Foresight Synergy Network Zoom Webinar November 18, 2022

Planetary Limits: Coming Future Threats?

by

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Outline of Talk

- Setting the Stage
- Climate Emergencies & Warnings from the Scientific Community
- Precautionary Principle
- How did we put Earth in this situation?
- The Big Picture: from Social Foundations to Ecological Ceilings
- Planetary Boundary Frameworks in 5 Models from 2009 – 2022
- A Case for Model Refinement
- Conclusions
- Bibliography

Note to Reader

- Highlighted text reflects the main points made during the presentation
- Indented & non-bold text are supplementary points, some used as highlights during the presentation
- Most slides have web links to source material

- Errata:
  - Timeframe on slide of the Last Glacial Cycle is 1 million years not 100 thousand years as stated in the presentation

Setting the Stage

- The climate crisis cannot be addressed as a stand alone issue
- It is part of a larger systemic problem comprised of multiple interacting processes (i.e., a polycrisis)
- Humans are on a collision course with the natural world
- Today human demands of Earth exceed the regenerative capacity of the biosphere
- Consequently, Earth is losing its resilience to deal with stress & disturbance

Climate Emergency Declarations

- **The 1st Climate Emergency Declaration by a local government in Melbourne, ASTL in December 2016 - since then over 2,100 local governments in 39 countries have made Climate Emergency Declarations (as of May 2022)**
- **A 2021 update to various Climate Emergency Declarations focused on 31 planetary vital signs & recent changes to them**
  - (e.g., greenhouse gases, temperature, rising sea levels, energy use, ice mass loss, ocean heat content, Amazon rainforest loss rate, etc.)
  - 18 of the vital signs are reaching critical levels
- **Many of these vital signs are incorporated into a new Framework as of 2009 called Planetary Boundaries**
- **Sometimes these boundaries are referred to as limits or tipping points**

https://academic.oup.com/bioscience/advance-article/doi/10.1093/biosci/biac083/6764747

World Scientists' Warning to Humanity

- **The "World Scientists' Warning to Humanity" was a document published in 1992 & signed by some 1,700 leading scientists, including most Nobel Laureate in the sciences**
- “Senior members of the world's scientific community hereby warn all humanity of what lies ahead. A great change in our stewardship of the Earth & the life on it is required, if vast human misery is to be avoided & our global home on this planet is not to be irretrievably mutilated.”

https://www.ucsusa.org/resources/1992-world-scientists-warning-humanity#:~:text=We%20the%20undersigned%2C%20senior%20members,not%20to%20be%20irretrievably%20mutilated

Background on World Scientists' Warning to Humanity: A Second Notice

- **Since 1992 humanity has failed to make sufficient progress in generally solving foreseen environmental challenges**
  - With the exception of stabilizing the stratospheric ozone layer (Montreal Protocol)
- **Most challenges are getting worse**
  - Especially potentially catastrophic climate change due to rising GHGs, deforestation, & agricultural production—particularly from farming ruminants for meat consumption
- **Humans have unleashed a mass extinction event**
  - The 6th in roughly 540 million years, with many current life forms being decimated or going extinct by 2100
- **Advancement of urgently needed changes in environmental policy, human behaviour & global inequities are still far from sufficient**

https://academic.oup.com/bioscience/article/67/12/1026/4605229

World Scientists' Warning to Humanity: The Second Notice

- **Published in November 2017 & signed by 15,364 scientists & calling for among other things, human population planning & drastically diminishing per capita consumption of fossil fuels, meat & other resources***

  *More scientist co-signers & formal supporters than any other journal article ever published (today over 17,000 signatures from qualified scientists)

https://academic.oup.com/bioscience/article/67/12/1026/4605229

World Scientists' Warning to Humanity: 2022

- **Humanity is jeopardizing its future** by:
  - Not reining in our intense geographically & demographically uneven material consumption
  - Not reassessing the role of an economy rooted in growth
  - Not perceiving continued rapid population growth as a primary driver behind many ecological & societal threats
  - Failing to reduce greenhouse gases, incentivize renewable energy, protect habitat, restore ecosystems, curb pollution, halt defaunation & constrain invasive species
- **Bottom line: humanity is not taking the urgent steps needed to safeguard our imperilled biosphere**

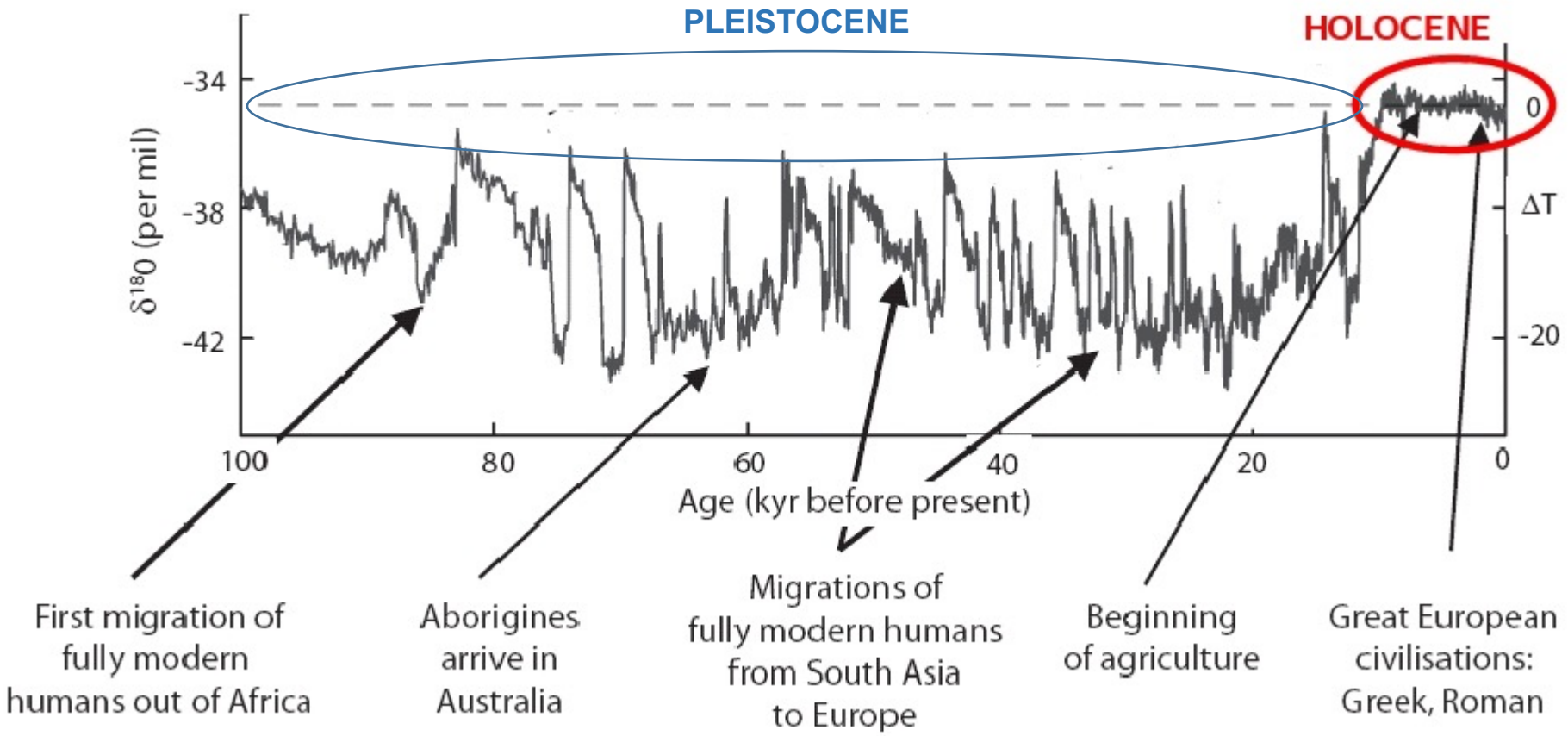
https://academic.oup.com/bioscience/advance-article/doi/10.1093/biosci/biac083/6764747

The Precautionary Principle

- **The precautionary principle encourages policies that protect human health & the environment in the face of uncertain risks**
- It is a broad epistemological, philosophical & legal approach to addressing change with potential for causing harm when extensive scientific knowledge on the matter is lacking
  - The precautionary principle has arisen because of the perception that the pace of efforts to combat problems such as climate change, ecosystem degradation, & resource depletion is too slow & that environmental & health problems continue to grow more rapidly than society's ability to identify & correct them
- In addition, the potential for catastrophic effects on global ecologic systems has weakened confidence in the abilities of environmental science & policy to identify & control hazards
- **Rio Declaration 1992** – "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"

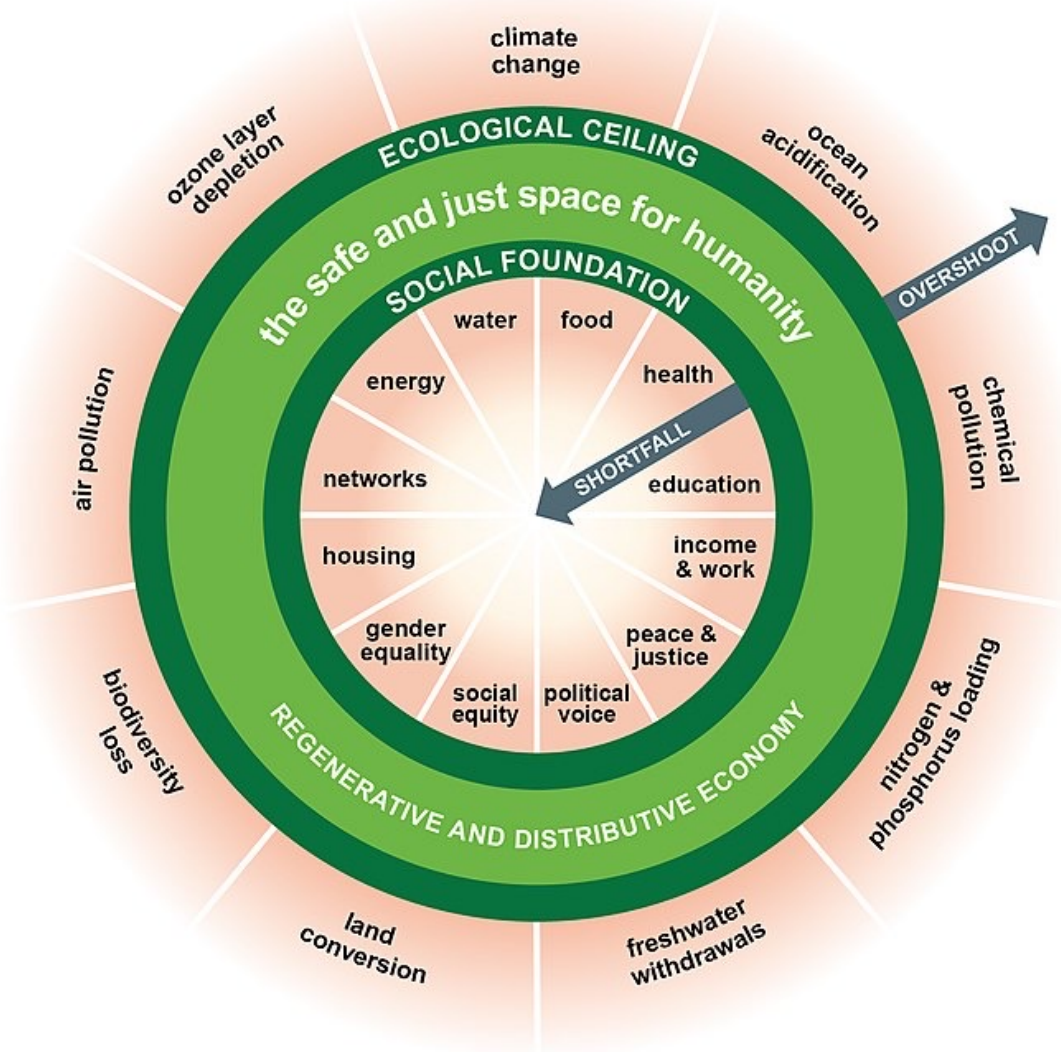
So how did put Earth in this situation?

The last glacial cycle of temperature as indicated by ^{18}O along with selected events in human history



https://www.ecologyandsociety.org/vol14/iss2/art32/figure1.html

The Big Picture: from Social Foundations to Ecological Ceilings



https://en.wikipedia.org/wiki/Planetary_boundaries#/media/File:Doughnut_(economic_model).jpg

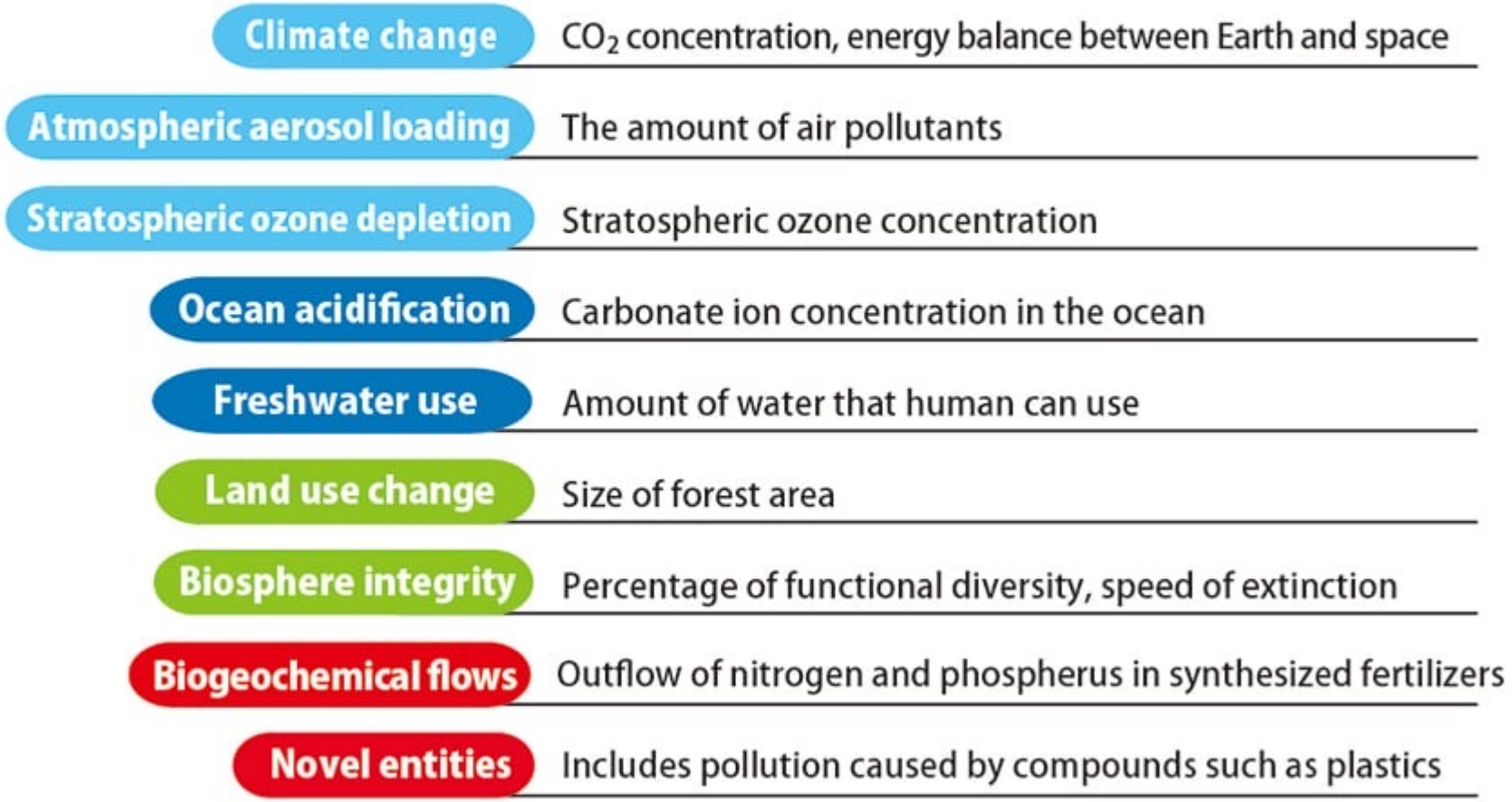
Planetary Boundaries Framework

- **The normative component of the framework is that human societies have been able to thrive under the comparatively stable climatic & ecological conditions of the Holocene, particularly the past 6 millennia or so**
- **The Framework is used to show how humanity is stressing the entire Earth system**
  - It defines boundaries for the biophysical processes that determine the Earth's capacity for self-regulation & if crossed could generate unacceptable environmental change
- **These boundaries define the safe operating space for humanity with respect to Earth systems & are associated with the planet's biophysical subsystems & processes**
- **Boundaries are associated with control variables**
  - Which are defined as a measurable parameter that is causally related to a specific boundary
- **The positions of the planetary boundaries are set at the lower end of the scientific uncertainty zone of “safe” Holocene-like conditions**

Planetary Boundaries Framework (2)

- **Crossing a planetary boundary comes at the risk of abrupt environmental change**
- **The framework is based on scientific evidence that human actions, especially those of industrialized societies have become the main driver of global environmental change**
- **To the extent that these Earth system process boundaries have not been crossed, they mark the "safe zone" for human societies on the planet**
- **The framework currently consists of nine global change processes**
  - The Framework is used to argue that humanity must stay within all of these boundaries in order to avoid catastrophic environmental change
- **Transgressing one or more planetary boundary may be disastrous or even catastrophic due to the risk of crossing thresholds**
  - Which will trigger non-linear, abrupt environmental change on a continental to planetary-scale in addition to influencing other planetary boundary conditions in complex non-linear ways

Nine Planetary Boundaries/Limits



Character of Planetary Boundary Categories

- **Climate Change**
  Recent evidence suggests that the Earth, now passing 415 ppm CO_2 in the atmosphere, has already transgressed the planetary boundary & is driving in part several other Boundary system thresholds
- **Atmospheric aerosol loading**
  An atmospheric aerosol planetary boundary was proposed primarily because of the influence of aerosols on Earth's climate system. Through their interaction with water vapour, aerosols play a important role in the hydrological cycle affecting cloud formation & global-scale & regional patterns of atmospheric circulation, such as the monsoon systems in tropical regions. They also have a direct effect on climate, by changing how much solar radiation is reflected or absorbed by the atmosphere
- **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 & marine biological systems

Character of Planetary Boundary Categories (2)

- **Ocean acidification**
  Around a quarter of the CO_2 that humanity emits into the atmosphere is ultimately dissolved in the oceans, where it forms carbonic acid, altering ocean chemistry & decreasing the pH of the surface water. This increased acidity reduces the amount of available carbonate ions, an essential 'building block' used by many marine species for shell & skeleton formation
- **Freshwater consumption & the global hydrological cycle**
  The freshwater cycle is strongly affected by climate change & its boundary is closely linked to the climate boundary; yet human pressure is now the dominant driving force determining the functioning & distribution of global freshwater systems
- **Land system change**
  Land is converted to human use all over the planet. Forests, grasslands, wetlands & other vegetation types have primarily been converted to agricultural land. This land-use change is one driving force behind the serious reductions in biodiversity, which has impacts on water flows & on the biogeochemical cycling of carbon, nitrogen, phosphorus among others

Character of Planetary Boundary Categories (3)

- **Loss of biosphere integrity**
  The main drivers of change are the human demand for food, water & natural resources, causing severe biodiversity loss and leading to changes in ecosystems. These drivers are either steady, showing no evidence of declining over time, or are increasing in intensity
- **Biochemical Flows: Nitrogen & phosphorus flows to the biosphere & oceans**
  The biogeochemical cycles of nitrogen and phosphorus have been radically changed by humans as a result of many industrial and agricultural processes. Nitrogen and phosphorus are both essential elements for plant growth, so fertilizer production & its application are the main concerns of these biochemical flows
- **Release of novel entities**
  Emissions of toxic & long-lived substances such as synthetic organic pollutants such as plastics, heavy metal compounds & radioactive materials represent some of the key human-driven changes to the planetary environment. These compounds can have potentially irreversible effects on living organisms & on the physical environment by affecting atmospheric processes & climate

Current Constraining Assumptions

- **For the most part, the exact values chosen as boundaries are arbitrary**
- **So too are some indicators of change**
  - e.g., what is the ideal CO_2 concentration we should aim to achieve?
- **Climate change & biosphere integrity—are highly integrated, emergent system-level phenomena that are connected to all of the other PBs**
  - They operate at the level of the whole Earth system & have coevolved for nearly 4 billion years
- **There is no consensus on what level to cap species extinctions above the background rate**
- **Boundaries can vary globally, even for processes that regulate the entire planet**
  - e.g., local conditions often determine how soon water shortages or biodiversity loss reach a critical threshold

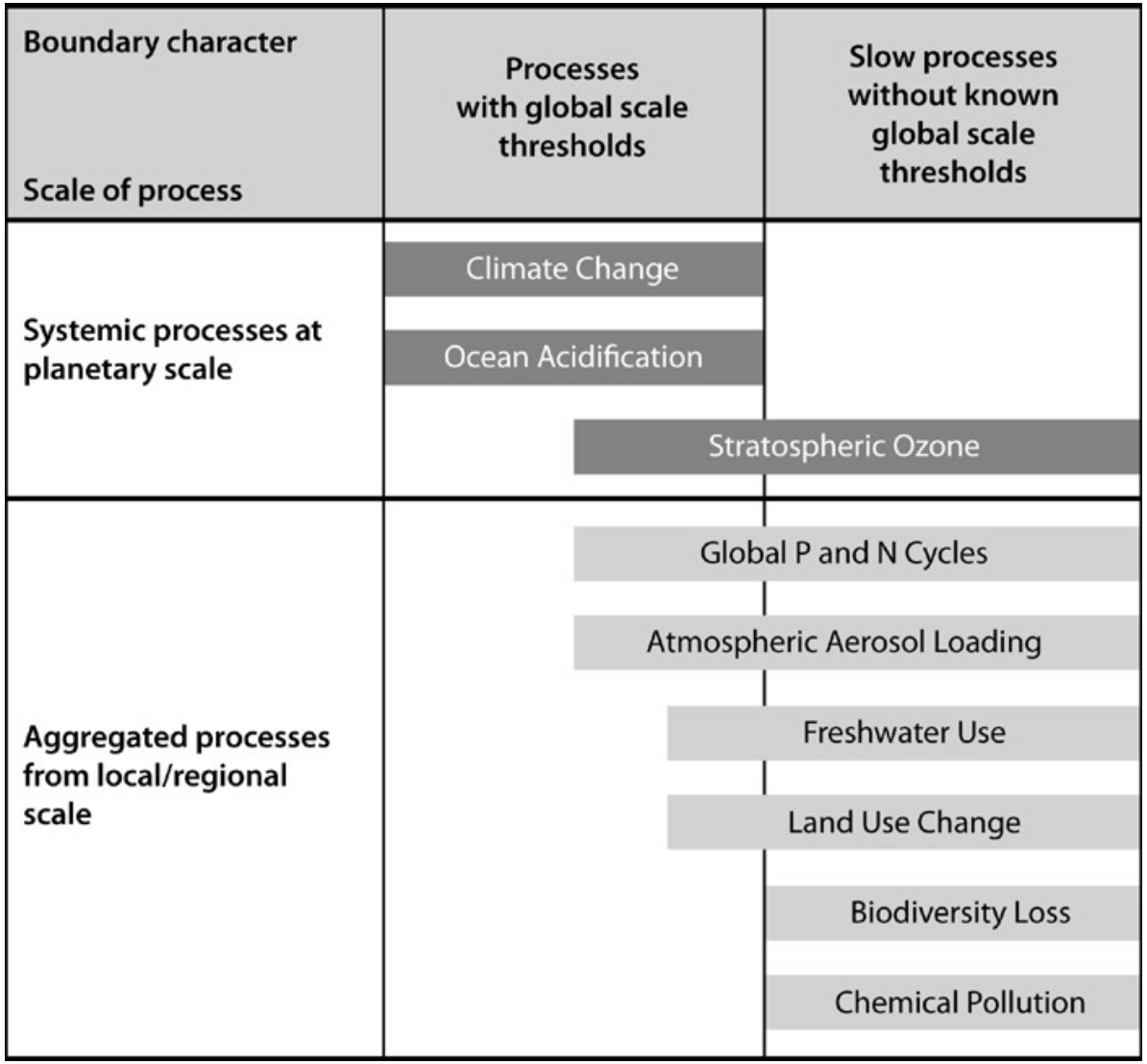
Current Constraining Assumptions (2)

- **Some limits may be easier to balance with ethical & economic issues than others**
  - e.g., human interference in the nitrogen cycle may well have damaging long-term consequences; however, the production of nitrogen for agriculture has also feeds large parts of humanity
- **Many subsystems of Earth react in a nonlinear, often abrupt way & 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 with disastrous consequences for humans
- **Most thresholds can be defined by a critical value for one or more control variable**
  - e.g., CO_2 concentration, nitrogen fixation rate & seawater aragonite saturation (a form of $CaCO_3$) that track both Earth system behaviour as indicators of Earth's temperature, nutrient limitation & ocean carbon sinks & the perturbations that may provoke crossing of thresholds, which are linked to one or several control variables

Current Constraining Assumptions (3)

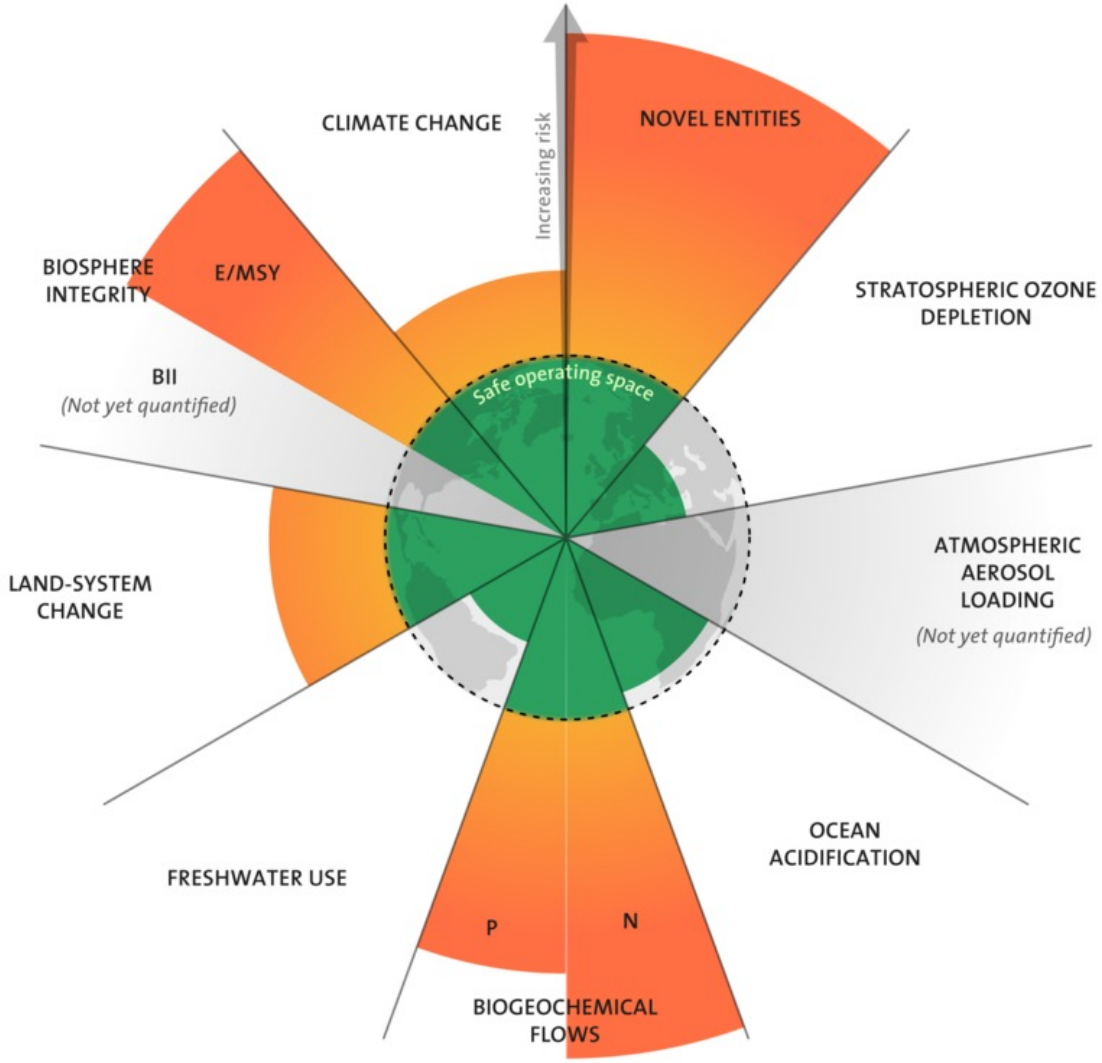
- **Not all processes or subsystems on Earth have well-defined thresholds**
- **Human actions that undermine the resilience of such processes or subsystems can increase the risk that thresholds will be crossed in other processes**
  - e.g., the climate system
- **Planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds**
  - e.g., for processes with evidence of threshold behaviour — or at dangerous levels — for processes without evidence of thresholds
- **Determining a safe distance from boundaries involves normative judgements of how societies choose to deal with risk & uncertainty**
  - e.g., incorporating a social science and economics perspective

Scale of Planetary Boundary Processes



https://www.ecologyandsociety.org/vol14/iss2/art32/figure4.html

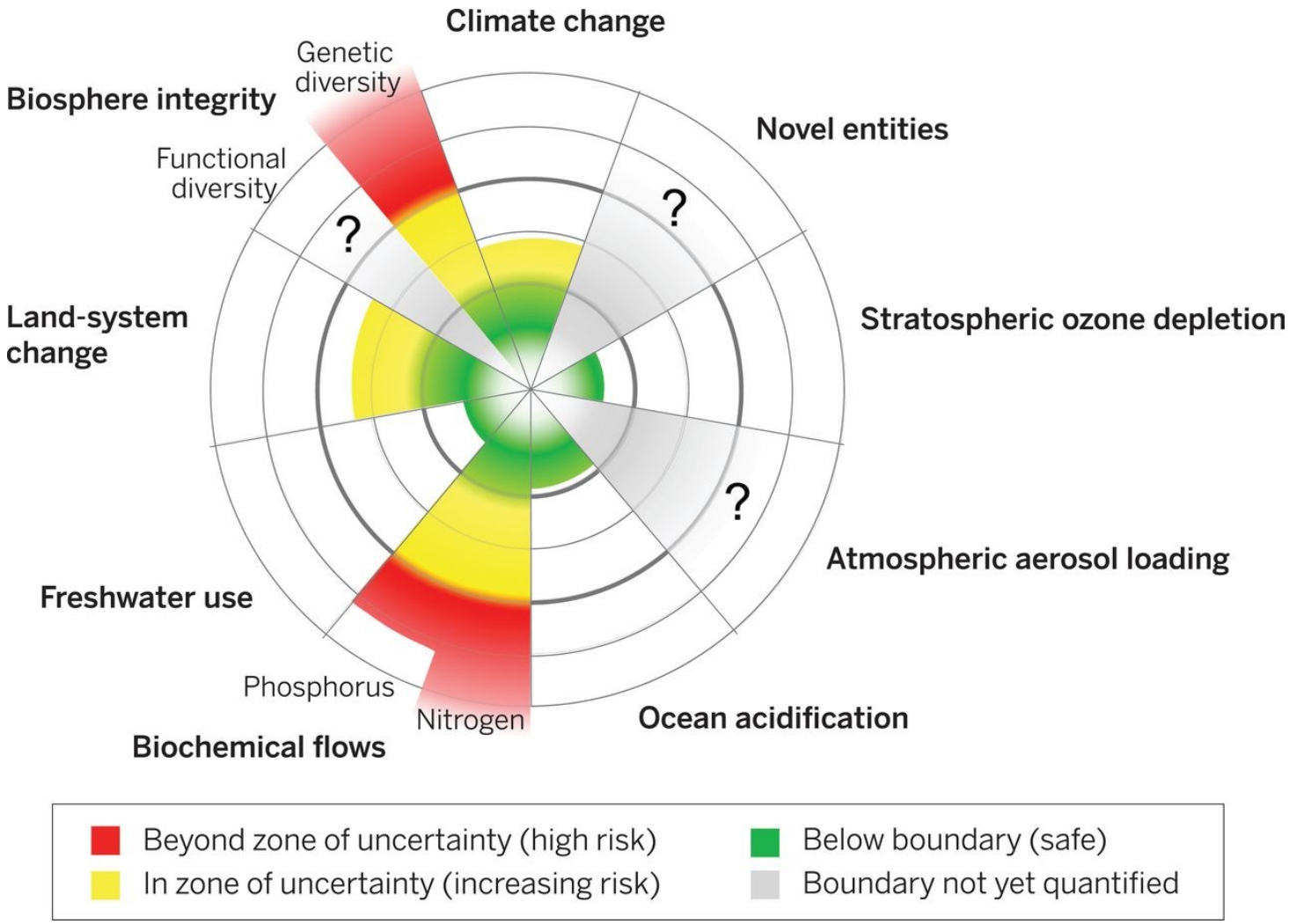
Coding of Planetary Boundary Diagrams

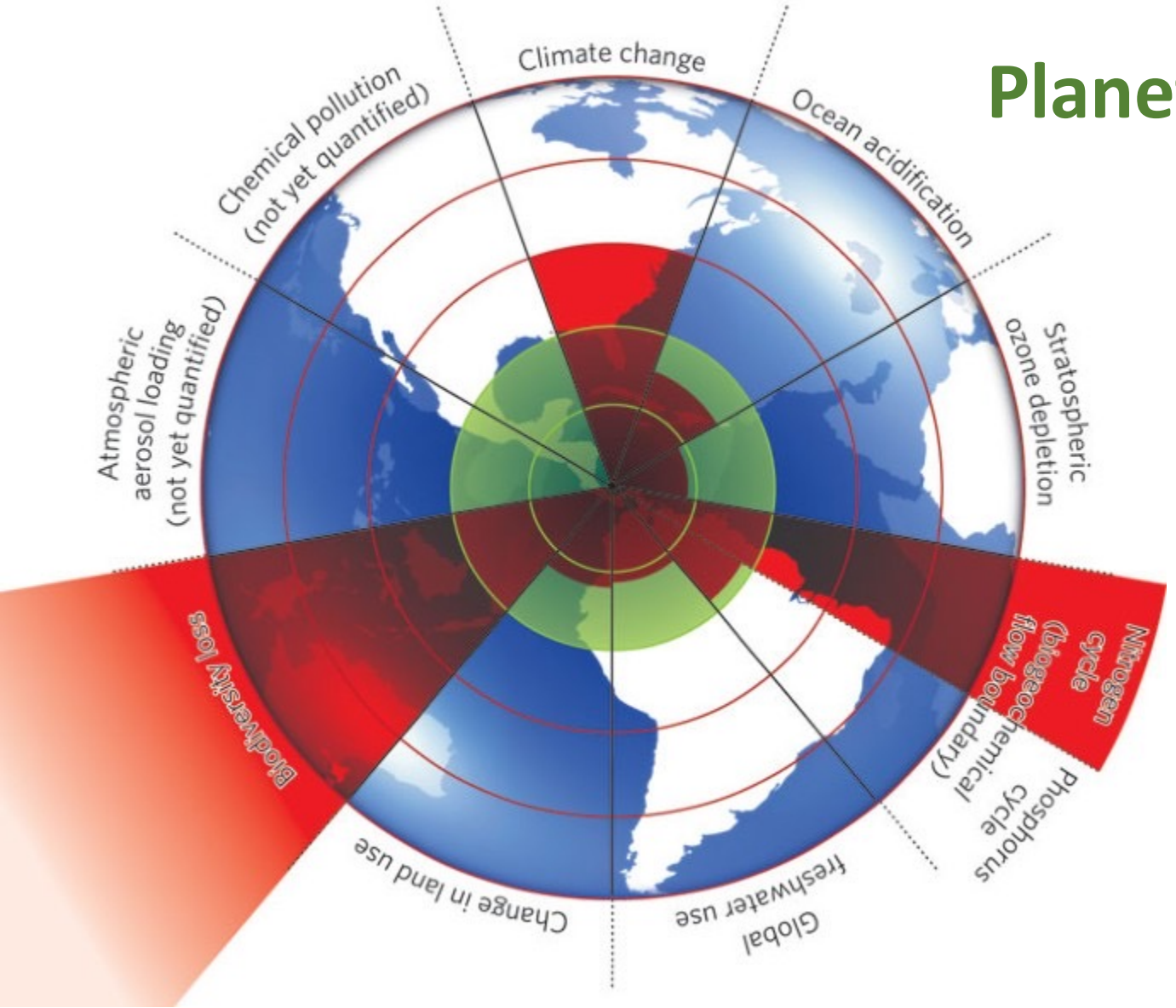


- **Orange sections indicate "overshoot" of boundaries**
- **Green sections indicate a "safe" state within the boundaries**
- **Gray sections are still unquantified**

https://en.wikipedia.org/wiki/Planetary_boundaries#/media/File:PB_pollutants_2022_update.png

Example: Level of Risk Associated with Planetary Boundaries





Planetary Boundary 1st Model – 3 Boundaries: 2009

- 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 3 systems (i.e., rate of biodiversity loss, climate change & human interference with the nitrogen cycle) have already been exceeded
- Red within the green zone indicates these 'safe zones' are under stress but have not reached their Planetary boundary

https://www.nature.com/articles/461472a

Key Parameters per Planetary Boundary

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Currently CO_2 is 415 ppm

Dobson Unit is the measure of total O_3 over any given geographic point

Aragonite is a carbonate mineral, one of the three most common naturally occurring crystal forms of calcium carbonate, $CaCO_3$

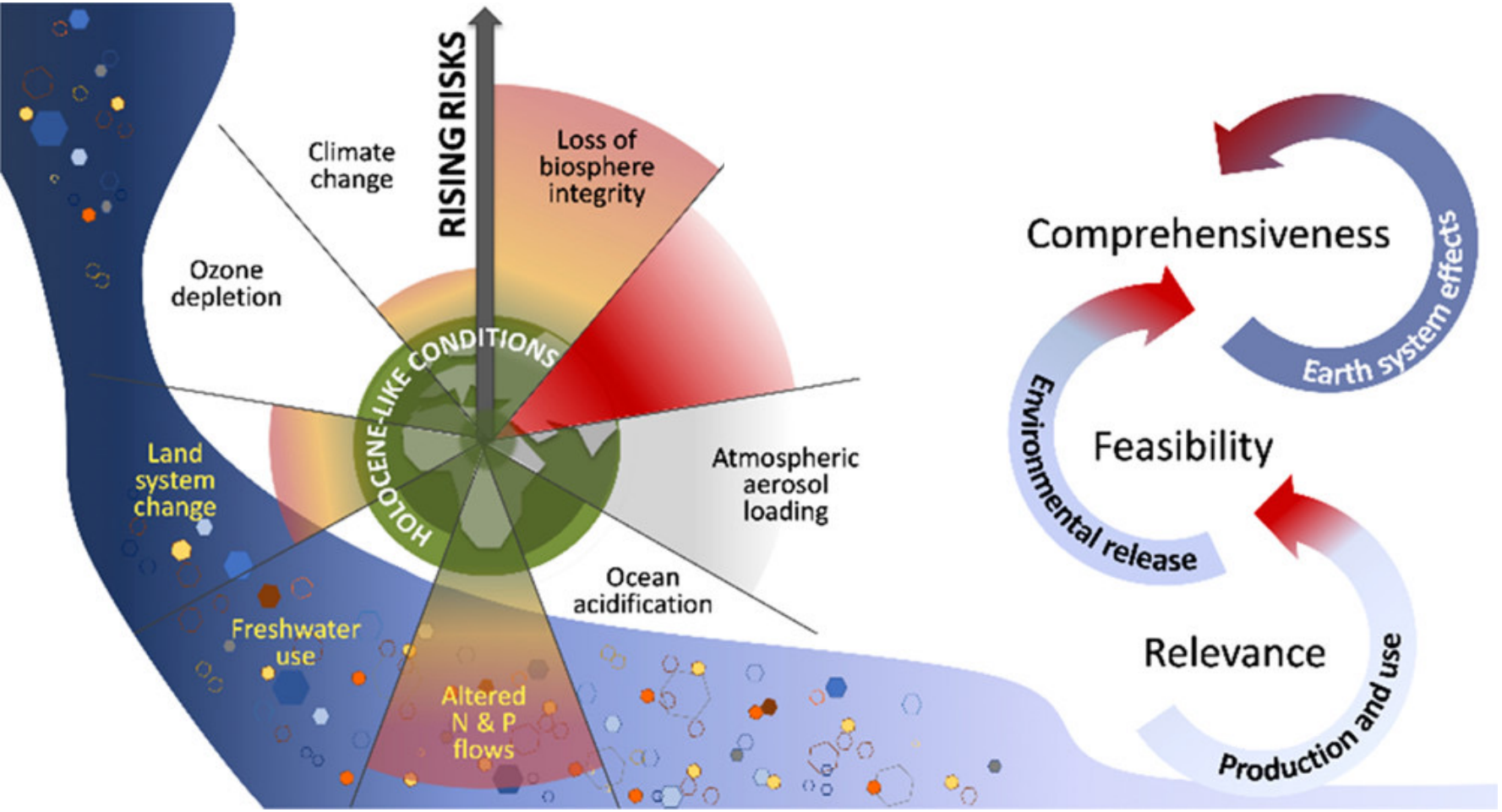
The Boundaries for Novel Entities: A Mini-Case

- **In 2015 the "chemical pollution" boundary was renamed the "novel entities" boundary with a broadened profile to include "new substances, new forms of existing substances & modified life forms"**
  - On its own, chemical pollution has the potential to cause severe ecosystem & human health problems at different scales
- **This boundary refers to entities that are novel in a geological sense & that could have large-scale impacts that threaten the integrity of Earth system processes**
- **Anthropogenic introduction of novel entities to the environment is of growing concern**
  - e.g., at the global level when these entities exhibit persistence, mobility across scales with consequent widespread distribution & accumulation in organisms & the environment, with potential negative impacts on vital Earth System processes & subsystems

Quantifying the Planetary Boundaries for Novel Entities

- **Novel Entities include human produced toxic chemical & physical materials**
  - e.g., pesticides, herbicides, fertilizers, detergents, petroleum in various states, industrial chemicals, plastics, sewage & nanoparticles
- **Three criteria are used for assessment of the suitability of control variables for this boundary**
  - Feasibility, relevance & comprehensiveness
- **Several complementary control variables are proposed to capture the complexity of this boundary**
  - While acknowledging major data limitations

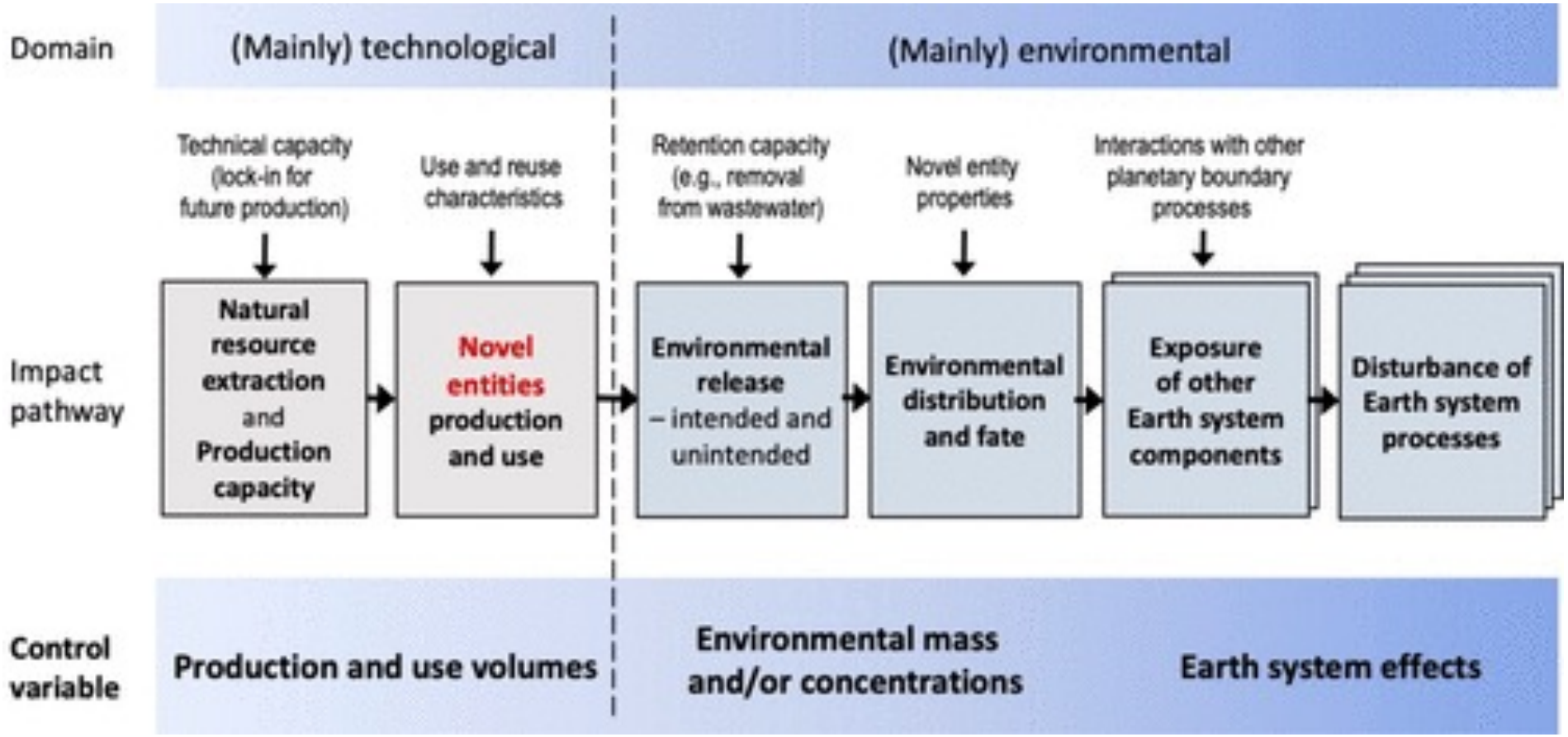
Quantifying the Planetary Boundaries for Novel Entities (2)



https://pubs.acs.org/cms/10.1021/acs.est.1c04158/asset/images/large/es1c04158_0003.jpeg

- **Three criteria for assessment** of control variables for this boundary are: feasibility, relevance & comprehensiveness
- **Several complementary control variables are used** to capture the complexity of this boundary
- **Humanity is currently operating outside the Novel Entities planetary boundary** based on the weight-of-evidence for several of these control variables
- **The increasing rate of production & releases of larger volumes & higher numbers of novel entities with diverse risk potentials exceed societies' ability to conduct safety related assessments & monitoring of new Novel Entities** (e.g., plastics, nanoparticles)

A Generalized Impact Pathway for Novel Entities



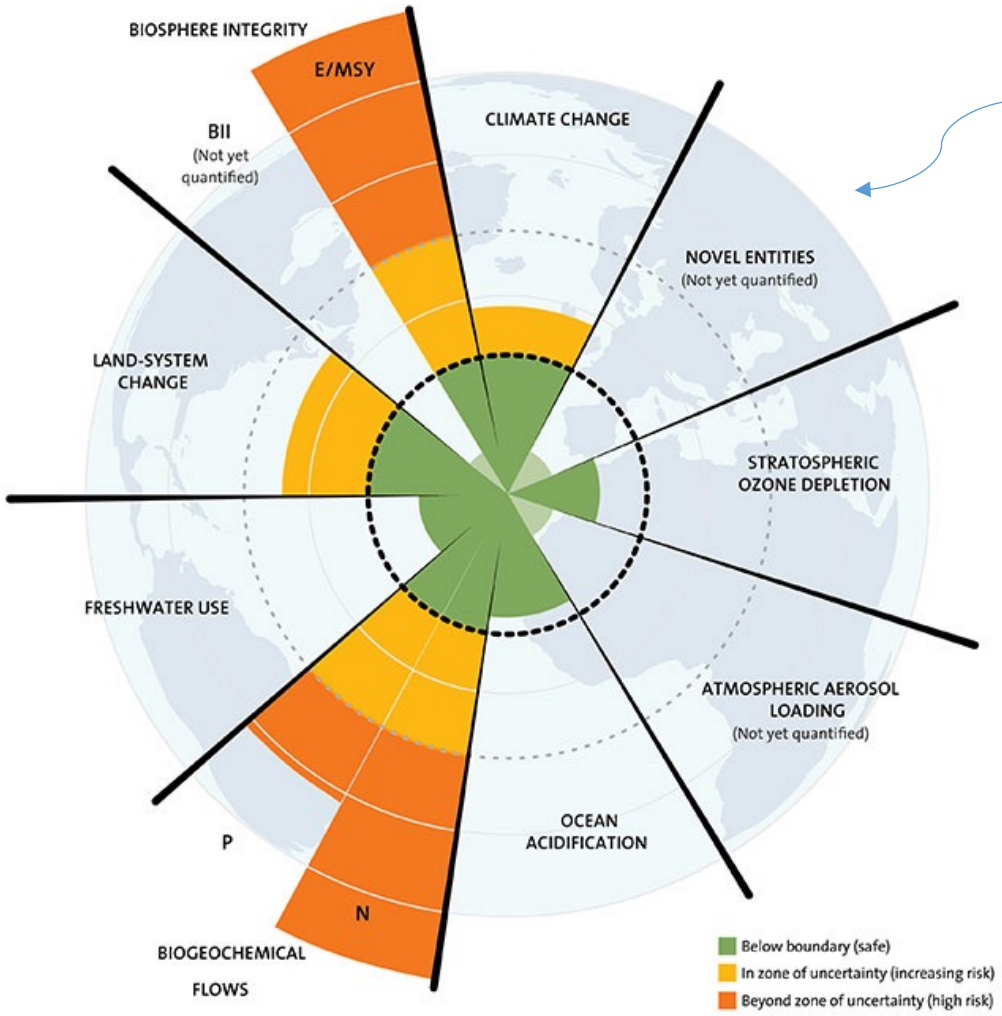
The diagram illustrates the connecting production capacity, environmental release, fate & distribution to perturbation of Earth system processes for Novel Entities

https://pubs.acs.org/doi/full/10.1021/acs.est.1c04158

An Evolving Framework: New Boundaries to Consider

- The current boundary/limit framework is still a work-in-progress, especially given the complexity of the system of systems it is trying to address
- A new boundary has been propose as the ‘green water planetary boundary’ along with its current status
- This status can be represented by the percentage of ice-free land area on which root-zone soil moisture (i.e., to 2 metres depth) deviates from Holocene variability for any month of the year
- Provisional estimates of departures from Holocene-like conditions indicate that the green water planetary boundary is already transgressed

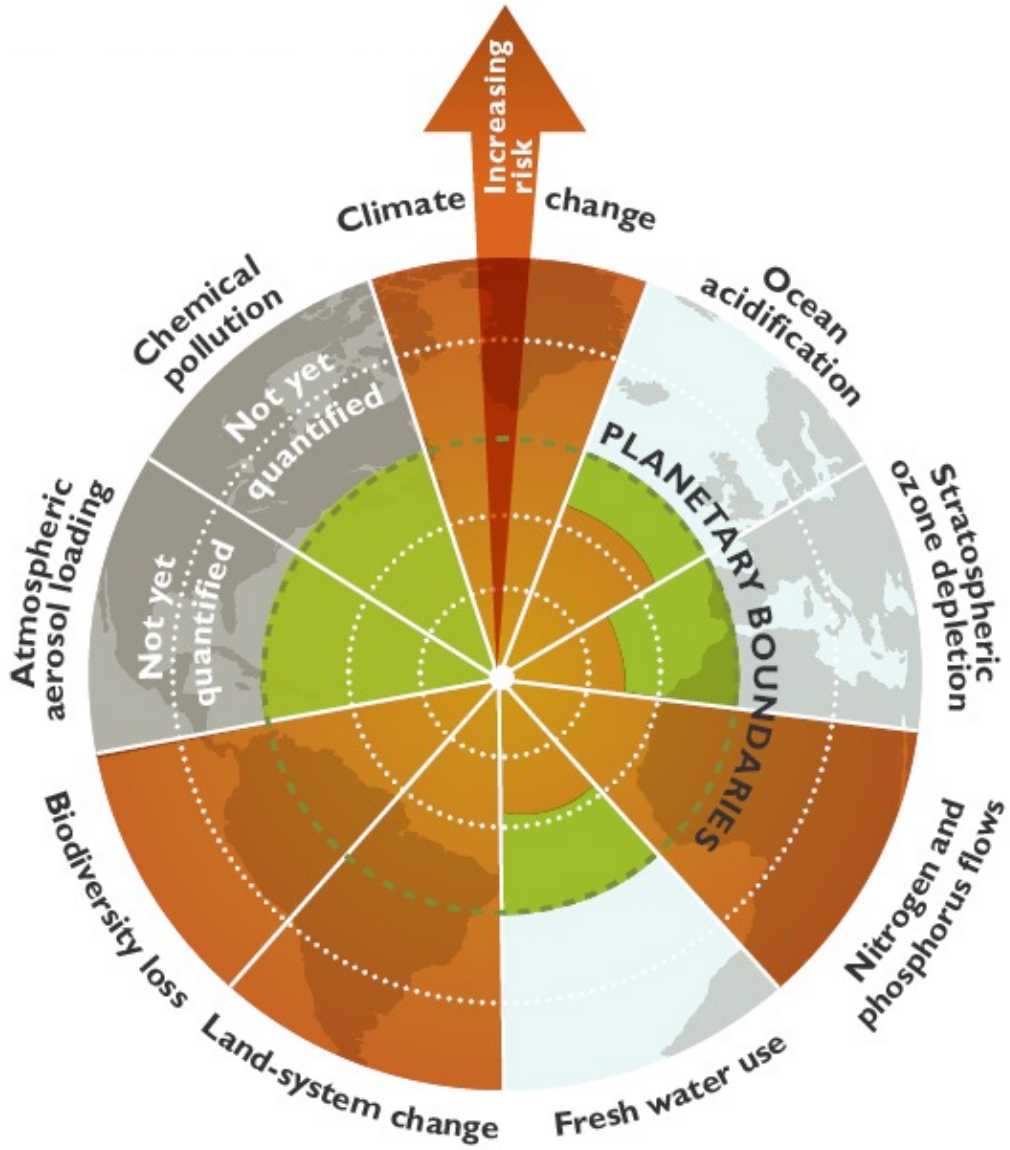
Planetary Boundary 2nd Model – 4 Boundaries: 2015



Watch this in Model 4 by 2022

https://www.stockholmresilience.org/planetary-boundaries

Planetary Boundary 3nd Model – 4 Boundaries: 2018



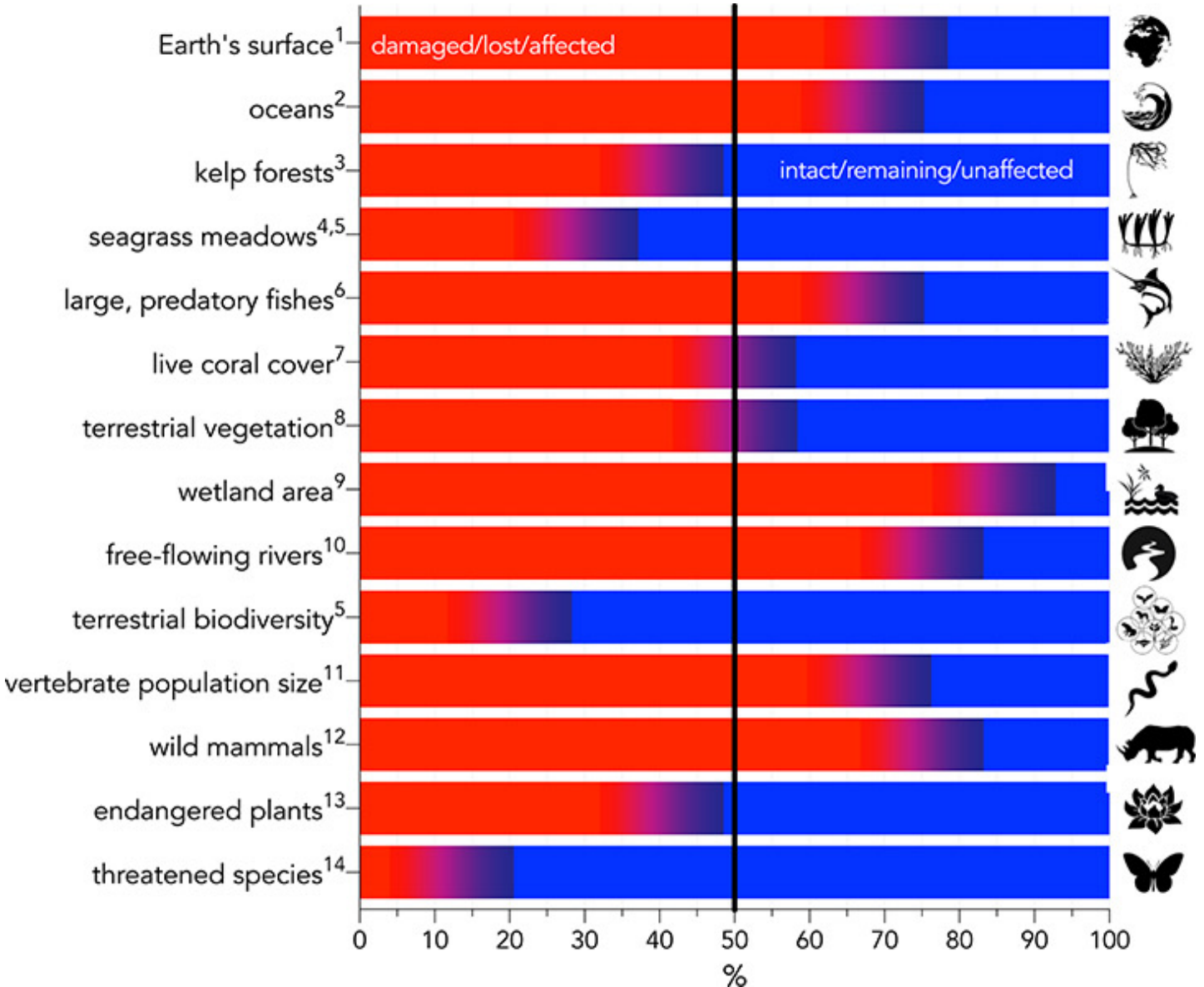
This work is from the Finnish Environmental Institute

https://www.syke.fi/en-US/Finland_and_sustainable_wellbeing/Planetary_boundaries_need_to_be_considered/Planetary_boundaries_already_partly_over(47931)

Planetary Boundaries Framework: Where are we today?

- **The boundaries are based on existing data**
- **The climate boundary is being forced by anthropogenic climate change** & is increasing beyond a sustainable stable climate
- Human modification of the **planetary nitrogen cycle** is at the point of crossing its boundary
- **Ocean acidification** is rapidly approaching a threshold beyond which there may be abrupt & nonlinear changes
- The world may soon be approaching the boundaries for **global change in land use**
- In January 2022, scientists concluded in the scientific journal *Environmental Science & Technology* that humanity has exceeded a planetary boundary related to **environmental pollutants & other "novel entities"** including plastics
- In April 2022, a reassessment of the planetary **boundary for freshwater** indicates that it has now been transgressed due to the inclusion of "green water" – the water available to plants – used in the boundary assessment for the first time
- Today, **Green water** — terrestrial precipitation, evaporation and soil moisture — is fundamental to Earth system dynamics & is now extensively perturbed by human pressures at continental to planetary scales

Biodiversity Loss: by Various Categories



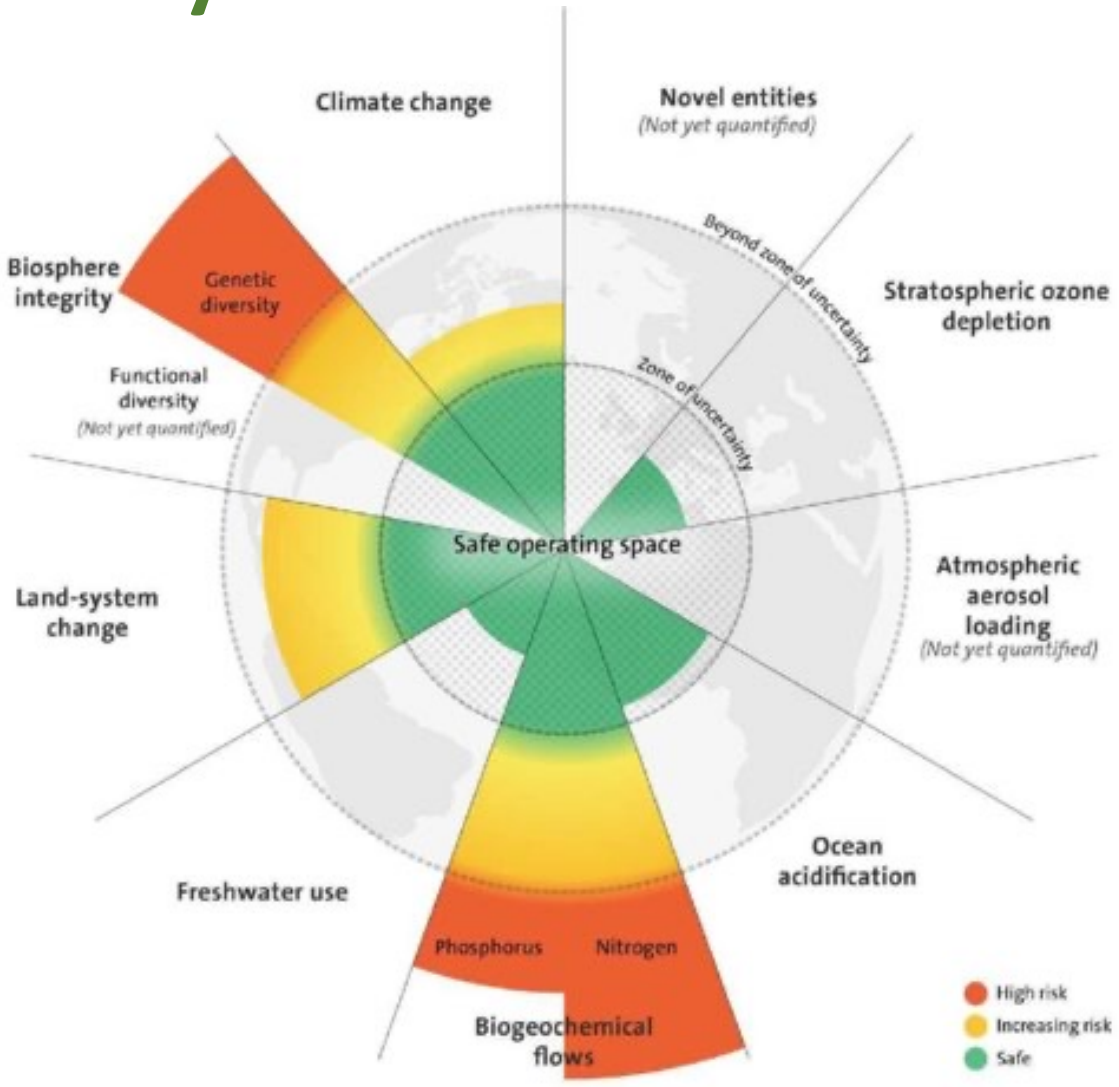
- **Summary of major environmental change categories** expressed as a percentage change relative to a baseline
- **Red indicates the percentage of the category that is damaged, lost, or otherwise affected**
- **Blue indicates the percentage that is intact, remaining, or otherwise unaffected**
- **Transition colours indicate zones of uncertainty**

https://en.wikipedia.org/wiki/Biodiversity_loss

Planetary Boundaries: The latest Assessments

- **Indications from 2022 models show that 4 to 6 of the 9 planetary boundaries are beyond their safe limits**
- **Protecting nature** (e.g., land, biodiversity, freshwater, nutrients) **can help determine whether or not we are able to meet the agreed Paris climate target of 1.5°C**
  - or the more likely outcome being overshoot, currently somewhere between 2°C to 3°C
- **To stop & reverse climate change will require massive action on both decarbonising the global energy system & tackling ecological overshoot, among other tasks related to adaptation & mitigation**

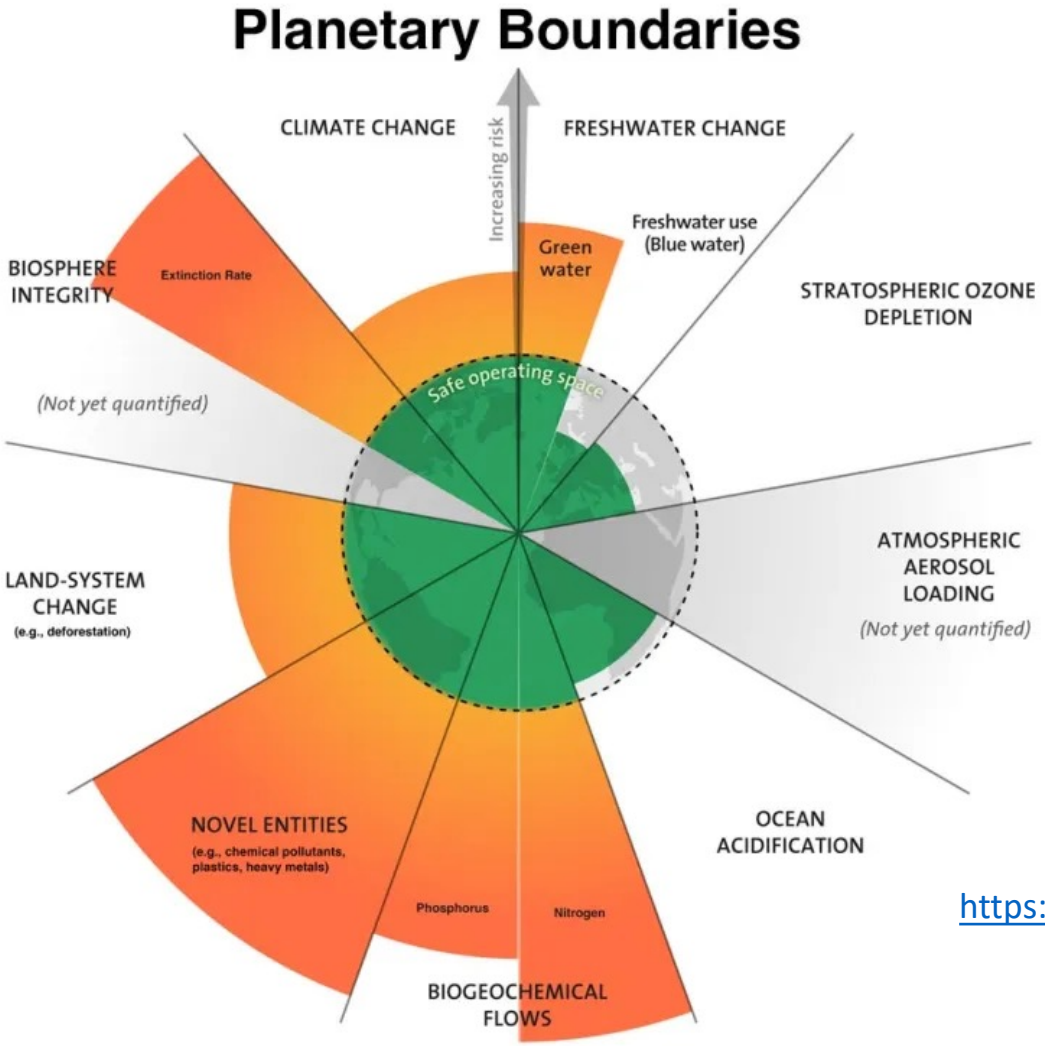
Planetary Boundaries 4th Model - 4 Boundaries: 2022



- **The green zone** is the safe-operating space (below the boundary),
- **The yellow is new** & represents the zone of uncertainty (increasing risk), and **red is the high-risk zone**
- **The planetary boundary itself lies at the inner circle**
- **The yellow zone does not represent a tipping point** or a threshold **so it is placed upstream of it well before the risk of crossing a critical threshold**
- **The buffer between the boundary and a potential threshold in the dangerous zone is to allow society time to react** to early warning signs of approaching abrupt or risky change
- **Processes for which global-level boundaries are not quantified are represented by grey wedges**
- **These are similar to earlier models**

https://www.researchgate.net/publication/350060399_Our_future_in_the_Anthropocene_biosphere/figures?lo=1

Planetary Boundaries 5th Model - 6 Boundaries: 2022



Humanity had crossed from the green "safe" space across 6 out of 9 boundaries & is close to crossing one other - ocean acidification

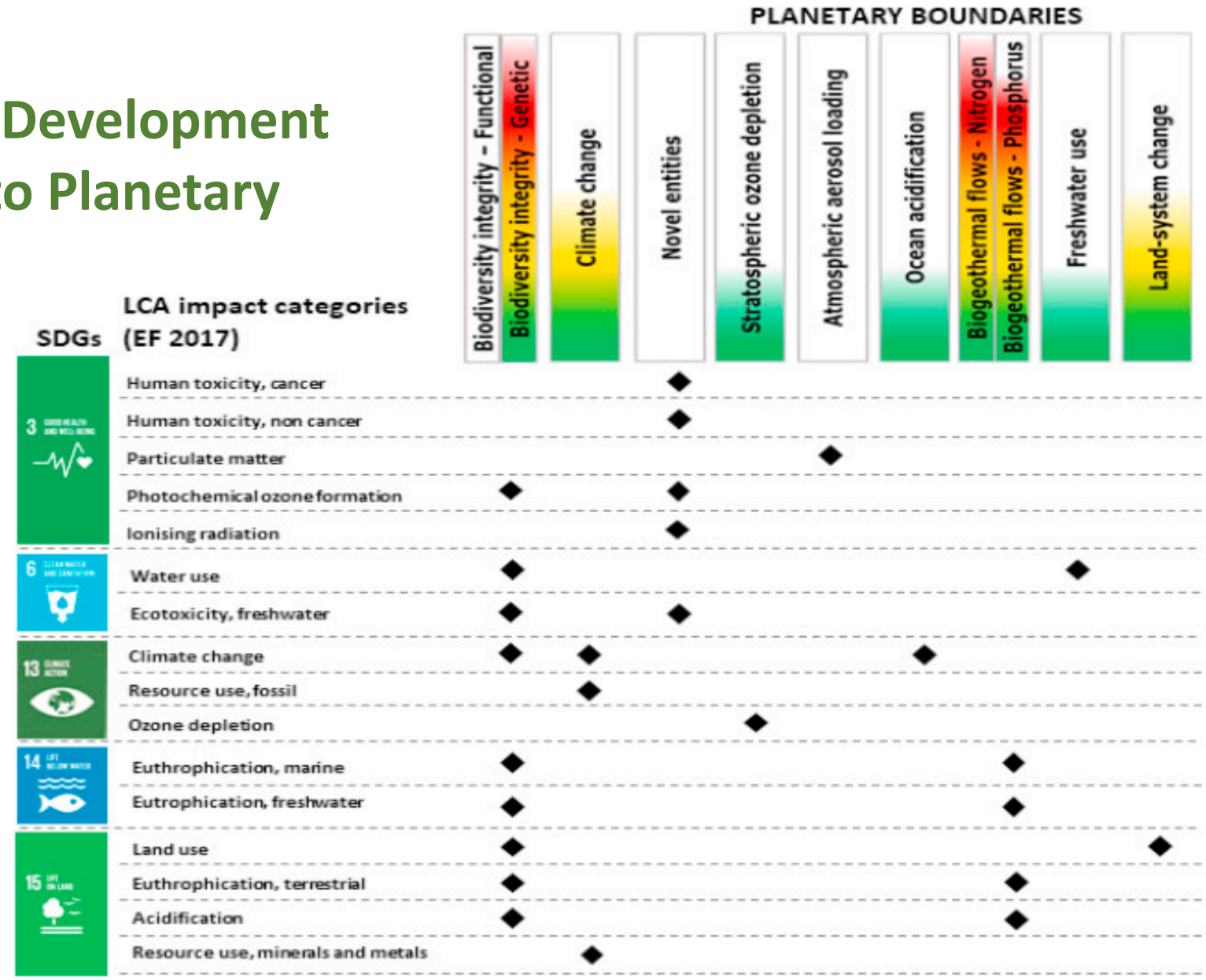
As noted, some boundary zones are not yet quantified

https://skepticalscience.com/recklessness-breaking-6-of-9-boundaries.html

Hierarchical structure of SDGs

SUSTAINABLE DEVELOPMENT GOALS

UN Sustainable Development Goals Mapped to Planetary Boundaries



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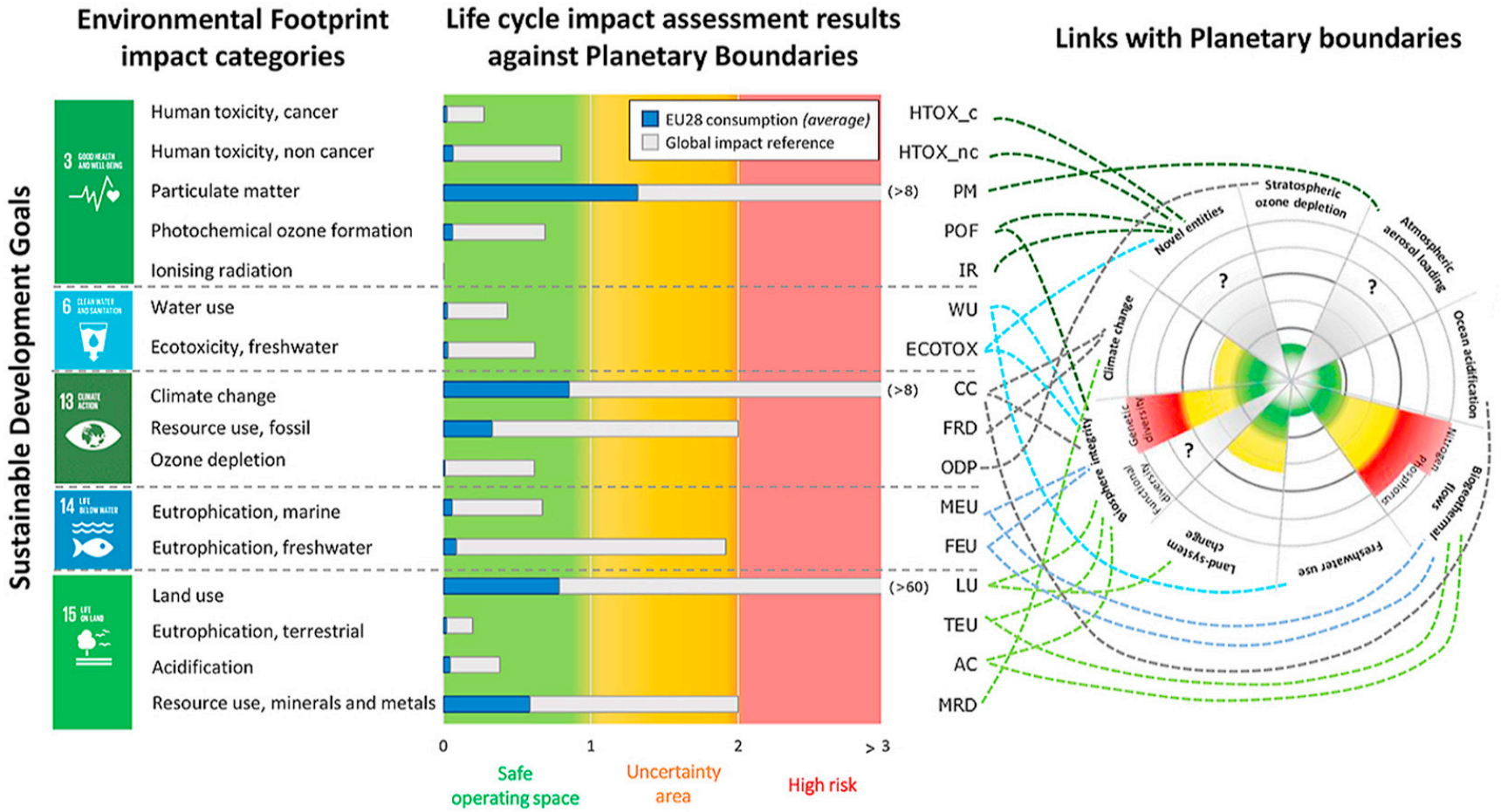
UN Sustainable Development Goals Mapped to Planetary Boundaries (2)



https://www.sciencedirect.com/science/article/pii/S0301479720306186

Conclusions

- The concept of Planetary Boundaries or Limits is a framework for viewing & assessing the vast range of natural & human-induced changes resulting from perturbations of our planetary systems
- The current planetary boundary framework has 9 themes
  - With more likely to be added (e.g., green water) & others subdivided (e.g., biogeochemical flows
- The Planetary Boundary approach maps to most of the UN's Sustainable Development Goals, which will not be met if these boundaries cross into their red zone
- We must recognize in our day-to-day lives & in our governing institutions that Earth with all its life is our only home

Biography

- The Precautionary Principle in Environmental Science Environmental - Health Perspectives•VOLUME109 |NUMBER9 |September 2001 https://ehp.niehs.nih.gov/doi/epdf/10.1289/ehp.01109871
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Merci – Thank You