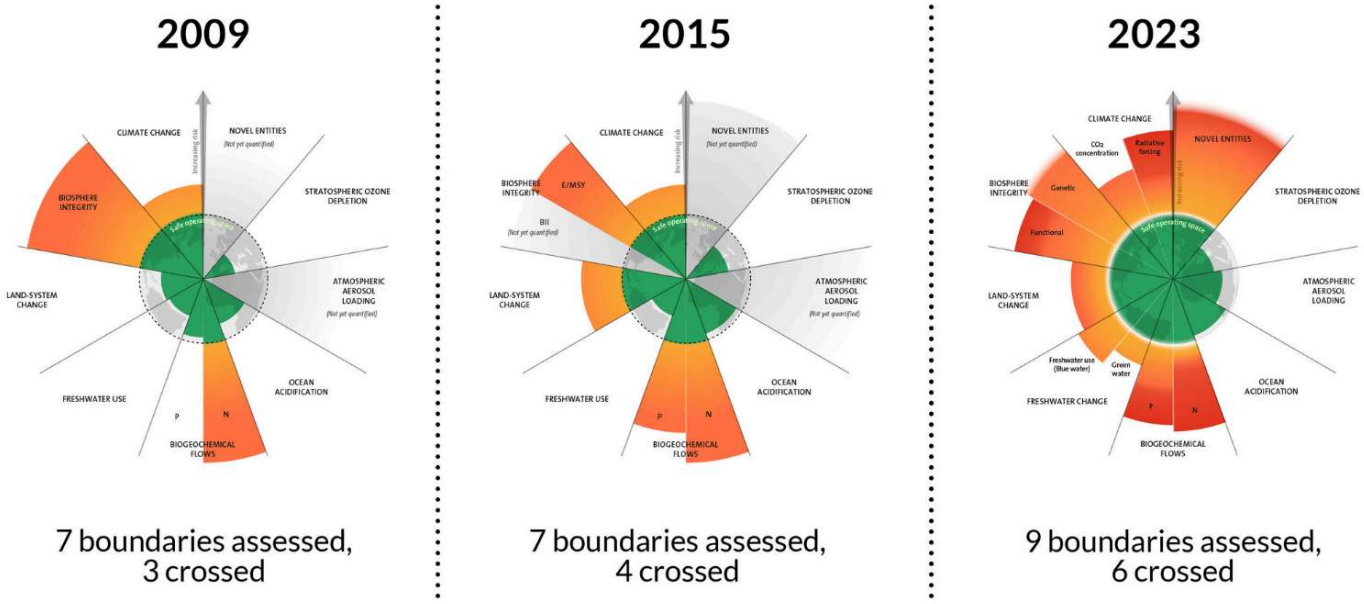
Planetary boundaries



The evolution of the planetary boundaries framework. Licenced under CC BY-NC-ND 3.0 (Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009) Click on the image to download.

> The planetary boundaries concept presents a set of nine planetary boundaries within which humanity can continue to develop and thrive for generations to come

In September 2023, a team of scientists quantified, for the first time, all nine processes that regulate the stability and resilience of the Earth system.

These nine Planetary Boundaries were first proposed by former centre director Johan Rockström and a group of 28 internationally renowned scientists in 2009. The Planetary Boundaries are the safe limits for human pressure on the nine critical processes which together maintain a stable and resilient Earth.

The 2023 update not only quantified all boundaries, it also concluded that six of the nine boundaries have been transgressed.

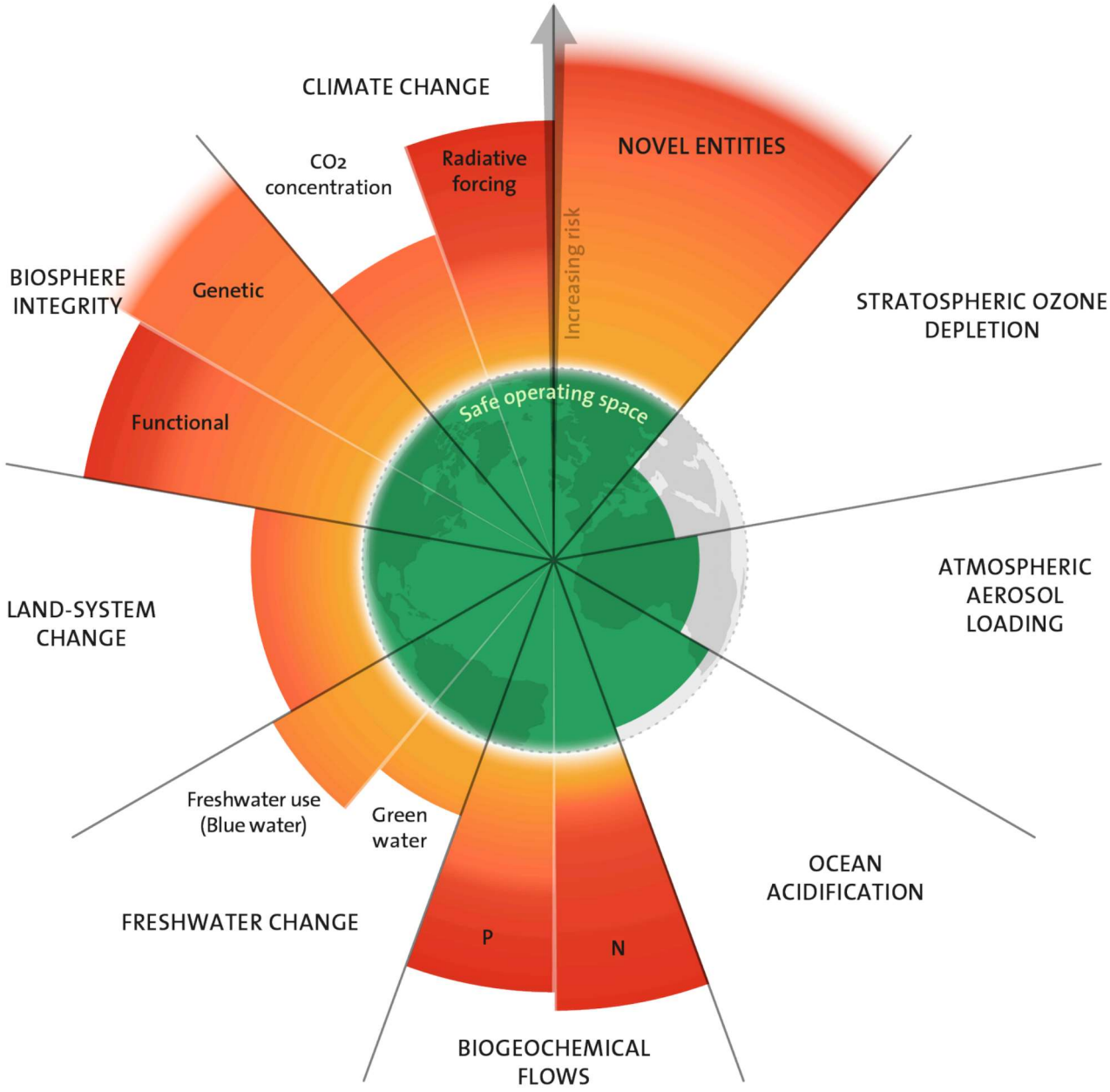
Crossing boundaries increases the risk of generating large-scale abrupt or irreversible environmental changes. Drastic changes will not necessarily happen overnight, but together the boundaries mark a critical threshold for increasing risks to people and the ecosystems we are part of.

Planetary Boundaries are interdependent, meaning that if we cross one Boundary, we will affect others, or even cause them to cross out of the safe operating space.

Boundaries are interrelated processes within the complex biophysical Earth system. We cannot consider Planetary Boundaries in isolation in any decision making on sustainability. Only by respecting all nine boundaries can we maintain the safe operating space for human civilization.

Over the years, the planetary boundaries framework has generated enormous interest within science, policy, and practice.

Since September 2024, the Potsdam Institute for Climate Impact Research produces a yearly update to the framework, called the Planetary Health Check.



The 2023 update to the Planetary boundaries. Licensed under CC BY-NC-ND 3.0. Credit: "Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023". Download the illustration here.

The nine planetary boundaries and their status

Climate change: The change in the ratio of incoming and outgoing energy of the Earth, caused by increased greenhouse gasses and aerosols. More trapped radiation causes an increase in global temperatures and alters climate patterns. This boundary is transgresseed.

Novel entities: The introduction of novel entities includes synthetic chemicals and substances (e.g. microplastics, endocrine disruptors, organic pollutants), anthropogenically mobilized radioactive materials (e.g. nuclear waste, nuclear weapons), and human interventions in evolutionary processes, such as genetically modified organisms (GMOs) and other direct modifications of evolution. Currently, the amount of synthetic substances released into the environment without adequate testing is above the safe level.

Stratospheric ozone depletion: The stratospheric ozone layer protects life on Earth from harmful ultraviolet radiation. The thinning of the ozone layer in the upper atmosphere, primarily due to human-made chemicals, allows more harmful UV radiation to reach Earth's surface. The current total amount of stratospheric ozone is within safe levels, and recovery is ongoing, with values still below mid-20th century levels.

Atmospheric aerosol loading: The rise in airborne particles from human activities or natural sources influences the climate by altering temperature and precipitation patterns. Currently, the interhemispheric difference in atmospheric aerosol loading is within the Safe Operating Space.

Ocean acidification: Ocean acidification is the phenomenon of increasing acidity (decreasing pH) in ocean water due to the absorption of atmospheric CO2. This process harms calcifying organisms, impacting marine ecosystems, and reduces the ocean's efficiency in acting as a carbon sink. The indicator for Ocean Acidification, the current aragonite saturation state, is within the Safe Operating Space but is close to crossing the safe boundary.

Modification of biogeochemical flows: The disruption of the natural nutrient cycles of key elements like nitrogen, and phosphorus through the environment and organisms, which are crucial for supporting life and maintaining ecosystems. Both the global phosphorus flow into the ocean and the industrial fixation of nitrogen (extracting nitrogen from the atmosphere), are disrupting the corresponding nutrient cycles beyond the safe level.

Freshwater change: The alteration of freshwater cycles, including rivers and soil moisture, impacts natural functions such as carbon sequestration and biodiversity, and can lead to shifts in precipitation levels. Human-induced disturbances of both blue water (e.g. rivers and lakes) and green water (i.e. soil moisture) have exceeded the safe level.

Land system change: The transformation of natural landscapes, such as through deforestation and urbanization, diminishes ecological functions like carbon sequestration, moisture recycling, and habitats for wildlife, all crucial for Earth system health. Globally, the remaining forest areas in all three biomes (tropical, boreal, and temperate) have fallen below the safe levels.

Biosphere integrity: The decline in the diversity, extent, and health of living organisms and ecosystems, threatens the biosphere's ability to co-regulate the state of the planet by impacting the energy balance and chemical cycles on Earth. Both the loss of genetic diversity, and the decline in the functional integrity of the biosphere, have exceeded their safe levels.

Key publications

2023

All boundaries are finally assessed in the third major update to the framework which is published in Science Advances. Six boundaries are now transgressed and pressure is increasing on all boundary processes except ozone depletion.

New scientific evidence now enabled the team to quantify the boundary of Atmospheric Aerosol Loading, which according to the study is not transgressed yet despite rising pressures.

The team behind this paper used a new approach to assess Biosphere integrity and concluded that this boundary was transgressed during the late 19th century.

Read "Earth beyond six of nine Planetary Boundaries" here »

2022

In January 2022, 14 scientists concluded in the scientific journal Environmental Science and Technology that humanity has exceeded a planetary boundary related to environmental pollutants and other "novel entities" including plastics.

In April 2022, a reassessment of the planetary boundary for freshwater indicated that it has now been transgressed. This conclusion is due to the inclusion of "green water" – the water available to plants - into the boundary assessment for the first time.

The assessment, published in the journal Nature Reviews Earth & Environment, is based on evidence of widespread changes in soil moisture relative to mid-Holocene and pre-industrial conditions and green-water driven destabilization of ecological, atmospheric, and biogeochemical processes.

2017

Since 2017, Johan Rockström's ERC Advanced Grant Earth Resilience in the Anthropocene funded a new phase in this work. Centre researchers including Sarah Cornell, Tiina Häyhä, Ingo Fetzer, Steve Lade, Andrea Downing, Jonathan Donges, and Avit Bhowmik have all been actively involved in advancing these frontier areas, and building collaborative research links among a growing international community of scientists.

2015

The second update of the whole framework was published in Science. It stated that society's activities have pushed climate change, biodiversity loss, shifts in nutrient cycles (nitrogen and phosphorus), and land use beyond the boundaries into unprecedented territory.

Read "Planetary boundaries: Guiding human development on a changing planet" here »

2009

The orignial conceptualisation of the Planetary Boundaries was first published in Ecology & Society and late in Nature.

Ecology & Society: Planetary Boundaries: Exploring the Safe Operating Space for Humanity

Nature: A safe operating space for humanity

Centre researcher Lan Wang-Erlandsson presents at a conference to commemorate ten years of planetary boundaries in 2019.

Policy and practice

2018

Operationalizing the concept of a safe operating space at the EU level – first steps and explorations. Stockholm Resilience Centre Technical Report, prepared in collaboration with Stockholm Environment Institute (SEI) and PBL Netherlands Environmental Assessment Agency. Stockholm Resilience Centre, Stockholm University, Sweden.

2017

Stockholm Resilience Centre became the scientific partner in a research project with the Ellen MacArthur

Foundation and the Swedish clothing retailer H&M group, working to integrate the planetary boundaries framework and the circular economy concept.

2013-2016

A report to the Swedish Environmental Protection Agency (Pdf, 901.8 kB) assessed Sweden's responsibility, and a 2016 study for the European Environment Agency assessed the contribution to global boundaries both of activities within Europe's territory and of effects of its citizens' consumption. Increasingly, companies are asking for guidance on putting the planetary boundaries into business practice.

The World Business Council on Sustainable Development, a forum for 200 companies including some of the best-known brands in the world, used the planetary boundaries framework to shape their Action 2020 strategy. Since then, there has been further engagement with companies in financial investment, food, textiles, building, technology, and household goods sectors.

2011

Former UN Secretary-General Ban Ki-moon urged global society to "Help us defend the science that shows we are destabilising our climate and stretching planetary boundaries to a perilous degree."

Centre researchers kept planetary boundaries in the forefront of policy-advisory processes leading up to the agreement of the global Sustainable Development Goals. Policy-makers working at national and European levels are also interested, catalysing a research network, PB-net.org, which links scientists involved in translating the global framework to operational decision-making scales.

Contact

For inquiries about the planetary boundaries, please contact us at

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Key publications

Richardson, J., Steffen W., Lucht, W., Bendtsen, J., Cornell, S.E., et.al. 2023. Earth beyond six of nine Planetary Boundaries. Science Advances, 9, 37.

Steffen, W., Richardson, K., Rockström, J. & Cornell, S.E., et.al. 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347: 736, 1259855

Rockström, J., Steffen, W., Noone, K., Persson, Å., et.al. 2009. A safe operating space for humanity. Nature 461: 472-475 DOI 10.1038/461472a

Rockström, J., W. Steffen, K. Noone, Å. Persson, et.al. 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32

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