INDICATORS FOR SUSTAINABLE DEVELOPMENT

SDEE – Sustainable Development, Energy and Environment

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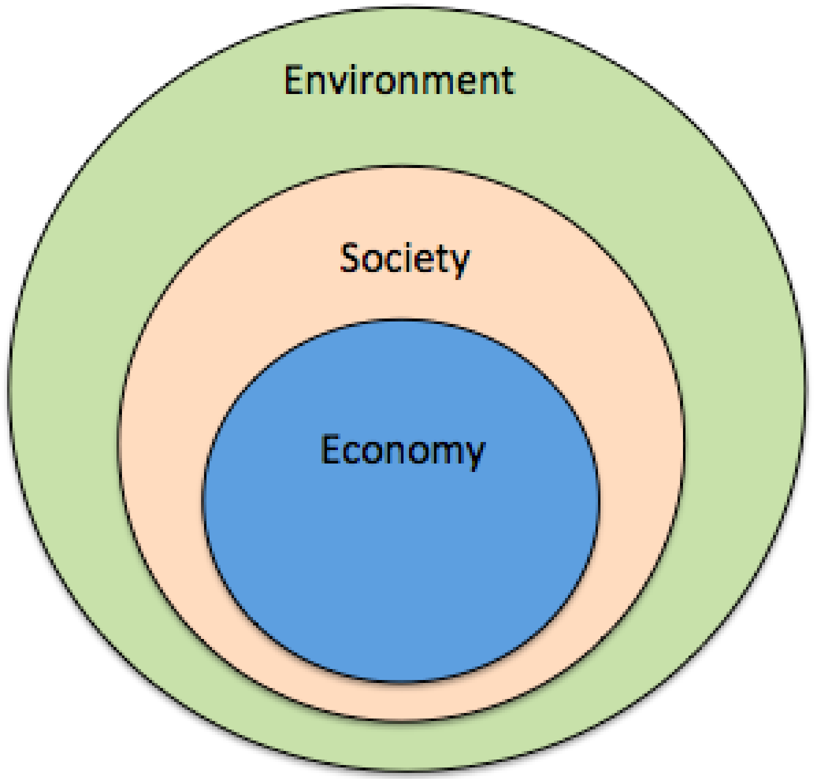
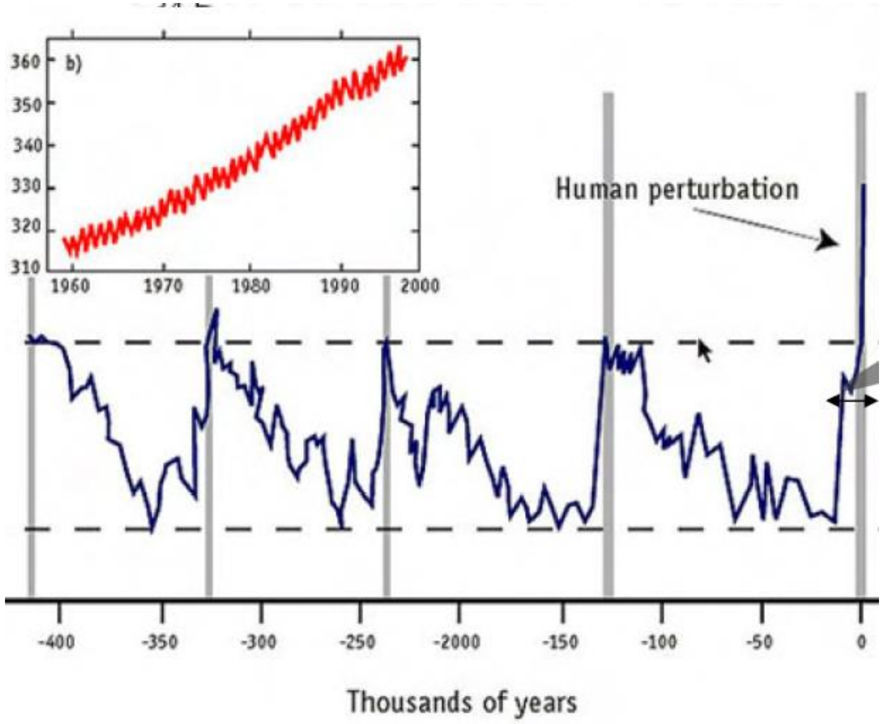
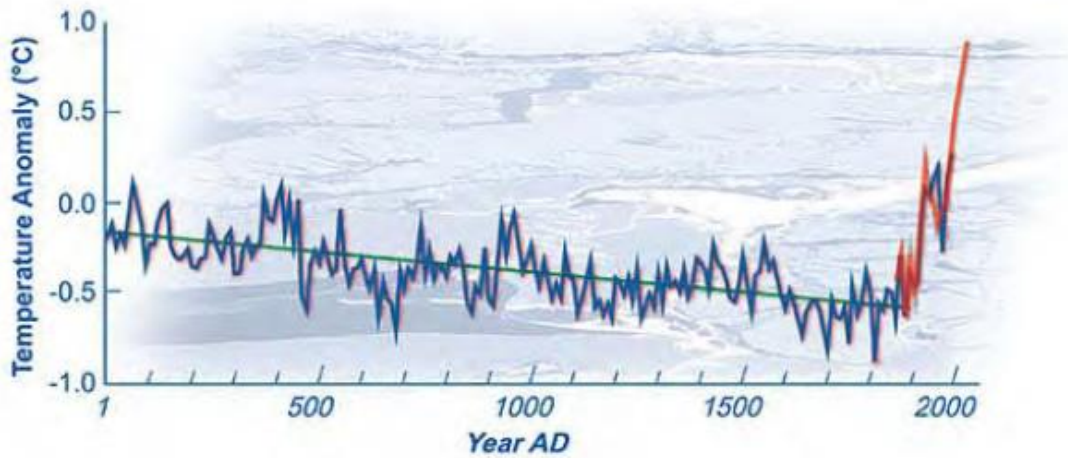
20 Nov 2019



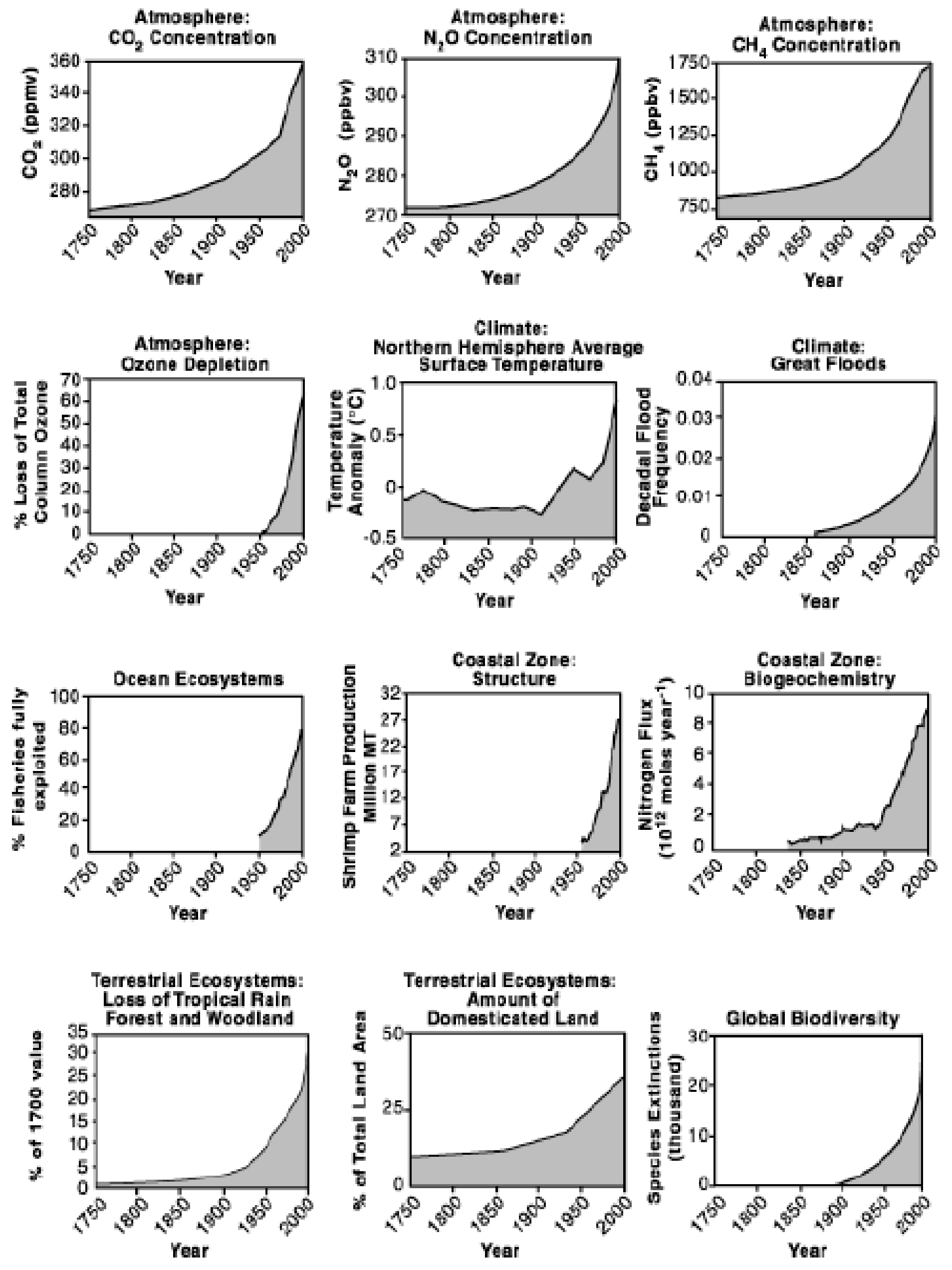
BACKGROUND





Kaufman, Darrell S., et al. 2009. Recent Warming Reverses Long-Term Arctic Cooling. *Science*, September 4, 2009

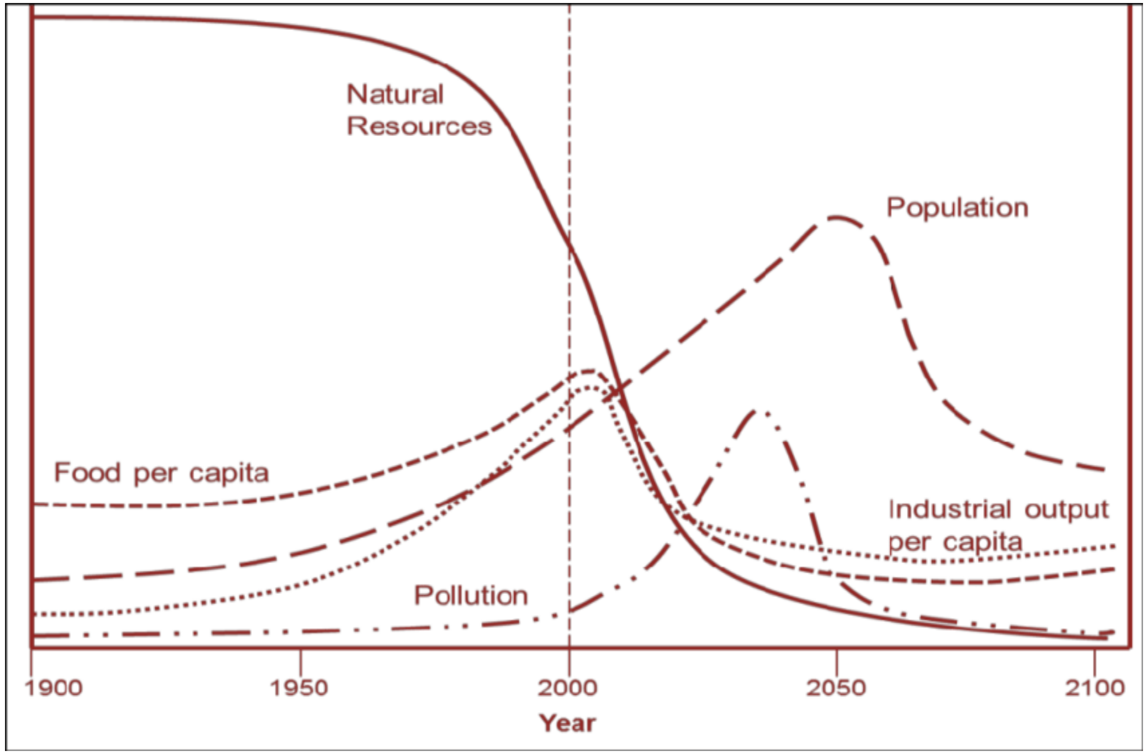
BACKGROUND



Atmosphere: CO_2 Concentration
CO_2 (ppmv)
Year
Atmosphere: N_2O Concentration
N_2O (ppbv)
Year
Atmosphere: CH_4 Concentration
CH_4 (ppbv)
Year
Atmosphere: Ozone Depletion
% Loss of Total Column Ozone
Year
Climate: Northern Hemisphere Average Surface Temperature
Temperature Anomaly (°C)
Year
Climate: Great Floods
Decadal Flood Frequency
Year
Ocean Ecosystems
% Fisheries fully exploited
Year
Coastal Zone: Structure
Shrimp Farm Production Million MT
Year
Coastal Zone: Biogeochemistry
Nitrogen Flux (10^{12} moles $year^{-1}$)
Year
Terrestrial Ecosystems: Loss of Tropical Rain Forest and Woodland
% of 1700 value
Year
Terrestrial Ecosystems: Amount of Domesticated Land
% of Total Land Area
Year
Global Biodiversity
Species Extinctions (thousand)
Year

BACKGROUND
HAVE WE CROSSED THE LIMITS?

Limits to growth, from Donella Meadows et al. 1972, for the Club of Rome

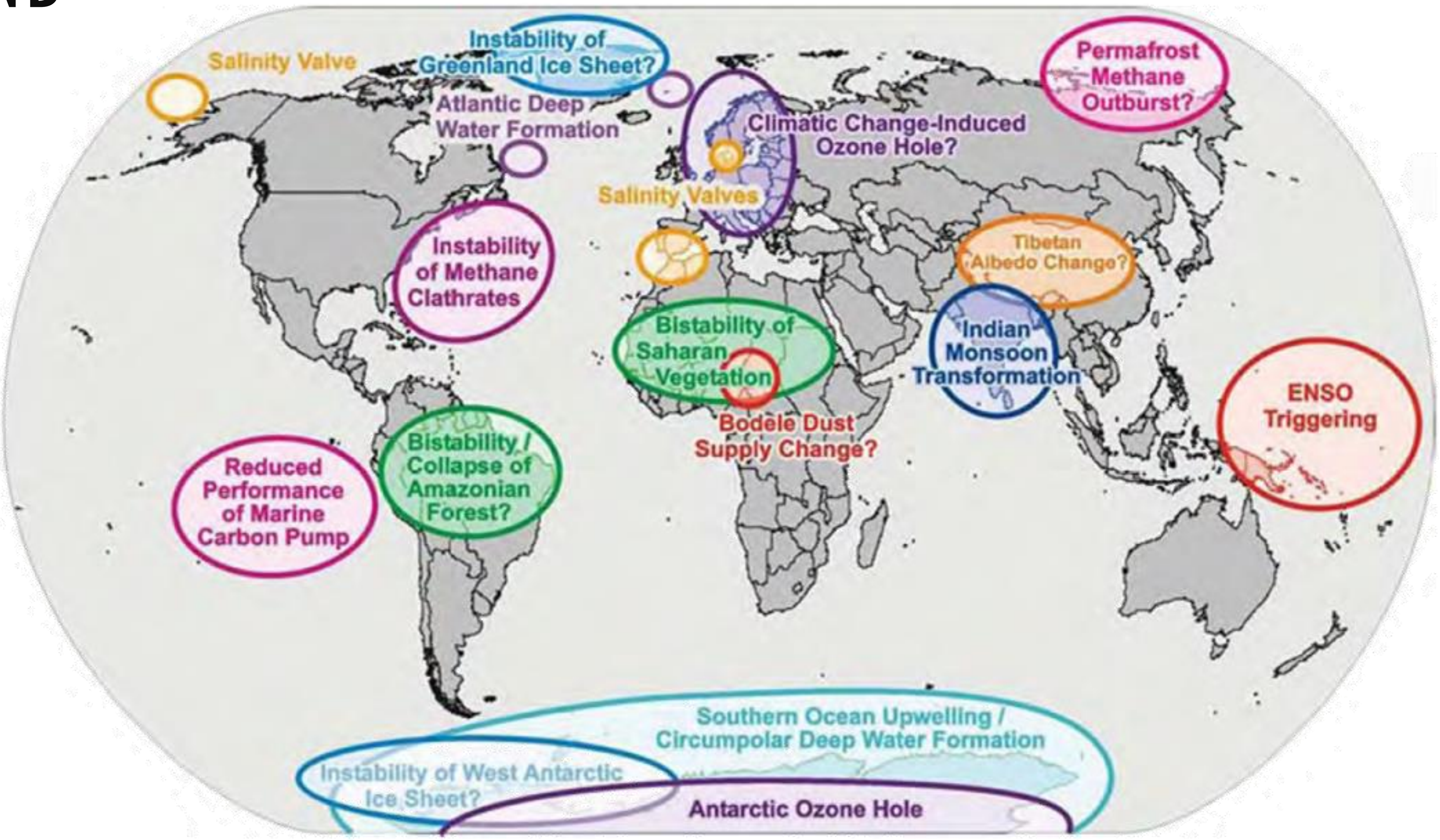


- Global Food per capita reaches a peak around 2020, followed by a rapid decline
- Global population reaches a peak in 2030, followed by a rapid decline

BACKGROUND

Tipping elements, IPCC AR5

Existence of negative feedback loops (irreversible, spiraling effects)
between climate and earth processes.



BIOPHYSICAL AND SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

- Ecological footprint
- Planetary Boundaries

A NOTE ON INDICATORS
TERRITORIAL VS. CONSUMPTION BASED INDICATORS

Territorial based

Consider only the activities that happen within the territorial borders. Excludes imports and exports.

So, if a product is produced in Europe, but exported to the US, its production is still accounted in Europe

This is the case of most environmental indicators. Ex.: National Inventory Reports (GHG emissions reporting by country) as reported to the UNCCC

Consumption based

Consider the impacts of the production activities associated with the products consumed, no matter where they occur. Accounts for imports and exports. Avoids "leakage" – closing factories and shifting them to other countries.

E.g., a product consumed in Europe, but produced elsewhere, it will be accounted in Europe

This is the case of economic indicators, the **Ecological Footprint, the planetary boundaries framework as developed by O'Neill et al (2018)**

A NOTE ON INDICATORS
AN ADDITIONAL WAY OF ACCOUNTING: INCOME BASED INDICATORS

Territorial based

Consider only the activities that happen within the territorial borders. Excludes imports and exports.

Consumption based

Consider the impacts of the production activities associated with the products consumed, no matter where they occur. Accounts for imports and exports.

Income (production) based

This is a novel approach, not yet used that much. The approach considers the impacts allocated to the money flows. Who makes the money gets penalized.

E.g., If China produces products that are consumed by the US, China would be penalized because it receives money by selling those products.

Norway, considered one of the most sustainable countries, exports oil. As it gets money from exporting oil, the emissions from their oil use will be allocated to Norway.

A NOTE ON INDICATORS
AN ADDITIONAL WAY OF ACCOUNTING: INCOME BASED INDICATORS

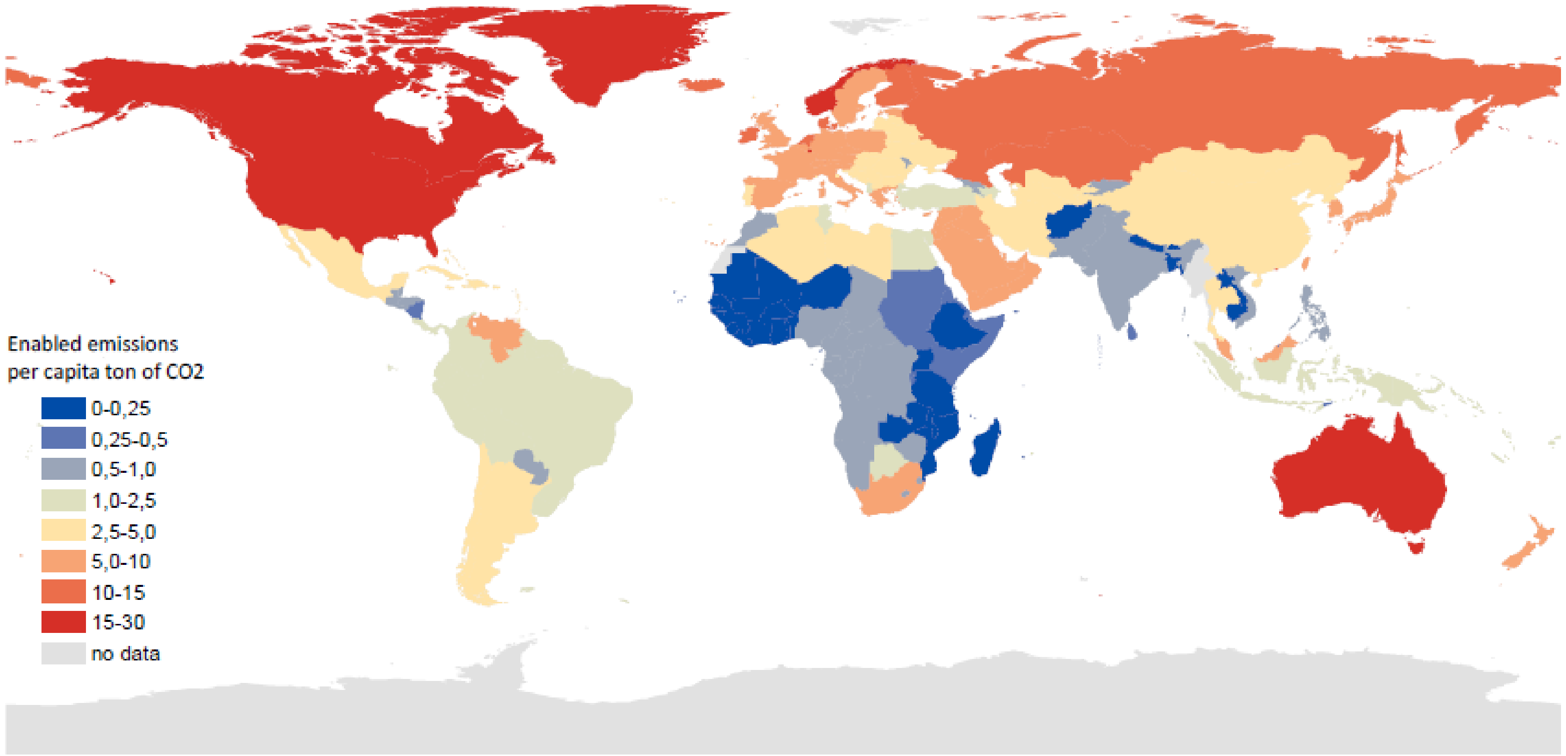
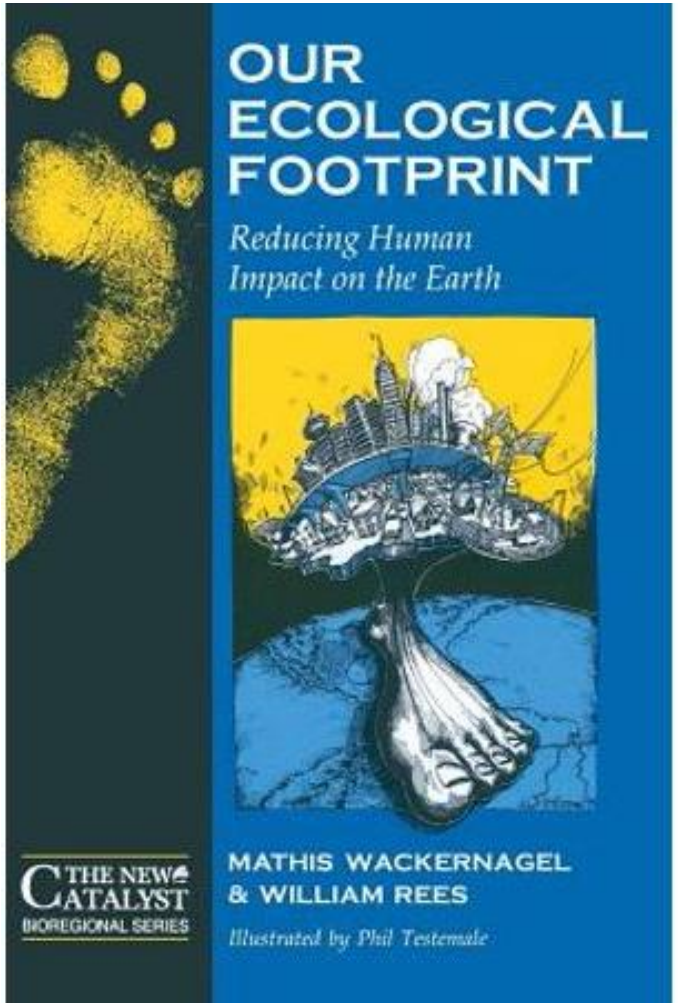


Figure: World per capita income-based responsibility (Mt CO_2)

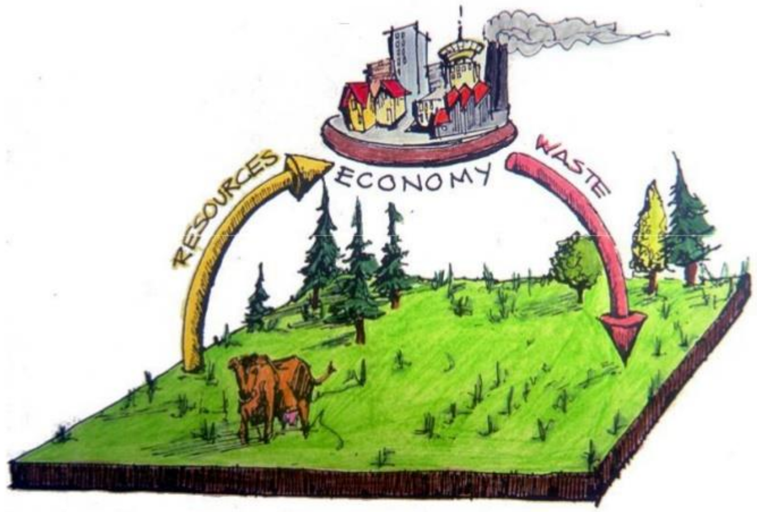
Source: Marques 2013

ECOLOGICAL FOOTPRINT



ECOLOGICAL FOOTPRINT
DEFINITION

The biologically productive land and sea area a population requires to produce the biotic resources it consumes and absorb the waste it generates, using prevailing technology and resource management practices (Borucke et al. 2013).



Ecological Footprint was developed by Wackernagel and Rees (1995).

ECOLOGICAL FOOTPRINT
METHOD

The ecological footprint is the sum of 6 components:

1. Grazing land
2. Forest products land
3. Fishing grounds
4. Cropland
5. Built-up land
6. Carbon land

ECOLOGICAL FOOTPRINT
METHOD

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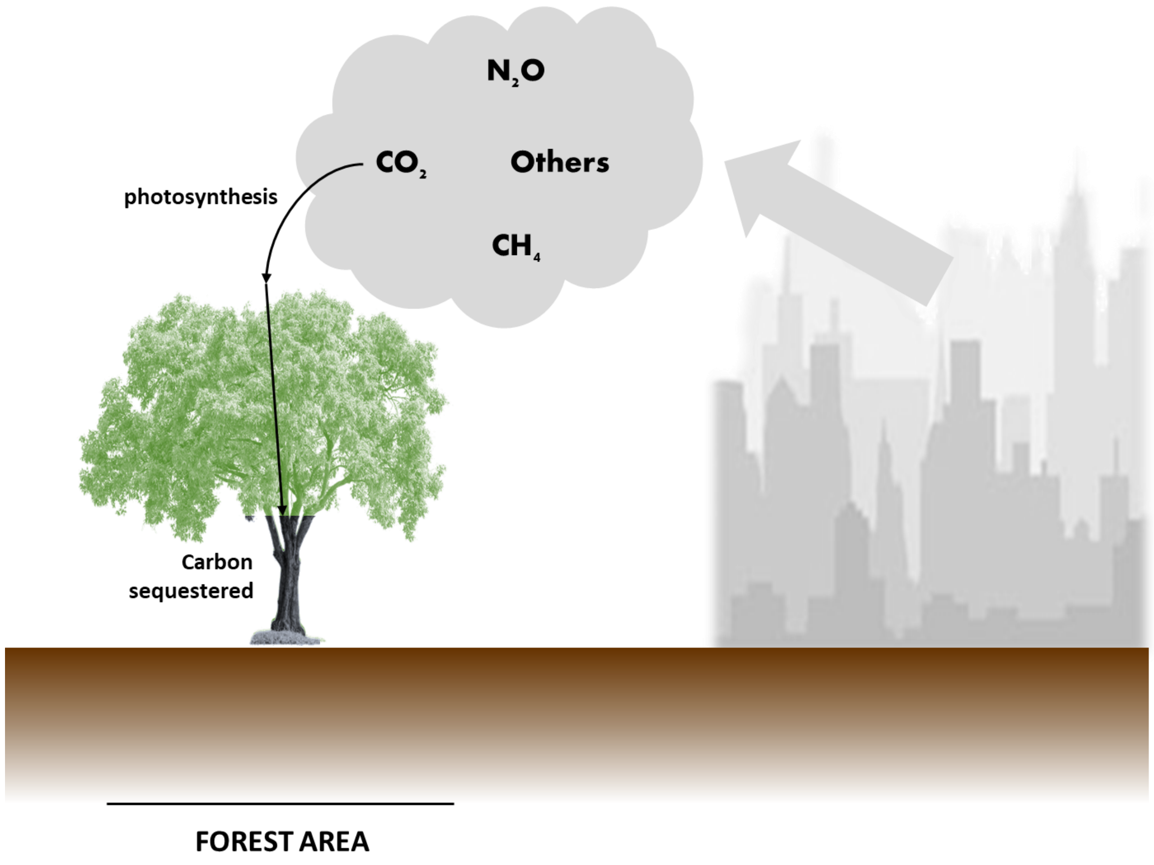


ECOLOGICAL FOOTPRINT
METHOD

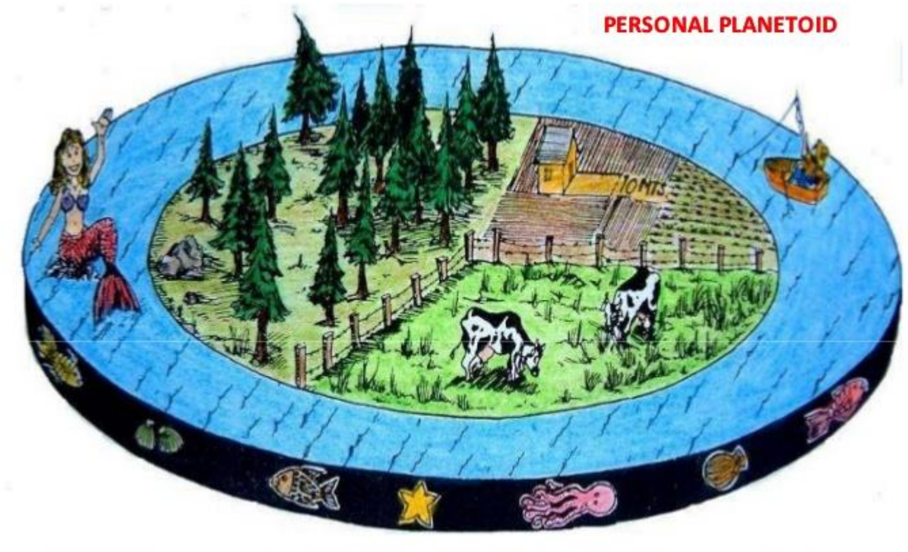
Ecological footprint allows to estimate the biophysical pressure

What it also allows you to do is to estimate the biocapacity

Biocapacity is the ability of ecosystems to renew themselves: “how much we still have available”

ECOLOGICAL FOOTPRINT
METHOD

Bottom line (biocapacity)
2.3 hectares of biologically productive land and sea per person



ECOLOGICAL FOOTPRINT
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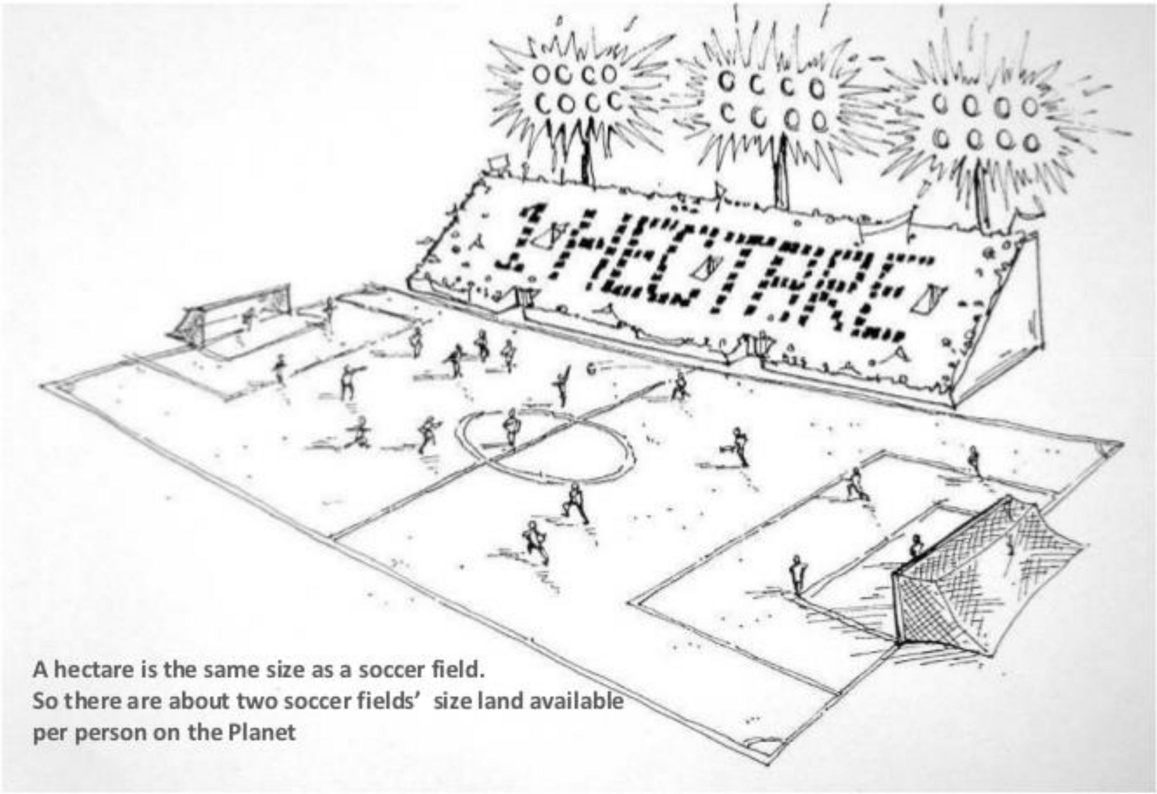

ECOLOGICAL FOOTPRINT
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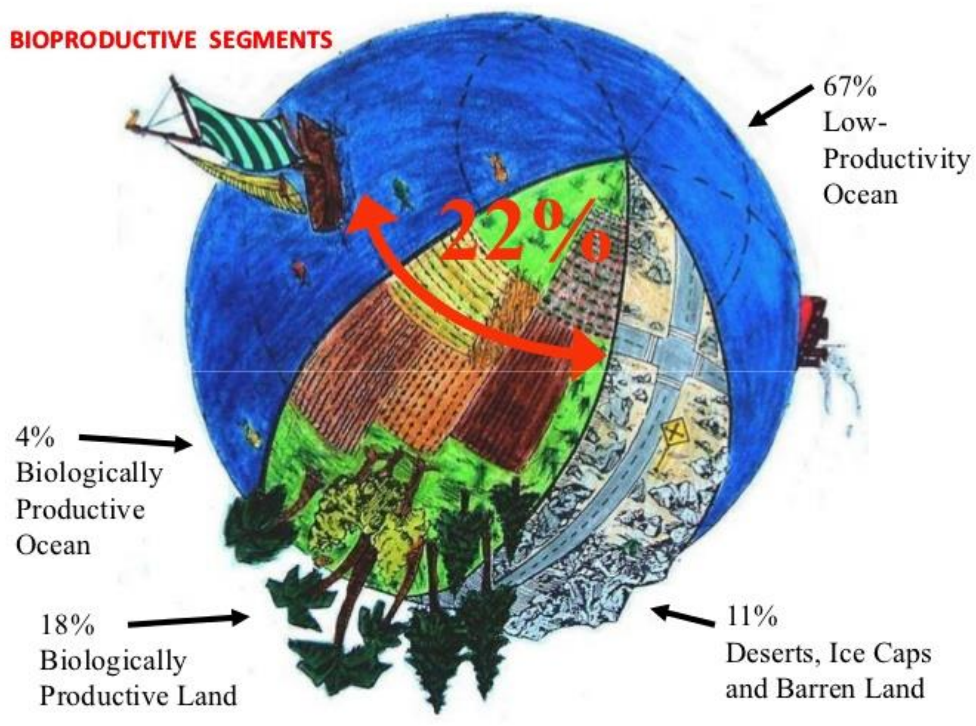


ECOLOGICAL FOOTPRINT
METHOD

Bottom line (biocapacity)

2.3 hectares of biologically productive land and sea per person

What about biodiversity?

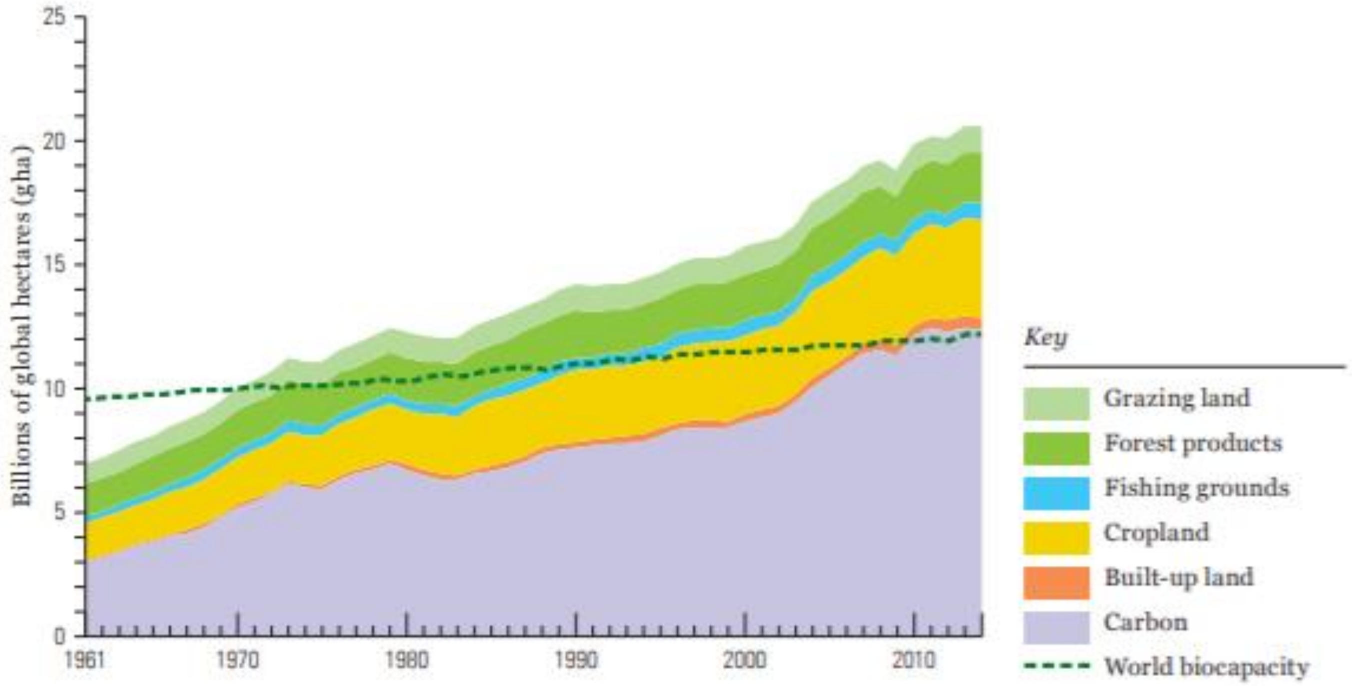
The Bruntland Commission recommended 12% of land to be left is left untouched to protect biodiversity

Personal biocapacity

1.7 $gha.person^{-1}.yr^{-1}$

ECOLOGICAL FOOTPRINT
GLOBAL TRENDS

- Biocapacity has increased about 27% in the past 50 years,
- But… ecological footprint has increased about 190% over the same period
- **World average footprint is 2.65** global hectares (gha) of land per capita, which is 50% above global biocapacity of 1.7 gha per capita



Source: Living Planet Report 2018

ECOLOGICAL FOOTPRINT
METHOD

Ecological Footprint Analysis allow us to…

- Estimate how much biological productive land we have (biocapacity)
- Estimate how much we are using
- Living sustainably would mean we are not living beyond what is available (making sure we do not cross the biocapacity of the earth)

ECOLOGICAL FOOTPRINT
REVIEWS AND CRITIQUES

Although widely used, the ecological footprint has also been widely criticized.

A review of the footprint based on a survey of 34 internationally-recognised experts and an assessment of more than 150 papers concluded that the **indicator is a strong communications tool, but that it has a limited role within a policy context**

ECOLOGICAL FOOTPRINT

REVIEWS AND CRITIQUES

01

Communication biases

02

Carbon ecological footprint

03

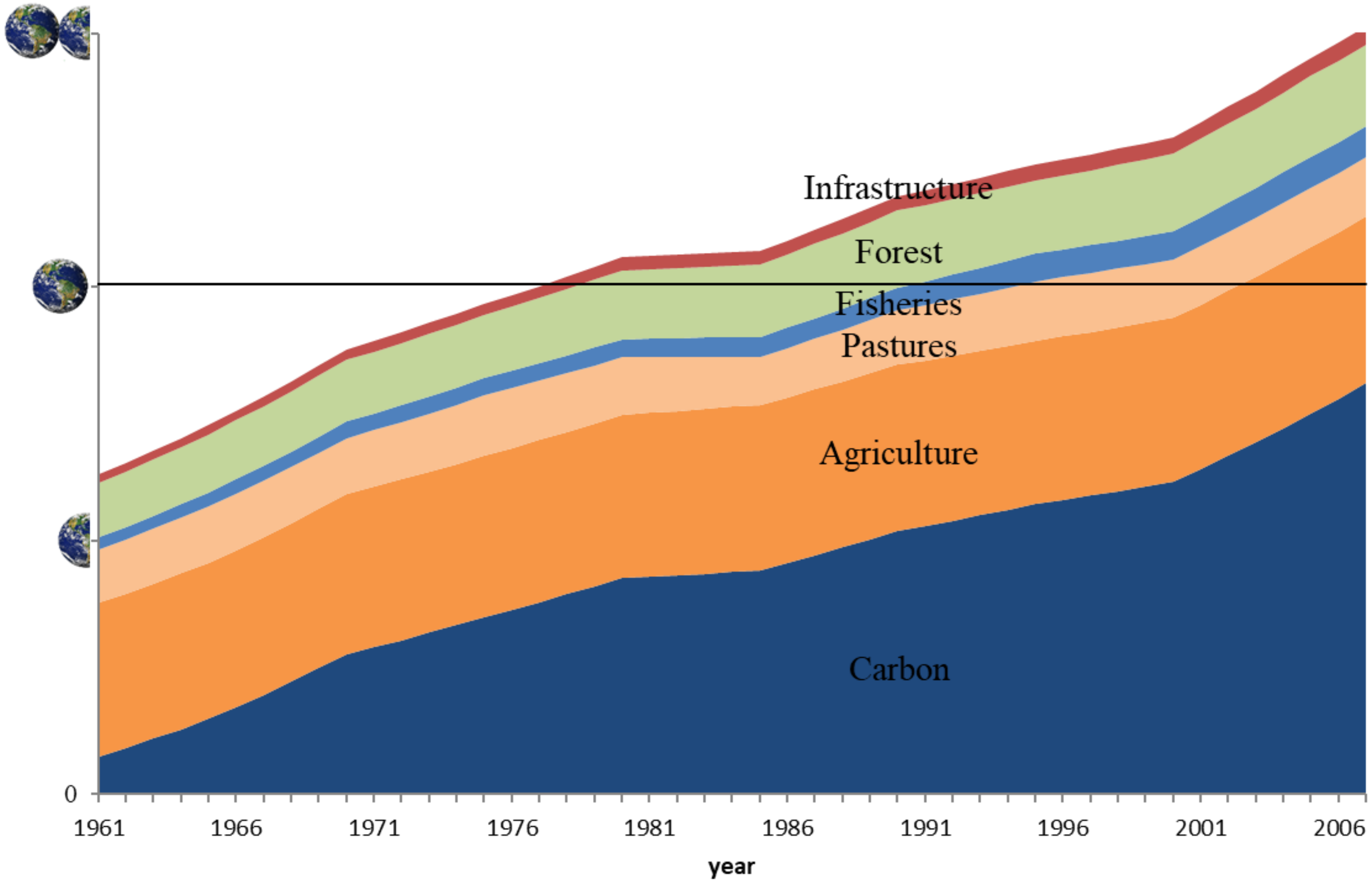
Wastes' ecological footprint

04

Loss of information at the aggregate level

EF - REVIEWS AND CRITIQUES
01 COMMUNICATION BIASES

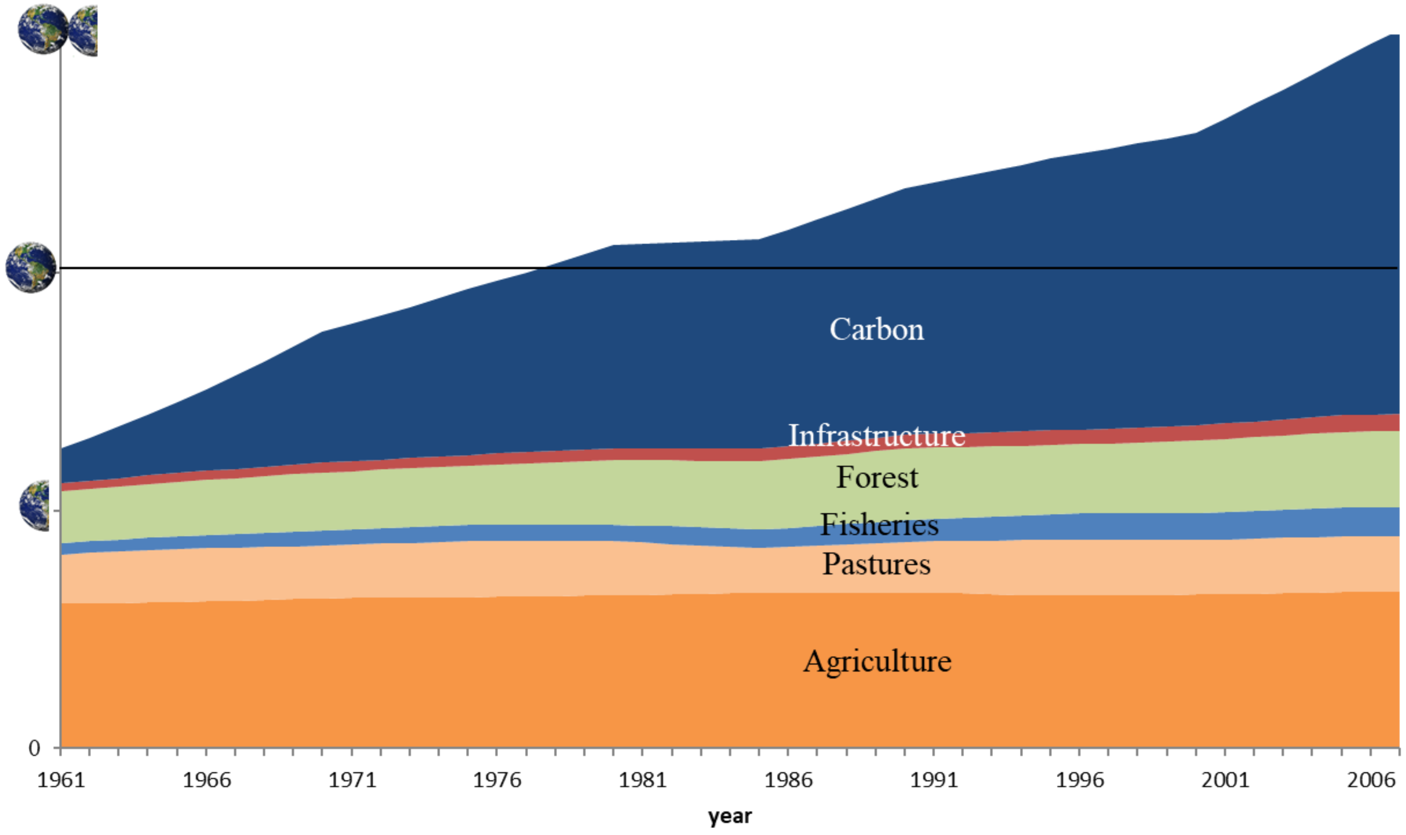
The Ecological Footprint as it is normally presented



EF - REVIEWS AND CRITIQUES
01 COMMUNICATION BIASES

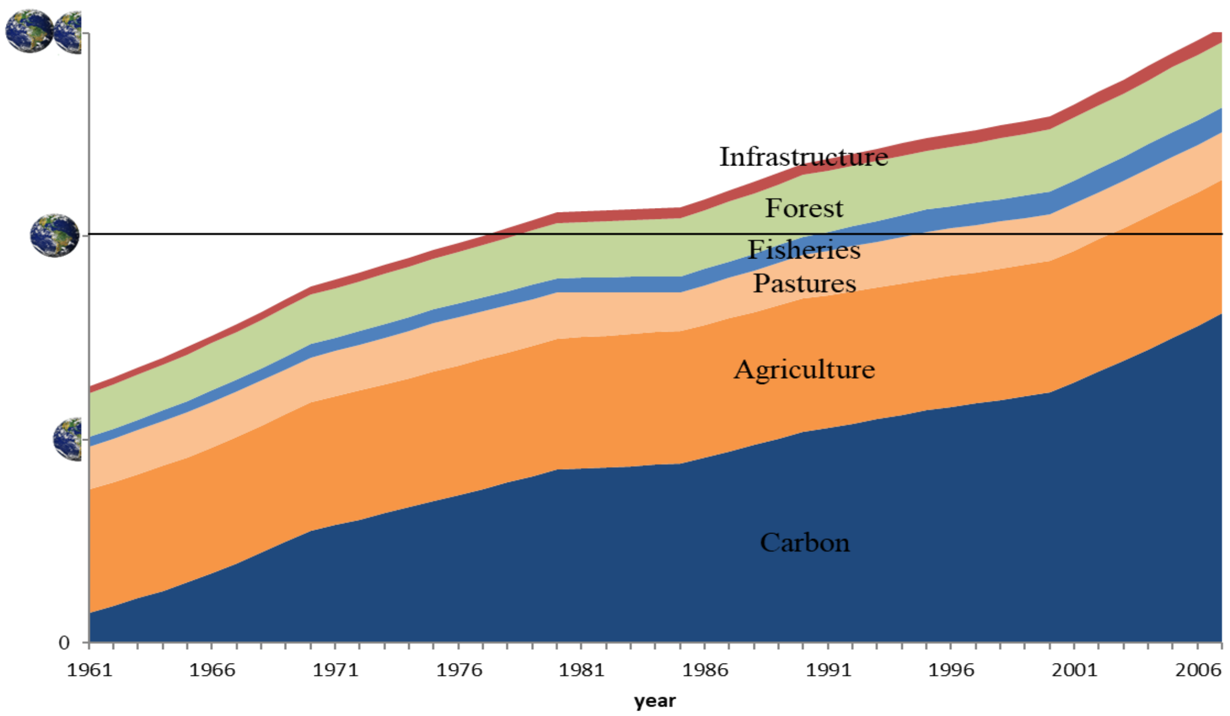
Slight change of the order of the layers presented: carbon on top

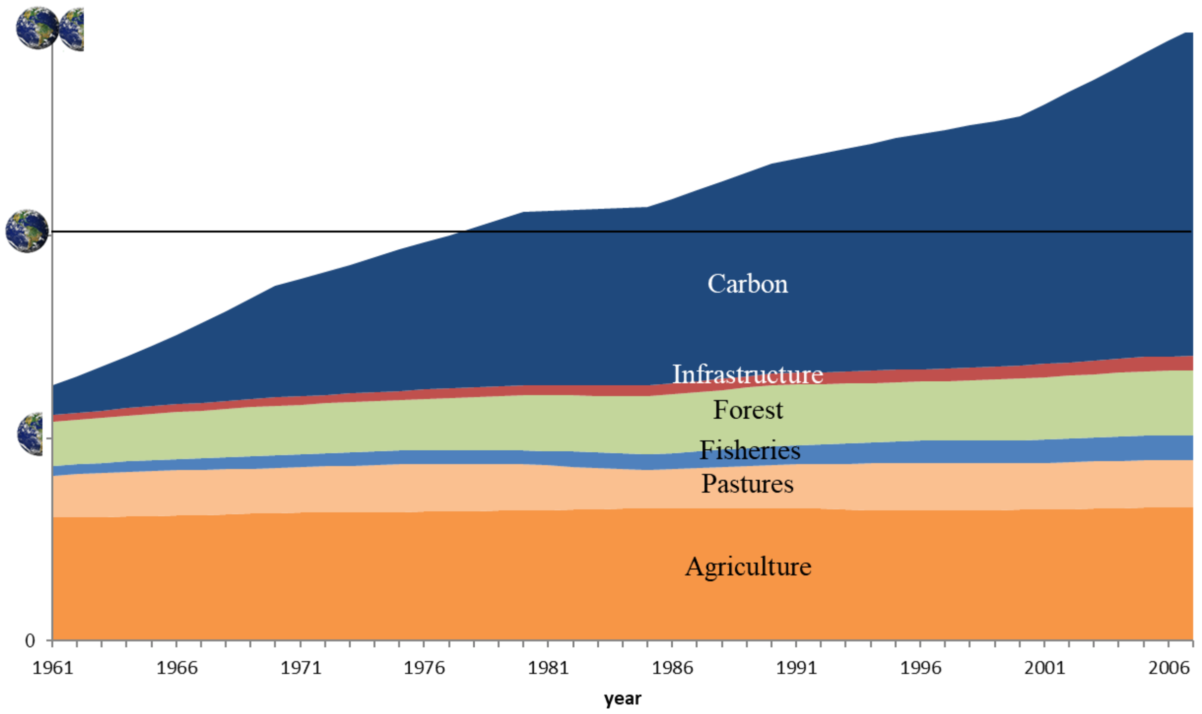
The picture changes dramatically



EF - REVIEWS AND CRITIQUES

01 COMMUNICATION BIASES





EF - REVIEWS AND CRITIQUES

02 CARBON ECOLOGICAL FOOTPRINT

"The biologically productive land and sea area a population requires to produce the biotic resources it consumes and absorb the waste it generates, using prevailing technology and resource management practices"

Why Forest?

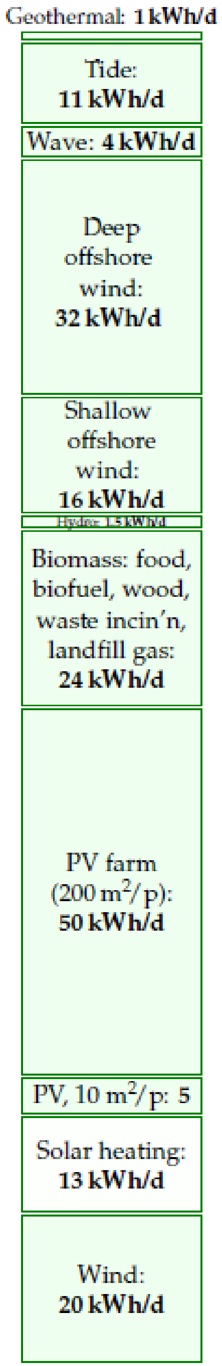
EF - REVIEWS AND CRITIQUES

02 CARBON ECOLOGICAL FOOTPRINT

Alternatives:

1. Considering all areas (not only forest)
2. Bioenergy (Wackernagel and Rees, 1996)
3. the number of global hectares originally needed to produce the living matter embodied in a given quantity of fossil fuel.

Shadow projects that can be considered either to compensate or avoid carbon emission…and
The most efficient should be chosen



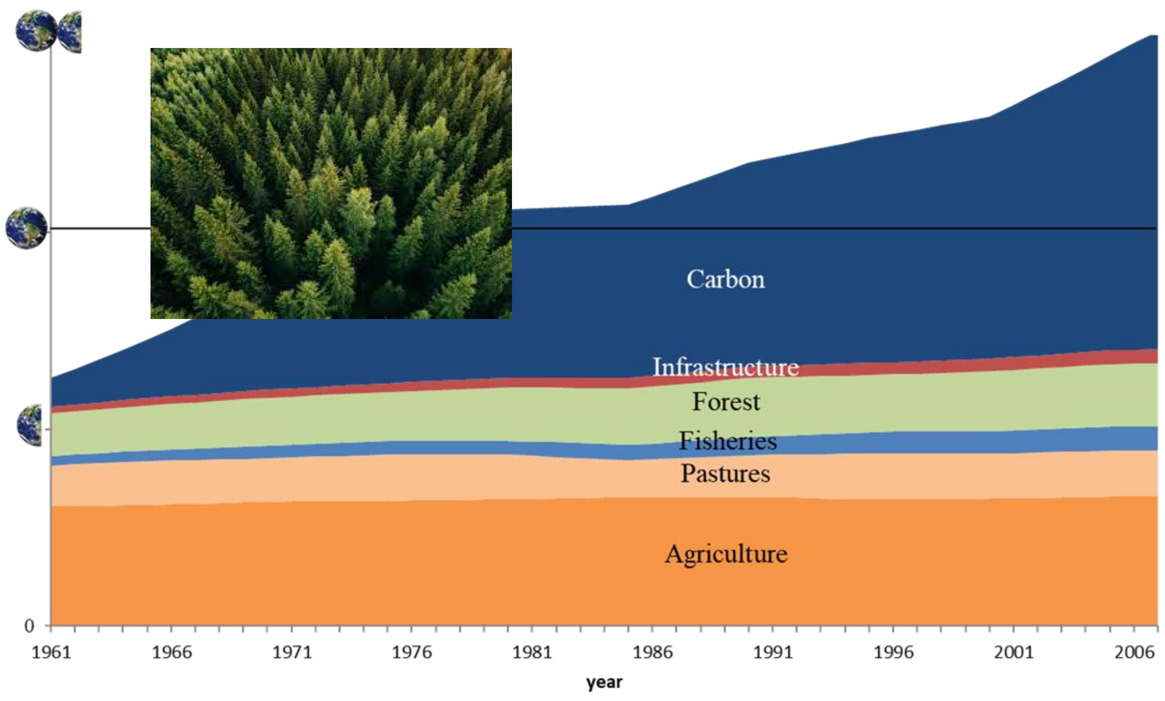
EF

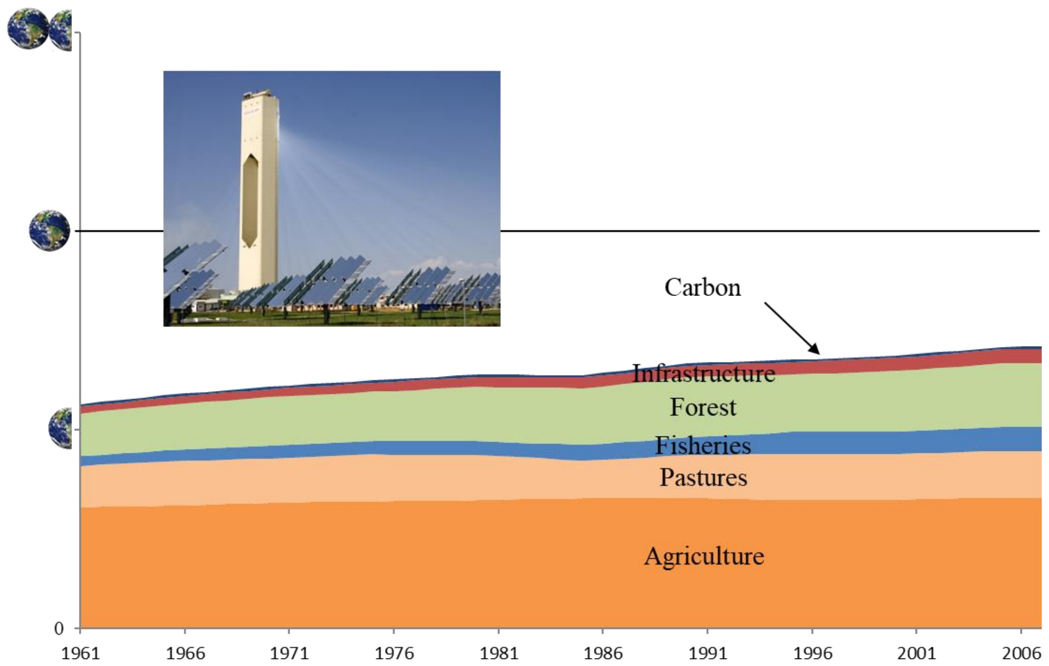
02

EF
02

Space needed for solar power plants to generate enough electric power in order to meet the electricity demand of the World, Europe (EU-25) and Germany (De) respectively. (Data by the German Center of Aerospace (DLR), 2005)

EF - REVIEWS AND CRITIQUES
02 CARBON ECOLOGICAL FOOTPRINT





EF - REVIEWS AND CRITIQUES
03 WASTES' ECOLOGICAL FOOTPRINT

"The biological productive land and sea area a population requires to produce the biotic resources it consumes and absorb the waste it generates, using prevailing technology and resource management practices"

No waste apart from CO_2 emissions (and buildings required for recycling buildings and landfills) is accounted.

Emissions such as other GHG, SOx, NOx, particles, water pollutants, radioactive waste, etc. are not accounted for.

04 LOSS OF INFORMATION AT THE AGGREGATE LEVEL

As an aggregated indicator of resource use with a single sustainability threshold, the footprint provides no information on when specific ecological limits might be reached, which brings limitations in terms of policy and action.

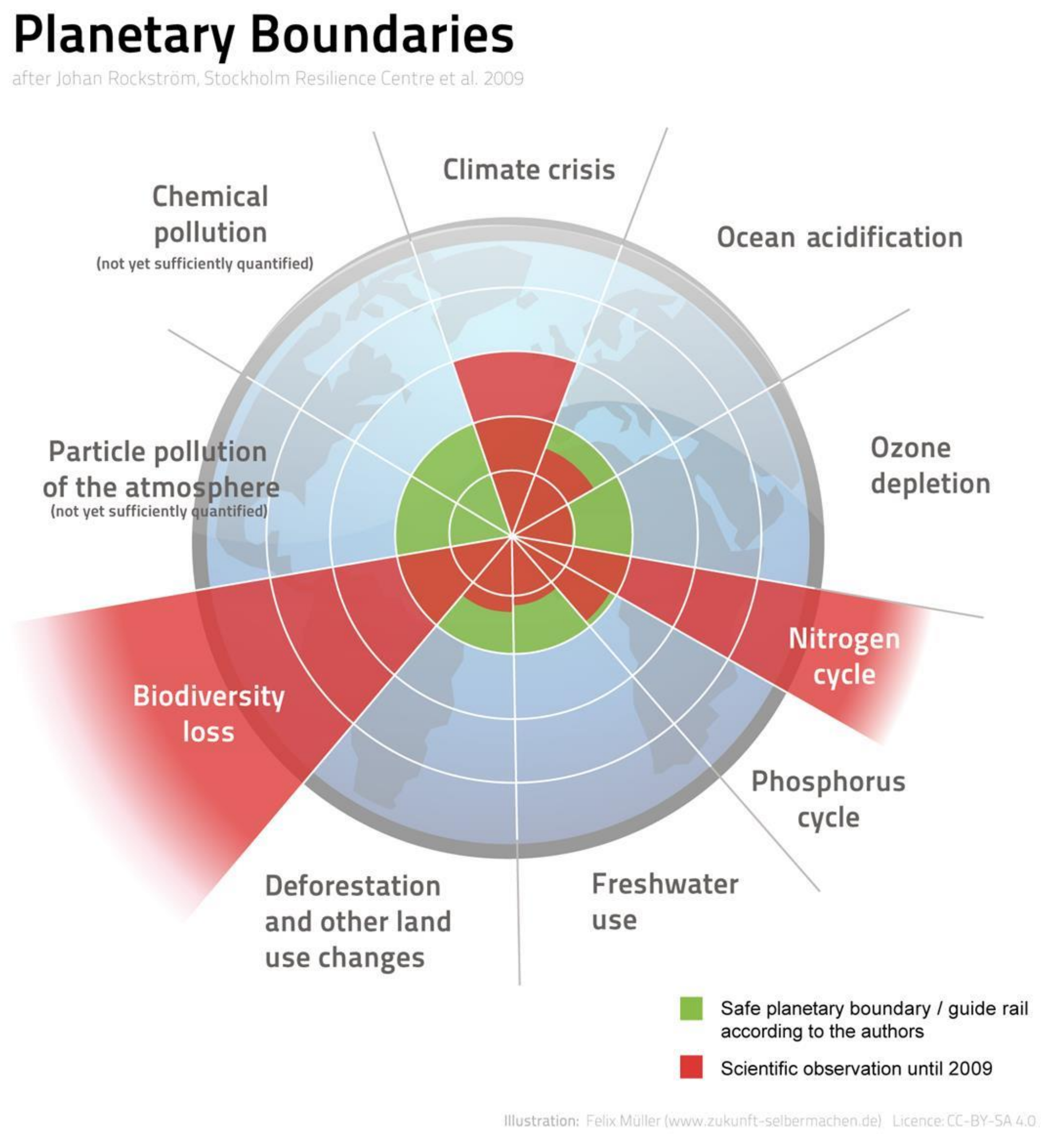
ECOLOGICAL FOOTPRINT

SUMMARY

+ Operationalises the biocapacity of Earth
+ Quantifies human pressure on Earth
+ Easy to understand unit – hectares. Good educational/ communication tool

- Leaves many environmental aspects out
- Some approaches used are questionable
- Oversimplified method (to describe a complex reality)

PLANETARY BOUNDARIES FRAMEWORK



PLANETARY BOUNDARIES
BACKGROUND

This framework proposes and quantifies boundaries for anthropogenic perturbation of critical Earth-system processes:

- Identified several (9) critical earth-system processes
- Estimated the biophysical boundaries for each
- Estimated the anthropogenic pressures exerted to these processes

Initially proposed by Rockström et al (2009), further developed by other works such as Steffen et al (2015) and O'Neill et al. (2018)

PLANETARY BOUNDARIES
BACKGROUND

nature Vol 461|24 September 2009

FEATURE

A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1-3]. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene[4], in which human actions have become the main driver of global environmental change[5]. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world.

During the Holocene, environmental change occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all stayed within a relatively narrow range. Now, largely because of a rapidly growing reliance on fossil fuels and industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state. The result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development[6]. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[7].

ROAD TO COPENHAGEN

SUMMARY
- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

Planetary boundaries

To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries'. These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although Earth's complex systems sometimes respond smoothly to changing pressures, it seems that this will prove to be the exception rather than the rule. Many subsystems of Earth react in a nonlinear, often abrupt, way and are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans[8,9].

Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (see Fig. 1 and Table).

In general, planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds — for processes with evidence of threshold behaviour — or at dangerous levels — for processes without

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

PLANETARY BOUNDARIES
THE BOUNDARIES

01 Climate change

09 Stratospheric ozone layer depletion

08 Atmospheric aerosol loading

02 Biogeochemical cycles

07 Ocean acidification

03 Biosphere integrity

06 Global freshwater use

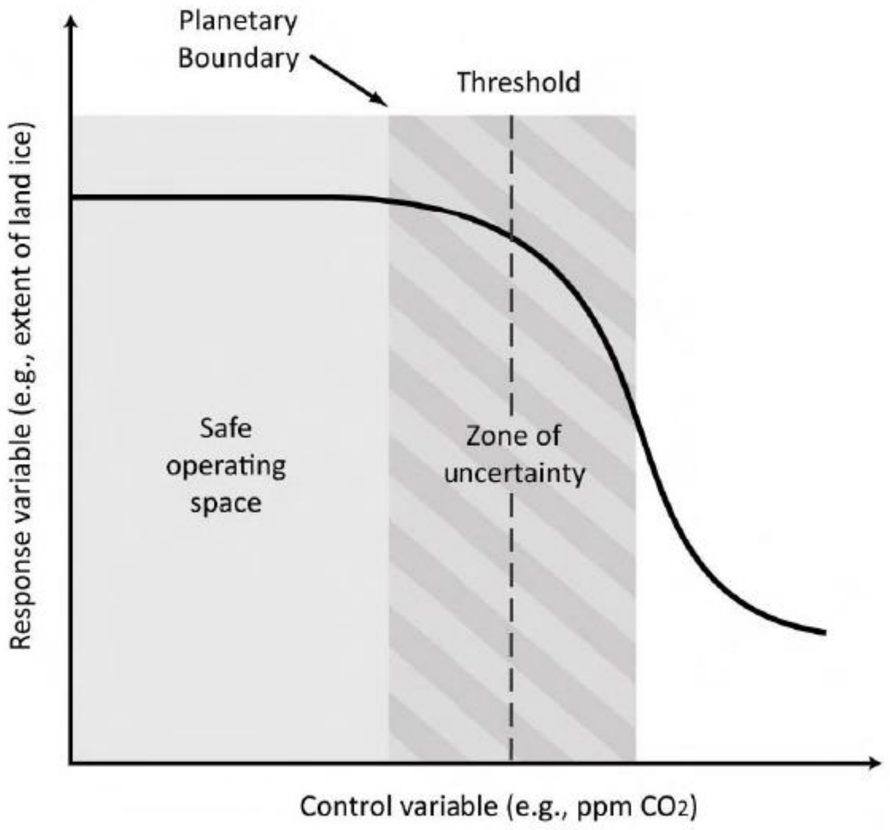
04 Land system change

05 Novel entities

PLANETARY BOUNDARIES
BACKGROUND

Boundaries

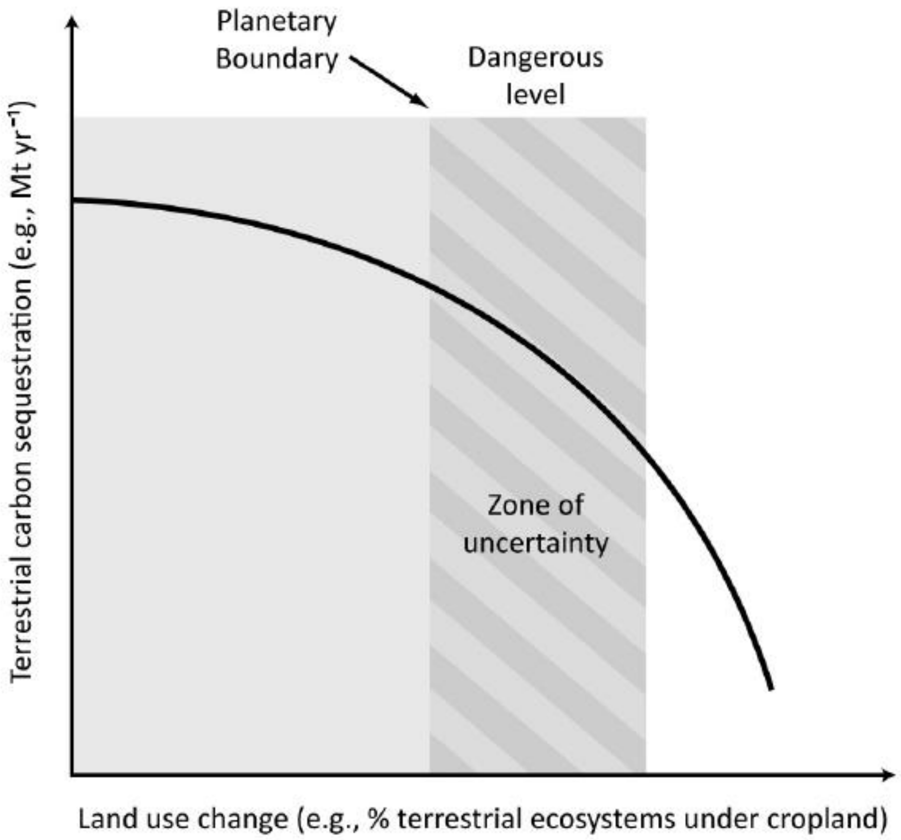
Boundary character / Scale of process	Processes with global scale thresholds	Slow processes without known global scale thresholds
Systemic processes at planetary scale	Climate Change	
	Ocean Acidification	
	Stratospheric Ozone	Stratospheric Ozone



PLANETARY BOUNDARIES
BACKGROUND

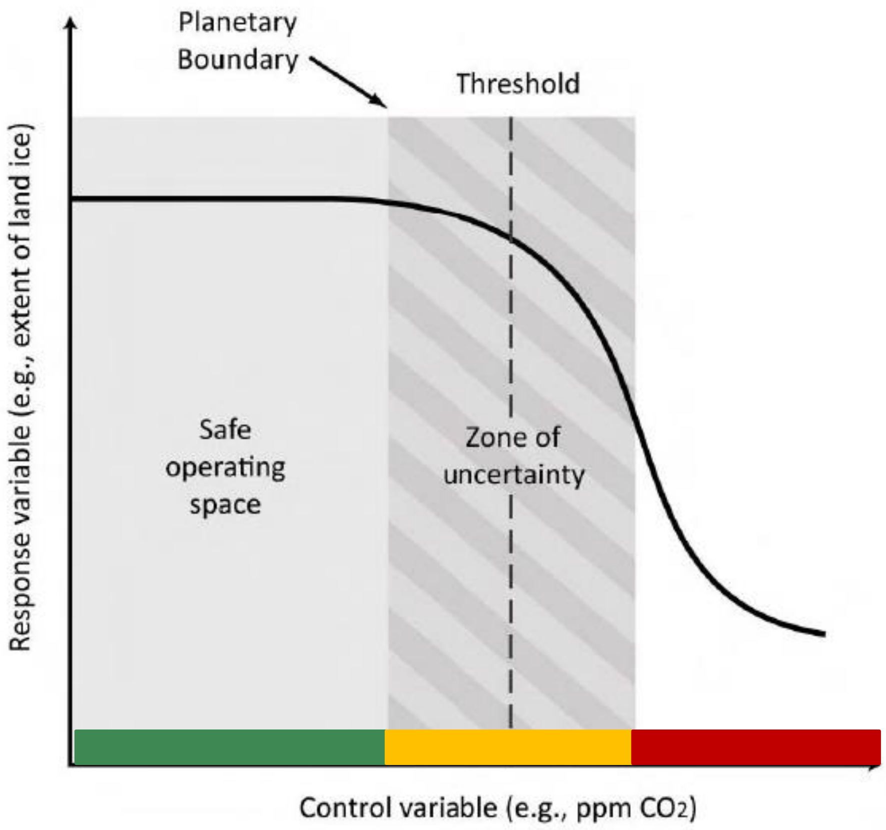
Boundaries

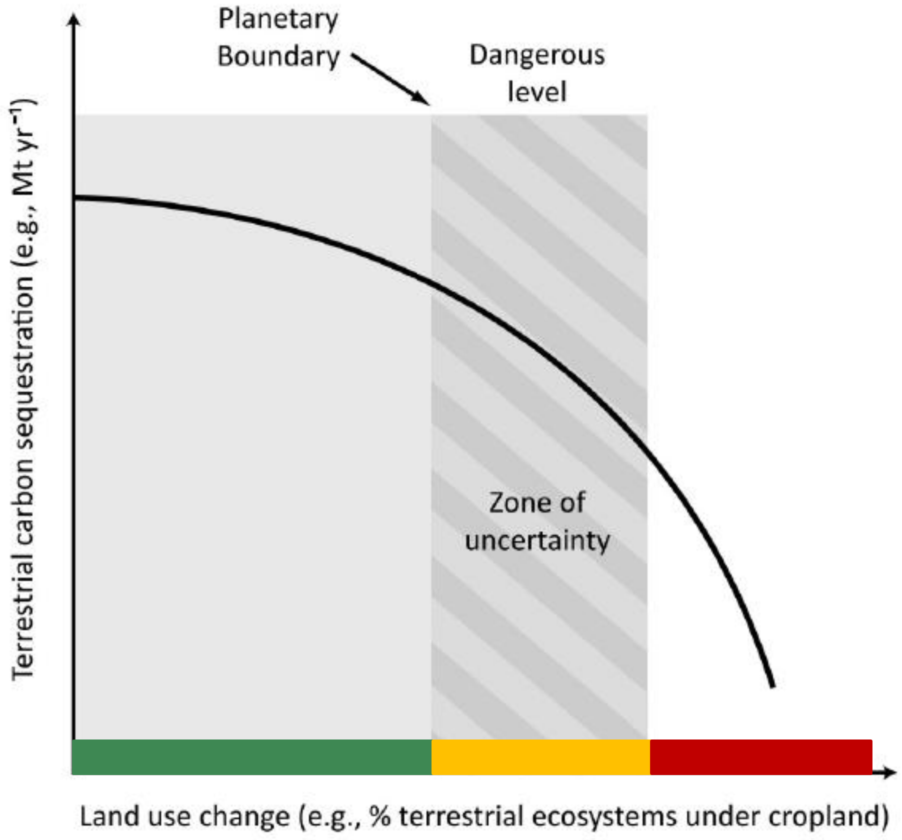
Boundary character / Scale of process	Processes with global scale thresholds	Slow processes without known global scale thresholds
Aggregated processes from local/regional scale	Global P and N cycles	Global P and N cycles
	Atmospheric Aerosol Loading	Atmospheric Aerosol Loading
	Freshwater Use	Freshwater Use
	Land Use Change	Land Use Change
		Biodiversity Loss
		Chemical Pollution



PLANETARY BOUNDARIES
BACKGROUND

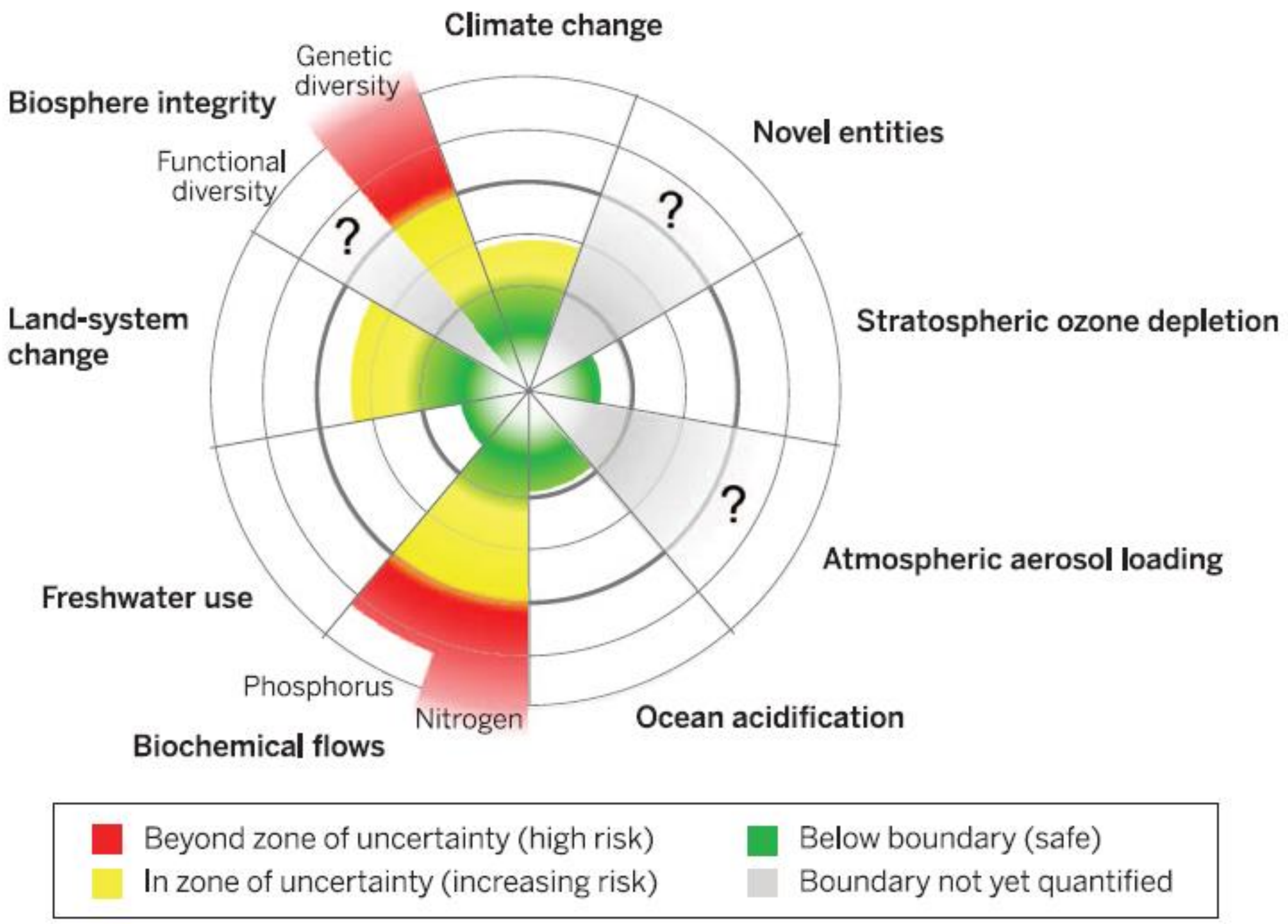
Boundaries





PLANETARY BOUNDARIES
BACKGROUND

Boundaries



PLANETARY BOUNDARIES
THE BOUNDARIES

01 Climate change

09 Stratospheric ozone layer depletion

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03 Biosphere integrity

06 Global freshwater use

04 Land system change

05 Novel entities

PLANETARY BOUNDARIES
01 CLIMATE CHANGE

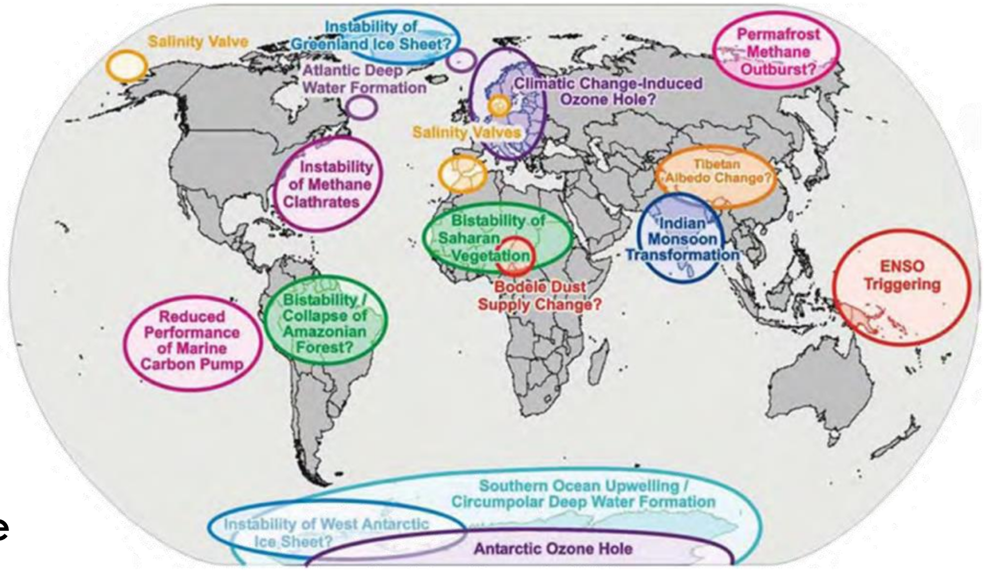
Recent evidence suggests that the Earth, now passing 390 ppmv CO_2 in the atmosphere, has already transgressed the planetary boundary and is approaching several Earth system thresholds.

We have reached a point at which the loss of summer polar sea-ice is almost certainly irreversible.

This is one example of a well-defined threshold above which rapid physical feedback mechanisms can drive the Earth system into a much warmer state with sea levels metres higher than present.

The weakening or reversal of terrestrial carbon sinks, for example through the on-going destruction of the world's rainforests, is another potential tipping point, where climate-carbon cycle feedbacks accelerate Earth's warming and intensify the climate impacts.

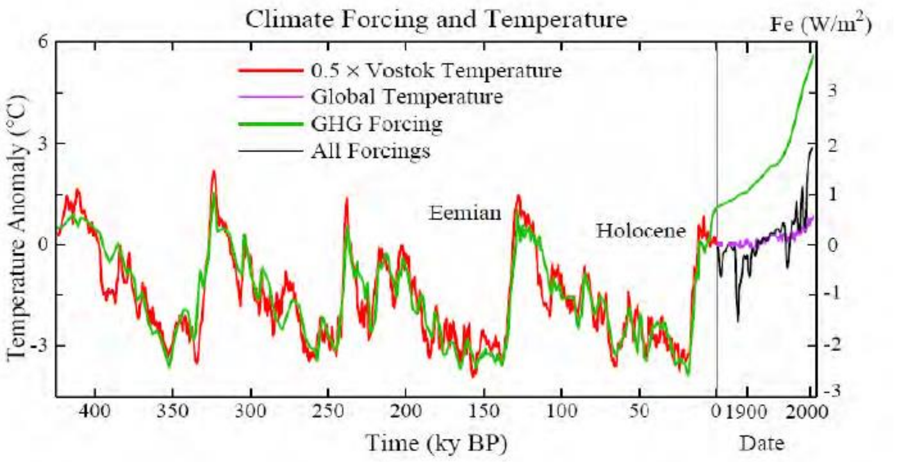
A major question is how long we can remain over this boundary before large, irreversible changes become unavoidable.



PLANETARY BOUNDARIES
01 CLIMATE CHANGE

Boundary

- Maximum concentration of CO_2 in the atmosphere of **350 ppm** - a value that would likely preserve the climate in a Holocene-like state (Steffen et al. 2015)
- However, it is generally regarded as unlikely that atmospheric CO_2 can be brought below 350 ppm in the 21st century. Even the most optimistic integrated assessment scenarios considered in the IPCC's Fifth Assessment Report (AR5) only achieve a range of 420–440 ppm by 2100.
- As an alternative boundary to 350 ppm, the 2°C temperature stabilisation goal emphasised in the **Paris Agreement**. approximately **1.61 t CO_2 per capita** (O'Neill et al. 2018)



PLANETARY BOUNDARIES

01 CLIMATE CHANGE

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Climate change (R2009: same)	Atmospheric CO_2 concentration, ppm	350 ppm CO_2 (350–450 ppm)	398.5 ppm CO_2
	Energy imbalance at top-of-atmosphere, W m^{-2}	+1.0 W m^{-2} (+1.0–1.5 W m^{-2})	2.3 W m^{-2} (1.1–3.3 W m^{-2})

PLANETARY BOUNDARIES

01 CLIMATE CHANGE

Pressures

$1.61\ tCO_2.person^{-1}.yr^{-1}$

Qatar	20.75
Singapore	19.19
Kuwait	18.22
United Arab Emirates	14.51
United States of America	13.14

Central African Republic, Liberia and Mali	0.08
Niger	0.07
Côte d'Ivoire	0.06
Somalia	0.05
Chad	0.04

34% countries are living below Earth's biocapacity

Consumption based approach

PLANETARY BOUNDARIES

02 BIOGEOCHEMICAL FLOWS

Considers the pollution caused by Phosphorous and Nitrogen loading (of soil and water).

It affects:

- Climate change
- Fresh water availability
- Biodiversity and human life

PLANETARY BOUNDARIES

02 BIOGEOCHEMICAL FLOWS

Considers the pollution caused by Phosphorous and Nitrogen loading (of soil and water).

Boundary

- Phosphorous
  The planetary boundary is 6.2 Tg P y-1 mined and applied to erodible (agricultural) soils. This gives a
  per capita boundary of 0.89 kg P y-1.
- Nitrogen
  The planetary boundary for nitrogen is 62Tg N y-1 from industrial and intentional biological fixation. This gives a
  per capita boundary of 8.9 kg N y-1.

PLANETARY BOUNDARIES
02 BIOGEOCHEMICAL FLOWS

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Biogeochemical flows: (P and N cycles) (R2009: Biogeochemical flows: (interference with P and N cycles))	*P Global*: P flow from freshwater systems into the ocean	11 Tg P yr^{-1} (11–100 Tg P yr^{-1})	~22 Tg P yr^{-1}
	P Regional: P flow from fertilizers to erodible soils	6.2 Tg yr^{-1} mined and applied to erodible (agricultural) soils (6.2-11.2 Tg yr^{-1}). Boundary is a global average but regional distribution is critical for impacts.	~14 Tg P yr^{-1}
	N Global: Industrial and intentional biological fixation of N	62 Tg N yr^{-1} (62–82 Tg N yr^{-1}). Boundary acts as a global 'valve' limiting introduction of new reactive N to Earth System, but regional distribution of fertilizer N is critical for impacts.	~150 Tg N yr^{-1}

PLANETARY BOUNDARIES

02 BIOGEOCHEMICAL FLOWS

Pressures $0.89\ TgP.person^{-1}.yr^{-1}$

New Zealand	17.36
Canada	16.20
Australia	9.61
Norway	8.48
Lithuania	8.14

(Portugal: 5.50)

Nigeria, Mozambique, Afghanistan and Chad	0.07
Madagascar	0.06
Côte d'Ivoire	0.05
Tanzania and Uganda	0.04
Somalia	0.03

44% countries are living below Earth's biocapacity

Consumption based approach

02 BIOGEOCHEMICAL FLOWS

Pressures 8.9 TgN .person^{-1}.yr^{-1}

Canada	15.16
Norway	12.13
Finland	10.82
Sweden	10.68
Lithuania	10.37

(Portugal: 5.42)

Ghana, Cameroon and Malawi	0.11
Mozambique	0.09
Nigeria and Madagascar	0.08
Côte d'Ivoire	0.07
Tanzania, Uganda and Somalia	0.05

44% countries are living below Earth's biocapacity

Consumption based approach

03 BIOSPHERE INTEGRITY

The Millennium Ecosystem Assessment of 2005 concluded that changes to ecosystems due to human activities were more rapid in the past 50 years than at any time in human history, increasing the risks of abrupt and irreversible changes.

The main drivers of change are the demand for food, water, and natural resources, causing severe biodiversity loss and leading to changes in ecosystem services. These drivers are either steady, showing no evidence of declining over time, or are increasing in intensity.

The current high rates of ecosystem damage and extinction can be slowed by efforts to protect the integrity of living systems (the biosphere), enhancing habitat, and improving connectivity between ecosystems while maintaining the high agricultural productivity that humanity needs. Further research is underway to improve the availability of reliable data for use as the 'control variables' for this boundary.

PLANETARY BOUNDARIES
03 BIOSPHERE INTEGRITY

Considers both genetic diversity (biodiversity) and functional diversity (ecosystem services).

Boundary

- Genetic diversity:
  Extinction rate. Ideally 1 E/MSY (extinction per million species year) - the order of magnitude of the natural background rate. Currently set at: **10 E/MSY**.
- Functional diversity:
  There is not enough data to define a boundary yet. A rough aprox. is the Biodiversity Intactness Index (BII). Temporary boundary set at **BII > 90%**.

PLANETARY BOUNDARIES

03 BIOSPHERE INTEGRITY

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Change in biosphere integrity (R2009: Rate of biodiversity loss)	*Genetic diversity:* Extinction rate	< 10 E/MSY (10–100 E/MSY) but with an aspirational goal of ca. 1 E/MSY (the background rate of extinction loss). E/MSY = extinctions per million species-years	100–1000 E/MSY
	Functional diversity: Biodiversity Intactness Index (BII) Note: These are interim control variables until more appropriate ones are developed	Maintain BII at 90% (90–30%) or above, assessed geographically by biomes/large regional areas (e.g. southern Africa), major marine ecosystems (e.g., coral reefs) or by large functional groups	84%, applied to southern Africa only

PLANETARY BOUNDARIES
04 LAND-SYSTEM CHANGE

This border accounts for deforestation

It affects:

- Biodiversity and ecosystem functions,
- Climate change

PLANETARY BOUNDARIES

04 LAND-SYSTEM CHANGE

Boundary

- In Steffen et al (2015), the boundary was the area of forested land as a % of the original forest cover. Value: 75% weighted average of three individual biome boundaries and their uncertainty zones. This means **1995 Mha, or about 0.3 ha per capita.**

- However:
  (i) the distribution of forests (and the use of forest products) varies substantially among countries, and
  (ii) the area of forested land associated with the consumption of goods and services is a crude (and difficult to measure) indicator

- O'Neill et al (2018) consider "human appropriation of net primary production" (HANPP). HANPP measures the amount of biomass harvested through agriculture and forestry, as well as biomass that is killed during harvest but not used, and biomass that is lost due to land use change. As a planetary boundary for HANPP, we use a more robust estimate that only (20%) **5 Gt C y-1 of NPPpot** remains available for appropriation by humans

04 LAND-SYSTEM CHANGE

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Land-system change (R2009: same)	*Global:* Area of forested land as % of original forest cover	*Global:* 75% (75–54%) Values are a weighted average of the three individual biome boundaries and their uncertainty zones	62%
	Biome: Area of forested land as % of potential forest	*Biome*: Tropical: 85% (85–60%) Temperate: 50% (50–30%) Boreal: 85% (85–60%)	
eHANPP	% of the Potential net primary production (NPPpot) that would exist in the absence of human activities	5 Gt C y-1 per capita	2.62t C. Person-1. y

PLANETARY BOUNDARIES
05 NOVEL ENTITIES

Emissions of toxic and long-lived substances such as synthetic organic pollutants, heavy metal compounds and radioactive materials represent some of the key human-driven changes to the planetary environment.

These compounds can have potentially irreversible effects on living organisms and on the physical environment (by affecting atmospheric processes and climate).

Even when the uptake and bioaccumulation of chemical pollution is at sub-lethal levels for organisms, the effects of reduced fertility and the potential of permanent genetic damage can have severe effects on ecosystems far removed from the source of the pollution.

PLANETARY BOUNDARIES

05 NOVEL ENTITIES

Boundary

- 2 complementary approaches: amounts of persistent pollutants with global distribution (e.g., mercury); Effects of chemical pollution on living organisms
- Difficult to find an appropriate aggregate control variable. Close interactions with Aerosol loading; may require sub-boundaries based on sub-impacts/categories of chemicals

PLANETARY BOUNDARIES
06 GLOBAL FRESHWATER USE

Global water consumption (withdrawal)

It affects biosphere integrity

PLANETARY BOUNDARIES

06 GLOBAL FRESHWATER USE

Boundary

- The original planetary boundary for freshwater use was specified as a maximum global withdrawal of **4000 km^3 y^{-1}** of blue water from rivers, lakes, reservoirs, and renewable groundwater stores
- per capita boundary of **574 m^3 y^{-1}**.
- However, freshwater varies considerably from country to country (basin to basin) and more local boundaries should be considered. The literature is still evolving and this value is likely to change accordingly.

PLANETARY BOUNDARIES

06 GLOBAL FRESHWATER USE

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Freshwater use (R2009: Global freshwater use)	*Global:* Maximum amount of consumptive blue water use (km^3yr^{-1})	*Global:* 4000 $km^3\ yr^{-1}$ (4000–6000 $km^3\ yr^{-1}$)	~2600 $km^3\ yr^{-1}$
	Basin: Blue water withdrawal as % of mean monthly river flow	*Basin:* Maximum monthly withdrawal as a percentage of mean monthly river flow. For low-flow months: 25% (25–55%); for intermediate-flow months: 30% (30–60%); for high-flow months: 55% (55–85%)	

06 GLOBAL FRESHWATER USE

Pressures

574 $m^3.person^{-1}.yr^{-1}$

Turkmenistan	3160
Iran	2520
Egypt	2260
Libya	2180
Tajikistan	1810

(Portugal: 1700)

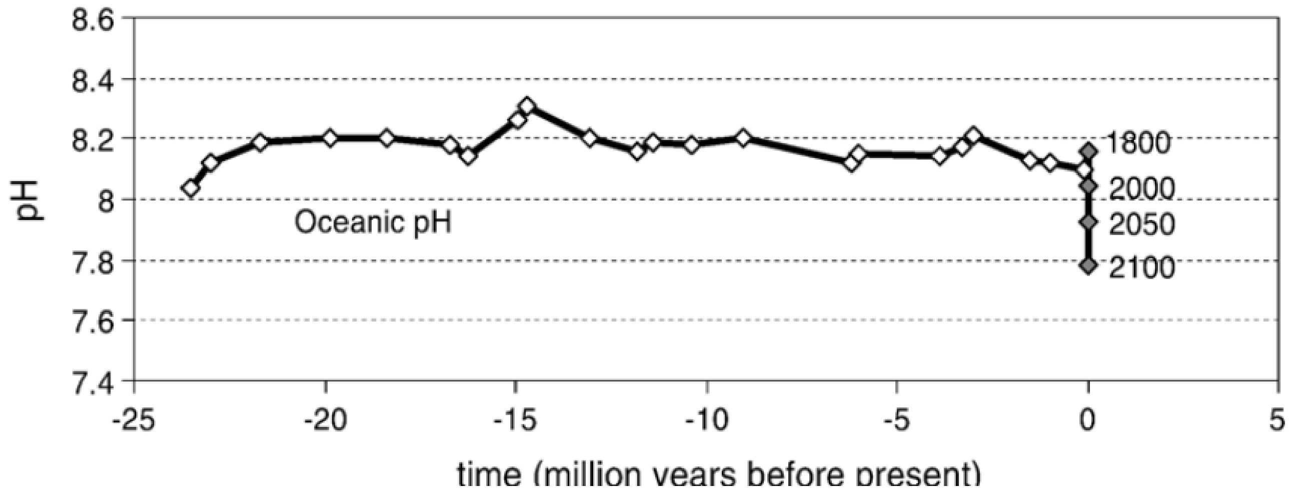
Benin and Togo	70
Malawi and Mozambique	60
Burundi	50
Uganda	40
Rwanda	30

84% countries are living below Earth's biocapacity

Consumption based approach

PLANETARY BOUNDARIES
07 OCEAN ACIDIFICATION

- Southern Ocean and Arctic ocean projected to become corrosive to aragonite by 2030-2060
- Globally surface aragonite saturation state is declining (*Ωarag*= 3.44 to a current value of 2.9)



This boundary affects:

- Biosphere integrity
- Novel entities

PLANETARY BOUNDARIES

07 OCEAN ACIDIFICATION

Boundary

- Proposed boundary > 80 % pre-industrial *Ωarag*= 2.75

PLANETARY BOUNDARIES

07 OCEAN ACIDIFICATION

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Ocean acidification (R2009: same)	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite (Ω_{arag})	≥80% of the pre-industrial aragonite saturation state of mean surface ocean, including natural diel and seasonal variability (≥80%– ≥70%)	~84% of the pre-industrial aragonite saturation state

PLANETARY BOUNDARIES
08 ATMOSPHERIC AEROSOL LOADING

Fine particle (PM2.5) air pollution

This boundary affects:

- Climate change (influence the radiative balance)
- Freshwater availability (hydrological cycle influences)
- Biosphere integrity and human health

08 ATMOSPHERIC AEROSOL LOADING

Boundary

- Goal: Avoid major influence on climate system and human health at regional to global scales
- Human activities have doubled the global concentration of most aerosols since the pre-industrial era
- **Processes and mechanisms behind these correlations remain to be fully explained**

PLANETARY BOUNDARY

08 ATMOSPHERIC AEROSOL LOADING

Pressures

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Atmospheric aerosol loading (R2009: same)	*Global:* Aerosol Optical Depth (AOD), but much regional variation		
	Regional: AOD as a seasonal average over a region. South Asian Monsoon used as a case study	*Regional*: (South Asian Monsoon as a case study): anthropogenic total (absorbing and scattering) AOD over Indian subcontinent of 0.25 (0.25–0.50); absorbing (warming) AOD less than 10% of total AOD	0.30 AOD, over South Asian region

?

PLANETARY BOUNDARIES

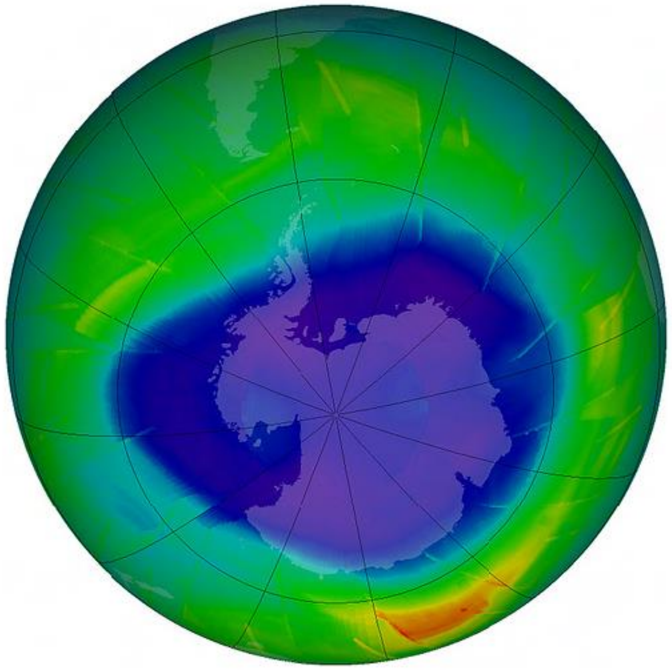
09 STRATOSPHERIC OZONE DEPLETION

The stratospheric ozone layer in the atmosphere filters out ultraviolet (UV) radiation from the sun.

If this layer decreases, increasing amounts of UV radiation will reach ground level. This can cause a higher incidence of skin cancer in humans as well as damage to terrestrial and marine biological systems.

The appearance of the Antarctic ozone hole was proof that increased concentrations of anthropogenic ozone-depleting chemical substances, interacting with polar stratospheric clouds, had passed a threshold and moved the Antarctic stratosphere into a new regime.

Fortunately, because of the actions taken as a result of the Montreal Protocol, we appear to be on the path that will allow us to stay within this boundary.



PLANETARY BOUNDARY

09 STRATOSPHERIC OZONE DEPLETION

Planetary boundary	Summary
Stratospheric ozone depletion	Less than 5 % below pre-industrial level of about 290 Dobson Units (DU)

One DU is 0.01 mm thick at standard temperature and pressure and relates to how thick the ozone layer would be if it were compressed in the Earth's atmosphere.

PLANETARY BOUNDARY

09 STRATOSPHERIC OZONE DEPLETION

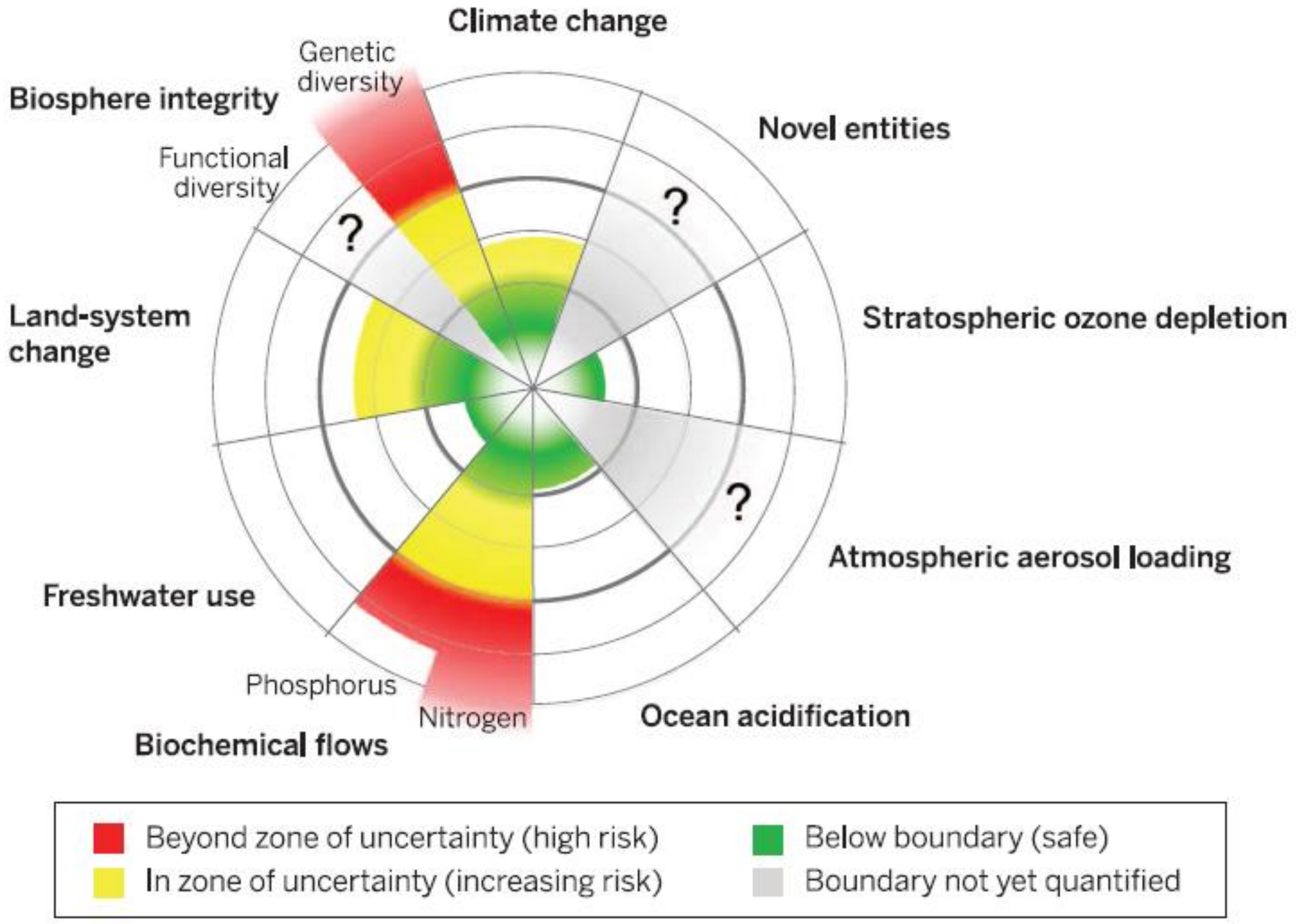
Planetary boundary	Summary	Where we were in 2015
Stratospheric ozone depletion	Less than 5 % below pre-industrial level of about 290 Dobson Units (DU)	Minimum level of 200 DU (Spring in Antarctica)

One DU is 0.01 mm thick at standard temperature and pressure and relates to how thick the ozone layer would be if it were compressed in the Earth's atmosphere.

PLANETARY BOUNDARIES

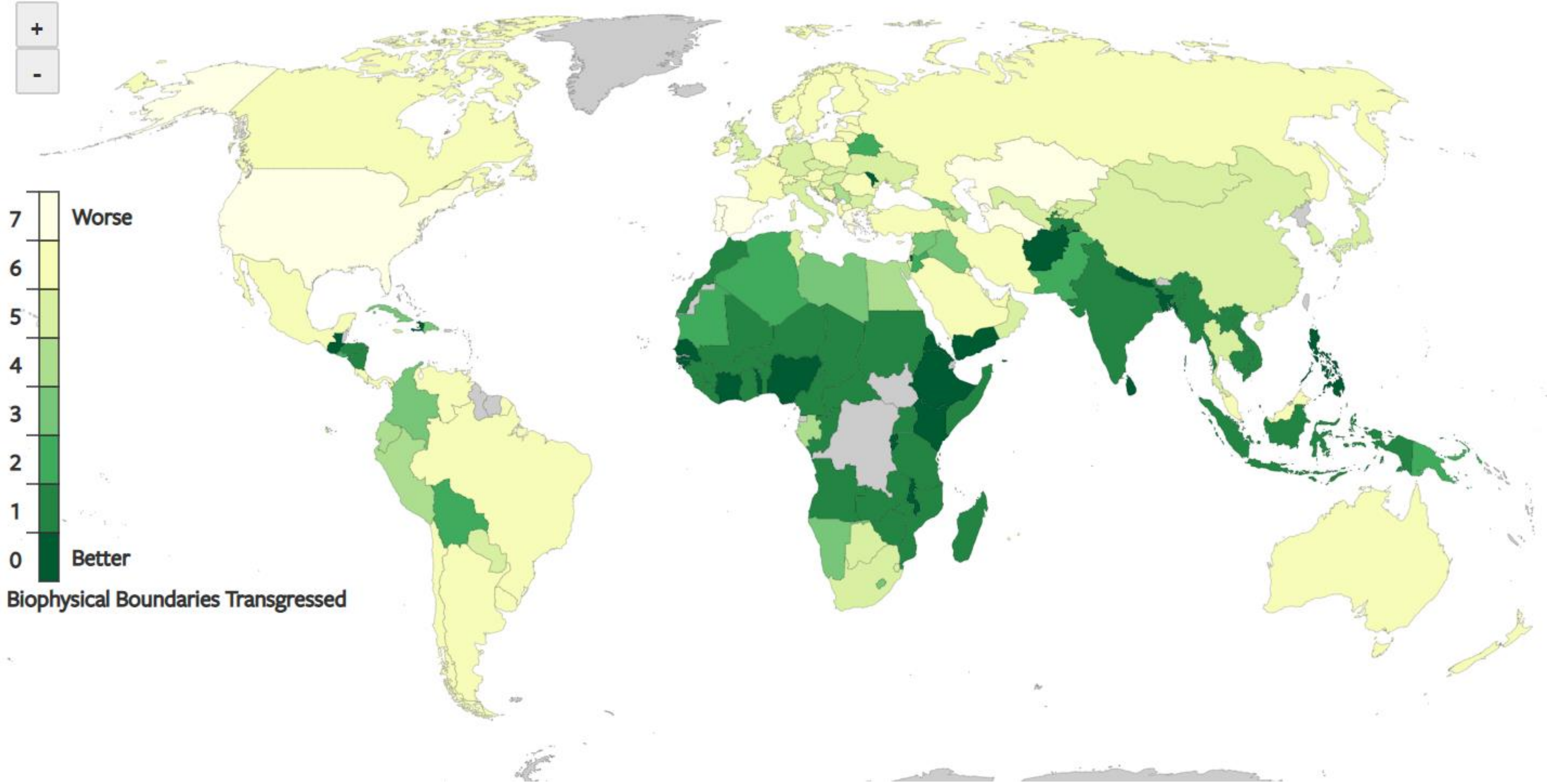
PLANETARY STATUS

- We are in the **safe place** in 3 categories: freshwater use, ocean acidification and stratospheric ozone depletion
- We are in the **danger zone** of 4 categories: climate change, genetic diversity, land-system change and biogeochemical flows
- There are 3 categories we still need more information to understand them better: atmospheric aerosol loading, novel entities and functional diversity



PLANETARY BOUNDARIES

PLANETARY STATUS



SUSTAINABLE DEVELOPMENT

To maintain society below the planetary boundaries, do we need to reduce our quality of life or our lifestyles? How far should we go?

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

What is human wellbeing, if we wanted to measure it?

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

Education

Income

Life satisfaction

Employment

Healthy life expectancy

Nutrition

Equality

Access to energy

Social support

Sanitation

Democratic quality

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

Aggregate social indicators

- Gross Domestic Product (GDP)
- Genuine Savings and Green GDP
- Human Development Index
- Happiness indicators

Frameworks of indicators

- United Nations Sustainable Development Goals (17 goals) (UN, 2015)
- Safe and just place framework (11 indicators) (Raworth, 2012; Cole et al 2014; Dearing et al 2014; O'Neill et al. 2018)

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

Aggregate social indicators

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- United Nations Sustainable Development Goals (17 goals) (UN, 2015)
- **Safe and just place framework** (11 indicators) (Raworth, 2012; Cole et al 2014; Dearing et al 2014; O'Neill et al. 2018)

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

Environment: Boundaries, thresholds, biocapacity

We cannot transgress the boundaries.

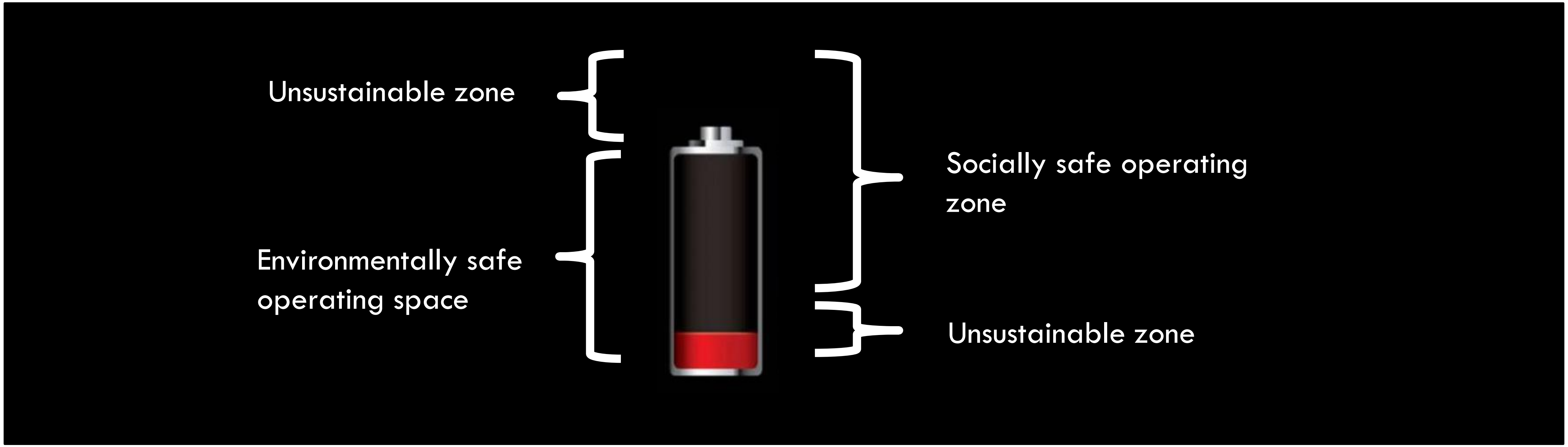
Social: Minimum standards, basic needs

We need to ensure the minimum is satisfied.

SOCIAL INDICATORS FOR SUSTAINABLE DEVELOPMENT

Environment: Boundaries, thresholds, biocapacity

Social: Minimum standards, quality, basic needs



We cannot transgress the boundaries.

We need to ensure the minimum is satisfied.

SAFE AND JUST SPACE

Linking social indicators with the Planetary Boundaries Framework

Developed by Kate Raworth, 2012. Subsequent developments: Cole et al 2014; Dearing et al 2014; O'Neill et al. 2018

1. Identify base social indicators for wellbeing
2. Quantify the boundaries/thresholds for each indicator
3. Estimate the current level

SAFE AND JUST SPACE

11 base social indicators of wellbeing

9 basic needs:

1. Nutrition
2. Sanitation
3. Income
4. Access to energy
5. Education
6. Social support
7. Equality
8. Democratic quality
9. Employment

2 overall measures of wellbeing:

10. Self-reported life satisfaction
11. Healthy life expectancy

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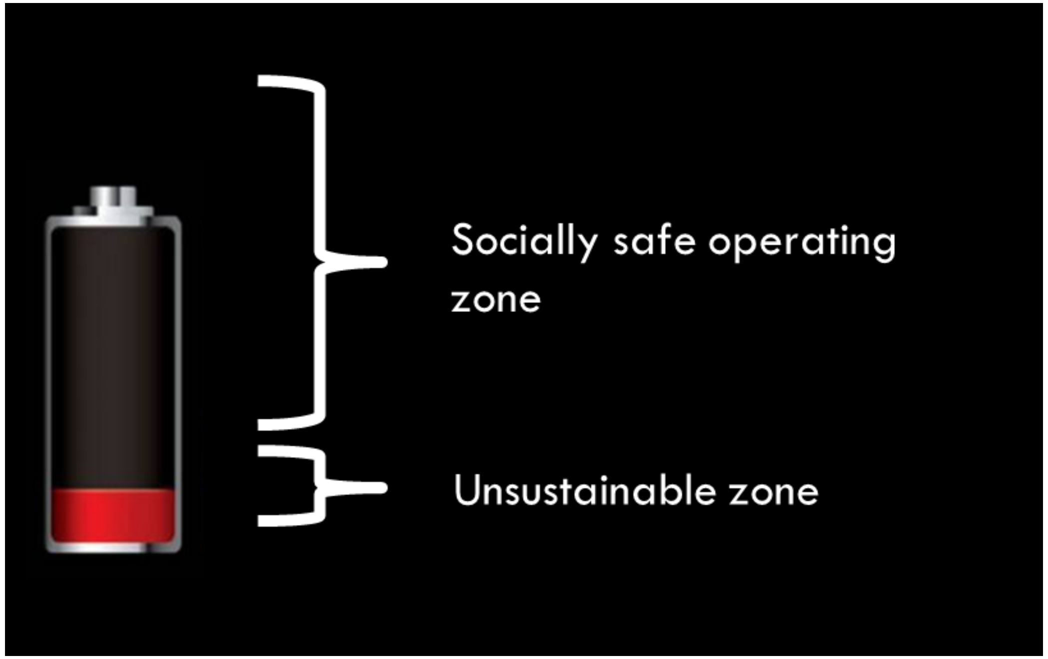
Social boundaries and thresholds



Social indicator	*N*	Threshold
Life satisfaction	134	6.5 on 0–10 Cantril ladder scale
Healthy life expectancy	134	65 years
Nutrition	144	2,700 kilocalories per person per day
Sanitation	141	95% of people have access to improved sanitation facilities
Income	106	95% of people earn above US$1.90 a day
Access to energy	151	95% of people have electricity access
Education	117	95% enrolment in secondary school
Social support	133	90% of people have friends or family they can depend on
Democratic quality	134	0.80 (approximate US/UK value)
Equality	133	70 on 0–100 scale (Gini index of 0.30)
Employment	151	94% employed (6% unemployment)

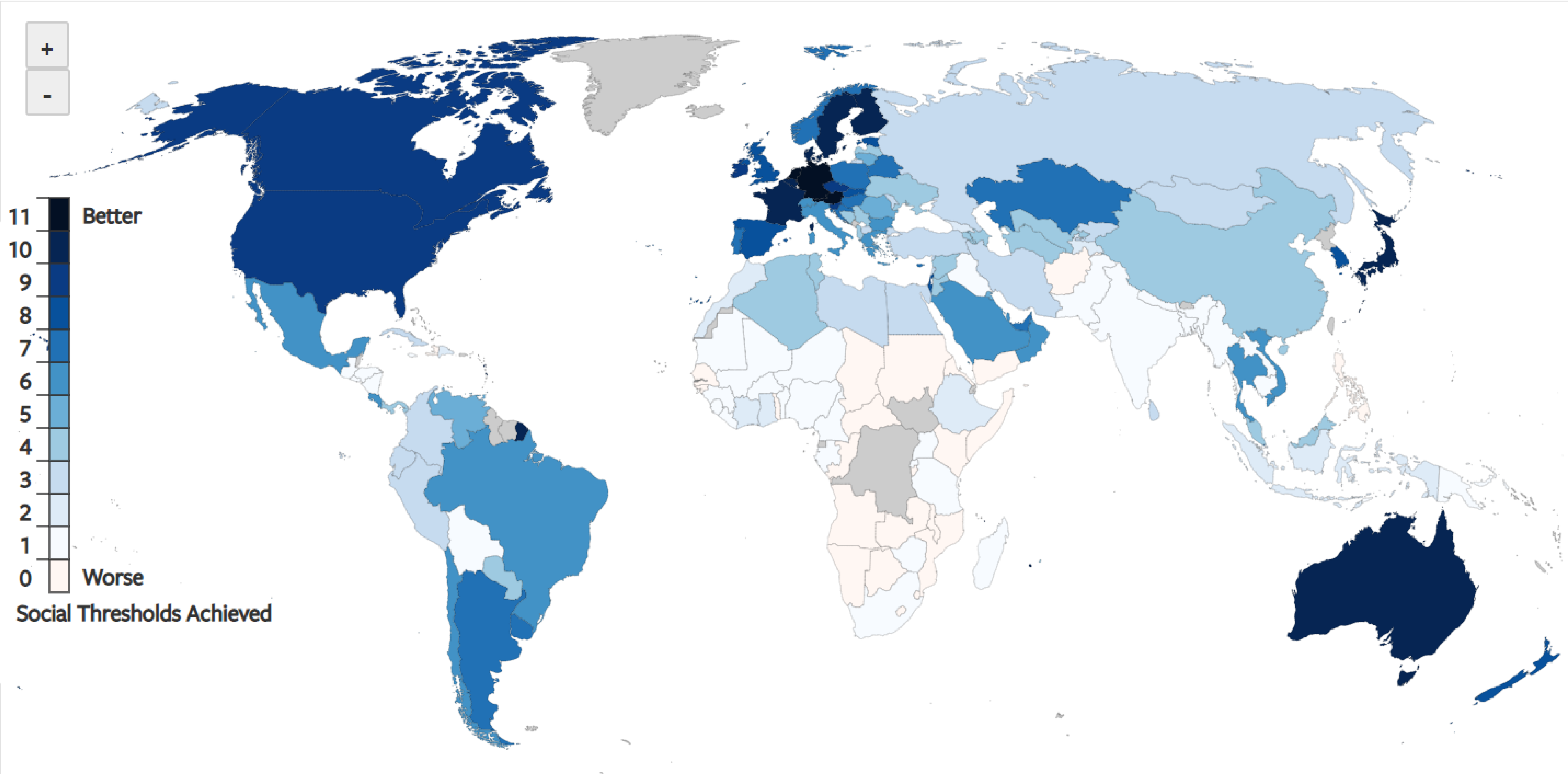
Source: O’Neill et al. 2018

SAFE AND JUST SPACE

Estimate current level of countries

Social indicator	*N*	Threshold	Countries above threshold (%)
Life satisfaction	134	6.5 on 0–10 Cantril ladder scale	25
Healthy life expectancy	134	65 years	40
Nutrition	144	2,700 kilocalories per person per day	59
Sanitation	141	95% of people have access to improved sanitation facilities	37
Income	106	95% of people earn above US$1.90 a day	68
Access to energy	151	95% of people have electricity access	59
Education	117	95% enrolment in secondary school	37
Social support	133	90% of people have friends or family they can depend on	26
Democratic quality	134	0.80 (approximate US/ UK value)	18
Equality	133	70 on 0–100 scale (Gini index of 0.30)	16
Employment	151	94% employed (6% unemployment)	38

Source: O'Neill et al. 2018



Source: O’Neill et al. 2018

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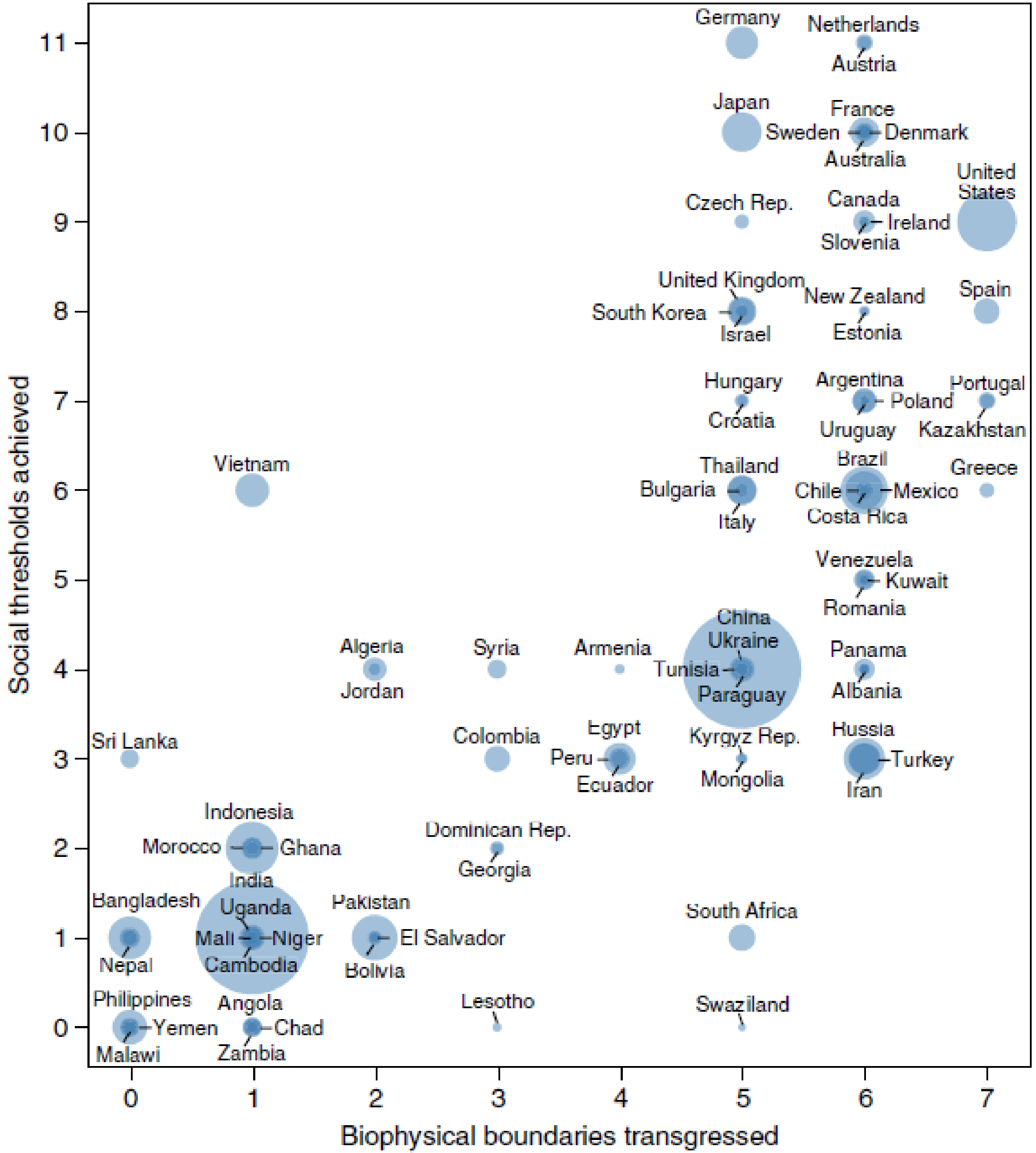
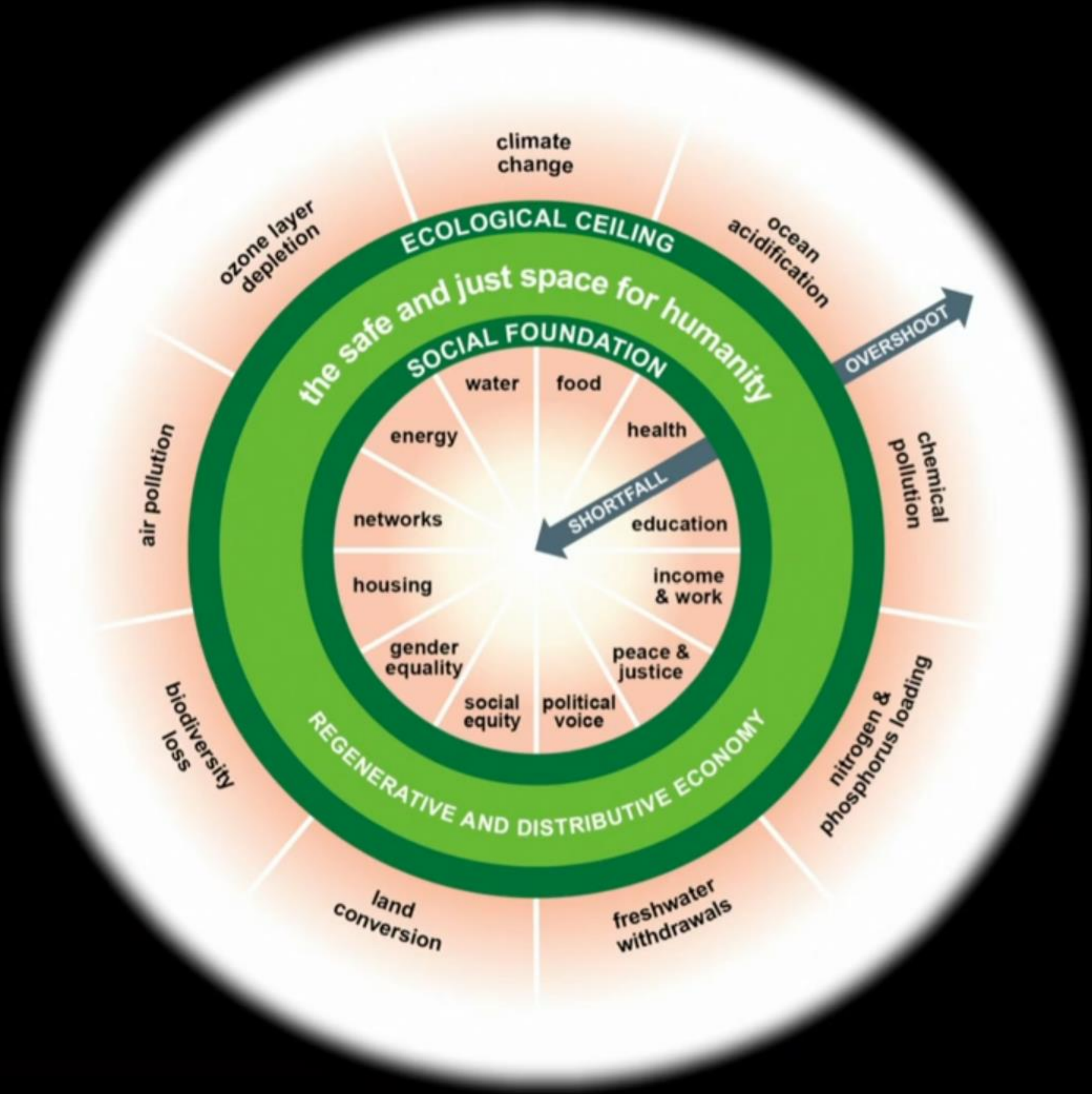
Linking environmental and social indicators



Source: O’Neill et al. 2018



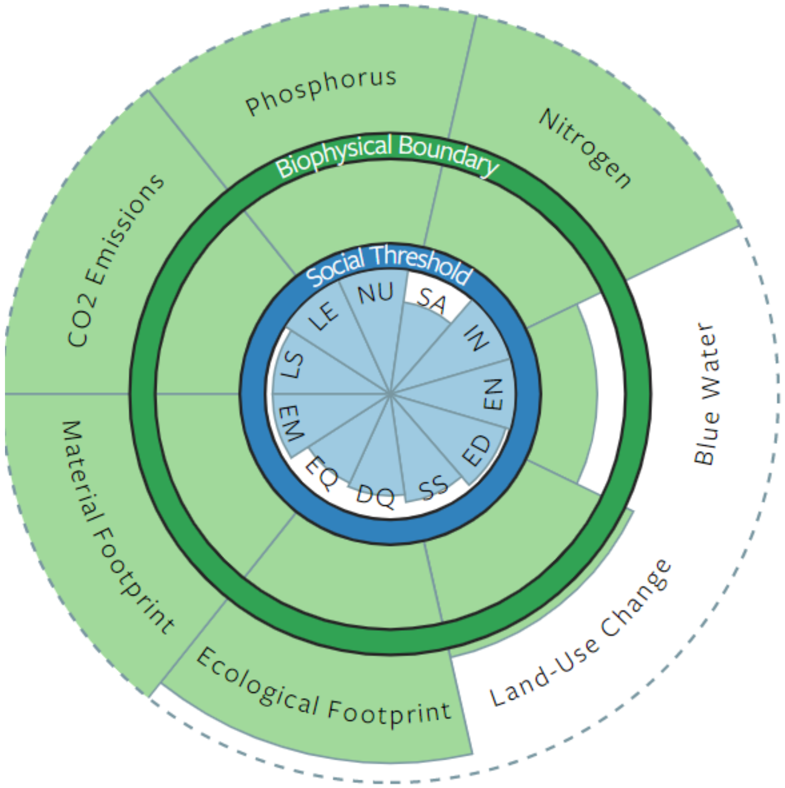
The "doughnut"
K. Raworth

SAFE AND JUST SPACE

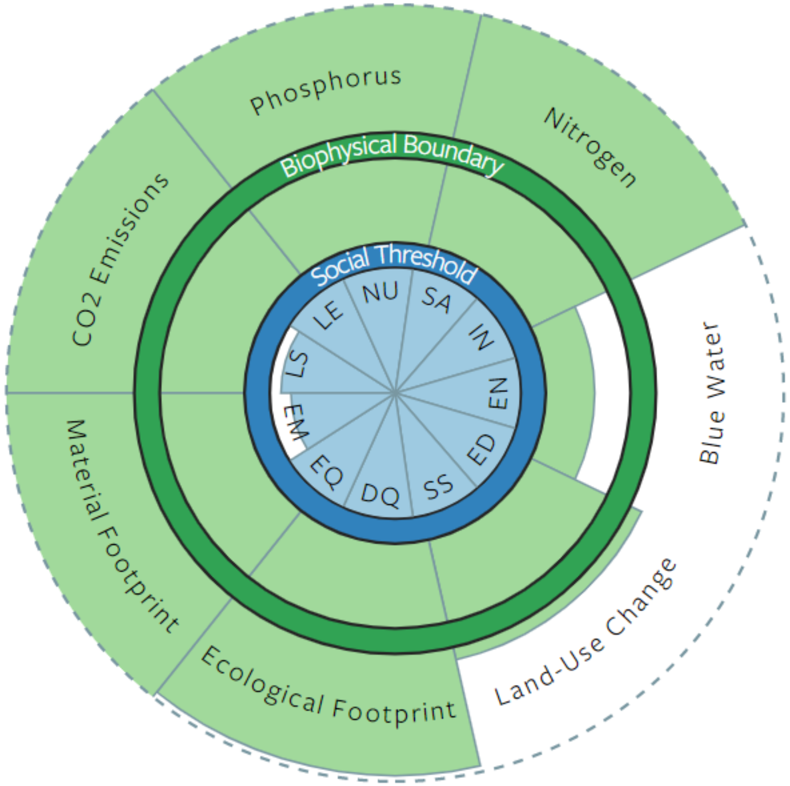
Linking environmental and social indicators

LS - Life Satisfaction
LE - Healthy Life Expect.
NU - Nutrition
SA - Sanitation
IN - Income
EN - Access to Energy
ED - Education
SS - Social Support
DQ - Democratic Quality
EQ - Equality
EM - Employment

G20



EU-28



Source: O’Neill et al. 2018

SAFE AND JUST SPACE

Linking environmental and social indicators

LS - Life Satisfaction	ED - Education
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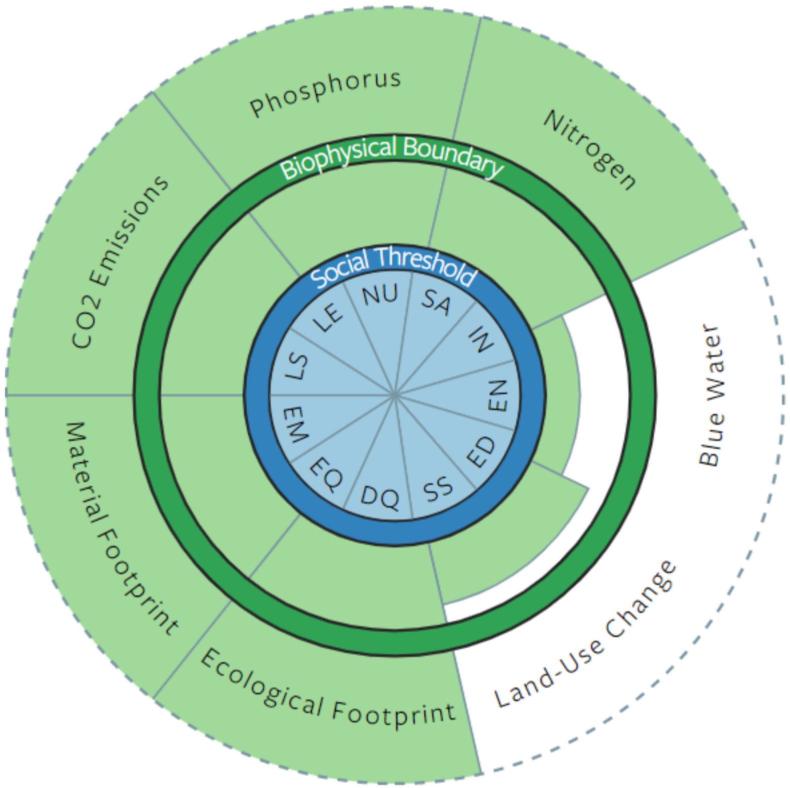
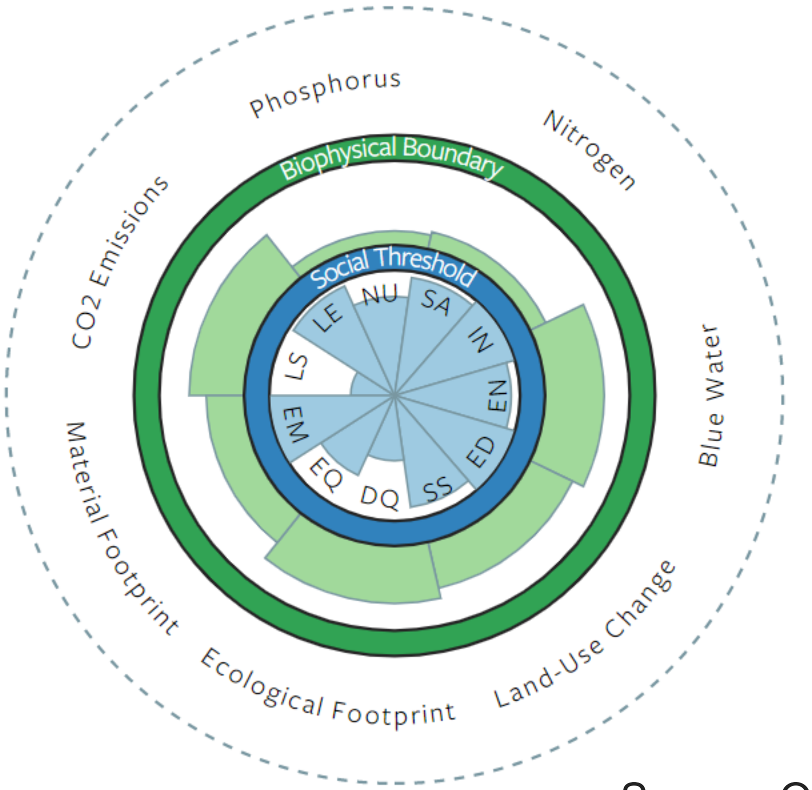
IN - Income	EM - Employment
EN - Access to Energy	

Germany



Sri Lanka



Source: O'Neill et al. 2018

SAFE AND JUST SPACE

Linking environmental and social indicators

Life Expectancy
Life Satisfaction
Carbon Footprint
GDP per Capita

LS - Life Satisfaction
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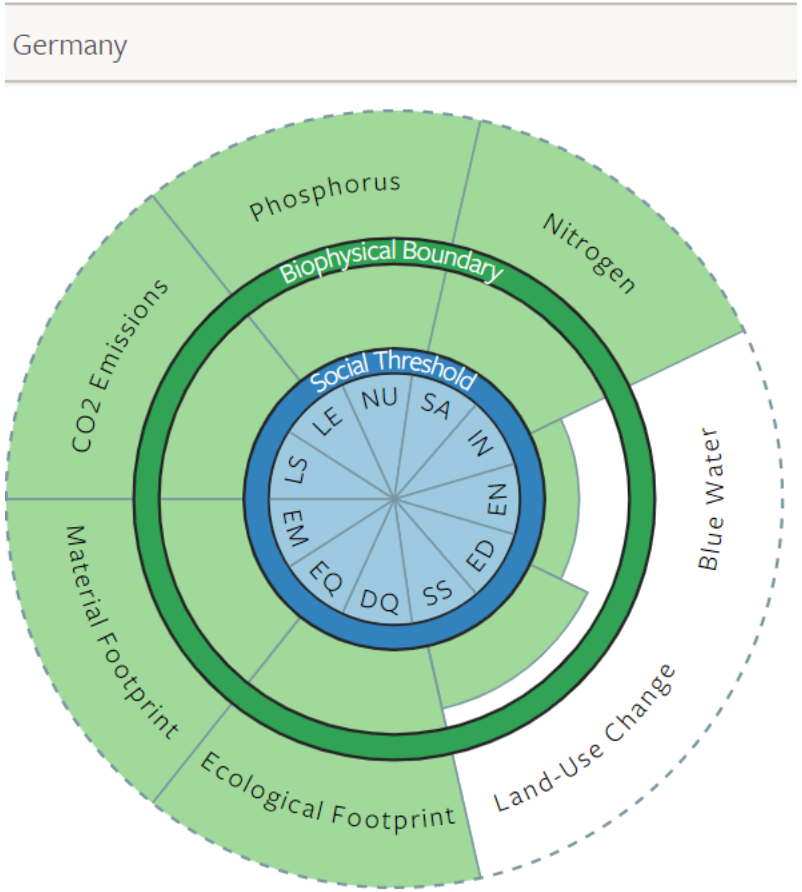

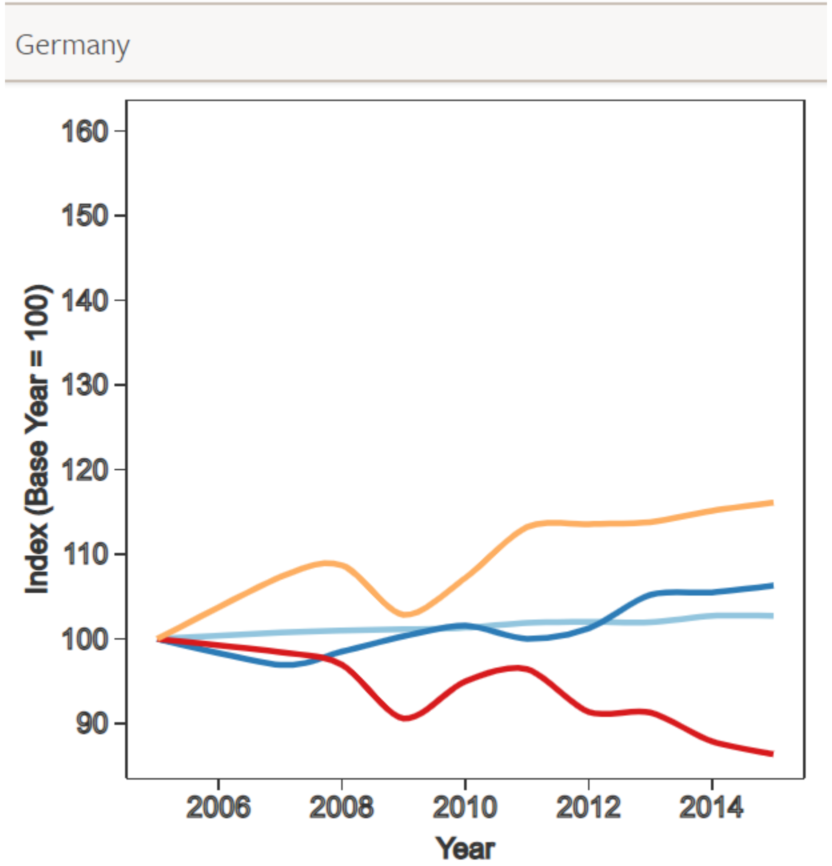

Source: O'Neill et al. 2018

SAFE AND JUST SPACE

Linking environmental and social indicators

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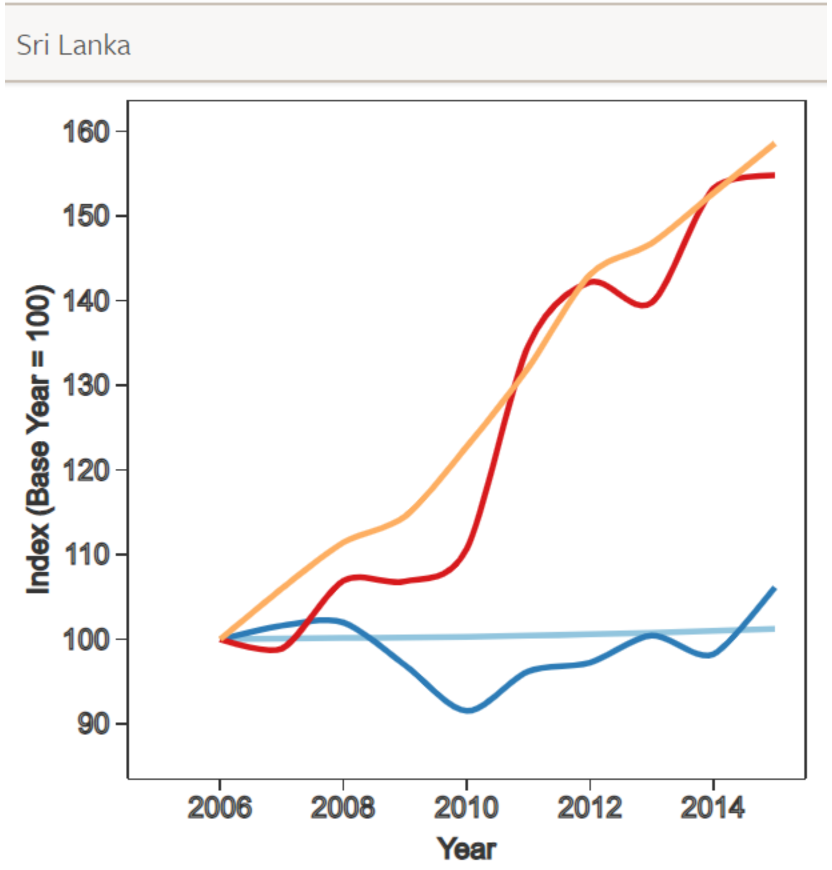

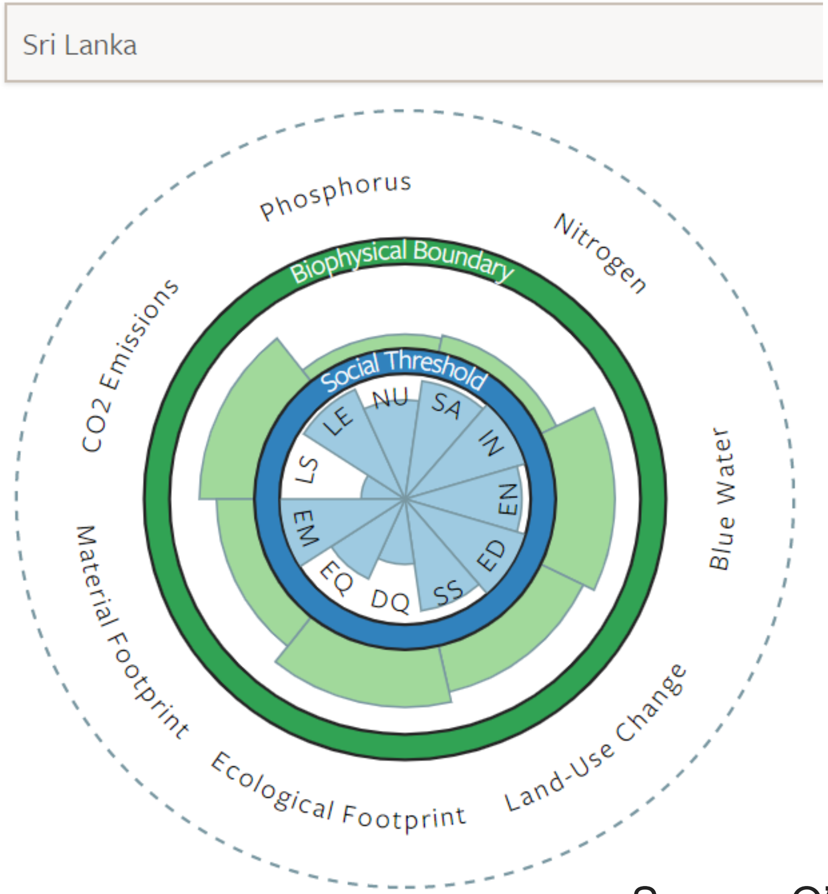

Source: O'Neill et al. 2018

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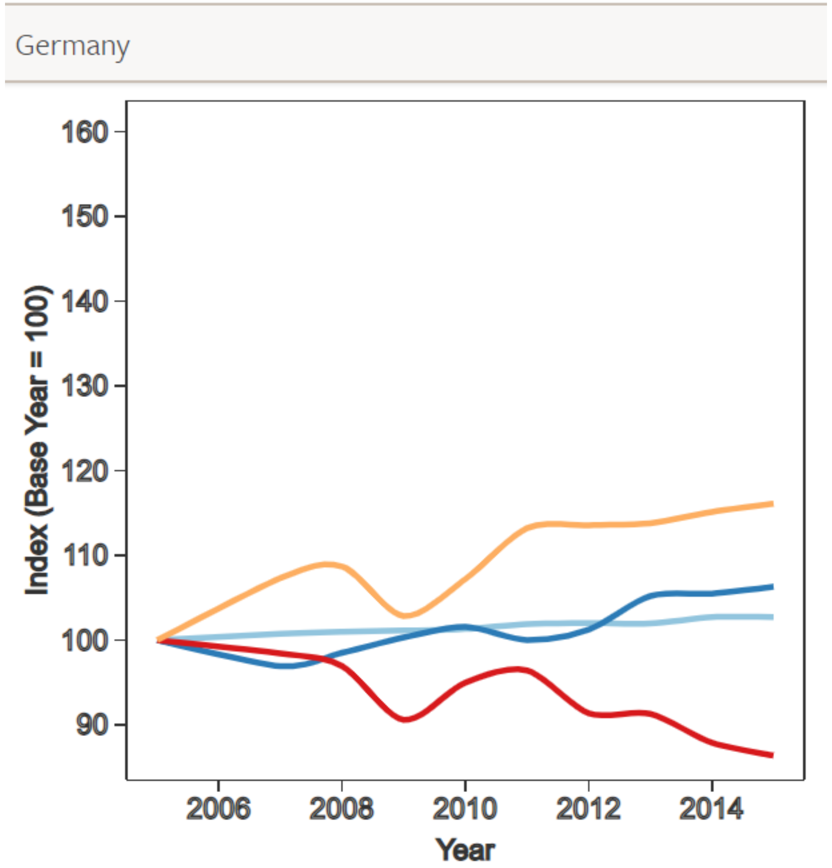
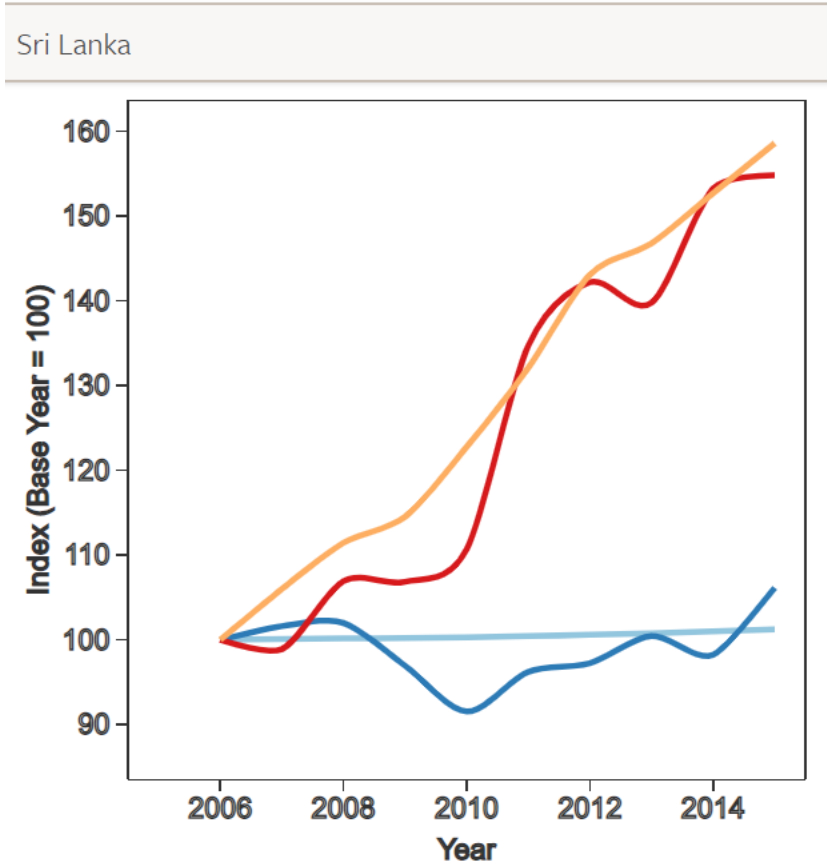
Linking environmental and social indicators

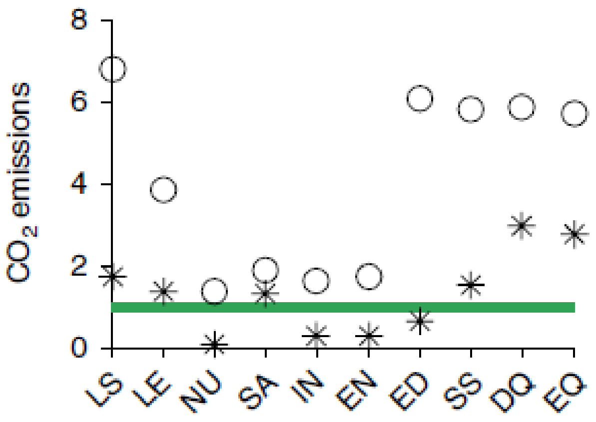




Source: O’Neill et al. 2018

SAFE AND JUST SPACE

Linking environmental and social indicators

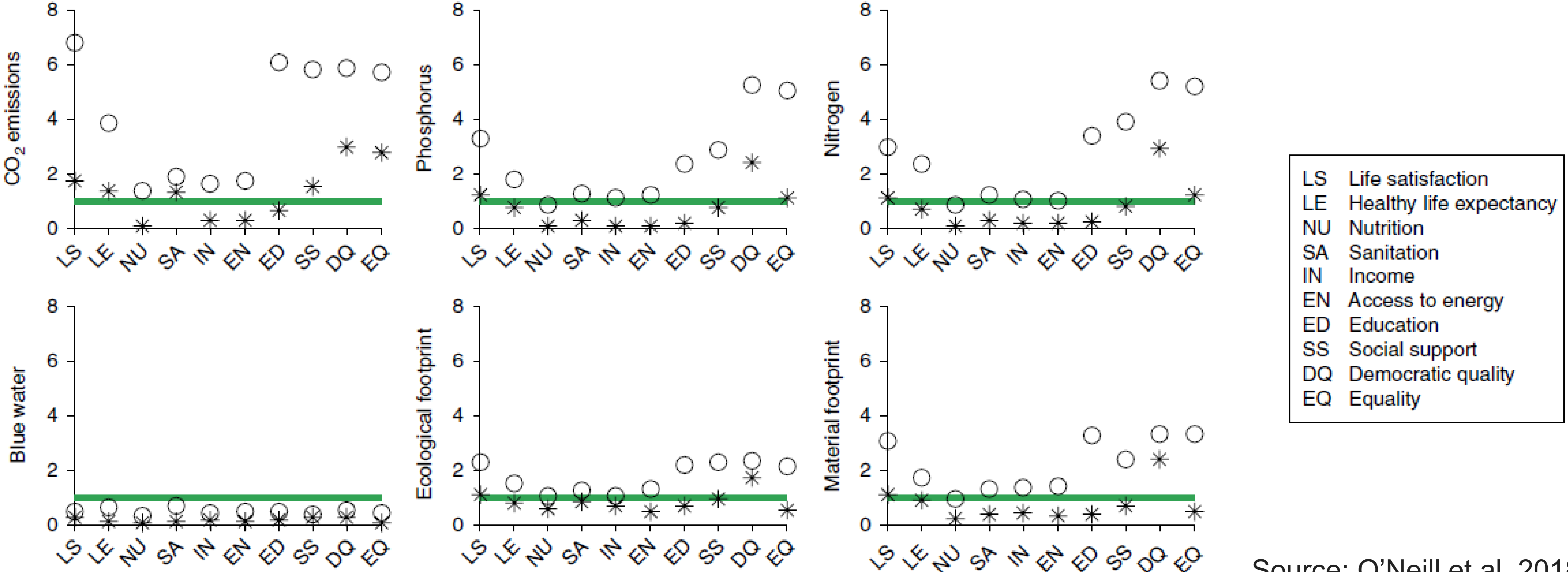


LS Life satisfaction
LE Healthy life expectancy
NU Nutrition
SA Sanitation
IN Income
EN Access to energy
ED Education
SS Social support
DQ Democratic quality
EQ Equality

Source: O’Neill et al. 2018

SAFE AND JUST SPACE

Linking environmental and social indicators



Source: O’Neill et al. 2018

SAFE AND JUST SPACE

- Overall, the data we have now suggest that the pursuit of universal human development has the potential to undermine the Earth-system processes upon which development ultimately depends.
- But this does not need to be the case.
  Change is necessary. All the analyses are conducted using statistical data. This means we are considering the countries' "machine" as it is. As it is, it seems we will not be able to satisfy social needs without compromising the environmental boundaries. We might need to change the machine.
  Machine: backbone of our system – the current economic system.

REFERENCES

Main bibliography

- Class slides
- Steffen, W. et al. (2015). Planetary boundaries: guiding human development on a changing planet. Science 347: 1259855.
- O'Neill, D., Fanning, A., Lamb, W., Steinberger, J. (2018). A good life for all within planetary boundaries. Nature Sustainability 1: 88-95 + Supplementary material

REFERENCES

Additional resources

- Territorial, consumption and income-based indicators:
  Domingos, T. (2015). Accounting for carbon responsibility: the consumer and income perspectives and their reconciliation. International Input Output Association newsletter 32.

- Ecological footprint:
  Living planet report:
  https://wwf.panda.org/knowledge_hub/all_publications/living_planet_report_2018/

- Social indicators:
  HDI: http://hdr.undp.org/en ,
  http://hdr.undp.org/sites/default/files/2018_human_development_statistical_update.pdf
  Better Life Index, OECD, http://www.oecdbetterlifeindex.org/#/11111111111
  World happiness report: https://s3.amazonaws.com/happiness-report/2019/WHR19.pdf
  Happy Planet Index: http://happyplanetindex.org/