PLANETARY BOUNDARIES DEFINE A SAFE SPACE FOR HUMANITY TO OPERATE

This is mainly a summary of Mark Lynas' book "The God Species – How humans really can save the planet". I have primarily used his words. I hope the summary will inspire you to read the book.

"All the great laws of society are laws of nature"
- Thomas Paine (1737 – 1809)

Humans put the rest of the world at mercy
Fire is perhaps the most important innovation in unbalancing our relationship with nature. Being armed with fire puts the rest of the world at humanity's mercy. Now, humanity must help earth regain the stability it needs to function as a self-regulating, highly dynamic and complex system.

Planetary boundaries define a safe operating space
Elimination of poverty is our top-level social and economic concern. Vastly more economic growth is a given. The challenge is, despite growing emissions, to deliver that growth within a safe space of planetary boundaries. Planetary Boundaries is a framework offering a new metric by which to judge the environmental sustainability of human civilization. It is designed to define a safe operating space within which humans can operate and flourish.

Crossing the boundaries is a big risk
Nine Planetary Boundaries were proposed by a group of Earth System and Environmental scientists in 2009. The boundaries are Climate Change, Biodiversity, Nitrogen & Phosphor, Ocean Acidification, Freshwater Use, Land Use Change, Ozone Layer Depletion, Aerosol Loading and Chemical Pollution. These boundaries will be dealt with one at a time. They are all summarized at the end of this document in Appendix 1. Crossing these boundaries, or tipping points, implies a risk of irreversible and abrupt change. Staying within planetary boundaries should be our top-level ecological concern.

Interactions between boundaries shrink the operating space
Interactions among planetary boundaries may shift the safe level of one or several boundaries. Interactions are likely to shrink the safe operating space for humanity. This suggests a need for extreme caution in approaching or transgressing any individual planetary boundary.

1 THE CLIMATE CHANGE BOUNDARY

Climate Change impacts our living conditions
The climate regulates living conditions. Therefore meeting the Climate Change boundary is a basic requirement for any level of sustainable plant management. If it is not met, Biodiversity, Ocean Acidification, Freshwater Use, Land Use and Ozone Layer Boundaries can't be met either.

Climate Change boundary was passed already 1988
The Climate Change boundary of 350ppm (parts per million) atmospheric CO_2 concentration was passed already 1988. CO_2 level in February 2013 was 396,8ppm. There is a lot of evidence that support the boundary: Rapidity of changes in the earth system, Positive feedbacks or tipping points (points of no return) getting close, and evidence from the past on the relationship between temperature and CO_2 concentration.

Many rapid changes seen in the earth system backs the boundary
The rapid thaw of arctic sea ice alters earth's heat balance and atmospheric circulation. This may eliminate entire marine ecosystem. Western US has seen fast increases in vast tree death rates caused by heat, drought and insect manifestations. We have also seen weather patterns shift due to a more energetic atmosphere.

The boundary makes sense because points of no return are getting close
Computer models help to project future climate change. Although imperfect, they are the only way to run experiments into the future. They give us information on possible Tipping Points. See Table 1. Climate Change Tipping Points. It summarizes identified tipping points and their consequences.

Evidence from the past also supports the chosen boundary
Sea levels during the Pliocene (3 million years ago) were 25m higher than today. The CO2 concentration was 360ppm. This supports the idea that 350ppm is the minimum (or maximum) necessary to protect the big polar ice sheets over the longer term.

Table 1. Climate Change Tipping Points

Tipping Point	**Additional warming to danger**	**Consequences / Remarks**
Arctic sea loss	Tipping point very close or already passed	Self-reinforcing. More heat is absorbed. 350ppm CO_2 conc. might prevent it
Melting of Greenland's ice sheet	1°C - 2°C to collapse	Ocean sea level rise +7m. Self-reinforcing process. 350ppm CO_2 conc. to protect it.
Melting of West Antarctic ice sheet	3°C - 5°C to complete collapse	Global sea level rise 5m
Collapsing Atlantic Ocean Circulation	3°C - 5°C	E.US and W.EU: temperature could drop for decades. Serious impacts.
Collapse of Amazonian rainforest (Models not in agreement)	Maximum 3°C	Turn into savannah type ecosystem. Release of carbon. Today deforestation & agriculture is probably bigger threat
Melting tundra (biggest tipping point)	?	Melting permafrost releases CO_2 and methane. Just 10 % => + 0,7°C warming
Ocean warn up		Very slow process. Irreversible changes. Methane hydrate releases

De-carbonization of global economy is needed
Climate Change is a technical problem. It should be dealt within the economical system. The carbon intensity of the economy should be reduced. This means that to achieve the boundary of 350ppm the global economy should be carbon neutral 2050 and carbon negative thereafter. Any successful policy to de-carbonize global economy must be designed such that economic growth and environmental progress go hand in hand.

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Politics should drive changes
Economic growth will win over emission reductions. Increasing prosperity (material consumption) is non-negotiable both politically and socially, especially in developing countries. For many poor countries growth is not a choice but a necessity. Reducing population with 80% is not possible. Therefore politics need to drive changes in technology and investment that will solve the climate problem. Energy should preferably be generated through centralized technologies and big corporations.

Establish a carbon cost to solve energy storage and other challenges
Figuring out how to store electricity reliably, efficiently and on a massive scale is probably humanity's greatest, single technological challenge. A carbon cost of 5$/t would give 150 billion $ to solve that and other challenges like Decarbonising aviation, Quick recharge of electric vehicles, Large scale CCS (= Carbon Capture &Storage) and Next generation nuclear technology, IFR (Integral Fast Reactor).

2 THE BIODIVERSITY BOUNDARY

Biodiversity increases planetary resilience
Living systems keep the air breathable and the water drinkable. For themselves, and us. They need to retain their complexity, diversity and resilience to continue to perform these vital services, The greater the diversity of species, the more resilient and stable an ecosystem can be. The same applies to biosphere as a whole.

Biodiversity loss damage ecosystems
By removing species we damage ecosystems, collapse food webs and undermine the planetary life support system on which our, and any other species depend on. Once humans pick off component parts, ecosystems may appear to function normal for a while, until unpredictable tipping point is reached, and collapse occurs. Effects are not only limited to biodiversity. There is a direct correlation between Biodiversity and Land Use Change. Biodiversity also influences and is influenced by Climate Change, Nitrogen, Ocean Acidification and Freshwater Use.

The worse mass extinction in 65 million years is coming closer
Earth is close to its most severe mass extinction in 65 million years. It is mainly due to climate change and land use change. This includes expanding urban land use, agriculture and aquaculture, introducing invasive species, mining, and building dams and transport routes. Today, already 25% of mammals, freshwater fishes & corals, and 13% of birds are globally threatened with extinction. The extinction rate today is >100 species/year/million species. Target is <10.

Protect biodiversity by law
Functioning ecosystems need varied number of species and habitat. Their protection needs force by law. Protection could be financed through payments for ecosystem services. The mitigation hierarchy for biodiversity change should be to 1) Avoid; 2) Minimize; 3) Restore; and 4) Offset. A quick win for biodiversity is to remove alien species.

3 THE NITROGEN (& PHOSPHOR) BOUNDARY

Shortage and excess of nitrogen has an effect on ecosystems
Nitrogen is essential to all life. It has an effect on the overall resilience of earth sub-systems. Nitrogen influences Climate Change, Biodiversity, Ocean Acidification, Freshwater Use, and Ozone Layer Depletion.

Shortage of nitrogen is the greatest limiting factor for natural biomass production on land and at sea. Excess of nitrogen on land causes biodiversity loss. Weedy, fast-growing species become dominant and crowd other species out. This leads to slow but chronic loss of biodiversity on land. Nitrogen runoff to water can best be described as “The rise of slime”. Nitrogen stimulates blooms of algae and depletes water columns of oxygen. This leads to eutrophication.

Reactive nitrogen should be handled with care
Reactive nitrogen is rare in nature why ecosystems are highly sensitive to it. It keeps on polluting as it transforms and circulates between different compounds such as nitrogen oxides, nitric acid, nitrates and nitrous oxide.

A significant part of humanity’s reactive nitrogen is a by-product of burning fossil fuels. Other sources are nitrates in wastewater, fertilizer production, and excessive use of fertilizers. NO_x- emissions from car exhaust pipes and coal stations are harmful to health. Production of nitrates for fertilizer production is energy intensive and emits both CO_2 and N_2O. Excessive use of nitrogen brings no benefit to agriculture.

Nitrogen Boundary is crossed
Human nitrogen flow should be reduced to 1/3 from what it is today. 121 million tons of Nitrogen is yearly removed from the atmosphere for human use. The amount should be maximum 35 million tons. That is tough to do. We are biologically dependent on nitrogen.

Minimize use of reactive nitrogen
There are actions to be taken to reduce nitrogen use. Create conditions for microbial de-nitrification on a wider scale i.e. provide space for nature to work its magic. This is to get reactive nitrogen back to harmless N_2. It includes protecting wetlands at river outlets. This is beneficial for Biodiversity, Freshwater Use and Land Use. Synthesize less ammonia and use the produced, reactive nitrogen more efficiently. Reduce runoff. Remove nitrates from wastewater. Ensure that more nitrogen is used into the crop rather than wasted. Use genetic engineering for more nitrogen efficient crops and plants. Reduce overuse of fertilizer, e.g. in China farmers typically use double dose.

Note about Phosphor
Phosphor is dealt with as a part of the Nitrogen Boundary. The phosphor boundary is not yet crossed. Excessive phosphor mainly influences marine ecosystems. “The rise of slime” is valid also for phosphor. It causes wide spread anoxia in coastal and shell seas.

4 THE OCEAN ACIDIFICATION BOUNDARY

Acidification risk for entire marine ecosystem

Oceans are today more acidic than in 20 million years. Up to 85% of human released carbon (CO_2) has been soaked up in the oceans since the invention of the steam engine in 1784. CO2 reacts with water and forms carbonic acid. Acidification turns oceans more hostile to many forms of marine life. The entire marine ecosystem is at risk from acidification, from the tropics to the poles.

Acidification can lead to "The rise of slime"

Acidification is likely to increase the area of low-oxygen dead zones. These are already affecting coastal areas because of nitrogen and other water borne pollutants. Like nitrogen, CO_2 has a fertilizing effect benefiting opportunistic weedy species. We will see a general shift from calcifying organisms to green algae and other photo-synthesisers. This is called "The rise of slime". With the current acidification trend, 50 % of oceans will be toxic to calcareous organisms by 2050.

Base of food chain is threatened

Warmer temperatures and CO_2 are bad for coral reefs. When combined, deadly. Acidification leads to loss of calcifying marine organisms. That has a serious impact on the productivity of coral reefs and likely ripple effects up the food chain. Mussels and clams suffer. Kelp forests, which support flourishing fisheries, are at risk. Impacts could be most severe at the base of the food chain on which all higher life forms depend. E.g. shells precipitated by Foraminifera plankton are today 30 % smaller than in pre-industrial times.

Ocean acidification can be equal threat as climate change

Ocean acidification could represent an equal threat to the biology of our planet than climate change alone. It affects Climate Change, Biodiversity, Nitrogen Boundaries and, the Ocean Acidification Boundary itself. The Ocean Acidification Boundary is 2,75 as the global mean saturation state of aragonite (CaCO3) in surface seawater. Today it is 2,90. The pre-industrial value was 3,44.

Meet at least the climate change boundary

The most important action to decrease ocean acidification is to meet the climate change boundary. In addition: Use ground-up olivine rock as beach nourishment. It will fertilize corals and reduce acidification when bicarbonate ions are formed. Add lime to oceans to sequester CO_2. Do increase public knowledge and concern about ocean acidification.

5 THE FRESHWATER USE BOUNDARY

Rivers are important

Rivers are important ecological zones. They are habitats for plants and animals. River, lake and wetland habitats provide home for 25% of vertebrates, but cover less than 1 % of surface. Rivers absorb nitrogen and phosphor. Deliver sediments and nutrients to delta areas and fisheries. Break down waste. Deliver clean water.

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Freshwater species extinct rate is 5 times the one for terrestrial species. 37% of freshwater species are threatened. 60 % of 227 largest rivers are fragmented by manmade infrastructure. Many rivers fail to reach the sea. 800 000 dams block natural flows. Dams support 12-16% of global food production. Irrigated agriculture covers 40% of food production, and 20% of land use covering 275 million hectares.

Freshwater Use Boundary is needed to maintain ecological flow
Human freshwater use impacts both food & health security, and ecosystem resilience. Ecological flow has to be maintained to furthest extent possible. That's why the Freshwater Use Boundary is a sum of many small boundaries operating at scale of single river systems in different continents and regions.

In pre-industrial time global consumption of freshwater by humans was 415 km^3/a. Today it is 2600 km^3/a. The Freshwater Use boundary is 4000 km3/a. Water use impacts regional climate patterns, moisture feedback, biomass production, carbon up-take and biodiversity. Thus, freshwater use has an effect on Climate Change, and Biodiversity boundaries.

Save freshwater through privatization and global trade
Make use of water more efficient: privatize it. Studies show it benefits also the poor. Increase global trade to reduce water scarcity. This makes sense for countries like Egypt and Arab Emirates to import food. In Egypt every imported kilogram of maize saves 500 litres of water. This entails a potential to save 10% of national water use per year. To free up trade barriers, eliminate water subsidies to farmers.

Increase agricultural productivity
Put a price on water that truly reflects its ecological scarcity. Agriculture should pay for the water it uses. Increase agricultural productivity further. Industrial farming and the green revolution have helped humanity to stay within the Freshwater Use Boundary. E.g. wheat yields in France tripled 1960-2000 due to new technologies. Agricultural productivity gains in EU 1960-2000 brought a saving of 1800 litres/person/day. Recycle water. E.g. Israel is using more than 80 % household wastewater for producing food.

6 THE LAND USE CHANGE BOUNDARY

The impact of human Land Use Change is vast
Natural landscapes filter water, produce oxygen, sequester carbon, and provide vital habitat for other species. According to one study, 83% of earth's ice-free land surface is influenced by humanity. It threatens the capacity of varied ecosystems to self-regulate, and maintain the living biosphere overall.

Converting natural forests and other ecosystems into agricultural land, plantations and urban settlements is Land use Change. It is a trigger of irreversible and widespread conversion of biomes. It impacts carbon storages and planetary resilience through biodiversity changes. Human land use has an effect on Climate Change, Biodiversity, Nitrogen and Freshwater Use Boundaries.

Population growth leads to need for more cropland, not much available
Growing population and increasing wealth leads to increased need for both energy and food, especially meat & dairy. More land is needed. A comparison of land areas needed for production of different forms of energy is found in Table 2.

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To avoid a global collapse in the functioning of the biosphere, maximum 15 % of earth's surface should be converted to cropland. We are today at around 12%. This leaves only 400 million hectares of land to be brought into production. Not very much, considering population growth.

Table 2. Comparison of land areas needed for production of different forms of energy

Land Use need	Bio-fuel	Wind	Solar PV[1]	Solar Thermal	Nuclear
$km^2/TWh_e/a$	300-600	72	36	15	2

[1]PV= Photovoltaic

Increase productivity of land, and minimize consequences of land use
There are actions to take to minimize Land Use Change. Direct 0,5% of VAT for ecosystem and habitat restoration. Intensify agriculture. Take the best of modern science and ecology to deliver maximum yields with minimum environmental damage. Integrate pest management, crop-combinations, genetic engineering and agriculture.

Urbanisation is good for sustainability. It concentrates human impact on land in a smaller area. It also reduces population growth. Rural depopulation leads to forest re-growth.

7 THE OZONE LAYER DEPLETION BOUNDARY

Depleted ozone layer has severe and irreversible effects
The ozone layer is a region located in the stratosphere several miles above the surface of the earth. It shields living beings from harmful ultraviolet (UV) light from the sun. The ozone layer is adversely affected by ozone depleting substances, cold temperatures, water vapour and Nitric acid. The biggest destruction takes place in extremely cold, thin ice clouds high in the springtime polar stratosphere. Ozone Layer Depletion has severe and irreversible UVB radiation effects. It has especially damaging effects on marine ecosystems, and on humans exposed to the radiation.

CFCs caused the Ozone Hole
Chlorofluorocarbons, or CFCs are manmade chemicals. They are effective in refrigerators, air conditioners and aerosol cans. Today they are banned because they destroy the ozone layer. CFC in the stratosphere can be split a part by UV-light. This leads to dangerously reactive free chlorine (Cl^-) atoms circulating high in the atmosphere. Cl^- atoms destroy stratospheric ozone on a scale no natural process has achieved. In 1985, in Antarctic, in the highest stratospheric regions, scientists discovered that up to 40% of the ozone layer was destroyed by CFC. This was called "the Ozone Hole". The same phenomenon was found in the Arctic.

Political leadership got CFCs banned
Without science and strong political leadership 2/3 of the ozone layer would have disappeared by 2065. At that time radiation in e.g. London would have been strong enough to cause sunburn in 5 minutes. We can thank the Vienna Convention in 1985 and, especially the Montreal Protocol from 1987. The protocol restricts the manufacture and use of manmade, ozone-depleting compounds, such as CFCs and halons. It was implemented despite industry protests. Nothing can change without strong political leadership

The ozone layer is slowly recovering
The Ozone Layer Depletion Boundary is set at 276 Dobson Units (DU), which is 5% below the Pre-industrial value of 290 DU. Current value is 283 DU. Experts project that the ozone layer will recover back to its pre-1980 level by 2060-2075.

8 THE AEROSOL LOADING BOUNDARY

Aerosols have many unwanted effects
Anthropogenic aerosols are airborne particles created mainly through burning fossil fuels or biomass. They cause forest degradation, crop damage, fish deaths and human health problems. Aerosols impact earth's hydrological cycle. They disrupt the monsoon system and alter the cloud precipitation mechanism. Aerosol pollutants concentrate in the Arctic. "Arctic Haze" is a significant contributor to global warming. Aerosols influence both the climate system and biodiversity.

Aerosols may have a warming, or cooling effect
The most common anthropogenic aerosols are sulphates and black carbon (major constituent of soot). In general, sulphate particles are bright in colour and reflect sunlight. Soot is dark and absorbs sunlight. But, the precise effect of aerosol haze depends on what's underneath it. The effect is warming if it dims sunshine heading toward the highly reflective icecaps, and cooling if it screens sunlight hitting dark-coloured ocean.

Black carbon is responsible for 30% of the warming
Soot deposited on snow and ice makes the surface darker. This accelerates melt rates. Black carbon's warming effect is 500 times the effect of CO_2. It is the 2^{nd} largest contributor to global warming after CO_2. By cleaning up black carbon, 25-33% of ongoing warming can be avoided. It would immediately stabilize polar ice caps and rapidly melting glaciers.

Aerosol pollution is (easily) solved by technology
Aerosols have merely a short lifetime of 1-2 weeks. The aerosol problem persists only as long as we are causing it. The Aerosol Loading Boundary is the easiest boundary to address even if no boundary can be set. Aerosol pollution is solved by technology.

Legislation and modernization are keys to solve Aerosol Loading problem
75% of black carbon can be addressed mainly through legislation and modernization. The rest of black carbon originates from wildfires and uncontrollable burning in open areas.

Legislation will globally increase the use of cleaner fuels, diesel particle filters, and catalytic converters. It will lead to a reduction in sulphur and soot pollution from the world's shipping fleet. Modernization will reduce emissions from smaller coal burning sites. In developing Asia, substituting old-style cooking with clean cookers could reduce emissions with 80%, Today, the smoke causes 1,6 million deaths /year.

9 THE CHEMICAL POLLUTION BOUNDARY

Chemical pollution is a risk to life
Chemical pollution adversely affects human and ecosystem health. It may act as a slow variable undermining resilience. It may also increase the risk of crossing other boundaries. The Chemical Pollution Boundary affects Climate Change, Biodiversity, Freshwater Use, Land Use, Ozone Depletion and Aerosol Loading Boundaries

Nature has no way to biologically decompose toxic waste
Chemical pollution includes emissions or concentrations of radioactive compounds, heavy metals and a wide range of organic manmade compounds. These include so-called Persistent Organic Pollutants like DDT, PCBs and dioxin. The problem with toxic wastes generally, is that the natural world has no way of biologically decomposing them. Extinctions of entire species and other enigmatic (mysterious) declines of species are probably due to environmental contaminants.

Many manmade chemicals are "gender-benders" and/or bio-accumalative
Some of the most troubling manmade chemicals are either "gender-benders" or bio-accumulative. Gender-benders are endocrine disrupting substances that mimic or block the action of natural biological hormones in an animal. DDT, Lindane, organophosphates, PCB's, TBT and synthetic oestrogen are gender-benders. Bio-accumulative substances are capable of accumulating in food chains. Because of weather systems and long-range atmospheric transport, these substances can also accumulate in Polar Regions. DDT, Mercury, PCBs and Brominated Flame Retardants are typical bio-accumulative substances.

Quantification of chemical pollution boundary not possible
We simply do not know how many chemicals are circulating in the environment, or what their effect might be. Therefore it is impossible to quantify this planetary boundary. The best action is to mandate pollution control to keep chemical pollution under control.

Please, note that the Planetary Boundaries are summarized in Appendix 1.

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APPENDIX 1. Summary of Planetary Boundaries

Planetary Boundary - Parameter	Importance	Value Aim	Values Now (Pre-ind.)	Process Description	Boundaries Effected	Remarks
Climate Change BC - Atm. CO_2 conc. / ppm (Parts per million volume)	Climate regulates life conditions	350	396,8 Feb. 2013 (280)	Systemic Planetary Scale, Global Scale Thresholds	Biodiversity, Ocean, H_2O, Land, Ozone, Toxics	After 2050 only "negative" CO_2 emissions should be allowed
Biodiversity BC - Extinction Rate Nr/a (number of species per million species per year)	Affects ecosystem functioning and resilience of other PBs. Impacts carbon storage	10	>100 (0,1-1)	Aggregated from local / regional scale, Slow, unknown global thresholds	Climate, N&P, Ocean, H_2O, Land	Vulnerable to disturbances. 6th mass extinction. Influenced by CC & Land use
Nitrogen N & BC - N2 removed from atmosphere for human use 10^6 t/a **Phosphor P** - P flowing into oceans 10^6 t/a	N: Affects overall resilience of earth sub-systems. P: influences marine ecosystems	35 11	121 (0) 8,5-9,5 (-1)	N&P: Aggregated from local / regional scale, Partly Global Scale Thresholds & Slow, unknown global thresholds	Climate, Biodiversity, Ozone Layer, Freshwater, Ocean Acidification	N excess: harmful to ecosystems P Excess: Local wide spread Anoxia in coastal & shelf seas
Ocean Acidification - Global mean saturation state of aragonite ($CaCO_3$) in surface sea water	Marine ecosystems are vulnerable to pH changes. CO2 up => pH down	2,75	2,90 (3,44)	Systemic Planetary Scale, Global Scale Thresholds	Climate, Biodiversity	Oceans important CO_2 sinks. Marine ecosystems in danger.
Freshwater H_2O Use - Consumption of freshwater by humans km^3/a	Can affect regional climate patterns, moisture feedback biomass prod., carbon up-take, biodiversity	4000	2600 (415)	Aggregated from local / regional scale, Some GST & Slow, unknown global thresholds	Climate, Biodiversity,	Affects food & health security and ecosystem resilience.
Land Use Change - % of global land cover converted to cropland	Trigger of irreversible and widespread conversion of biomes	15	11,7 (low)	Aggregated from local / regional scale, Some GST & Slow, unknown global thresholds	Climate, Biodiversity, N&P, Freshwater	Affects carbon storage and resilience through biodiversity changes.
Ozone Layer Depletion - Concentration of ozone (Dobson Unit)	Severe and irreversible UVB radiation effects. Negative impact on ecosystems and human health	276	283 (290)	Systemic Planetary Scale, Partly GST, Slow, unknown global thresholds	Biodiversity	Ozone layer affected by Ozone depleting substances, cold temperatures, H_2O vapour, Nitric Acid
Aerosol Loading - Overall particulate concentration in the atmosphere on regional basis. Parameter difficult to determine	Monsoon system disruption, Cloud precipitation mechanism alteration, cloud reflectivity influence.	-	- (.)	N&P: Aggregated from local / regional scale, Partly GST & Slow, unknown global thresholds	Climate, Biodiversity	Influences climate system. Causes forest degradation, crop damage, fish deaths and human health problems.
Chemical Pollution - E.g. amount emitted to or conc. Of persistent organic pollutants, heavy metals, nuclear waste, effects on earth systems. Parameter difficult to determine	Thresholds possibly leading to unacceptable impacts on ecosystem functioning and human health	-	- (-)	Aggregated from local / regional scale, Slow, unknown global thresholds	Climate, Biodiversity, H2O, Land, Ozone, Aerosols	May act as a slow variable undermining resilience and increasing risk of crossing other thresholds.

BC = Border Crossed, CC= Climate Change, GST = Global Scale Threshold, PB= Planetary Boundary,

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