mineral dust, aerosols from volcanic activities and natural forest fires. Such activities are not included in LCI data, which models only man-made or human-induced

[24] For example, the ecoinvent LCI database features particulate emissions in three classes: $PM_{<2.5}$, $PM_{2.5-10}$, and $PM_{>10}$. The sum of the first two classes result in the more common PM_{10} metric, i.e. particulate matter with an aerodynamic diameter of less than 10 micrometers.

activities. Nor can these natural activities be influenced to a significant degree by humans. So in order to be compatible with LCI data, the boundary is reformulated here to refer only to the anthropogenic part of AOD, as shown in Tab. 1.2. Steffen et al. give a natural background for South Asia of 0.15. Therefore the *anthropogenic* contribution to the aerosol boundary must not be above 0.1, while the current anthropogenic AOD in South Asia is 0.15. Therefore the required reduction factor of the anthropogenic AOD is 1.5.

Tab. 1.2 Data given by Steffen et al. 2015 for the current total AOD, boundary AOD, natural background AOD over South Asia. From this calculation of anthropogenic AOD and its reduction factor.

Values for South Asia	Total AOD	Natural background AOD	Anthropogenic AOD
	(A)	*(B)*	*= A – B*
Current value	0.3	0.15	0.15
Boundary value	0.25	0.15	0.1
Required reduction factor			**1.5**

Linking anthropogenic emissions to AOD

Aerosol-forming emissions are usually inventoried in LCIs in mass emissions of SO_2, NO_x, NH_3, $PM_{2.5}$ and/or PM_{10}, VOCs. How do those mass emissions contribute to the AOD, the opacity of the atmosphere? Studies on AOD formation commonly discern SO_2, black carbon, organic matter, sea salt, and mineral dust. Sulfur dioxide therefore provides an avenue to connect the LCI emissions with AOD. The literature source used by Steffen et al. is (Chin et al. 2014) using the GOCART model. The GOCART model assumes a proportionality between emitted mass and contribution to AOD (Chin 2005)[25]. So for a generic assessment a direct linear proportionality between an air emission and its AOD contribution can be assumed, while for different emissions different proportionalities result. An earlier work shows emissions and caused AOD contributions for various emissions and regions from which these linear conversion factors can be inferred (Streets et al. 2009). For South Asia an annual emission of 3.33 million tons of sulfur lead to an AOD contribution of 0.08. From this a typical linear conversion factor of $1.2 \cdot 10^{-11}$ AOD.yr per kg of emitted SO_2 can be calculated[26]. This can be interpreted as an emission of sulfur dioxide in South Asia causing an increase in AOD over South Asia for a length of time, hence the unit AOD.yr.

Scaling up from South Asia to a global scope

Since we want to weigh worldwide emissions, we need to take into account a *scaling factor* to adjust the conversion factor, which was derived for South Asia only, to worldwide emissions. This scaling factor represents the fact that a global emission can be distributed over a larger air volume, and that for a generic *global* average the emissions are also emitted in other climates than South Asia, leading to variations in aerosol fates. This scaling factor amounts to 0.00558 and is determined recursively using global aerosol emissions (Tab. 1.4). So in order to move from the effect of 1 kg *South Asian* SO_2 emissions on *South Asian* AOD to the effect of 1 kg *global* SO_2 emissions on *global* AOD, we arrive at a new *global* generic conversion factor of $6.69776 \cdot 10^{-14}$ AOD.yr per kg of emitted SO_2 , resulting from 0.00558 * $1.2 \cdot 10^{-11}$.

Extending to other emissions

From the above we have *one* conversion factor for SO_2 emissions. The other aerosol-forming emissions are heeded here with a characterisation approach: How strongly are air emissions causing aerosols? While of course dependent on climate and conditions, generic aerosol formation factors can be found in (de Leeuw 2002). This allows a characterisation according to the typical "aerosol causing

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25 This proportionality depends on relative air humidity. For the purposes of an average generic figure as targeted here an average constant relative humidity can be assumed.

26 From 0.08 AOD / $3.33 \cdot 10^{12}$ [kg Sulfur /yr] / 2 [kg SO_2 / kg Sulfur]

strength" of different emissions, as shown in Tab. 1.3. The values for sulfur dioxide are used here as a hinge from which the conversion factors of other substances are derived. [27]

Tab. 1.3 Aerosol formation factors and conversion factors for global emissions into global AOD.yr loads.

Air emission X	Aerosol formation factor kg aerosol / kg emission X	Global generic conversion factor AOD.yr / kg emission X
Source	*(de Leeuw 2002)*	
SO_2	0.54	6.69776E-14
NO_2	0.88	1.09149E-13
NH_3	0.64	7.93809E-14
NMVOC	0.02	2.48065E-15
$PM_{2.5}$	1.7137 ◊	2.12556E-13
$PM_{2.5-10}$	1	1.24033E-13

◊ A mass unit of $PM_{2.5}$ is more powerful at aerosol dimming than a mass unit of PM_{10}. The factor of 1.7137 is an arithmetic mean derived from measurements in 5 South Asian cities (Karachi, Mumbai, New Dheli, Kolkatta, Dhaka) and the relative AOD contributions of emissions of "other $PM_{2.5}$" versus "other $PM_{2.5-10}$" (Carmichael et al. 2009)

Global anthropogenic AOD and the atmospheric dimming boundary

Using global annual emission figures, we are now able to calculate the current global anthropogenic AOD. This value must equal 0.0333, as given by (Chin et al. 2015: Fig 15)[28]. The scaling factor mentioned before is adjusted so that the value of 0.0333 for global anthropogenic AOD results in Tab. 1.4.

Tab. 1.4 Calculation of the global mean anthropogenic AOD from global annual emissions of particle-forming emissions.

Air emission	Global annual emissions kg emission / year	Global generic conversion factor AOD.yr / kg emission	Global mean anthropogenic AOD AOD
Source	*(Dentener & Keating 2015)*	*(Tab. 1.3 above)*	
Calculation	*(A)*	*(B)*	*= A · B*
SO_2	106'873'047'782	6.69776E-14	0.007158102
NO_2	115'941'270'887	1.09149E-13	0.01265484
NH_3	48'635'688'787	7.93809E-14	0.003860744
NMVOC	146'222'338'280	2.48065E-15	0.000362727
$PM_{2.5}$	34'306'594'892	2.12556E-13	0.007292065
$PM_{2.5-10}$	16'163'943'801 ◊	1.24033E-13	0.002004856
Total			0.0333

◊ An annual emission of 50'470'538'694 kg PM_{10} per year is given in Dentener & Keating 2015. To avoid double counting the difference to $PM_{2.5}$ is calculated here as $PM_{2.5-10}$

Applying the reduction factor from Tab. 1.2, we calculate the planetary boundary level for global anthropogenic AOD as 0.0222 AOD.yr (=0.0333/1.5). For 10 billion people the annual per-capita allowance is $2.22 \cdot 10^{-12}$ AOD.yr/capita.yr. Using this planetary boundary and the conversion factors for various emissions in Tab. 1.3 we can now calculate characterisation factors of generic global emissions regarding aerosol dimming.

27 For instance the conversion factor for NO_2 of 1.09149E-13 is calculated from (6.69776E-14 / 0.54 * 0.88), where 0.88 is the aerosol formation factor for NO_2.

28 The total global AOD (including natural background) is 0.111 (Chin et al. 2015: Fig 15).

Tab. 1.5 Calculation of PBA'06 characterisation factors for aerosol dimming.

Air emission	Per-capita allowance AOD.yr / capita.yr	Global generic conversion factor AOD.yr / kg emission	PBA'06 characterisation factors for aerosol dimming per-capita allowance PBA_{PM}/ kg emission
	(A)	*(B)*	*= B / A*
Allowance	2.2222E-12		
SO_2		6.69776E-14	0.030139927
NO_2		1.09149E-13	0.049116918
NH_3		7.93809E-14	0.035721395
NMVOC		2.48065E-15	0.001116294
$PM_{2.5}$		2.12556E-13	0.095650096
$PM_{2.5-10}$		1.24033E-13	0.05581468
PM_{10}		1.84205E-13 †	0.082892209 †

† The factor for PM_{10} is calculated here as a weighted mean between $PM_{2.5}$ and $PM_{2.5-10}$ Using global emissions figures as weights. This represents a mass share of 68% of $PM_{2.5}$ in PM_{10}. It is advised to avoid valuation of PM_{10} if possible and split it up into $PM_{2.5}$ and $PM_{2.5-10}$.

The characterisation factors define the amounts of emissions that lead to overshoot of per-capita allowances. For instance an emission of 10.45 kg of $PM_{2.5}$ leads to a PBA_{PM} of one (from 1 / 0.09565). Or an emission of 33.18 kg SO_2 leads also to a PBA_{PM} of one (from 1 / 0.03014).

1.14 Chemical pollution / introduction of novel entities

Neither Rockström et al. 2009 nor Steffen et al. 2015 have defined a planetary boundary for chemical pollution. Rockström et al. mention heavy metals, organic compounds of human origin and radioactive compounds as examples of chemical pollution, affecting human health and ecosystem health. A problem of setting a boundary for the aggregated effects of the 80 – 100'000 chemicals in use is lack of toxicity data of individual substances and mixtures, and lack of ambient measurements.

Steffen et al. rename the issue 'introduction of novel entities' and include also modified lifeforms, for instance GMOs and antibiotic-resistant bacteria. The term 'novel' is however partly misleading since Steffen expressly also include naturally occurring elements which were merely mobilized by human activities, for example heavy metals, which are not really novel materials.

They make it clear that they would like to include substances with as yet *unknown* disruptive effects on Earth-system processes. This makes setting a boundary impossible: if the effect is currently unknown and undescribed, then it can presently not be known what a safe threshold would be.

Steffen et al. also mention that a *single boundary* might not be sensible for the complex effects of all kinds of different substances. Essentially, it seems, this boundary is a "catch-all" for as yet uncategorised and undetected planetary threats, as well as for the better-known pollution-related effects. The notion that maybe not all crucial planetary boundaries are already found is valuable and important in understanding that future additions might become necessary. New quantified and separate boundaries might spring from this unquantified catch-all boundary in the future.

On pollutant toxicity

Going back to the former chracterisation of this boundary in Rockström et al. 2009 as relating chiefly to *toxic effects of pollutants*, a few observations can be made. Within LCA, the ecotoxic and humanotoxic potentials of inventoried emissions can well be captured. Modern LCA Impact Assessement methods (LCIA) have *characterisation factors* for a few thousand pollutants expressing these toxic damages. [29]

[29] However, in order for these effects to be considered in the analysis, the *inventoried processes* must feature emission data of these pollutants to begin with. Inventoried pollutants data varies in range and quality, depending on availability of data →

In modern LCIA, ecotoxic effects are expressed as increased disappearance of species (which was used in the operationalisation of the biodiversity loss boundary above). Humanotoxic effects can be expressed in LCIA as disability-adjusted life years lost (DALY), which includes premature deaths and years lived with disease[30]. For instance, data from the ReCiPe'08 LCIA method suggest that the total humanotoxic effects of the world's emissions in the year 2000 amounted to 4.36 million DALYs[31]. This includes health damages of those emissions in the future. Per person and year that makes 712 *micro*-DALYs, or 6 hours of healthy life lost. So per person the toxic pollutants emitted in the year 2000 caused or will cause the loss of 6 hours of healthy life from either themselves, from their fellow human beings or from future humans.

For 2001 WHO estimated the total burden of disease (with all causes of health impairment, including for instance accidents, malnourishment, infections) to be 2654 million DALYs[32], or 0.43 DALY per person. So on average per person and year 157 days or 3770 hours of healthy life are lost. This figure only refers to damages to people alive in 2001, which might include lagged damages from previous decades, but not damages in the future to people not born yet. WHO observes a decreasing trend due to better health care and prevention, especially in communicable diseases.

Though not strictly comparable, the DALYs effects from humanotoxic emissions in 2000 appears much lower than the total occurring DALY burden in 2001, even though the former includes future damages (6 vs. 3770 hours of healthy life lost per capita each year). Also other health burdens calculated in LCIA from the year 2000 emissions appear to be more relevant than toxic effects, e.g. 119 million DALYs from climate change, or 22.4 million DALYs from particles/aerosols. Detecting toxic effects is however an important feature in a circumspect LCIA method in order to avoid burden shifting (from observed damages to unobserved ones) so it should be heeded.

The DALY yardstick provides a convenient way to aggregate the vast diversity of toxic pollutants into one measure for health impairments[33]. **One way to arrive at a planetary boundary for chemical pollution would be to establish a level of planet-wide acceptable health damage.**

Rockström et al. mention impaired reproduction, developmental impairments such as autism and ADHD, disrupted endocrine systems, neurobehavioral deficits, compromised immune systems and mutagenesis as examples of toxic damages. The DALY scale suggests that health impairments are interconvertible, for instances damages from severe illnesses like cancer are made commensurable with damages from less severe impairments like skin rashes[34]. For planetary boundaries, which want to define a safe working space for humanity, it might be necessary to discuss if only toxic effects as such or rather all measurable human health impairments shall be considered.

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sources and the diligence of the process inventory researcher. Also new pollutants like nanomaterials or endocrine disruptors are often underrepresented and synergistic effects of pollutants can commonly not be modelled in LCA. That said, LCA data is today probably the most comprehensive approach to analyse particular human activities and goods for their undesirable toxic effects.

30 The DALY concept originated in WHO's global burden of disease reports (http://www.who.int/healthinfo/global_burden_disease/en/).

31 Sum of the normalisation values for the World 2000 for humanotoxic effect including ionising radiation including a long assessment time horizon. This is based on a set of roughly 500 substances for which there are annual emission estimates and characterisation factors to calculate their toxicity.

32 The variant value without any temporal discounting is used here from (WHO 2013:49). WHO's Global Burden of Diseases studies have a 3% temporal discounting of future burdens, e.g. cancer deaths in 10 years.

33 Also other damages can be converted into DALY estimates, for instance ozone depletion damages from higher incidences of skin cancer or climate change damages from increased areas with malaria. Also more direct, but-non-toxic impairments like summer smog from VOCs or respiratory impairments from aerosols can be expressed with DALYs.

34 Of course while heeding the severity of the health impairment. For instance one cancer death in the DALY scale might represent a damage equivalent to 10'000 persons living with skin rashes.

Conclusion

At present the PBA'06 method does not have an operationalisation of the chemical pollution boundary for reasons stated at the beginning of this chapter. For humanotoxic damages a clear boundary value is missing and it might be necessary to establish which kind of health impairments shall be part of the boundary calculation. Ecotoxic damages from a large range of pollutants, most of which are also humanotoxic, are however already included in the biodiversity loss boundary.

2 Conclusion

2.1 Comparison with other sustainable limit methods

With the present PBA method some of the most severe environmental damage effects are linked to LCI data and together can produce qualified checks on ecological sustainability of lifestyles. The PBA'06 method was applied in a case study of present and future lifestyles (Doka 2016). There, global warming, biodiversity loss, and nitrogen flows were the limiting boundaries, determining the limits of ecological sustainable consumption. This result is however dependent on the inventoried processes and technologies. The three boundaries are identical to the ones which are already today exceeded according to (Steffen et al. 2015).

It could also be shown in (Doka 2016) that some other existing methods, which can be used to express sustainability boundaries, apparently feature *less severe criteria*. The **ecological footprint method** considers land use in different classes and only CO_2 as an emission (Wackernagel & Rees 1996). A range of lifestyles that were identified in Doka 2016 as being right at the edge of sustainability according to PBA'06, showed ecological footprints of 0.2 to 0.3 planets.[35] So conversely, if ecological footprint identifies a lifestyle as sustainable (i.e. $\leq$ 1 planet per capita.year), it might overshoot the PBA boundaries by a factor 3 to 5. Thus, the PBA method has more severe boundaries.

Similarity, the **2000 Watt society** promotes as a goal for equitable sustainability (Novatlantis 1998). Here only primary energy resources are counted, including renewable sources like wood, hydropower, wind etc. Land use or pollutants are not part of the 2000 Watt boundary. The range of sustainable lifestyles derived in Doka 2016 showed demands between 300 and 660 Watts. So while the 2000 watt boundary would suggest these lifestyles are sustainable with room to spare, they are indeed right at the edge of being sustainable according to PBA'06. Conversely, lifestyles that are sustainable according to the 2000 watt boundary (i.e. $\leq$ 2000 Watt per capita), might overshoot the PBA boundaries by a factor 3 to 7.

Another sustainability goal is the **1 ton CO_2 target**. It's an additional boundary of the 2000 Watt society (Boulouchos et al. 2008).[36] It is intended to limit the global temperature increase from the anthropogenic greenhouse effect to 2 degrees. The target allows 1 ton of CO_2-equivalents per capita and year. The PBA method has a similar target at 1.15 tons CO_2-equivalent. Some of the sustainable lifestyles in (Doka 2016) – especially when food heavy – are not limited by the climate boundary, but by the biodiversity loss boundary. For these lifestyles the GHG emissions are 0.6 to 0.9 tons CO_2-eq, but the biodiversity loss is at 1 PBA_{BD}. So while the 1 ton CO_2 target might be fulfilled, boundaries not considered this approach could be overshot. Only optimising for Climate Change could lead to burden shifting onto other areas. While the 1 ton CO_2 target often has much better accordance with PBA results in identifying sustainable lifestyles than the ecological footprint or the 2000 Watt concept, this illustrates the advantage of a multi-boundary approach like employed in the PBA method.

The finding that the 2000 watt boundary is less severe than the 1 ton CO_2 boundary – at least with current technology – is also apparent from an evaluation of present Swiss individuals (Notter et al. 2013). From 3369 respondents, 64 persons (2%) were able to comply with the 2000 watt boundary already today, while *none* of the respondents were able to undershoot the 1 t CO_2eq target.

[35] Footprint boundaries based on a population of 10 billion were employed.

[36] Originally (Boulouchos et al. 2008) diminished the 2000 Watt target to be merely a "qualitative metaphor" for the "reduced demand for primary energy" and gave overriding importance to adhere to the 1 ton CO_2eq target. Currently (2016) the ETH/novatlantis maintains that both targets are to be understood as quantitative targets, not metaphors (*"Die Vision der 2000-Watt-Gesellschaft sieht eine kontinuierliche Absenkung des Energiebedarfs auf 2000 Watt vor. Dieses Ziel soll so rasch wie möglich erreicht werden.... Ein CO_2-Ausstoss von einer Tonne pro Kopf der Bevölkerung und Jahr gilt auch für die Schweiz als langfristiges Ziel."* http://www.novatlantis.ch/wissenstransfer/2000-watt-gesellschaft/ (19 Apr 2016))

2.2 Outlook

As some of the planetary boundaries are as yet unquantified, tentative, or not yet amenable to operationalisation in the PBA method, in the future additions and extensions to the PBA method are likely and desirable.

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4 Annex: characterisation factors for PBA'06 and ecoinvent v3 exchanges

The following table lists the exchanges in ecoinvent v3 and the corresponding characterisation factors for 8 boundaries of the PBA'06 method. Exchanges with no characterisation factors have been removed from the table.

To save space, abbreviations in the subcategories are:

Category	Abbreviation	Full subcategory name
(several)	unspec.	unspecified
Air	urban rural rural LT upper troppo	urban air close to ground non-urban air or from high stacks low population density, long-term lower stratosphere + upper troposphere
Soil	agri indus	agricultural industrial
Water	surf. ground LT	surface water ground-, long-term

The table is available as Excel workbook at http://www.doka.ch/DokaCFPBA06.xlsx .

Tab. 4.1 Characterisation factors for PBA'06

name	category	subcategory	unit	CAS No	Climate change PBA(CC)	Biodiversity loss PBA(BD)	Nitrogen flow PBA(N)	P in oceans PBA(P)	Non-forest land use PBA(LO)	Freshwater (blue water) PBA(FW)	Ozone depletion PBA(OD)	Aerosol Dimming PBA(PM)
Boundaries					1150.747986 kg CO2eq / cap.year	1.95E-05 species.yr/yr per capita	6.2 kg N emissions per cap.yr	1.1 kg P in ocean per capita.yr	8510 m2.year non-forest occupation per cap	400000 liter /yr per capita	0.040938788 kg ODPeq /yr per capita	2.22222E-12 AOD.yr per capita.yr
1-Pentanol	Air	urban	kg	000071-41-0		1.29991E-06						
2,4-D	Air	rural	kg	000094-75-7		0.000682608						
2-Methyl-1-propanol	Air	urban	kg	000078-83-1		1.14398E-06						
2-Propanol	Air	urban	kg	000067-63-0		1.29627E-07						
4-Methyl-2-pentanone	Air	urban	kg	000108-10-1		8.28698E-08						
Acenaphthene	Air	rural	kg	000083-32-9		2.26946E-06						
Acenaphthene	Air	unspec.	kg	000083-32-9		3.56889E-06						
Acenaphthene	Air	urban	kg	000083-32-9		3.56889E-06						
Acephate	Air	rural	kg	030560-19-1		0.000164849						
Acetaldehyde	Air	rural	kg	000075-07-0		3.3265E-06						
Acetaldehyde	Air	unspec.	kg	000075-07-0		4.33946E-06						
Acetaldehyde	Air	urban	kg	000075-07-0		4.33946E-06						
Acetamide	Air	rural	kg	000060-35-5		1.83507E-06						
Acetic acid	Air	rural	kg	000064-19-7		0.000366116						
Acetic acid	Air	unspec.	kg	000064-19-7		0.000417834						
Acetic acid	Air	urban	kg	000064-19-7		0.000417834						
Acetone	Air	rural	kg	000067-64-1		2.03497E-07						
Acetone	Air	unspec.	kg	000067-64-1		2.35835E-07						
Acetone	Air	urban	kg	000067-64-1		2.35835E-07						
Acetonitrile	Air	rural	kg	000075-05-8		2.49455E-06						
Acrolein	Air	rural	kg	000107-02-8		0.006960747						
Acrolein	Air	unspec.	kg	000107-02-8		0.008643515						
Acrolein	Air	urban	kg	000107-02-8		0.008643515						
Acrylic acid	Air	urban	kg	000079-10-7		0.000143102						
Alachlor	Air	rural	kg	015972-60-8		0.000863797						
Aldehydes, unspecified	Air	rural	kg	HC aldehydes		0.000221159						
Aldehydes, unspecified	Air	unspec.	kg	HC aldehydes		0.000221159						
Aldehydes, unspecified	Air	urban	kg	HC aldehydes		0.000285569						
Ammonia	Air	rural	kg	007664-41-7		0.000728718	0.132827324					0.035721395
Ammonia	Air	unspec.	kg	007664-41-7		0.000728718	0.132827324					0.035721395
Ammonia	Air	urban	kg	007664-41-7		0.000728718	0.132827324					0.035721395
Ammonium carbonate	Air	urban	kg	000506-87-6		0.010398492	0.016362786					
Aniline	Air	urban	kg	000062-53-3		0.000246203						
Antimony	Air	rural	kg	007440-36-0		0.015607864						
Antimony	Air	rural LT	kg	007440-36-0		0.015607864						
Antimony	Air	unspec.	kg	007440-36-0		0.020916762						
Antimony	Air	urban	kg	007440-36-0		0.020916762						
Arsenic	Air	rural	kg	007440-38-2		0.001042221						
Arsenic	Air	rural LT	kg	007440-38-2		0.001042221						
Arsenic	Air	unspec.	kg	007440-38-2		0.001264399						
Arsenic	Air	urban	kg	007440-38-2		0.001264399						
Atrazine	Air	rural	kg	001912-24-9		0.015398106						
Azoxystrobin	Air	rural	kg	131860-33-8		0.101346316						
Barium	Air	rural	kg	007440-39-3		0.002531658						
Barium	Air	rural LT	kg	007440-39-3		0.002531658						
Barium	Air	unspec.	kg	007440-39-3		0.003397367						
Barium	Air	urban	kg	007440-39-3		0.003397367						

Bentazone	Air	rural	kg	025057-89-0		0.000221428	
Benzaldehyde	Air	urban	kg	000100-52-7		1.38418E-05	
Benzene	Air	rural	kg	000071-43-2		7.24317E-07	
Benzene	Air	unspec.	kg	000071-43-2		7.45348E-07	
Benzene	Air	upper tropo	kg	000071-43-2		7.24317E-07	
Benzene	Air	urban	kg	000071-43-2		7.45348E-07	
Benzene, dichloro	Air	urban	kg	000095-50-1		4.03473E-05	
Benzene, ethyl-	Air	rural	kg	000100-41-4		1.45628E-07	
Benzene, ethyl-	Air	unspec.	kg	000100-41-4		1.67053E-07	
Benzene, ethyl-	Air	urban	kg	000100-41-4		1.67053E-07	
Benzene, hexachloro-	Air	unspec.	kg	000118-74-1		0.00854163	
Benzene, hexachloro-	Air	urban	kg	000118-74-1		0.00854163	
Benzene, pentachloro-	Air	urban	kg	000608-93-5		0.001441652	
Benzo(a)pyrene	Air	rural	kg	000050-32-8		0.000799005	
Benzo(a)pyrene	Air	unspec.	kg	000050-32-8		0.001450178	
Benzo(a)pyrene	Air	urban	kg	000050-32-8		0.001450178	
Beryllium	Air	rural	kg	007440-41-7		0.519202596	
Beryllium	Air	rural LT	kg	007440-41-7		0.519202596	
Beryllium	Air	unspec.	kg	007440-41-7		0.704277272	
Beryllium	Air	urban	kg	007440-41-7		0.704277272	
Bromine	Air	rural	kg	007726-95-6		0.005783845	
Bromine	Air	unspec.	kg	007726-95-6		0.005854993	
Bromine	Air	urban	kg	007726-95-6		0.005854993	
Butanol	Air	urban	kg	000071-36-3		1.23138E-06	
Cadmium	Air	rural	kg	007440-43-9		0.039506987	
Cadmium	Air	rural LT	kg	007440-43-9		0.039506987	
Cadmium	Air	unspec.	kg	007440-43-9		0.088047148	
Cadmium	Air	upper tropo	kg	007440-43-9		0.039506987	
Cadmium	Air	urban	kg	007440-43-9		0.088047148	
Carbaryl	Air	rural	kg	000063-25-2		0.001594812	
Carbon dioxide, fossil	Air	rural	kg	000124-38-9	0.000869	0.000406612	
Carbon dioxide, fossil	Air	unspec.	kg	000124-38-9	0.000869	0.000406612	
Carbon dioxide, fossil	Air	upper tropo	kg	000124-38-9	0.000869	0.000406612	
Carbon dioxide, fossil	Air	urban	kg	000124-38-9	0.000869	0.000406612	
Carbon dioxide, from soil or biomass stock	Air	rural	kg	000124-38-9	0.000869	0.000406612	
Carbon dioxide, from soil or biomass stock	Air	unspec.	kg	000124-38-9	0.000869	0.000406612	
Carbon disulfide	Air	rural	kg	000075-15-0		8.46391E-07	
Carbon disulfide	Air	unspec.	kg	000075-15-0		8.78416E-07	
Carbon disulfide	Air	urban	kg	000075-15-0		8.78416E-07	
Chloramine	Air	urban	kg	010599-90-3		0.510430333	
Chlorimuron-ethyl	Air	rural	kg	090982-32-4		0.0033427	
Chlorine	Air	rural	kg	007782-50-5		0.003446107	
Chlorine	Air	rural LT	kg	007782-50-5		0.003446107	
Chlorine	Air	unspec.	kg	007782-50-5		0.003447006	
Chlorine	Air	urban	kg	007782-50-5		0.003447006	
Chloroacetic acid	Air	urban	kg	000079-11-8		0.010000005	
Chloroform	Air	rural	kg	000067-66-3	0.026939	0.012616808	
Chloroform	Air	unspec.	kg	000067-66-3	0.026939	0.012616872	
Chloroform	Air	urban	kg	000067-66-3	0.026939	0.012616872	
Chlorosulfonic acid	Air	urban	kg	007790-94-5		0.002814093	
Chlorpyrifos	Air	rural	kg	002921-88-2		0.002181215	
Chromium	Air	rural	kg	007440-47-3		0.000438321	
Chromium	Air	unspec.	kg	007440-47-3		0.000562448	
Chromium	Air	upper tropo	kg	007440-47-3		0.000438321	
Chromium	Air	urban	kg	007440-47-3		0.000562448	
Chromium IV	Air	urban	kg	007440-47-3		0.000562448	
Cobalt	Air	rural	kg	007440-48-4		0.062975573	
Cobalt	Air	rural LT	kg	007440-48-4		0.062975573	
Cobalt	Air	unspec.	kg	007440-48-4		0.084734254	
Cobalt	Air	urban	kg	007440-48-4		0.084734254	
Copper	Air	rural	kg	007440-50-8		0.043845888	
Copper	Air	rural LT	kg	007440-50-8		0.043845888	
Copper	Air	unspec.	kg	007440-50-8		0.256982725	
Copper	Air	upper tropo	kg	007440-50-8		0.043845888	
Copper	Air	urban	kg	007440-50-8		0.256982725	
Cumene	Air	rural	kg	000098-82-8		1.69738E-07	
Cumene	Air	unspec.	kg	000098-82-8		1.91611E-07	
Cumene	Air	urban	kg	000098-82-8		1.91611E-07	
Cyanide	Air	rural	kg	000057-12-5		0.001437377	
Cyanide	Air	unspec.	kg	000057-12-5		0.001594081	
Cyanide	Air	urban	kg	000057-12-5		0.001594081	
Cyclohexane	Air	urban	kg	000110-82-7		1.56327E-07	
Cyclohexane (for all cycloalkanes)	Air	urban	kg	000110-82-7		1.56327E-07	
Cyfluthrin	Air	rural	kg	068359-37-5		0.062066547	
Dicamba	Air	rural	kg	001918-00-9		0.00055975	
Diethyl ether	Air	urban	kg	000060-29-7		4.22028E-08	
Diethylamine	Air	urban	kg	000109-89-7		1.23985E-06	
Diethylene glycol	Air	urban	kg	000111-46-6		3.32525E-06	
Diflubenzuron	Air	rural	kg	035367-38-5		0.058331562	
Dimethylamine	Air	urban	kg	000124-40-3		6.98051E-06	
Dinitrogen monoxide	Air	rural	kg	010024-97-2	0.258962	0.121170284	0.415254116
Dinitrogen monoxide	Air	unspec.	kg	010024-97-2	0.258962	0.121170284	0.415254116
Dinitrogen monoxide	Air	upper tropo	kg	010024-97-2	0.258962	0.121170284	0.415254116
Dinitrogen monoxide	Air	urban	kg	010024-97-2	0.258962	0.121170284	0.415254116
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	rural	kg	001746-01-6		0.393801457	
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	unspec.	kg	001746-01-6		0.491081654	
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	urban	kg	001746-01-6		0.491081654	
Esfenvalerate	Air	rural	kg	066230-04-4		2.068245938	
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	rural	kg	000811-97-2	1.24267	0.58145472	
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	unspec.	kg	000811-97-2	1.24267	0.58145472	
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	urban	kg	000811-97-2	1.24267	0.58145472	
Ethane, 1,1,1-trichloro-, HCFC-140	Air	rural	kg	000071-55-6	0.126874	0.059379349	7.344668381
Ethane, 1,1,1-trichloro-, HCFC-140	Air	unspec.	kg	000071-55-6	0.126874	0.059379364	7.344668381
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	unspec.	kg	000076-13-1	5.32697	2.492529674	24.42671268
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	urban	kg	000076-13-1	5.32697	2.492529674	24.42671268
Ethane, 1,1-difluoro-, HFC-152a	Air	rural	kg	000075-37-6	0.107756	0.05041985	
Ethane, 1,1-difluoro-, HFC-152a	Air	urban	kg	000075-37-6	0.107756	0.05041985	
Ethane, 1,2-dichloro-	Air	rural	kg	000107-06-2		7.99432E-06	

Ethane, 1,2-dichloro-	Air	unspec.	kg	000107-06-2		8.08041E-06	
Ethane, 1,2-dichloro-	Air	urban	kg	000107-06-2		8.08041E-06	
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	rural	kg	000076-14-2	8.69	4.066116923	22.96110992
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Air	unspec.	kg	002837-89-0	0.529221	0.247626521	1.013153424
Ethane, hexafluoro-, HFC-116	Air	unspec.	kg	000076-16-4	10.6018	4.960662646	
Ethane, hexafluoro-, HFC-116	Air	urban	kg	000076-16-4	10.6018	4.960662646	
Ethanol	Air	rural	kg	000064-17-5		2.17515E-07	
Ethanol	Air	unspec.	kg	000064-17-5		2.87744E-07	
Ethanol	Air	urban	kg	000064-17-5		2.87744E-07	
Ethene, tetrachloro-	Air	rural	kg	000127-18-4		2.05309E-05	
Ethene, tetrachloro-	Air	unspec.	kg	000127-18-4		2.06229E-05	
Ethene, tetrachloro-	Air	urban	kg	000127-18-4		2.06229E-05	
Ethyl acetate	Air	urban	kg	000141-78-6		8.21598E-07	
Ethylamine	Air	urban	kg	000075-04-7		3.08225E-06	
Ethylene oxide	Air	rural	kg	000075-21-8		7.03486E-06	
Ethylene oxide	Air	unspec.	kg	000075-21-8		7.72468E-06	
Ethylene oxide	Air	upper tropo	kg	000075-21-8		7.03486E-06	
Ethylene oxide	Air	urban	kg	000075-21-8		7.72468E-06	
Fluazifop-p-butyl	Air	rural	kg	079241-46-6		0.000271886	
Fomesafen	Air	rural	kg	072178-02-0		0.00012717	
Formaldehyde	Air	rural	kg	000050-00-0		0.000305586	
Formaldehyde	Air	unspec.	kg	000050-00-0		0.000394573	
Formaldehyde	Air	upper tropo	kg	000050-00-0		0.000305586	
Formaldehyde	Air	urban	kg	000050-00-0		0.000394573	
Formic acid	Air	rural	kg	000064-18-6		5.39598E-05	
Formic acid	Air	urban	kg	000064-18-6		6.9241E-05	
Furan	Air	rural	kg	000110-00-9		2.48909E-08	
Furan	Air	unspec.	kg	000110-00-9		3.75374E-08	
Glyphosate	Air	rural	kg	001071-83-6		7.67057E-06	
Heptane	Air	urban	kg	000142-82-5		7.41777E-11	
Hexane	Air	rural	kg	000110-54-3		1.05497E-09	
Hexane	Air	unspec.	kg	000110-54-3		1.17292E-09	
Hexane	Air	urban	kg	000110-54-3		1.17292E-09	
Hydrocarbons, aliphatic, alkanes, cyclic	Air	rural	kg	HC alkanes cyclic		2.68013E-07	
Hydrocarbons, aliphatic, alkanes, cyclic	Air	urban	kg	HC alkanes cyclic		3.05962E-07	
Hydrocarbons, aliphatic, alkanes, unspecified	Air	rural	kg	HC alkanes	0.01933525	0.009047127	
Hydrocarbons, aliphatic, alkanes, unspecified	Air	unspec.	kg	HC alkanes	0.01933525	0.009047129	
Hydrocarbons, aliphatic, alkanes, unspecified	Air	urban	kg	HC alkanes	0.01933525	0.009047129	
Hydrocarbons, aliphatic, unsaturated	Air	rural	kg	HC aliphatic unsatuarted		1.07835E-08	
Hydrocarbons, aliphatic, unsaturated	Air	unspec.	kg	HC aliphatic unsatuarted		1.85992E-08	
Hydrocarbons, aliphatic, unsaturated	Air	urban	kg	HC aliphatic unsatuarted		1.85992E-08	
Hydrocarbons, aromatic	Air	rural	kg	HC aromatic		7.00579E-07	
Hydrocarbons, aromatic	Air	unspec.	kg	HC aromatic		7.21304E-07	
Hydrocarbons, aromatic	Air	urban	kg	HC aromatic		7.21304E-07	
Hydrocarbons, chlorinated	Air	rural	kg	HC chlorinated	0.0092114	0.004327208	2.79358E-06
Hydrocarbons, chlorinated	Air	unspec.	kg	HC chlorinated	0.0092114	0.004327337	2.79358E-06
Hydrocarbons, chlorinated	Air	urban	kg	HC chlorinated	0.0092114	0.004327337	2.79358E-06
Hydrocarbons, unspecified	Air	rural	kg	000110-54-3		4.40278E-05	
Hydrogen sulfide	Air	rural	kg	007783-06-4		0.000559879	
Hydrogen sulfide	Air	unspec.	kg	007783-06-4		0.000559879	
Hydrogen sulfide	Air	urban	kg	007783-06-4		0.000559879	
Imazaquin	Air	rural	kg	000083-32-9		2.26946E-06	
Imazethapyr	Air	rural	kg	081335-77-5		0.000113815	
Iodine	Air	rural	kg	007553-56-2		0.000844735	
Iodine	Air	unspec.	kg	007553-56-2		0.000878452	
Iodine	Air	urban	kg	007553-56-2		0.000878452	
Isoprene	Air	rural	kg	000078-79-5		5.44463E-10	
Isoprene	Air	unspec.	kg	000078-79-5		9.37382E-10	
Isopropylamine	Air	urban	kg	000075-31-0		6.18559E-07	
Lactofen	Air	rural	kg	077501-63-4		0.000266307	
Lead	Air	rural	kg	007439-92-1		6.69369E-05	
Lead	Air	rural LT	kg	007439-92-1		6.69369E-05	
Lead	Air	unspec.	kg	007439-92-1		0.000559144	
Lead	Air	upper tropo	kg	007439-92-1		6.69369E-05	
Lead	Air	urban	kg	007439-92-1		0.000559144	
Manganese	Air	rural	kg	007439-96-5		7.45872E-05	
Manganese	Air	rural LT	kg	007439-96-5		7.45872E-05	
Manganese	Air	unspec.	kg	007439-96-5		5.19403E-05	
Manganese	Air	urban	kg	007439-96-5		5.19403E-05	
Mercury	Air	rural	kg	007439-97-6		0.613784144	
Mercury	Air	rural LT	kg	007439-97-6		0.613784144	
Mercury	Air	unspec.	kg	007439-97-6		0.795503798	
Mercury	Air	upper tropo	kg	007439-97-6		0.613784144	
Mercury	Air	urban	kg	007439-97-6		0.795503798	
Methane	Air	urban	kg	000074-82-8	0.01933525	0.00904711	
Methane, bromo-, Halon 1001	Air	unspec.	kg	000074-83-9	0.004345	0.002258095	24.89304083
Methane, bromochlorodifluoro-, Halon 1211	Air	rural	kg	000353-59-3	1.64241	0.768496098	219.8404141
Methane, bromotrifluoro-, Halon 1301	Air	rural	kg	000075-63-8	6.20466	2.903207483	439.6808283
Methane, bromotrifluoro-, Halon 1301	Air	urban	kg	000075-63-8	6.20466	2.903207483	439.6808283
Methane, chlorodifluoro-, HCFC-22	Air	rural	kg	000075-45-6	1.57289	0.735967163	2.525944152
Methane, chlorodifluoro-, HCFC-22	Air	urban	kg	000075-45-6	1.57289	0.735967163	2.525944152
Methane, dichloro-, HCC-30	Air	rural	kg	000075-09-2	0.0075603	0.003539057	
Methane, dichloro-, HCC-30	Air	urban	kg	000075-09-2	0.0075603	0.003539072	
Methane,	Air	rural	kg	000075-71-8	9.4721	4.432067446	24.42671268

dichlorodifluoro-, CFC-12												
Methane, dichlorodifluoro-, CFC-12	Air	unspec.	kg	000075-71-8	9.4721	4.432067446					24.42671268	
Methane, dichlorodifluoro-, CFC-12	Air	urban	kg	000075-71-8	9.4721	4.432067446					24.42671268	
Methane, dichlorofluoro-, HCFC-21	Air	urban	kg	000075-43-4	0.131219	0.061398366						
Methane, fossil	Air	rural	kg	000074-82-8	0.01933525	0.00904711						
Methane, fossil	Air	unspec.	kg	000074-82-8	0.01933525	0.00904711						
Methane, fossil	Air	upper tropo	kg	000074-82-8	0.01933525	0.00904711						
Methane, fossil	Air	urban	kg	000074-82-8	0.01933525	0.00904711						
Methane, from soil or biomass stock	Air	rural	kg	000074-82-8	0.01933525	0.00904711						
Methane, monochloro-, R-40	Air	rural	kg	000074-87-3	0.011297	0.005287573					1.013153424	
Methane, non-fossil	Air	rural	kg	000074-82-8	0.01933525	0.00904711						
Methane, non-fossil	Air	unspec.	kg	000074-82-8	0.01933525	0.00904711						
Methane, non-fossil	Air	urban	kg	000074-82-8	0.01933525	0.00904711						
Methane, tetrachloro-, R-10	Air	unspec.	kg	000056-23-5	1.2166	0.569369636					33.43406298	
Methane, tetrachloro-, R-10	Air	urban	kg	000056-23-5	1.2166	0.569369636					33.43406298	
Methane, tetrafluoro-, R-14	Air	unspec.	kg	000075-73-0	6.42191	3.004860406						
Methane, tetrafluoro-, R-14	Air	urban	kg	000075-73-0	6.42191	3.004860406						
Methane, trichlorofluoro-, CFC-11	Air	urban	kg	000075-69-4	4.12775	1.931405538					24.42671268	
Methane, trifluoro-, HFC-23	Air	urban	kg	000075-46-7	12.8612	6.017853046						
Methanol	Air	rural	kg	000067-56-1		8.49255E-07						
Methanol	Air	unspec.	kg	000067-56-1		1.07717E-06						
Methanol	Air	urban	kg	000067-56-1		1.07717E-06						
Methyl acetate	Air	urban	kg	000079-20-9		4.80212E-06						
Methyl acrylate	Air	urban	kg	000096-33-3		8.24604E-06						
Methyl ethyl ketone	Air	urban	kg	000078-93-3		3.4733E-07						
Methyl lactate	Air	urban	kg	000547-64-8		9.43075E-05						
Methyl parathion	Air	rural	kg	000298-00-0		0.000832269						
Metolachlor	Air	rural	kg	051218-45-2		0.009455862						
Metribuzin	Air	rural	kg	021087-64-9		2.89573E-07						
Molybdenum	Air	rural	kg	007439-98-7		0.000145177						
Molybdenum	Air	rural LT	kg	007439-98-7		0.000145177						
Molybdenum	Air	unspec.	kg	007439-98-7		0.000188199						
Molybdenum	Air	urban	kg	007439-98-7		0.000188199						
Monoethanolamine	Air	urban	kg	000141-43-5		0.000111724						
m-Xylene	Air	unspec.	kg	000108-38-3		9.87869E-08						
m-Xylene	Air	urban	kg	000108-38-3		9.87869E-08						
Nickel	Air	rural	kg	007440-02-0		0.020701789						
Nickel	Air	rural LT	kg	007440-02-0		0.020701789						
Nickel	Air	unspec.	kg	007440-02-0		0.040635613						
Nickel	Air	upper tropo	kg	007440-02-0		0.020701789						
Nickel	Air	urban	kg	007440-02-0		0.040635613						
Nitrate	Air	rural LT	kg	014797-55-8			0.036420395					
Nitrate	Air	rural LT	kg	014797-55-8			0.036420395					
Nitrate	Air	urban	kg	014797-55-8			0.036420395					
Nitrobenzene	Air	urban	kg	000098-95-3		9.85191E-05						
Nitrogen	Air	unspec.	kg	007727-37-9			0.161290323					
Nitrogen fluoride	Air	urban	kg	007783-54-2	14.9468	6.993721108						
Nitrogen oxides	Air	rural	kg	011104-93-1		0.000166564	0.049088359					0.049116918
Nitrogen oxides	Air	unspec.	kg	011104-93-1		0.000166564	0.049088359					0.049116918
Nitrogen oxides	Air	upper tropo	kg	011104-93-1		0.000166564	0.049088359					0.049116918
Nitrogen oxides	Air	urban	kg	011104-93-1		0.000166564	0.049088359					0.049116918
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	rural	kg	HC NMVOC		4.92901E-05						0.001116294
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	unspec.	kg	HC NMVOC		4.92901E-05						0.001116294
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	upper tropo	kg	HC NMVOC		4.40278E-05						0.001116294
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	urban	kg	HC NMVOC		4.92901E-05						0.001116294
o-Nitrotoluene	Air	urban	kg	000088-72-2		8.17022E-05						
Organic carbon	Air	urban	kg	000110-54-3		1.17292E-09						
o-Xylene	Air	urban	kg	000095-47-6		2.27208E-07						
PAH, polycyclic aromatic hydrocarbons	Air	rural	kg	130498-29-2		0.000879641						
PAH, polycyclic aromatic hydrocarbons	Air	unspec.	kg	130498-29-2		0.001365565						
PAH, polycyclic aromatic hydrocarbons	Air	urban	kg	130498-29-2		0.001365565						
Paraquat	Air	rural	kg	004685-14-7		0.007263297						
Particulates, < 2.5 um	Air	rural	kg	SUM PM - 2.5um								0.095650096
Particulates, < 2.5 um	Air	rural LT	kg	SUM PM - 2.5um								0.095650096
Particulates, < 2.5 um	Air	unspec.	kg	SUM PM - 2.5um								0.095650096
Particulates, < 2.5 um	Air	upper tropo	kg	SUM PM - 2.5um								0.095650096
Particulates, < 2.5 um	Air	urban	kg	SUM PM - 2.5um								0.095650096
Particulates, > 2.5 um, and < 10um	Air	rural	kg	SUM PM 2.5-10um								0.05581468
Particulates, > 2.5 um, and < 10um	Air	rural LT	kg	SUM PM 2.5-10um								0.05581468
Particulates, > 2.5 um, and < 10um	Air	unspec.	kg	SUM PM 2.5-10um								0.05581468
Particulates, > 2.5 um, and < 10um	Air	urban	kg	SUM PM 2.5-10um								0.05581468
Pendimethalin	Air	rural	kg	040487-42-1		0.000916098						
Pentane	Air	rural	kg	000109-66-0		1.38598E-07						
Pentane	Air	unspec.	kg	000109-66-0		1.49631E-07						
Pentane	Air	urban	kg	000109-66-0		1.49631E-07						
Perfluoropentane	Air	unspec.	kg	000678-26-2	7.96004	3.724563102						
Permethrin	Air	rural	kg	052645-53-1		0.014553854						
Phenol	Air	rural	kg	000108-95-2		4.33448E-05						
Phenol	Air	unspec.	kg	000108-95-2		5.68893E-05						
Phenol	Air	urban	kg	000108-95-2		5.68893E-05						
Phenol, 2,4-dichloro	Air	urban	kg	000120-83-2		0.000317415						
Phenol, pentachloro-	Air	rural	kg	000087-86-5		0.000796253						
Phenol, pentachloro-	Air	unspec.	kg	000087-86-5		0.001258768						
Phenol, pentachloro-	Air	urban	kg	000087-86-5		0.001258768						

Phosphoric acid	Air	urban	kg	007664-38-2				0.153550006			
Phosphorus	Air	rural	kg	007723-14-0		0.022291845		0.485763762			
Phosphorus	Air	rural LT	kg	007723-14-0		0.022291845		0.485763762			
Phosphorus	Air	unspec.	kg	007723-14-0		0.02238266		0.485737896			
Phosphorus	Air	urban	kg	007723-14-0		0.02238266		0.485737896			
Phosphorus trichloride	Air	urban	kg	007719-12-2				0.109548468			
Polychlorinated biphenyls	Air	unspec.	kg	SUM PCB		5.05028E-05					
Polychlorinated biphenyls	Air	urban	kg	SUM PCB		5.05028E-05					
Propanal	Air	unspec.	kg	000123-38-6		1.4931E-06					
Propanal	Air	urban	kg	000123-38-6		1.4931E-06					
Propanol	Air	urban	kg	000071-23-8		1.08651E-06					
Propiconazole	Air	rural	kg	060207-90-1		0.003930968					
Propionic acid	Air	rural	kg	000079-09-4		0.000268297					
Propionic acid	Air	unspec.	kg	000079-09-4		0.000313498					
Propionic acid	Air	urban	kg	000079-09-4		0.000313498					
Propylamine	Air	urban	kg	000107-10-8		1.10442E-06					
Propylene oxide	Air	urban	kg	000075-56-9		1.01864E-05					
Quizalofop-ethyl	Air	rural	kg	000078-51-3		3.51331E-06					
Selenium	Air	rural	kg	007782-49-2		0.147107777					
Selenium	Air	rural LT	kg	007782-49-2		0.147107777					
Selenium	Air	unspec.	kg	007782-49-2		0.198132128					
Selenium	Air	upper tropo	kg	007782-49-2		0.147107777					
Selenium	Air	urban	kg	007782-49-2		0.198132128					
Sethoxydim	Air	rural	kg	074051-80-2		3.15081E-05					
Silver	Air	rural LT	kg	007440-22-4		3.760517643					
Silver	Air	rural LT	kg	007440-22-4		3.760517643					
Silver	Air	unspec.	kg	007440-22-4		5.04455563					
Silver	Air	urban	kg	007440-22-4		5.04455563					
Sodium formate	Air	urban	kg	000141-53-7		6.27779E-05					
Styrene	Air	rural	kg	000100-42-5		5.95065E-08					
Styrene	Air	unspec.	kg	000100-42-5		8.88553E-08					
Styrene	Air	urban	kg	000100-42-5		8.88553E-08					
Sulfur dioxide	Air	rural	kg	007446-09-5		0.000297436					0.030139927
Sulfur dioxide	Air	unspec.	kg	007446-09-5		0.000297436					0.030139927
Sulfur dioxide	Air	upper tropo	kg	007446-09-5		0.000297436					0.030139927
Sulfur dioxide	Air	urban	kg	007446-09-5		0.000297436					0.030139927
Sulfur hexafluoride	Air	rural	kg	002551-62-4	19.8132	9.270746585					
Sulfur hexafluoride	Air	unspec.	kg	002551-62-4	19.8132	9.270746585					
Sulfur hexafluoride	Air	urban	kg	002551-62-4	19.8132	9.270746585					
Sulfur oxides	Air	unspec.	kg	007446-09-5		0.000297436					0.030139927
Sulfuric acid	Air	rural	kg	007664-93-9							0.019683218
Sulfuric acid	Air	unspec.	kg	007664-93-9							0.019683218
Sulfuric acid	Air	urban	kg	007664-93-9							0.019683218
Sulphur dioxide	Air	urban	kg	007446-09-5		0.000297436					0.030139927
Sulphur trioxide	Air	urban	kg	007446-11-9		0.000297436					0.024111942
t-Butyl methyl ether	Air	urban	kg	001634-04-4		2.40158E-07					
t-Butylamine	Air	urban	kg	000075-64-9		2.29379E-05					
Tetramethyl ammonium hydroxide	Air	urban	kg	000075-59-2			0.0237691				
Thallium	Air	rural	kg	007440-28-0		0.014030503					
Thallium	Air	unspec.	kg	007440-28-0		0.01858013					
Thallium	Air	urban	kg	007440-28-0		0.01858013					
Tin	Air	rural	kg	007440-31-5		0.001074012					
Tin	Air	rural LT	kg	007440-31-5		0.001074012					
Tin	Air	unspec.	kg	007440-31-5		0.001413603					
Tin	Air	urban	kg	007440-31-5		0.001413603					
Toluene	Air	rural	kg	000108-88-3		9.39087E-08					
Toluene	Air	unspec.	kg	000108-88-3		1.05648E-07					
Toluene	Air	urban	kg	000108-88-3		1.05648E-07					
Toluene, 2-chloro	Air	urban	kg	000095-49-8		1.12349E-06					
Trifluralin	Air	rural	kg	001582-09-8		7.49922E-06					
Vanadium	Air	rural	kg	007440-62-2		0.036805203					
Vanadium	Air	rural LT	kg	007440-62-2		0.036805203					
Vanadium	Air	unspec.	kg	007440-62-2		0.048973227					
Vanadium	Air	urban	kg	007440-62-2		0.048973227					
Water	Air	rural	m3	007732-18-5						0.0025	
Water	Air	unspec.	m3	007732-18-5						0.0025	
Water	Air	upper tropo	m3	007732-18-5						0.0025	
Water	Air	urban	m3	007732-18-5						0.0025	
Xylene	Air	rural	kg	001330-20-7		5.35384E-08					
Xylene	Air	unspec.	kg	001330-20-7		6.61265E-08					
Xylene	Air	urban	kg	001330-20-7		6.61265E-08					
Zinc	Air	rural	kg	007440-66-6		0.010398466					
Zinc	Air	rural LT	kg	007440-66-6		0.010398466					
Zinc	Air	unspec.	kg	007440-66-6		0.027659908					
Zinc	Air	upper tropo	kg	007440-66-6		0.010398466					
Zinc	Air	urban	kg	007440-66-6		0.027659908					
Occupation, annual crop	natural resource	land	m2*year	OCC CORINE 21		0.000865392			0.000117509		
Occupation, annual crop, greenhouse	natural resource	land	m2*year	OCC CORINE 21		0.000904122			0.000117509		
Occupation, annual crop, irrigated	natural resource	land	m2*year	OCC CORINE 21		0.000904122			0.000117509		
Occupation, annual crop, irrigated, intensive	natural resource	land	m2*year	OCC CORINE 21		0.000904122			0.000117509		
Occupation, annual crop, non-irrigated	natural resource	land	m2*year	OCC CORINE 211		0.000865392			0.000117509		
Occupation, annual crop, non-irrigated, extensive	natural resource	land	m2*year	OCC CORINE 211b		0.000905584			0.000117509		
Occupation, annual crop, non-irrigated, intensive	natural resource	land	m2*year	OCC CORINE 211a		0.000904122			0.000117509		
Occupation, construction site	natural resource	land	m2*year	OCC CORINE 133		0.000819623			0.000117509		
Occupation, dump site	natural resource	land	m2*year	OCC CORINE 132		0.000802943			0.000117509		
Occupation, forest, extensive	natural resource	land	m2*year	OCC CORINE 31a		0.000109162					
Occupation, forest, intensive	natural resource	land	m2*year	OCC CORINE 31b		0.000199498					
Occupation, industrial area	natural resource	land	m2*year	OCC CORINE 121		0.000819623			0.000117509		
Occupation, lake, artificial	natural resource	land	m2*year	OCC CORINE 512a		0.000873454			0.000117509		
Occupation, mineral extraction site	natural resource	land	m2*year	OCC CORINE 131		0.00085829			0.000117509		
Occupation, pasture, man made	natural resourc	land	m2*year	OCC CORINE 231		0.000412514			0.000117509		

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Occupation, pasture, man made, extensive	natural resource	land	m2*year	OCC CORINE 231b	0.00063071	0.000117509
Occupation, pasture, man made, intensive	natural resource	land	m2*year	OCC CORINE 231a	0.000638597	0.000117509
Occupation, permanent crop	natural resource	land	m2*year	OCC CORINE 22	-0.000149801	0.000117509
Occupation, permanent crop, irrigated, intensive	natural resource	land	m2*year	OCC CORINE 222a	-5.34428E-05	0.000117509
Occupation, permanent crop, non-irrigated, intensive	natural resource	land	m2*year	OCC CORINE 221a	0.000884392	0.000117509
Occupation, river, artificial	natural resource	land	m2*year	OCC CORINE 511a	0.000873454	0.000117509
Occupation, seabed, drilling and mining	natural resource	land	m2*year	OCC CORINE 132a	0.001062352	
Occupation, seabed, infrastructure	natural resource	land	m2*year	OCC CORINE 121c	0.001062352	
Occupation, shrub land, sclerophyllous	natural resource	land	m2*year	OCC CORINE 323	-0.000276272	0.000117509
Occupation, traffic area, rail network	natural resource	land	m2*year	OCC CORINE 122c	0.00079612	0.000117509
Occupation, traffic area, rail/road embankment	natural resource	land	m2*year	OCC CORINE 122b	0.000881794	0.000117509
Occupation, traffic area, road network	natural resource	land	m2*year	OCC CORINE 122a	0.00079612	0.000117509
Occupation, urban, discontinuously built	natural resource	land	m2*year	OCC CORINE 112	0.00085829	0.000117509
Transformation, from forest, extensive	natural resource	land	m2	FROM CORINE 31a	0.098646986	
Transformation, from forest, intensive	natural resource	land	m2	FROM CORINE 31b	0.098646986	
Transformation, from forest, primary (non-use)	natural resource	land	m2	FROM CORINE primary forest	3.255350554	
Transformation, from forest, secondary (non-use)	natural resource	land	m2	FROM CORINE 31	0.098646986	
Transformation, from forest, unspecified	natural resource	land	m2	FROM CORINE 31	0.098646986	
Transformation, from unspecified	natural resource	land	m2	FROM CORINE x	0.038699972	
Transformation, to forest, extensive	natural resource	land	m2	TO CORINE 31a	-0.098646986	
Transformation, to forest, intensive	natural resource	land	m2	TO CORINE 31b	-0.098646986	
Transformation, to forest, unspecified	natural resource	land	m2	TO CORINE 31	-0.098646986	
Transformation, to unspecified	natural resource	land	m2	TO CORINE x	-0.038699972	
2,4-D	Soil	agri	kg	000094-75-7	0.005147773	
Acephate	Soil	agri	kg	030560-19-1	0.001557574	
Acetamide	Soil	agri	kg	000060-35-5	6.57261E-06	
Aclonifen	Soil	agri	kg	074070-46-5	0.008403906	
Alachlor	Soil	agri	kg	015972-60-8	0.007489816	
Aldicarb	Soil	agri	kg	000116-06-3	1.816057131	
Aldrin	Soil	agri	kg	000309-00-2	0.926163523	
Alpha-cypermethrin	Soil	agri	kg	000067-45-8	2.102451621	
Ametryn	Soil	agri	kg	000834-12-8	0.153583856	
Amidosulfuron	Soil	agri	kg	120923-37-7	0.007437123	
Amitraz	Soil	agri	kg	033125-97-2	0.026326463	
Anthraquinone	Soil	agri	kg	000084-65-1	0.003383662	
Antimony	Soil	agri	kg	007440-36-0	0.02953797	
Antimony	Soil	unspec.	kg	007440-36-0	0.02953797	
Arsenic	Soil	agri	kg	007440-38-2	0.001589168	
Arsenic	Soil	industrial	kg	007440-38-2	0.001763761	
Arsenic	Soil	unspec.	kg	007440-38-2	0.001589168	
Asulam	Soil	agri	kg	003337-71-1	0.000289499	
Atrazine	Soil	agri	kg	001912-24-9	0.269813774	
Azinphos-methyl	Soil	agri	kg	000086-50-0	0.358411539	
Azoxystrobin	Soil	agri	kg	131860-33-8	0.278338673	
Barium	Soil	agri	kg	007440-39-3	0.004798498	
Barium	Soil	indus	kg	007440-39-3	0.005343004	
Barium	Soil	unspec.	kg	007440-39-3	0.004798498	
Benfluralin	Soil	agri	kg	001861-40-1	0.000174069	
Benomyl	Soil	agri	kg	017804-35-2	0.00089349	
Bentazone	Soil	agri	kg	025057-89-0	0.003569592	
Bifenox	Soil	agri	kg	042576-02-3	0.001225783	
Bifenthrin	Soil	agri	kg	082657-04-3	0.305189725	
Bitertanol	Soil	agri	kg	055179-31-2	0.001535978	
Bromacil	Soil	agri	kg	031934-88-0	0.029957299	
Bromine	Soil	unspec.	kg	007726-95-6	0.527109725	
Bromoxynil	Soil	agri	kg	001689-84-5	0.028572115	
Bromuconazole	Soil	agri	kg	116255-48-2	0.06636172	
Cadmium	Soil	agri	kg	007440-43-9	0.042403118	
Cadmium	Soil	indus	kg	007440-43-9	0.140166517	
Cadmium	Soil	unspec.	kg	007440-43-9	0.042403118	
Captan	Soil	agri	kg	000133-06-2	0.001424011	
Carbaryl	Soil	agri	kg	000063-25-2	0.016635927	
Carbendazim	Soil	agri	kg	010605-21-7	0.088438055	
Carbetamide	Soil	agri	kg	016118-49-3	0.004783913	
Carbofuran	Soil	agri	kg	001563-66-2	0.388691824	
Chlorfenvinphos	Soil	agri	kg	000479-27-6	0.010798305	
Chloridazon	Soil	agri	kg	001698-60-8	0.003726807	
Chlorimuron-ethyl	Soil	agri	kg	090982-32-4	0.009054775	
Chlorothalonil	Soil	agri	kg	001897-45-6	0.023278782	
Chlorotoluron	Soil	agri	kg	015545-48-9	0.009845673	
Chlorpyrifos	Soil	agri	kg	002921-88-2	0.136000734	
Chlorsulfuron	Soil	agri	kg	064902-72-3	0.061333578	
Chromium	Soil	agri	kg	007440-47-3	0.000758947	
Chromium	Soil	indus	kg	007440-47-3	0.000841419	
Chromium	Soil	unspec.	kg	007440-47-3	0.000758947	
Clodinafop-propargyl	Soil	agri	kg	105512-06-9	0.009266722	
Clomazone	Soil	agri	kg	081777-89-1	0.015861789	
Clopyralid	Soil	agri	kg	001702-17-6	0.01429647	
Cloquintocet-mexyl	Soil	agri	kg	099607-70-2	7.0852E-05	
Cobalt	Soil	agri	kg	007440-48-4	0.12011035	

Cobalt	Soil	indus	kg	007440-48-4	0.133634918	
Cobalt	Soil	unspec.	kg	007440-48-4	0.12011035	
Copper	Soil	agri	kg	007440-50-8	0.046544064	
Copper	Soil	indus	kg	007440-50-8	0.131907258	
Copper	Soil	unspec.	kg	007440-50-8	0.046544064	
Cycloxydim	Soil	agri	kg	101205-02-1	5.39064E-05	
Cyfluthrin	Soil	agri	kg	068359-37-5	0.127076888	
Cymoxanil	Soil	agri	kg	057966-95-7	9.95603E-05	
Cypermethrin	Soil	agri	kg	052315-07-8	86.95336816	
Cyproconazole	Soil	agri	kg	094361-06-5	0.004955263	
Deltamethrin	Soil	agri	kg	052918-63-5	0.007971028	
Diazinon	Soil	agri	kg	000333-41-5	0.127778928	
Dicamba	Soil	agri	kg	001918-00-9	0.001860161	
Dichlorprop-P	Soil	agri	kg	015165-67-0	6.54631E-05	
Diclofop-methyl	Soil	agri	kg	051338-27-3	0.002716761	
Dicrotophos	Soil	agri	kg	000141-66-2	0.21842547	
Difenoconazole	Soil	agri	kg	119446-68-3	0.007882028	
Diflubenzuron	Soil	agri	kg	035367-38-5	0.161551303	
Diflufenican	Soil	agri	kg	083164-33-4	2.00945E-05	
Dimethachlor	Soil	agri	kg	050563-36-5	0.030925749	
Dimethenamid	Soil	agri	kg	087674-68-8	0.039037447	
Dimethoate	Soil	agri	kg	000060-51-5	0.088396873	
Dimethomorph	Soil	agri	kg	110488-70-5	0.003987705	
Diquat dibromide	Soil	agri	kg	000086-53-3	0.004484629	
Dithianon	Soil	agri	kg	003347-22-6	0.099484962	
Diuron	Soil	agri	kg	000330-54-1	0.226119008	
Endosulfan	Soil	agri	kg	000115-29-7	0.010016898	
Endothall	Soil	agri	kg	000145-73-3	0.002528718	
Epoxiconazole	Soil	agri	kg	106325-08-0	0.026473889	
EPTC	Soil	agri	kg	000759-94-4	0.002612119	
Esfenvalerate	Soil	agri	kg	066230-04-4	4.727795562	
Ethephon	Soil	agri	kg	016672-87-0	0.003978012	
Ethofumesate	Soil	agri	kg	026225-79-6	0.003287099	
Ethoprop	Soil	agri	kg	013194-48-4	0.495007313	
Fenamiphos	Soil	agri	kg	022224-92-6	0.336941221	
Fenbuconazole	Soil	agri	kg	114369-43-6	0.028886395	
Fenoxaprop-P ethyl ester	Soil	agri	kg	071283-80-2	0.002286087	
Fenoxycarb	Soil	agri	kg	074070-46-5	0.008403906	
Fenpiclonil	Soil	agri	kg	074738-17-3	0.014663471	
Fenpropimorph	Soil	agri	kg	067306-03-0	0.000812844	
Fentin hydroxide	Soil	agri	kg	000076-87-9	0.219608062	
Fipronil	Soil	agri	kg	120068-37-3	0.598288017	
Fluazifop-P-butyl	Soil	agri	kg	079241-46-6	0.001358241	
Fluroxypyr	Soil	agri	kg	069377-81-7	0.011843436	
Flutolanil	Soil	agri	kg	066332-96-5	0.000937867	
Folpet	Soil	agri	kg	000135-88-6	0.00686031	
Fomesafen	Soil	agri	kg	072178-02-0	0.000376437	
Fosetyl-aluminium	Soil	agri	kg	039148-24-8	0.015504067	
Fungicides, unspecified	Soil	agri	kg	PEST fungicides unspec	0.060043536	
Glufosinate ammonium	Soil	agri	kg	077182-82-2	0.049434673	
Glyphosate	Soil	agri	kg	001071-83-6	8.26255E-05	
Glyphosate	Soil	indus	kg	001071-83-6	8.19819E-05	
Haloxyfop- (R) Methylester	Soil	agri	kg	072619-32-0	0.006131728	
Hexazinone	Soil	agri	kg	005221-49-8	0.002319226	
Hydramethylnon	Soil	agri	kg	006923-22-4	0.134015793	
Imazapyr	Soil	agri	kg	081334-34-1	0.2586408	
Imazaquin	Soil	agri	kg	000083-32-9	0.002770136	
Imazethapyr	Soil	agri	kg	081335-77-5	0.000303982	
Ioxynil	Soil	agri	kg	001689-83-4	0.012642317	
Iprodion	Soil	agri	kg	036734-19-7	0.001743582	
Isoproturon	Soil	agri	kg	034123-59-6	0.203904885	
Isoxaflutole	Soil	agri	kg	141112-29-0	0.890547162	
Kresoxim-methyl	Soil	agri	kg	143390-89-0	0.481603384	
Lactofen	Soil	agri	kg	077501-63-4	0.000654399	
Lambda-cyhalothrin	Soil	agri	kg	091465-08-6	0.091876826	
Lead	Soil	agri	kg	007439-92-1	4.51836E-05	
Lead	Soil	indus	kg	007439-92-1	0.000154658	
Lead	Soil	unspec.	kg	007439-92-1	4.51836E-05	
Lenacil	Soil	agri	kg	002275-23-2	0.001918191	
Linuron	Soil	agri	kg	000330-55-2	0.143932733	
Malathion	Soil	agri	kg	000121-75-5	0.00644563	
Maleic hydrazide	Soil	agri	kg	000123-33-1	0.006162599	
Mancozeb	Soil	agri	kg	008018-01-7	0.000364593	
Maneb	Soil	agri	kg	012427-38-2	0.012788683	
Manganese	Soil	agri	kg	007439-96-5	9.55678E-07	
Manganese	Soil	indus	kg	007439-96-5	1.05423E-06	
Manganese	Soil	unspec.	kg	007439-96-5	9.55678E-07	
MCPA	Soil	agri	kg	000094-74-6	0.001082657	
MCPB	Soil	agri	kg	000094-81-5	0.000659567	
Mecoprop-P	Soil	agri	kg	016484-77-8	7.58875E-05	
Mepiquat chloride	Soil	agri	kg	024307-26-4	0.004557676	
Mercury	Soil	agri	kg	007439-97-6	2.10994542	
Mercury	Soil	indus	kg	007439-97-6	2.337742444	
Metalaxil	Soil	agri	kg	057837-19-1	0.017444177	
Metamitron	Soil	agri	kg	041394-05-2	0.001732267	
Metam-sodium	Soil	agri	kg	000137-42-8	1.898507758	
Metazachlor	Soil	agri	kg	067129-08-2	0.011057755	
Methoxyfenozide	Soil	agri	kg	161050-58-4	0.025500387	
Methyl parathion	Soil	agri	kg	000298-00-0	0.013251404	
Metiram	Soil	agri	kg	009006-42-2	0.522188954	
Metolachlor	Soil	agri	kg	051218-45-2	0.116637018	
Metribuzin	Soil	agri	kg	021087-64-9	0.040230084	
Metsulfuron-methyl	Soil	agri	kg	074223-64-6	4.152735587	
Mineral oil	Soil	agri	kg	HC oils fossil	6.04656E-05	
Molinate	Soil	agri	kg	002212-67-1	0.000674177	
Molybdenum	Soil	agri	kg	007439-98-7	0.000256122	
Molybdenum	Soil	unspec.	kg	007439-98-7	0.000256122	
Monocrotophos	Soil	agri	kg	006923-22-4	0.134015793	
MSMA	Soil	agri	kg	002163-80-6	0.007713828	
Napropamide	Soil	agri	kg	015299-99-7	0.006647152	
Nickel	Soil	agri	kg	007440-02-0	0.014561378	
Nickel	Soil	indus	kg	007440-02-0	0.082640889	
Nickel	Soil	unspec.	kg	007440-02-0	0.014561378	
Nicosulfuron	Soil	agri	kg	111991-09-4	0.011567108	
Nitrate	Soil	unspec.	kg	007727-37-9		0.036420395
Nitrogen	Soil	indus	kg	007727-37-9		0.161290323
Oils, unspecified	Soil	agri	kg	HC oils unspec	6.04656E-05	
Oils, unspecified	Soil	forestry	kg	HC oils unspec	6.064E-05	
Oils, unspecified	Soil	indus	kg	HC oils unspec	6.02525E-05	
Oils, unspecified	Soil	unspec.	kg	HC oils unspec	6.02525E-05	
Orbencarb	Soil	agri	kg	034622-58-7	0.00359547	
Oryzalin	Soil	agri	kg	019044-88-3	0.01334226	
Oxamyl	Soil	agri	kg	023135-22-0	0.058224597	
Oxydemeton-methyl	Soil	agri	kg	000301-12-2	0.024984335	
Oxyfluorfen	Soil	agri	kg	042874-03-3	0.003543905	
PAH, polycyclic aromatic hydrocarbons	Soil	unspec.	kg	130498-29-2	0.005750206	
Paraquat	Soil	agri	kg	004685-14-7	0.047073549	
Parathion	Soil	agri	kg	000056-38-2	0.023294895	
Pendimethalin	Soil	agri	kg	040487-42-1	0.008654139	
Permethrin	Soil	agri	kg	052645-53-1	0.034883947	
Pesticides, unspecified	Soil	agri	kg	PEST unspec	0.171478304	

Phenmedipham	Soil	agri	kg	013684-63-4	3.41689E-05		
Phorate	Soil	agri	kg	000298-02-2	0.036932097		
Phosmet	Soil	agri	kg	000732-11-6	0.049762906		
Phosphorus	Soil	agri	kg	007723-14-0	1.034143647		0.306085791
Phosphorus	Soil	indus	kg	007723-14-0	1.021609374		0.308086167
Picloram	Soil	agri	kg	001918-02-1	0.022108504		
Piperonyl butoxide	Soil	agri	kg	000051-03-6	0.000600941		
Pirimicarb	Soil	agri	kg	023103-98-2	0.004871073		
Prochloraz	Soil	agri	kg	067747-09-5	0.007861249		
Procymidone	Soil	agri	kg	032809-16-8	0.000798559		
Profenofos	Soil	agri	kg	041198-08-7	0.068569167		
Prometryn	Soil	agri	kg	007287-19-6	0.023390993		
Pronamide	Soil	agri	kg	023950-58-5	0.003655266		
Propachlor	Soil	agri	kg	002032-59-9	0.126276532		
Propamocarb HCl	Soil	agri	kg	025606-41-1	0.002881676		
Propanil	Soil	agri	kg	000709-98-8	0.004301156		
Propargite	Soil	agri	kg	002312-35-8	0.004401864		
Propiconazole	Soil	agri	kg	060207-90-1	0.015414024		
Pyrethrin	Soil	agri	kg	008003-34-7	0.003574559		
Quizalofop ethyl ester	Soil	agri	kg	076578-14-8	0.002549129		
Quizalofop-p-ethyl	Soil	agri	kg	000103-05-9	0.000361045		
Rimsulfuron	Soil	agri	kg	122931-48-0	0.046543042		
Rotenone	Soil	agri	kg	000087-62-7	0.001191213		
Selenium	Soil	agri	kg	007782-49-2	0.280853033		
Selenium	Soil	unspec.	kg	007782-49-2	0.280853033		
Sethoxydim	Soil	agri	kg	074051-80-2	0.00027323		
Silver	Soil	agri	kg	007440-22-4	7.147191375		
Silver	Soil	unspec.	kg	007440-22-4	7.147191375		
Simazine	Soil	agri	kg	000122-34-9	0.079846845		
TCMTB	Soil	agri	kg	021564-17-0	0.88384867		
Teflubenzuron	Soil	agri	kg	083121-18-0	0.036150746		
Terbacil	Soil	agri	kg	000060-34-4	0.205998129		
Terbufos	Soil	agri	kg	013071-79-9	0.835452236		
Thidiazuron	Soil	agri	kg	051707-55-2	0.04144103		
Thiobencarb	Soil	agri	kg	028249-77-6	0.011543611		
Thiram	Soil	agri	kg	000137-26-8	0.134266367		
Tin	Soil	agri	kg	007440-31-5	0.00196345		
Tolylfluanid	Soil	agri	kg	000075-47-8	0.005460195		
Triadimenol	Soil	agri	kg	055219-65-3	0.004315738		
Tri-allate	Soil	agri	kg	002303-17-5	0.003319628		
Triasulfuron	Soil	agri	kg	082097-50-5	0.026225395		
Tribenuron-methyl	Soil	agri	kg	101200-48-0	0.008499738		
Tribufos	Soil	agri	kg	000078-48-8	0.000913886		
Trichlorfon	Soil	agri	kg	000052-68-6	0.030383882		
Triclopyr	Soil	agri	kg	055335-06-3	0.01128101		
Trifluralin	Soil	agri	kg	001582-09-8	0.004772884		
Triforine	Soil	agri	kg	002870-32-8	0.000295242		
Trinexapac-ethyl	Soil	agri	kg	095266-40-3	0.003583432		
Vanadium	Soil	agri	kg	007440-62-2	0.068705107		
Vanadium	Soil	unspec.	kg	007440-62-2	0.068705107		
Vinclozolin	Soil	agri	kg	050471-44-8	0.003734259		
Zinc	Soil	agri	kg	007440-66-6	0.008800118		
Zinc	Soil	indus	kg	007440-66-6	0.040032624		
Zinc	Soil	unspec.	kg	007440-66-6	0.008800118		
1-Pentanol	Water	surf.	kg	000071-41-0	9.2646E-07		
2-Methyl-1-propanol	Water	surf.	kg	000078-83-1	6.984E-07		
2-Propanol	Water	surf.	kg	000067-63-0	7.97562E-08		
4-Methyl-2-pentanol	Water	surf.	kg	000108-11-2	7.58553E-07		
4-Methyl-2-pentanone	Water	surf.	kg	000108-10-1	3.03383E-07		
4-Methyl-2-pentanone	Water	unspec.	kg	000108-10-1	3.03383E-07		
Acenaphthene	Water	ocean	kg	000083-32-9	6.12171E-07		
Acenaphthene	Water	surf.	kg	000083-32-9	0.000107876		
Acetaldehyde	Water	surf.	kg	000075-07-0	6.82549E-06		
Acetic acid	Water	surf.	kg	000064-19-7	3.01278E-06		
Acetone	Water	surf.	kg	000067-64-1	1.28641E-07		
Acetone	Water	unspec.	kg	000067-64-1	1.28641E-07		
Acetonitrile	Water	surf.	kg	000075-05-8	2.25908E-06		
Acetyl chloride	Water	surf.	kg	000075-36-5	6.56051E-05		
Acrylate, ion	Water	surf.	kg	000079-10-7	1.75348E-06		
Allyl chloride	Water	unspec.	kg	000107-05-1	1.05618E-05		
Ammonium, ion	Water	ground-	kg	014798-03-9		0.125448029	
Ammonium, ion	Water	groundLT	kg	014798-03-9		0.125448029	
Ammonium, ion	Water	ocean	kg	014798-03-9		0.125448029	
Ammonium, ion	Water	surf.	kg	014798-03-9		0.125448029	
Ammonium, ion	Water	unspec.	kg	014798-03-9		0.125448029	
Aniline	Water	surf.	kg	000062-53-3	2.77218E-05		
Antimony	Water	ground-	kg	007440-36-0	0.000817906		
Antimony	Water	groundLT	kg	007440-36-0	0.000817906		
Antimony	Water	surf.	kg	007440-36-0	0.000817906		
Antimony	Water	unspec.	kg	007440-36-0	0.000817906		
AOX, Adsorbable Organic Halogen as Cl	Water	ocean	kg	HC AOX	8.16751E-05		
AOX, Adsorbable Organic Halogen as Cl	Water	unspec.	kg	HC AOX	1.93565E-05		
Arsenic, ion	Water	ground-	kg	007440-38-2	0.000826524		
Arsenic, ion	Water	groundLT	kg	007440-38-2	0.000826524		
Arsenic, ion	Water	ocean	kg	007440-38-2	0.000435832		
Arsenic, ion	Water	surf.	kg	007440-38-2	0.000826524		
Arsenic, ion	Water	unspec.	kg	007440-38-2	0.000826524		
Barium	Water	ground-	kg	007440-39-3	0.00014362		
Barium	Water	groundLT	kg	007440-39-3	0.00014362		
Barium	Water	ocean	kg	007440-39-3	3.34209E-05		
Barium	Water	surf.	kg	007440-39-3	0.00014362		
Barium	Water	unspec.	kg	007440-39-3	0.00014362		
Benzene	Water	ocean	kg	000071-43-2	3.48039E-07		
Benzene	Water	surf.	kg	000071-43-2	3.61732E-06		
Benzene	Water	unspec.	kg	000071-43-2	3.61732E-06		
Benzene, chloro-	Water	surf.	kg	000108-90-7	4.06136E-05		
Benzene, ethyl-	Water	ocean	kg	000100-41-4	4.88776E-07		
Benzene, ethyl-	Water	surf.	kg	000100-41-4	9.8847E-06		
Benzene, ethyl-	Water	unspec.	kg	000100-41-4	9.8847E-06		
Benzyl alcohol	Water	surf.	kg	000100-51-6	2.6521E-06		
Beryllium	Water	ground-	kg	007440-41-7	0.023287709		
Beryllium	Water	groundLT	kg	007440-41-7	0.023287709		
Beryllium	Water	surf.	kg	007440-41-7	0.023287709		
Beryllium	Water	unspec.	kg	007440-41-7	0.023287709		
Bromate	Water	surf.	kg	015541-45-4	1.15814E-05		
Bromine	Water	ground-	kg	007726-95-6	0.006068453		
Bromine	Water	groundLT	kg	007726-95-6	0.006068453		
Bromine	Water	ocean	kg	007726-95-6	0.001003675		
Bromine	Water	surf.	kg	007726-95-6	0.006068453		
Bromine	Water	unspec.	kg	007726-95-6	0.006068453		
Butanol	Water	surf.	kg	000071-36-3	4.91554E-07		
Butyl acetate	Water	surf.	kg	000123-86-4	2.44179E-06		
Cadmium, ion	Water	ground-	kg	007440-43-9	0.000463902		
Cadmium, ion	Water	groundLT	kg	007440-43-9	0.000463902		
Cadmium, ion	Water	ocean	kg	007440-43-9	0.000786959		
Cadmium, ion	Water	surf.	kg	007440-43-9	0.000463902		
Cadmium, ion	Water	unspec.	kg	007440-43-9	0.000463902		
Carbon disulfide	Water	surf.	kg	000075-15-0	1.41196E-05		
Carboxylic acids, unspecified	Water	ocean	kg	HC acids	2.04673E-08		
Carboxylic acids, unspecified	Water	surf.	kg	HC acids	1.48979E-06		
Chloramine	Water	surf.	kg	010599-90-3	0.001628519		
Chlorinated solvents, unspecified	Water	ocean	kg	HC solvents chlor	7.5083E-06		

Chlorinated solvents, unspecified	Water	surf.	kg	HC solvents chlor	1.93565E-05		
Chlorine	Water	ground-	kg	007782-50-5	0.003700948		
Chlorine	Water	surf.	kg	007782-50-5	0.003700948		
Chlorine	Water	unspec.	kg	007782-50-5	0.003700948		
Chloroacetic acid	Water	surf.	kg	000079-11-8	7.62324E-05		
Chloroform	Water	surf.	kg	000067-66-3	1.7899E-05		
Chlorosulfonic acid	Water	surf.	kg	007790-94-5	0.000235848		
Chromium VI	Water	ground-	kg	018540-29-9	1.20592E-05		
Chromium, ion	Water	ground-	kg	007440-47-3	4.58593E-05		
Chromium, ion	Water	ocean	kg	007440-47-3	8.96209E-05		
Chromium, ion	Water	surf.	kg	007440-47-3	4.58593E-05		
Chromium, ion	Water	unspec.	kg	007440-47-3	4.58593E-05		
Cobalt	Water	ground-	kg	007440-48-4	0.001753991		
Cobalt	Water	groundLT	kg	007440-48-4	0.001753991		
Cobalt	Water	ocean	kg	007440-48-4	0.000577853		
Cobalt	Water	surf.	kg	007440-48-4	0.001753991		
Cobalt	Water	unspec.	kg	007440-48-4	0.001753991		
Copper, ion	Water	ground-	kg	007440-50-8	0.006110486		
Copper, ion	Water	groundLT	kg	007440-50-8	0.006110486		
Copper, ion	Water	ocean	kg	007440-50-8	0.007563984		
Copper, ion	Water	surf.	kg	007440-50-8	0.006110486		
Copper, ion	Water	unspec.	kg	007440-50-8	0.006110486		
Cumene	Water	surf.	kg	000098-82-8	1.71004E-05		
Cyanide	Water	ocean	kg	000057-12-5	9.12541E-05		
Cyanide	Water	surf.	kg	000057-12-5	0.001086585		
Cyanide	Water	unspec.	kg	000057-12-5	0.001086585		
Cyclohexane	Water	surf.	kg	000110-82-7	2.51841E-06		
Diethylamine	Water	surf.	kg	000109-89-7	2.66911E-06		
Diethylene glycol	Water	surf.	kg	000111-46-6	3.18868E-08		
Diisobutyl ketone	Water	surf.	kg	000108-83-8	7.19317E-06		
Dimethylamine	Water	surf.	kg	000124-40-3	2.00591E-06		
Dissolved solids	Water	ground-	kg	SUM solids dissolved	0.000655144		
Dissolved solids	Water	ocean	kg	SUM solids dissolved	0.000128827		0.06
Dissolved solids	Water	surf.	kg	SUM solids dissolved	0.000655144		
Dissolved solids	Water	unspec.	kg	SUM solids dissolved	0.000655144		
Ethane, 1,1,1-trichloro-, HCFC-140	Water	surf.	kg	000071-55-6	1.89624E-05		
Ethane, 1,2-dichloro-	Water	surf.	kg	000107-06-2	1.01864E-05		
Ethanol	Water	surf.	kg	000064-17-5	3.23039E-08		
Ethanol	Water	unspec.	kg	000064-17-5	3.23039E-08		
Ethyl acetate	Water	surf.	kg	000141-78-6	7.8528E-07		
Ethylamine	Water	surf.	kg	000075-04-7	1.72405E-06		
Ethylene oxide	Water	surf.	kg	000075-21-8	7.90822E-06		
Formaldehyde	Water	surf.	kg	000050-00-0	1.25575E-05		
Formaldehyde	Water	unspec.	kg	000050-00-0	1.25575E-05		
Formic acid	Water	surf.	kg	000064-18-6	1.13287E-06		
Glutaraldehyde	Water	ocean	kg	000111-30-8	1.97747E-06		
Hexane	Water	surf.	kg	000110-54-3	6.10649E-06		
Hydrocarbons, aliphatic, alkanes, unspecified	Water	ocean	kg	HC alkanes	6.3642E-07		
Hydrocarbons, aliphatic, alkanes, unspecified	Water	surf.	kg	HC alkanes	4.41338E-06		
Hydrocarbons, aliphatic, unsaturated	Water	ocean	kg	HC aliphatic unsatuarted	1.7881E-06		
Hydrocarbons, aliphatic, unsaturated	Water	surf.	kg	HC aliphatic unsatuarted	2.86601E-05		
Hydrocarbons, aliphatic, unsaturated	Water	unspec.	kg	HC aliphatic unsatuarted	2.86601E-05		
Hydrocarbons, aromatic	Water	ocean	kg	HC aromatic	2.8289E-07		
Hydrocarbons, aromatic	Water	surf.	kg	HC aromatic	5.12057E-06		
Hydrocarbons, unspecified	Water	ocean	kg	HC unspecified	1.16434E-05		
Hydrocarbons, unspecified	Water	surf.	kg	HC unspecified	0.000187115		
Hydrocarbons, unspecified	Water	unspec.	kg	HC unspecified	0.000187115		
Isopropylamine	Water	surf.	kg	000075-31-0	9.64631E-07		
Lead	Water	ground-	kg	007439-92-1	2.09177E-05		
Lead	Water	groundLT	kg	007439-92-1	2.09177E-05		
Lead	Water	ocean	kg	007439-92-1	4.37648E-05		
Lead	Water	surf.	kg	007439-92-1	2.09177E-05		
Lead	Water	unspec.	kg	007439-92-1	2.09177E-05		
Manganese	Water	ground-	kg	007439-96-5	0.000232161		
Manganese	Water	groundLT	kg	007439-96-5	0.000232161		
Manganese	Water	ocean	kg	007439-96-5	0.000154085		
Manganese	Water	surf.	kg	007439-96-5	0.000232161		
Manganese	Water	unspec.	kg	007439-96-5	0.000232161		
Mercury	Water	ground-	kg	007439-97-6	0.009756289		
Mercury	Water	groundLT	kg	007439-97-6	0.009756289		
Mercury	Water	ocean	kg	007439-97-6	0.024508594		
Mercury	Water	surf.	kg	007439-97-6	0.009756289		
Mercury	Water	unspec.	kg	007439-97-6	0.009756289		
Methane, dichloro-, HCC-30	Water	surf.	kg	000075-09-2	2.41603E-06		
Methanol	Water	ocean	kg	000067-56-1	7.60962E-09		
Methanol	Water	surf.	kg	000067-56-1	1.99607E-07		
Methanol	Water	unspec.	kg	000067-56-1	1.99607E-07		
Methyl acetate	Water	surf.	kg	000079-20-9	2.66639E-06		
Methyl acrylate	Water	surf.	kg	000096-33-3	2.19423E-05		
Molybdenum	Water	ground-	kg	007439-98-7	9.68999E-05		
Molybdenum	Water	groundLT	kg	007439-98-7	9.68999E-05		
Molybdenum	Water	ocean	kg	007439-98-7	2.16811E-05		
Molybdenum	Water	surf.	kg	007439-98-7	9.68999E-05		
Molybdenum	Water	unspec.	kg	007439-98-7	9.68999E-05		
m-Xylene	Water	surf.	kg	000108-38-3	1.92118E-05		
m-Xylene	Water	unspec.	kg	000108-38-3	1.92118E-05		
Nickel	Water	ground-	kg	007440-02-0	0.005211998		
Nickel, ion	Water	ground-	kg	007440-02-0	0.005211998		
Nickel, ion	Water	groundLT	kg	007440-02-0	0.005211998		
Nickel, ion	Water	ocean	kg	007440-02-0	0.002423151		
Nickel, ion	Water	surf.	kg	007440-02-0	0.005211998		
Nickel, ion	Water	unspec.	kg	007440-02-0	0.005211998		
Nitrate	Water	ground-	kg	014797-55-8		0.036420395	
Nitrate	Water	groundLT	kg	014797-55-8		0.036420395	
Nitrate	Water	ocean	kg	014797-55-8		0.036420395	
Nitrate	Water	surf.	kg	014797-55-8		0.036420395	
Nitrate	Water	unspec.	kg	014797-55-8		0.036420395	
Nitrite	Water	groundLT	kg	014797-65-0		0.049088359	
Nitrite	Water	ocean	kg	014797-65-0		0.049088359	
Nitrite	Water	surf.	kg	014797-65-0		0.049088359	
Nitrobenzene	Water	surf.	kg	000098-95-3	0.00010317		
Nitrogen	Water	ground-	kg	007727-37-9		0.161290323	
Nitrogen	Water	ocean	kg	007727-37-9		0.161290323	
Nitrogen	Water	surf.	kg	007727-37-9		0.161290323	
Nitrogen	Water	unspec.	kg	007727-37-9		0.161290323	
Nitrogen, organic bound	Water	ground-	kg	007727-37-9		0.161290323	
Nitrogen, organic	Water	groundLT	kg	007727-37-9		0.161290323	

bound											
Nitrogen, organic bound	Water	ocean	kg	007727-37-9		0.161290323					
Nitrogen, organic bound	Water	surf.	kg	007727-37-9		0.161290323					
o-Dichlorobenzene	Water	surf.	kg	000095-50-1	7.18202E-05						
Oils, unspecified	Water	ocean	kg	HC oils unspec	1.44885E-07						
Oils, unspecified	Water	surf.	kg	HC oils unspec	5.8144E-06						
Oils, unspecified	Water	unspec.	kg	HC oils unspec	5.8144E-06						
o-Xylene	Water	unspec.	kg	000095-47-6	2.05799E-05						
PAH, polycyclic aromatic hydrocarbons	Water	ground-	kg	130498-29-2	0.000381469						
PAH, polycyclic aromatic hydrocarbons	Water	ocean	kg	130498-29-2	2.74911E-06						
PAH, polycyclic aromatic hydrocarbons	Water	surf.	kg	130498-29-2	0.000381469						
PAH, polycyclic aromatic hydrocarbons	Water	unspec.	kg	130498-29-2	0.000381469						
Phenol	Water	ocean	kg	000108-95-2	2.6916E-08						
Phenol	Water	surf.	kg	000108-95-2	2.60468E-06						
Phenol	Water	unspec.	kg	000108-95-2	2.60468E-06						
Phosphate	Water	ground-	kg	014265-44-2	0.000751385		0.10424386				
Phosphate	Water	groundLT	kg	014265-44-2	0.000751385		0.10424386				
Phosphate	Water	ocean	kg	014265-44-2			0.296363636				
Phosphate	Water	surf.	kg	014265-44-2	0.000751385		0.10424386				
Phosphate	Water	unspec.	kg	014265-44-2	0.000751385		0.10424386				
Phosphorus	Water	ground-	kg	007723-14-0	0.021165737		0.319766441				
Phosphorus	Water	ocean	kg	007723-14-0	0.001797142		0.909090909				
Phosphorus	Water	surf.	kg	007723-14-0	0.021165737		0.319766441				
Phosphorus	Water	unspec.	kg	007723-14-0	0.021165737		0.319766441				
Propanal	Water	surf.	kg	000123-38-6	2.95713E-06						
Propanol	Water	surf.	kg	000071-23-8	2.55702E-07						
Propionic acid	Water	surf.	kg	000079-09-4	6.05798E-06						
Propylamine	Water	surf.	kg	000107-10-8	8.6686E-07						
Propylene oxide	Water	surf.	kg	000075-56-9	8.20656E-06						
Selenium	Water	ground-	kg	007782-49-2	0.004575335						
Selenium	Water	groundLT	kg	007782-49-2	0.004575335						
Selenium	Water	ocean	kg	007782-49-2	0.000924616						
Selenium	Water	surf.	kg	007782-49-2	0.004575335						
Selenium	Water	unspec.	kg	007782-49-2	0.004575335						
Silver, ion	Water	ground-	kg	007440-22-4	0.020422018						
Silver, ion	Water	groundLT	kg	007440-22-4	0.020422018						
Silver, ion	Water	ocean	kg	007440-22-4	0.032401131						
Silver, ion	Water	surf.	kg	007440-22-4	0.020422018						
Silver, ion	Water	unspec.	kg	007440-22-4	0.020422018						
Sodium formate	Water	surf.	kg	000141-53-7	3.22718E-07						
Solids, inorganic	Water	ground-	kg	SUM solids inorganic	1.52771E-05						
Solids, inorganic	Water	surf.	kg	SUM solids inorganic	1.52771E-05						
Solids, inorganic	Water	unspec.	kg	SUM solids inorganic	1.52771E-05						
Suspended solids, unspecified	Water	ground-	kg	SUM solids suspended	1.52771E-05						
Suspended solids, unspecified	Water	ocean	kg	SUM solids suspended	1.7935E-06		0.06				
Suspended solids, unspecified	Water	surf.	kg	SUM solids suspended	1.52771E-05						
Suspended solids, unspecified	Water	unspec.	kg	SUM solids suspended	1.52771E-05						
t-Butyl methyl ether	Water	ocean	kg	001634-04-4	1.87846E-07						
t-Butyl methyl ether	Water	surf.	kg	001634-04-4	4.99876E-07						
t-Butylamine	Water	surf.	kg	000075-64-9	2.22074E-05						
Thallium	Water	ground-	kg	007440-28-0	0.003574215						
Thallium	Water	groundLT	kg	007440-28-0	0.003574215						
Thallium	Water	surf.	kg	007440-28-0	0.003574215						
Thallium	Water	unspec.	kg	007440-28-0	0.003574215						
Tin, ion	Water	ground-	kg	007440-31-5	4.74477E-05						
Tin, ion	Water	groundLT	kg	007440-31-5	4.74477E-05						
Tin, ion	Water	surf.	kg	007440-31-5	4.74477E-05						
Tin, ion	Water	unspec.	kg	007440-31-5	4.74477E-05						
Toluene	Water	ocean	kg	000108-88-3	2.05881E-07						
Toluene	Water	surf.	kg	000108-88-3	4.96088E-06						
Toluene	Water	unspec.	kg	000108-88-3	4.96088E-06						
Toluene, 2-chloro	Water	surf.	kg	000095-49-8	1.25903E-05						
Tributyltin compounds	Water	ocean	kg	056573-85-4	0.019146808						
Triethylene glycol	Water	ocean	kg	000112-27-6	1.68956E-10						
Triethylene glycol	Water	unspec.	kg	000112-27-6	1.23395E-08						
Urea	Water	surf.	kg	000057-13-6	2.39647E-07						
Vanadium, ion	Water	ground-	kg	007440-62-2	0.005075408						
Vanadium, ion	Water	groundLT	kg	007440-62-2	0.005075408						
Vanadium, ion	Water	ocean	kg	007440-62-2	0.001953812						
Vanadium, ion	Water	surf.	kg	007440-62-2	0.005075408						
Vanadium, ion	Water	unspec.	kg	007440-62-2	0.005075408						
VOC, volatile organic compounds, unspecified origin	Water	ocean	kg	SUM VOC	1.16434E-05						0.001116294
VOC, volatile organic compounds, unspecified origin	Water	surf.	kg	SUM VOC	0.000187115						0.001116294
Xylene	Water	ocean	kg	001330-20-7	5.38869E-07						
Xylene	Water	surf.	kg	001330-20-7	6.1031E-06						
Xylene	Water	unspec.	kg	001330-20-7	6.1031E-06						
Zinc, ion	Water	ground-	kg	007440-66-6	0.000386067						
Zinc, ion	Water	groundLT	kg	007440-66-6	0.000386067						
Zinc, ion	Water	ocean	kg	007440-66-6	0.000628366						
Zinc, ion	Water	surf.	kg	007440-66-6	0.000386067						
Zinc, ion	Water	unspec.	kg	007440-66-6	0.000386067						