Planetary Boundary Allowance PBA'05

A tentative implementation of Rockström's planetary boundaries as Life Cycle Impact Assessment method

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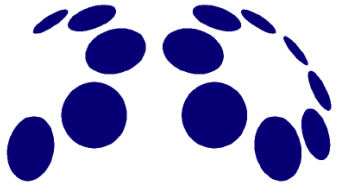


Allowances

Planetary boundaries express the limits of human pressure the whole planet can absorb/endure without critical damage.

An allowance is the per-capita share of those limits, i.e. the annual tolerable impact per person.

Allowances and LCA of whole lifestyles can be used to make sustainability checks of lifestyles.

Definition of environmental sustainability:

Total cumulative human burden ≤ planetary capacity to absorb burdens

Some existing LCIA methods featuring personal limits

Ecological Footprint (Wackernagel/Rees 1996)

Assesses: land uses and CO_2 emissions (not other GHG)

Boundary set by: available land surface and its bio-productivity = 1 planet

2000 Watt Society (ETH 1998/Novatlantis)

Assesses: all energy carriers

Boundary set by: world's average per-capita power demand around 1990
→ approx. 2000 watt per capita (63 GJ primary energy per person.year)

2000 Liter Society (Heeb et al. 2013)

Assesses: green, blue and grey water footprint (Hoekstra & Mekonnen)

Boundary set by: half of the world's average current per-capita water footprint
→ 2000 Liter per capita.day

What I like about these methods

Personal limits

An expressed personal target value of burdens.

Equality

All humans get the same maximal allowance or fair share

What I don't like

The methods have limited scope

i.e. only a few environmental effects or proxies thereof are considered (land use, CO_2, energy, water)

→ big risk of burden shifting

e.g. saving the climate, but polluting soils

The foundation of the target setting is weak (2000W, 2000L)

Was the world's average energy demand in 1990 sustainable?

Who says halving the world's water footprint is a sustainable limit?

Planetary capacity apparently assumed to increase along with population growth (every human gets 2000W, 2000L ...)

Rockström et al's planetary boundaries

Rockström, Steffen, Noone, Persson, et al. *"Planetary boundaries: exploring the safe operating space for humanity"* Ecology and Society 14(2): 32 2009. www.stockholmresilience.org

Rockström's study is expressedly concerned with the limits of burdens the planetary systems are able to absorb without dangerous status shifts.

This is a good foundation to establish environmental sustainability checks.

As opposed to ad hoc targets merely expressing a desire to reduce overconsumption, e.g. 2000W-Soc

:-(But Rockström's employed metrics are not always directly adaptable to the metrics of LCI.

:-(Some boundaries are not quantified

→ Let's try an implementation of Rockström's Planetary boundaries as LCIA

Name: Planetary Boundary Allowance'05 – PBA '05

Calculating Per-Capita Allowances

Rockström expresses planetary boundaries for the whole planet

I calculate per-capita allowances based on 10 Mia humans;
an estimate of the maximal planetary human population

→ **Allowances are more stable**
and do have not to be adjusted to population growth

→ **Expresses a fair equal share for every human**

→ **Disregards any regional differences**
(like many other LCIAs. But some generic regionalisation below)

Climate Change

A two-fold boundary by Rockström et al.:

Maximally 350 ppm CO_2 atmospheric concentration

and

Maximally + 1 Watt / m^2 warming over pre-industrial levels.

I want to assess various GHGs, so I use the second boundary.

LCA usually has the IPCCs Global Warming Power (GWP) as metric for GHGs (CO_2-Equivalents).

So what is the link between W/m^2 and CO_2-Eq ?

What is the annual emission allowance of CO_2-Eq?

Answer: 1 W / m^2 is equal to 11.5 Gt CO_2-Eq /year *

* using data from Forster et al. 2007 *"Changes in Atmospheric Constituents and in Radiative Forcing"*

A personal allowance of 1150 kg CO_2-Eq /year (@ 10 Mia. People)

Nitrogen cycle

Rockström's boundary:

Maximally 35 Mt "fixed nitrogen" per year.

Rockström includes in human-driven nitrogen conversion also eg. fossil-fuel or biomass combustion, leguminous crops.

So problematic is not the industrial uptake from the atmosphere (fixation), but the release of reactive nitrogen compounds, i.e. nitrogen emissions.

Simple link to LCI results: emissions of

Ammonia NH_3

Nitrate NO_3

Nitrogen oxides NO_x *

Organic bound nitrogen N_{org}

* Rockström excludes nitrous oxide (N_2O) which is has a long atmospheric lifetime and is heeded as GHG and ozone depleter

A personal allowance of 3.5 kg N-Eq /year (@ 10 Mia. People)

Stratospheric ozone depletion

Rockström's boundary:

276 Dobson Units (DU) stratospheric ozone concentration (minimal!)

Conversion to a *maximal* tolerable boundary:

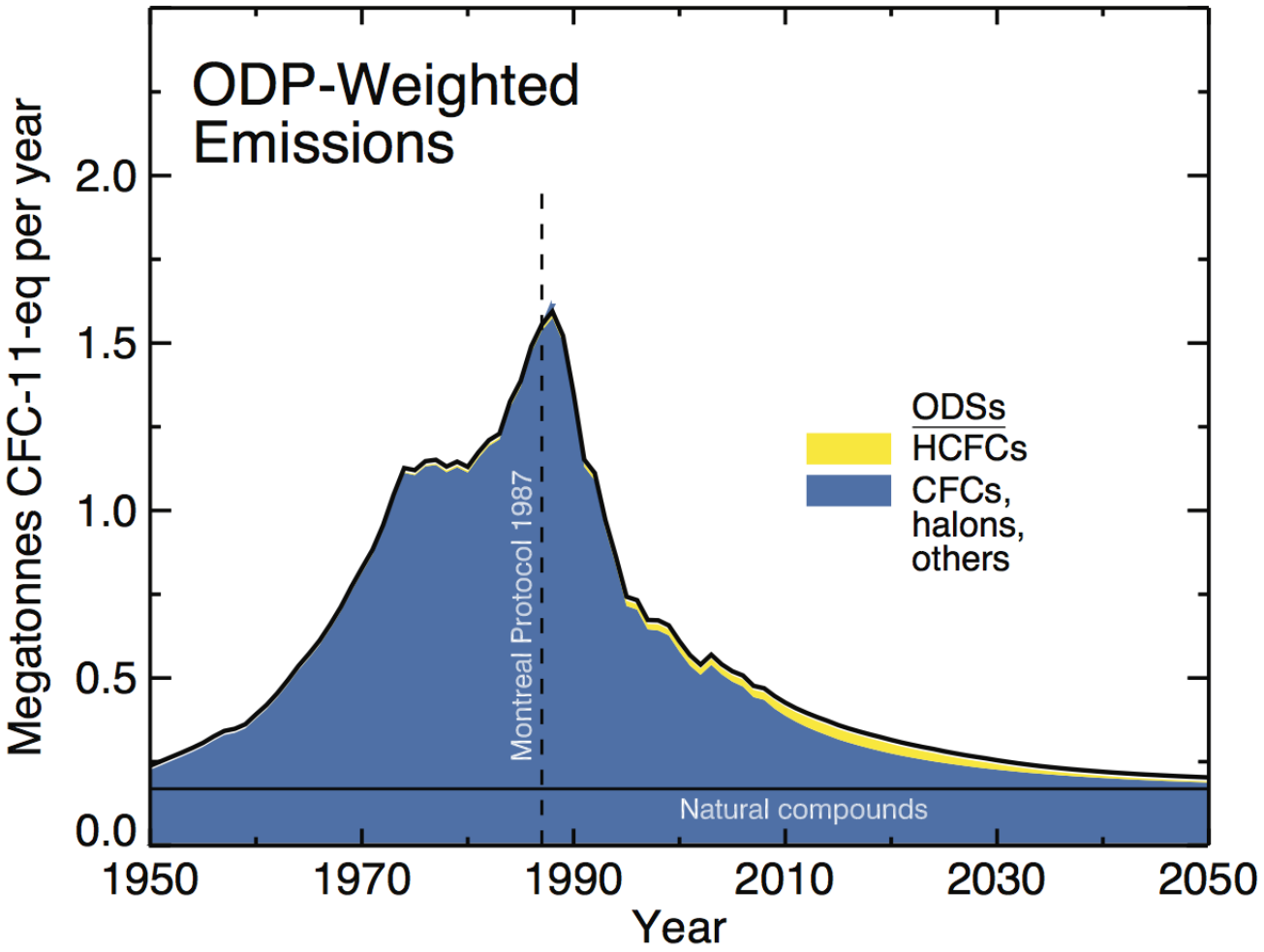
From a minimal target concentration to a *maximal* loss

14 DU ozone loss over pre-industrial levels

LCA has Ozone Depletion Potentials (ODP) as metrics of ozone destruction (R11-Equivalents)

How link Dobson Units and Ozone Depletion Potentials ?

ODP emissions



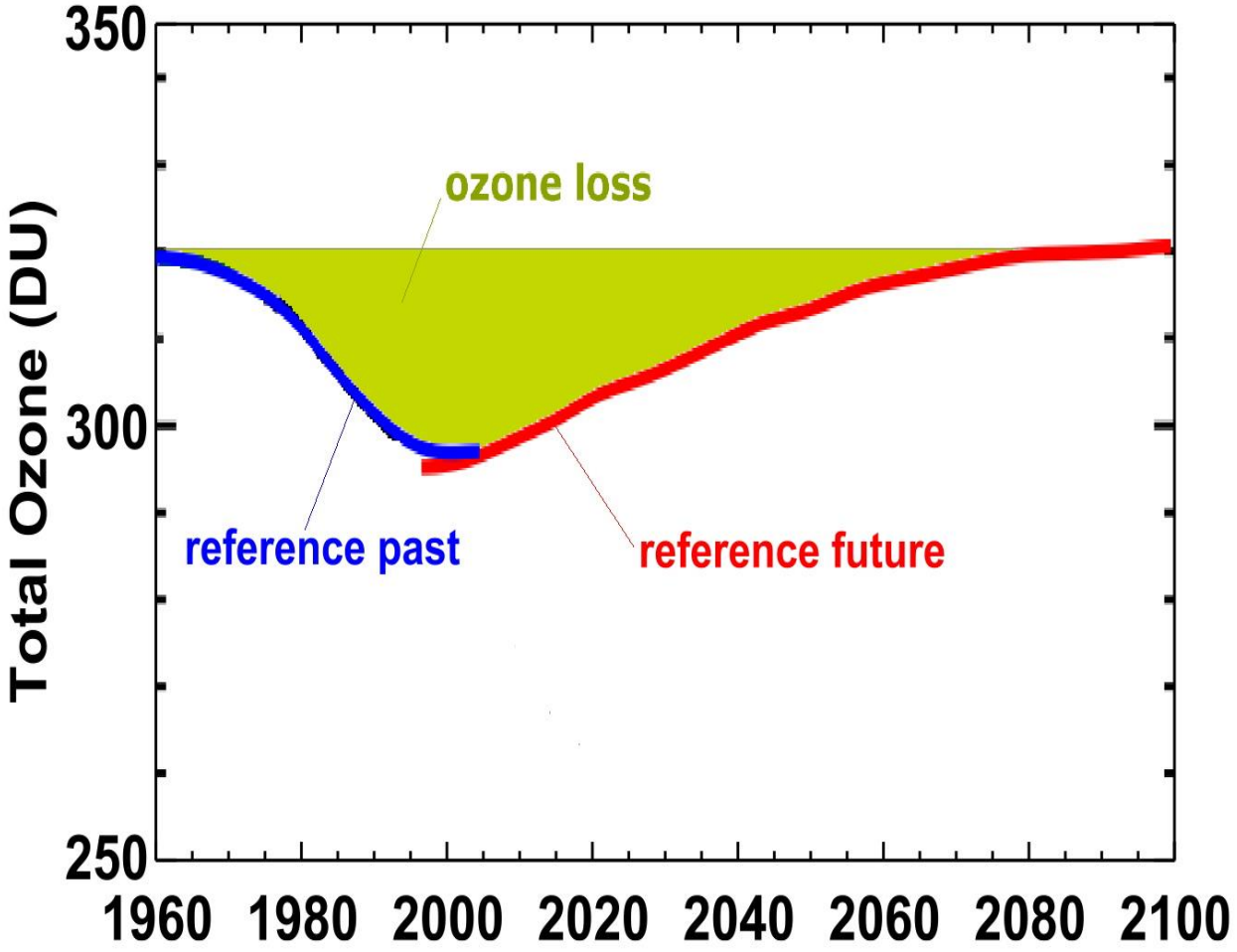
Total ODP emissions in the period 1940-2050 are

48.85 Mt ODP

= integral of the emission curve, without natural background

World Meteorological Organization 2010 *"Scientific Assessment of Ozone Depletion Executive Summary"*

Effect of stratospheric ozone



Total resulting average global ozone loss 1960-2100 of

1397 DU.year

= integral of the DU loss over time

Adopted Fig. 2 from Newman et al. 2009 *"What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?"*

Stratospheric ozone depletion

The overall emission of 48.85 Mt ODP
is responsible for an overall ozone loss of 1397 DU.year.

So the emission of 1 Mt of ODP causes 34 DU.year ozone loss.

If the boundary of globally 14 DU ozone loss shall be maintained, maximally 0.409 Mt ODP/year can be emitted.
(=14 DU.yr / 34.197 DU.yr/Mt ODP)

A personal allowance of 0.0409 kg ODP-Eq /year (@ 10 Mia. People)

Biodiversity loss

Rockström's boundary is 10 extinctions per year and per million existing species (10 E/MSY).

These are *irreversible* extinctions of species.

LCA has measures of *reversible* biodiversity loss:

the elimination of species on an area of land *for a certain time* with the unit species.year

Assumption: the sum of reversible losses is directly proportional to the pressures which cause the more susceptible species to go extinct

So in order to reduce irreversible extinctions, the reversible eliminations must be reduced to the same degree.

Rockström has current extinction rates of >100 E/MSY

I use a tentative reduction factor of 20

Using normalisation values from ReCiPe'08 LCIA, I get a personal allowance of 0.0000281 species.yr/ year (@ 10 Mia. People)

Aerosol loading

Rockström et al. 2008 have not quantified this boundary.
Mentioned problems: climate systems + human health
I looked at human health only
Humbert 2009 [1] compiled human health effects of PM_x, NO_2, SO_2, NH_3
From this I calculate PM_{10}-Equivalents as my metric:
→ 2010 Worldwide emissions estimated at 51.7 Mt PM_{10}-Eq
Reduction factor? Largest aerosol health burdens occur in cities:
Current world average urban PM_{10}-concentration [2] : 71 µg PM_{10}/m^3
WHO air quality guideline value is 20 µg PM_{10}/m^3
→ Reduction factor is therefore 3.55
→ Boundary value 1.457 kg PM_{10}-Eq per capita (@ 10 Mia. People)
Data from Humbert allows generic regional distinction of emissions in urban vs. rural settings

1 Humbert S. (2009) Geographically Differentiated Life-cycle Impact Assessment of Human Health

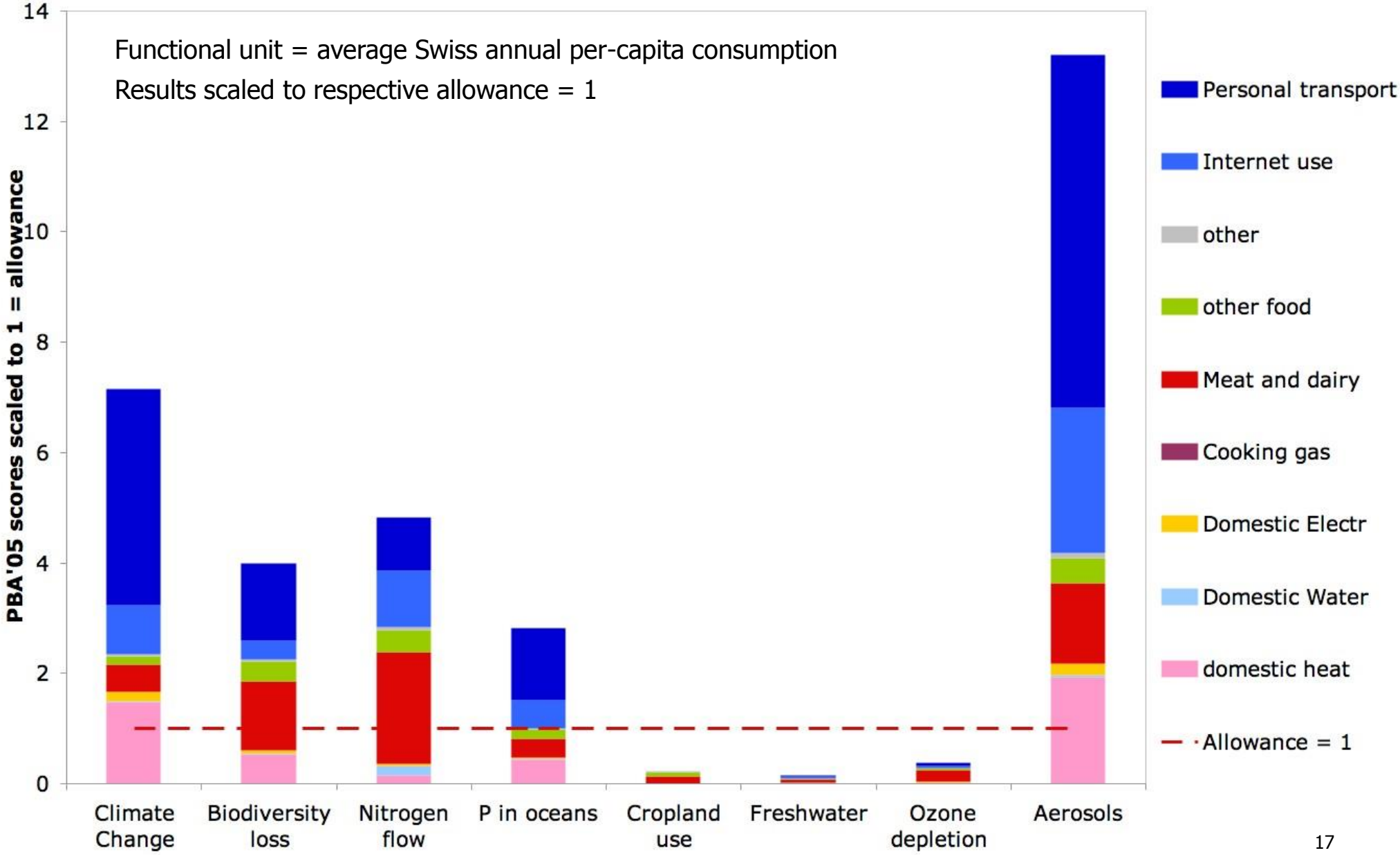
2 WHO (2014) Ambient Air Pollution database - Update 2014 data summary

PBA'05 Synopsis

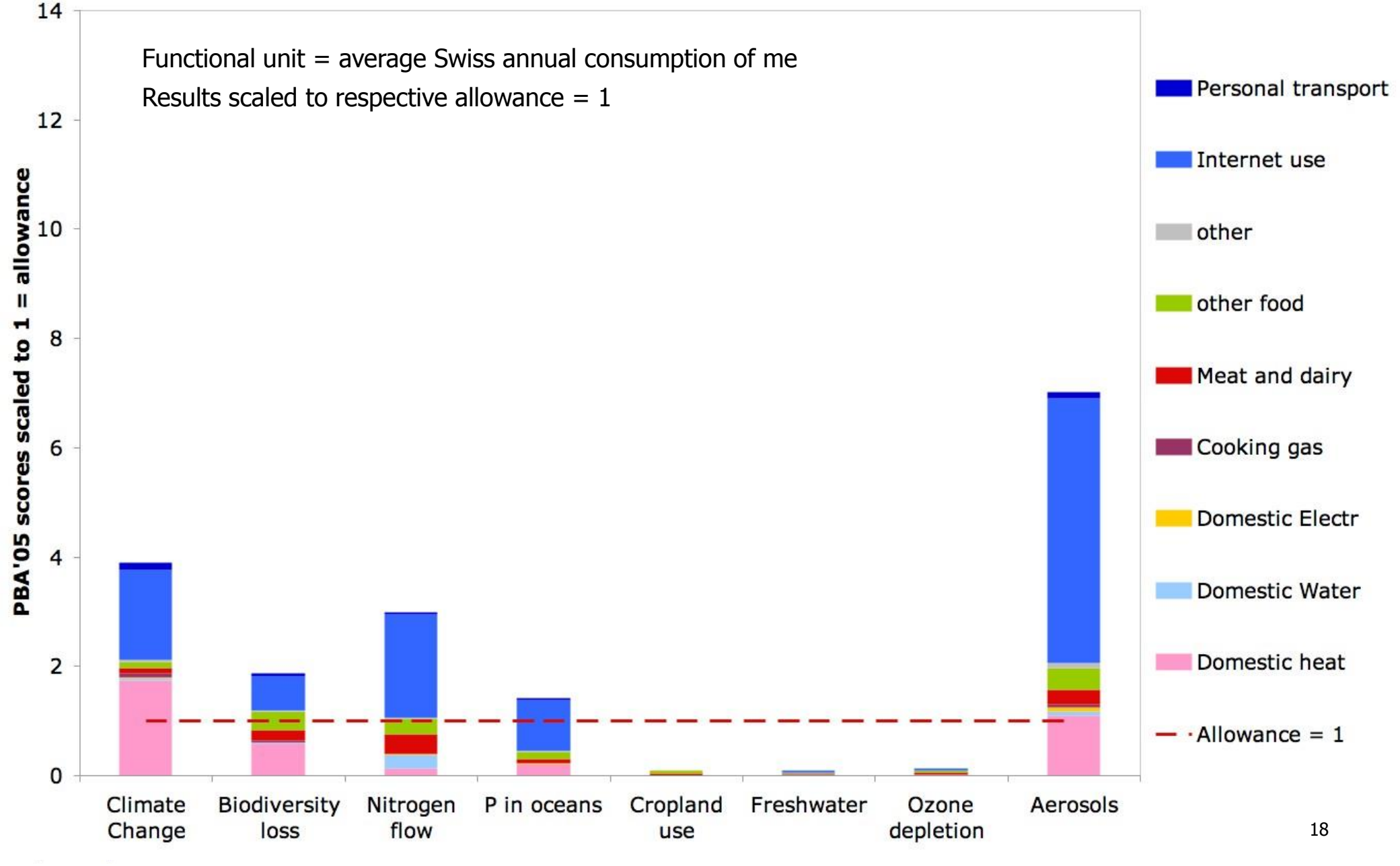
Red = already exceeded boundaries

Plantary system damage	Rockström planetary boundary	PBA'05 Allowance Per Capita.Yr
Climate change	≤ +1 W/m^2	1150.7 kg CO_2-Eq
Loss of biodiversity	≤ 10 extinctions per million species.yr (E/MSY)	0.0000281 species.yr reversible eliminations
Nitrogen cycle	≤ 35 Mt N /yr fixation	3.5 kg N-Eq emissions
Phosphorus cycle	≤ 11 Mt P /yr emitted to ocean	0.0011 kg P in ocean
Land occupation	≤ 1995 Mio ha cropland land occupation	1995 m^2yr cropland occupation
Global freshwater use	≤ 4000 km^3 / yr blue water use	400'000 liter
Stratospheric ozone depletion	≤ 14 reduction of Dobson Units	0.0409 kg ODP-Eq
Atmospheric aerosol loading	*undefined*	1.457 kg PM_{10}-Eq
Chemical pollution	*undefined*	*undefined*
Ocean acidification	≤ 20% reduction aragonite saturation	*undefined*

PBA'05 Results: average Swiss



PBA'05 Results: me

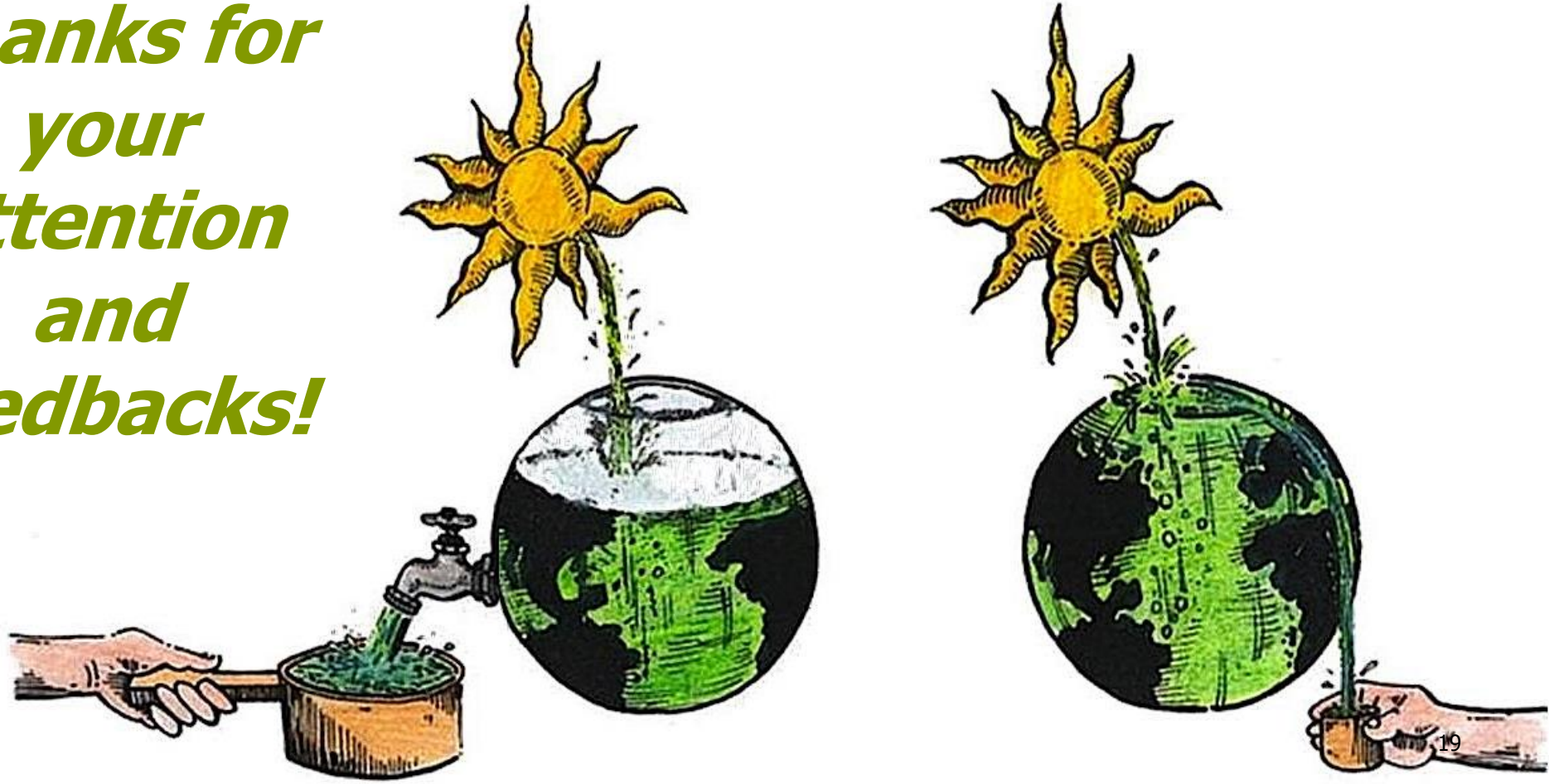


PBA'05 methodology report

Draft report and characterisation factors available for free at:

www.doka.ch/publications.htm

Thanks for your attention and feedbacks!



P in ocean exceeded?

Only 3 Sources for "P + PO_4 in ocean" in ecoinvent LCI data:

1. Treatment of spent nuclear fuel, reprocessing

0.836 g of P emitted during operation per kg metal processed
Average data for La Hague, France plant 1996/97
100% to ocean

2. Petroleum refinery operation

0.185 mg P per kg refinery product
(from 0.7 m^3 wastewater @ 100 ppb P per t crude refined)
Based on refinery capacities in Europe w/o CH of 1994
63.5% wastewater emitted to ocean (rest to rivers)

3. Phosphoric acid production, dihydrate process

0.0388 kg PO_4 emitted per kg H_3PO_4 produced
In Moroccan production only (9% of world H_3PO_4 production):
Disposal of Phospho-gypsum waste directly into ocean

New publication Steffen et al. 2015

Plantary system damage	Rockström 2009 planetary boundary	Steffen 2015 planetary boundary
Climate change	≤350 ppm CO2 + ≤ +1 W/m^2	**Same**
Loss of biodiversity	≤ 10 extinctions per million species.yr (E/MSY)	**Kept** & ≤ 1 E/MSY aspirational target & ≤ 10% loss of Biodiversity Intactness Index
Nitrogen cycle	≤ 35 Mt N /yr fixation	**NEW** ≤ 62 Mt N /yr fixation
Phosphorus cycle	≤ 11 Mt P /yr emitted to ocean	**Kept** and augmented with & 6.2 Mt P mined + applied to erodible soils
Land occupation	≤ 1995 Mio ha cropland land occupation	**NEW** ≤ 25% loss of original forest cover (global average) & regional distinctions
Global freshwater use	≤ 4000 km^3 / yr blue water use	**Kept** and augmented with maximal monthly withdrawal in basin per flow-regime
Stratospheric ozone depletion	≤ 14 reduction of Dobson Units	**Same**
Atmospheric aerosol loading	*undefined*	**NEW** ≤ 0.25 AOD on Indian Subcontinent & ≤ 10% warming Aerosols in total AOD
Chemical pollution	*undefined*	Undefined, renamed to "Introduction of novel entities" (incudes GMO)
Ocean acidification	≤ 20% reduction aragonite saturation	**Same**