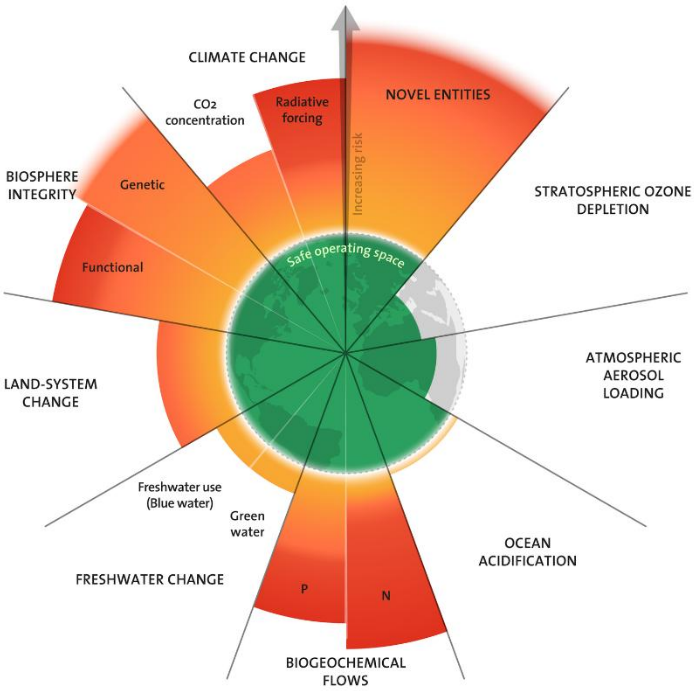
Planetary boundaries, background paper

Scientific insights and policy options



Title:
Planetary boundaries, background paper: Scientific insights and policy options

Purpose:
Preparatory background paper for the conference "Planetary Boundaries in Belgium", 17 December 2025.

Publication:
Belgian Federal council for sustainable development (FRDO-CFDD)

Prepared by:
Secretariat FRDO-CFDD (Esther Vande Cavey)

Scientific contributions and review:
The paper was reviewed by several scientists to verify its scientific substantiation. This paper has been compiled by the FRDO-CFDD secretariat. It does not bind the members of the FRDO-CFDD in any way.

Date:
November 2025

Contact:
mail@frdo-cfdd.be
https://frdo-cfdd.be/

Recommended reference:
Secretariat Belgian Federal council for sustainable development. (2025). *Planetary boundaries note: Scientific insights and policy options.* Preparatory note for the conference "Planetary Boundaries in Belgium", 17 December 2025.

Content

1. The purpose of this paper

This paper has primarily been made as a scientific document providing background on the concept of planetary boundaries and the accompanying conference on 17 December 2025. Several scientists have reviewed this paper and offered valuable suggestions to improve its substantive quality. The paper serves a dual purpose. On the one hand, it provides a clear explanation of the concept itself, highlighting both its strengths and limitations. On the other hand, it shows how Belgium relates to these ecological boundaries. In addition, the paper outlines possible policy options and necessary actions, with the aim of providing a well-founded basis for further reflection and decision-making on sustainability challenges. The paper largely follows the structure of the conference programme.

2. Scientific context

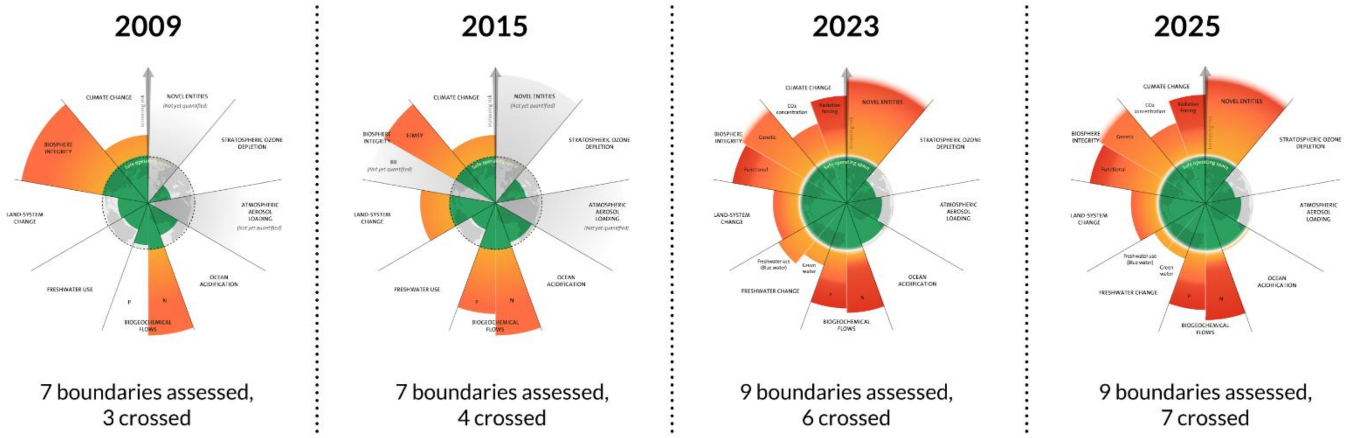
The planetary boundaries describe the limits within which humanity can operate safely without jeopardizing the stability of the Earth system. Crossing one or more of these planetary boundaries can lead to irreversible and dangerous changes in the Earth system. Humanity therefore has every interest in living within these boundaries.

The original conceptualization of the planetary boundaries was launched by the *Stockholm Resilience Centre*[1] in the scientific journal *Ecology & Society* in 2009. Later that year, the influential publication also appeared in the scientific journal *Nature*.

The 9 planetary boundaries according to the Stockholm Resilience Centre (2025) are:

1. Climate change
2. Biosphere integrity
3. Modification of biogeochemical flows (Nitrogen & Phosphorus)
4. Stratospheric ozone depletion
5. Ocean acidification
6. Freshwater change
7. Land system change
8. Atmospheric aerosol loading
9. Novel entities

The thresholds for climate change, biodiversity loss, and nitrogen saturation had already been crossed at the time the framework was launched in 2009. A revision by Steffen et al. (2015) showed that the thresholds for land-use change and phosphorus saturation had also been exceeded. The revision by Richardson et al. (2023) further added freshwater use and new (chemical) entities to the list of transgressed boundaries. The *Planetary Health Check*,[2] an initiative of the *Potsdam Institute for Climate Impact Research*,[3] published a new report in September 2025 indicating that the boundary for ocean acidification has now also been crossed (Planetary Boundaries Science, 2025). Shortly before that, a study by the *Plymouth Marine Laboratory*[4] had already shown that the threat to marine ecosystems from ocean acidification is much greater than previously thought (Findlay et al., 2025). According to the Potsdam Institute for Climate Impact Research, two boundaries have not yet been crossed: atmospheric aerosols and stratospheric ozone depletion.



Azote for Stockholm Resilience Centre, Stockholm University. Based on Sakschewski and Caesar et al. 2025, Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009.

Although the planetary boundaries are measured at the global level, the original authors are also aware that these boundaries are not inherently fair (Gupta et al., 2023). If there is a global limit on CO_2 emissions, who is allowed to emit how much? Historically, wealthy countries have emitted far more than poorer countries, so applying the same boundary to everyone would be unfair. For this reason, natural scientists and social scientists are working together to further develop the concept of Earth system justice. In doing so, they take into account limiting harm to humans and nature, increasing well-being, and ensuring both substantive and procedural justice. Consequently, the boundaries sometimes need to be redefined in order to achieve these objectives.

Methodology

To determine the thresholds of the planetary boundaries, the nine critical global processes were studied. For each process, a boundary was established well below the level of critical *tipping points*. Once these tipping points are crossed, sudden and irreversible environmental changes can occur. The planetary boundaries therefore do not represent absolute limits but rather a safety margin before reaching these points of irreversibility. Crossing a boundary does not necessarily lead immediately to severe consequences, but collectively, these transgressions indicate an increased risk of serious disruptions to ecosystems and societies worldwide (Stockholm Resilience Centre, 2025). For example, the lower boundary for climate change has been set at 350 parts per million (ppm) CO_2, while the upper boundary is 450 ppm. This range roughly corresponds to a temperature increase of 1°C to 2°C (Richardson et al., 2023). This is not an absolute limit beyond which tipping points are immediately triggered, but it indicates that we are moving significantly into the danger zone. Today, we have already surpassed 423 ppm (Planetary Boundaries Science, 2025).

It is important to note that these thresholds are not absolute or fixed. The framework is regularly revised based on new insights. This was the case in 2015 with Steffen, in 2023 with Richardson, and in 2025 with Caesar.

For each planetary boundary, one or more indicators are used. Measuring biodiversity loss is extremely complex, which is why multiple indicators are available: genetic diversity, human appropriation of net primary production (HANPP), and the Biodiversity Intactness Index (BII). The threshold for synthetic chemicals has not yet been established due to a lack of data and reporting. However, it is assumed that this boundary has been crossed due to the widespread presence of "forever chemicals" in our food and clothing, as well as microplastics in our blood and in the oceans (Planetary Health Check, 2024).

Below is an overview of each planetary boundary with its corresponding indicator, threshold value, and the global value for 2025.

Category	Indicator	Planetary threshold	Value 2025
Biogeochemical flows	Phosphorus (Tg/year)	6,2	**18,2**
	Nitrogen (Tg/year)	62	**165**
Land system change	Afforestation (%)	> 75	**59**
Freshwater change	Blue water (%)	12,9	**22,6**
	Green water (%)	12,4	**22**
Biodiversity loss	BII (%)	> 90	**70**
Climate change	CO_2-concentration (ppm)	350	**423**
Aerosols	Aerosol Optical Depth (AOD)	0,10	**0,06**
Ozone depletion	Concentration (DU)	> 277	**285,7**
Ocean acidification	Aragonite saturation status	> 2,86	**2,84**
Chemical pollution (novel entities)	**2025 value exceeded**		

Planetary Health Check, 2025

Since planetary boundaries describe a planetary system, translating them to the various sublevels is not straightforward. The question, therefore, is: how can the global indicators of planetary boundaries be converted into national indicators? Since there is no clear methodology, any choice to use this or that indicator is ideologically driven.

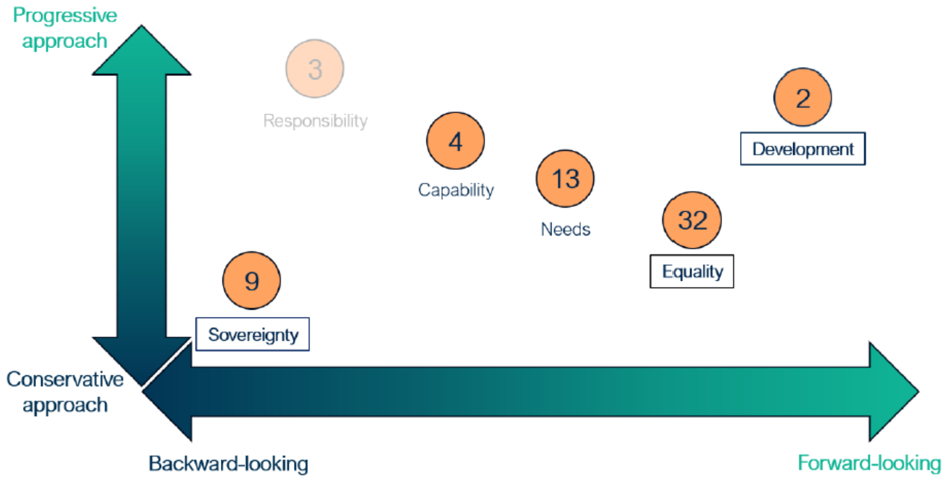
Allocation principles

In 2020, an influential study was published by the *European Environment Agency*[5] and the *Swiss Federal Office for the Environment*,[6] which focused on the different allocation principles that can be applied (EEA & FOEN, 2020). An allocation principle is a method for distributing finite and therefore limited resources among all organisms (i.e., humans) for essential life and development processes, while remaining within the planetary boundaries. This can be implemented in various ways.

Here, the six allocation principles are explained.

- **Equality**: An equal per capita share in access to resources.
- **Needs**: Differentiated needs based on factors such as location, household composition, and age.
- **Right to Development**: The principle is long-term convergence toward comparable per capita wealth.
- **Sovereignty**: Countries are governed according to national policies and have a legal right to use their own territory as they see fit.
- **Capacity**: Countries have different levels of economic wealth. Countries with greater financial resources can proportionally contribute more to mitigation efforts or use fewer resources than allocated, as their ability to pay is higher.
- **Responsibility**: Countries have historically used resources and thereby contributed to environmental change. The degree of responsibility for addressing the problem can then be linked to the "polluter pays" principle.

Studies for Sweden (Swedish Environmental Protection Agency, 2022), the Netherlands (RIVM, 2025), France (Statistical Data and Studies Department, 2019), and Flanders (Department Omgeving, 2024) each rely on one or more of these allocation principles. The study by the *Centre for Climate Change Risk Analysis*[7] (CERAC, 2024) is based on the two ends of this spectrum: on the one hand, the "right to development" and, on the other, "sovereignty." **The right to development** is considered the most progressive and future-oriented principle. In this scenario, the threshold for crossing a planetary boundary is the lowest, meaning a boundary is crossed most quickly. **Sovereignty** is the most conservative and historically oriented principle, resulting in a high threshold for crossing a planetary boundary. The remaining allocation principles fall somewhere between these two extremes.



Cerac, 2024. Classification of the allocation principles based on their temporal perspective (backward- or forward-looking) (Bai et al., 2024) and their normative perspective (conservative or progressive). The number of national studies using each principle is indicated in orange (according to the literature review by Bai et al., 2024). The degree of opacity indicates whether the data are available for Belgium.

However, it is not always possible to follow this operationalization strictly. The extent to which it is applicable depends on the specific planetary boundary and the situation of a region or country with respect to that boundary. This is clearly a limitation of the planetary boundaries' methodology. These and other limitations of the planetary boundaries are discussed in more detail in section 5.

Consumption, production or territorial perspectives

In addition to the allocation principles, the question arises as to which perspective is most relevant for a particular planetary boundary. In this context, three perspectives can be distinguished, which are briefly explained below. It is important to note that these perspectives are based on a systems approach.

- The **production-based approach** considers the environmental impact based on the goods and services produced within a country. The consumption of these goods and services may occur outside that country.
- The **consumption-based approach** considers the environmental impact based on the goods and services consumed within a country. These goods and services may have been produced outside that country.
- The **territorial approach** considers the environmental impact within the borders of a country, regardless of where production and consumption take place.

PB Belgium	Territorial	Production	Consumption
Climate change		X	X
Biodiversity loss	X		
Biogeochemical flows		X	X
Land system change		X	X
Freshwater change		X	X
Air quality	X		

Different approaches to looking at PG in Belgium

3. Planetary boundaries in Belgium

To describe the situation in Belgium, CERAC (2024) chooses to translate six of the nine planetary boundaries to the Belgian level. This is due to the lack of operationalization for stratospheric ozone depletion, ocean acidification, and chemical pollution. Science indicates that ocean acidification is a consequence of climate change, meaning that this planetary boundary is indirectly addressed at the Belgian level as well.

Belgium overshoots five of the six planetary boundaries examined at the production level and all six boundaries at the consumption level. This follows from an analysis of Belgium's performance on the six identified boundaries (CERAC, 2024). Below is an overview of the situation in Belgium for each planetary boundary, based on CERAC's findings.

1. Air pollution as an alternative translation of aerosols at the Belgian level. Air quality in Belgium still exceeds the World Health Organization's threshold values by nearly a factor of two.

µg/m³	EU threshold	WHO threshold	Footprint Belgium
Particulate matter	25	5	8

2. Nitrogen & phosphorus: Nitrogen levels are up to three times higher than the most conservative threshold value. Belgium consumes more nitrogen and phosphorus than the global ecosystem can sustain in the longer term. Nitrogen is a problem that is concentrated at the local level and must be addressed as such.

Tg/year		Sovereignty	Right to Development	Footprint Belgium
Phosphorus	*Production*	0,002	0,002	0,006
	Consumption	0,036	0,002	0,103
Nitrogen	*Production*	0,090	0,021	0,394
	Consumption	0,169	0,021	0,431

3. Biodiversity loss: The situation in Belgium is alarming, as the threshold value of a maximum 10% loss of biodiversity has been exceeded by a factor of 3.

BII	Sovereignty	Right to Development	Footprint Belgium
Biodiversity preservation	> 90		65

4. Climate change: Here too, Belgium significantly exceeds even the most conservative threshold. Belgium must decarbonise faster and more than the global average in order to take historical responsibility.

Gt CO2 1850-2021		Sovereignty	Right to Development	Footprint Belgium
Emission	*Production*	7	< 1	> 12
	Consumption	9	< 1	16

5. Land system change: Belgium has a high historical deforestation rate of 78% (the threshold is 50%), mainly due to industrialisation, urbanisation and agriculture. Belgium also lives beyond its means in terms of production and consumption of arable land.

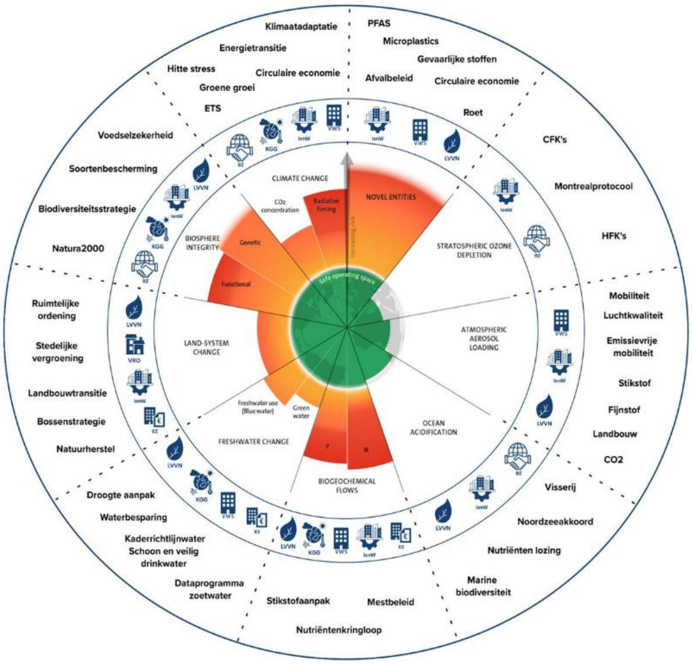
kha		Sovereignty	Right to Development	Footprint Belgium
Arable land	*Production*	460		863,5
	Consumption	13.119	650	10.629
Deforestation	*Production*	1534 (50% deforestation)		2.464
	Consumption	0 (net zero deforestation)		15

6. Freshwater change: The downscaling model falls short in assessing local water risks. Belgium does not exceed the global freshwater limit in terms of production, but does experience water stress in the summer. From a consumption point of view, Belgium uses slightly more than its fair share of blue water (drinkable water). Import decisions must take into account water risks in other countries in order to prevent negative impacts elsewhere.

Km^3/year		Sovereignty		Right to Development	Footprint Belgium
Blue water	*Productie*	3,17		1,39	~ 0,07
	Consumptie	14,82		1,39	6,30

4. Action to take

In order to remain within planetary boundaries, a fundamental review of how we deal with raw materials, energy, nature and food is needed. Policymakers appear to be sensitive to the concept of planetary boundaries. For example, the European Union refers to *living well and within planetary boundaries* in its 8th Environment Action Programme (European Commission, 2025). This framework can also be used to evaluate the Sustainable Development Goals. In the Netherlands, an integrated framework has been developed on behalf of *Statistics Netherlands*[8] and the *National Institute for Public Health and the Environment*[9] (RIVM, 2025) that not only helps to identify the causes and consequences of environmental pressure, but also highlights solutions that look beyond planetary boundaries. By gaining insight into the interrelationships between boundaries, policy measures can be taken that are more effective and future-proof.



These boundaries are represented by icons for each boundary, indicating the various ministries that have areas of overlap with these boundaries. The outer circle lists policy topics related to planetary boundaries, illustrating current social challenges. RIVM, (2025).

Raw materials policy can help keep life within planetary boundaries by using natural resources more sustainably, cutting down on waste and emissions, and encouraging a circular economy. Measures that tackle the absolute level of raw material consumption should also be part of the policy. This is something that's currently missing from European policy (Zero Waste Europe, 2025). To arrive at a policy that can internalise negative externalities, Zero Waste Europe (2025) proposes three alternative approaches. The first is to expand the CBAM to cover more products. The second option is to impose a tax on air pollutants under the CBAM and ETS. Finally, they propose moving away from the ETS towards a fully-fledged tax system for emissions.

The action to be taken to remain within planetary boundaries is threefold: (1) respecting scientific thresholds as a planet, (2) differentiated responsibility, and (3) guaranteeing that all people have the conditions necessary to live with dignity.

Scientific tresholds

Most attention in political discussions is focused on climate change. There is something to be said for this, as tackling climate change contributes positively to greater respect for other planetary boundaries such as ocean acidification, biodiversity loss, nitrogen emissions and land use change. Today, the Paris Climate Agreement (1.5°C scenario) is the most ambitious global climate target. According to CERAC (2024), Belgium must reduce its emissions to negative emissions because it has exceeded its “fair share” based on population. van Vuuren et al. (2025) even argue that achieving the 1.5°C scenario is not enough to stay below the planetary climate limit. Factors limiting action include slow natural responses (such as the absorption of CO_2 emissions by oceans), limitations in negative emission techniques (such as land use for reforestation), and the slowness of societal change. As a result, climate adaptation actions will become increasingly important. These actions are closely linked to biodiversity issues.

Biodiversity loss in Belgium is mainly due to densely populated areas and agriculture. Belgium must protect valuable habitats, expand nature areas through green corridors and actively restore impoverished ecosystems. According to CERAC (2024), Belgium will not reach the threshold by 2050 in the most ambitious scenario. In addition, both food production and consumption must become more sustainable. A transformative shift in the food system and ambitious nature conservation measures are key factors for an effective biodiversity strategy.

Closely linked to this are agriculture and nitrogen emissions in Belgium. A transition is needed to a more sustainable agricultural model with reduced use of pesticides and artificial fertilisers, including through the introduction of stricter nitrogen standards – particularly in the vicinity of nature reserves, as this is a local environmental problem (European Commission, 2023). In consultation with the agricultural sector, a transition plan must also be drawn up to reduce livestock numbers and limit changes in land use (Zenodo, 2023).

The recent EAT-Lancet report (Rockström et al., 2025) emphasises that such reforms are essential. In addition, Li et al. (2024) point to the need for a differentiated strategy: regions with high meat consumption, such as Belgium and Western Europe, should focus primarily on reducing meat consumption and achieving food sufficiency, while regions with low consumption but high production inefficiencies should focus on more efficient agricultural practices.

Air pollution is also a major problem in Belgium. The policy on particulate matter deserves to be continued, as it has already led to a significant reduction over the years. Nevertheless, concentrations in Belgium are still twice as high as the WHO threshold value (CERAC, 2024).

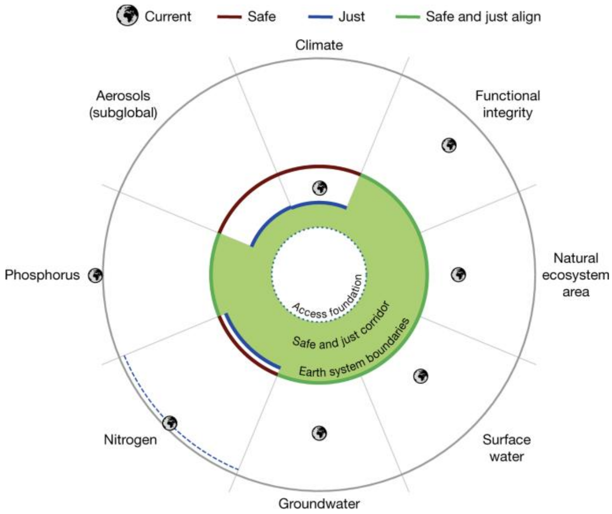
The most important lesson to be learned from this is that action on one planetary boundary has spillover effects on the other planetary boundaries. This is a consequence of the systems approach of this framework. It offers opportunities to return to the *safe operating space for humanity* with a coherent policy.

Don’t overshoot

Planetary boundaries must therefore not be crossed. An important insight comes from Agarwal and Narain (1991). They pointed out the difference and inequality in global emissions. On the one hand, there are survival emissions that result from basic human needs such as cooking, heating or basic transport, and are therefore difficult to avoid. On the other hand, there are luxury emissions that result from overconsumption and non-essential activities such as flying holidays, large cars or air conditioning, especially in richer countries. This framework of shared but differentiated responsibilities must also be integrated into the planetary boundaries’ framework.

Recognising these inequalities is crucial for a just transition: while poorer populations or countries contribute least to crossing planetary boundaries, they bear the heaviest burden of the consequences in relative terms. Examples include extreme weather conditions, food insecurity or pollution of the living environment.

In his more recent work, Rockström refers to the *safe and just boundaries* (2023). ‘Safe’ means staying within the ecological limits of the planet — in other words, ensuring that we do not disrupt ecosystems, climate, biodiversity, water and nitrogen cycles to such an extent that life on Earth is threatened. 'Just' means ensuring that all people, regardless of where they live or how much power they have, are protected from harm. It is therefore about avoiding disproportionate burdens on vulnerable groups and respecting human rights. Consequently, a just boundary may be stricter than a planetary boundary. This can be illustrated with the example of climate change. A global temperature increase of 1.5°C poses a lower risk of reaching tipping points than an increase of 2°C, but even in the 1.5°C scenario, many people will be severely affected. In particular, inhabitants of island states will suffer disproportionately from sea level rise, which will already be reached at 1.5°C.



Visualisation of the safe and just planetary boundaries, Rockström et al., 2023

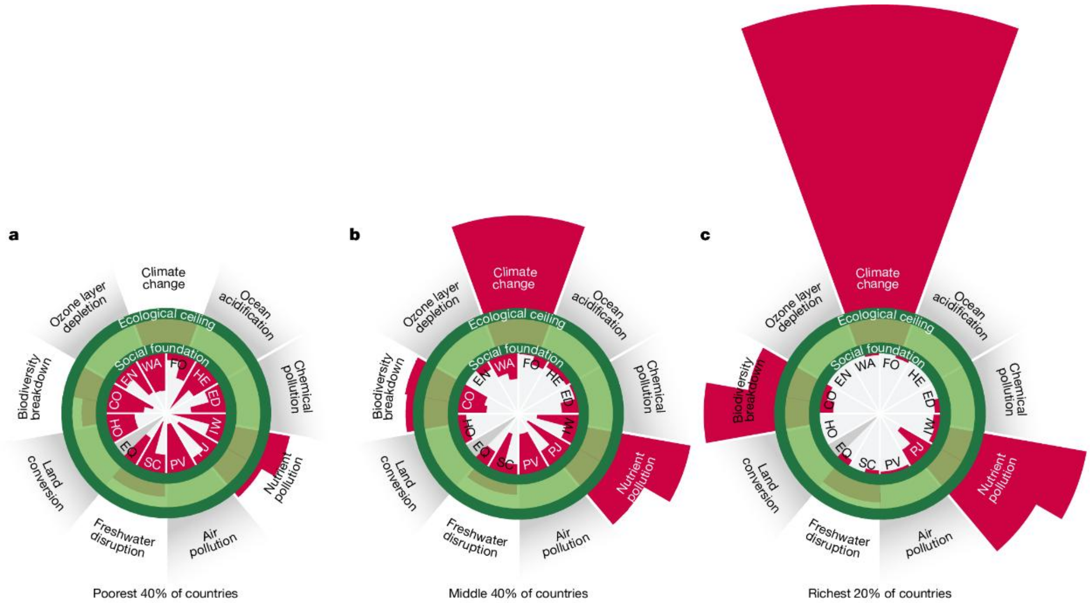
Furthermore, poverty and structural inequalities limit the ability of vulnerable groups to adapt or invest in environmentally friendly technologies. Rich countries or population groups, on the other hand, have the means to become more sustainable more quickly, reduce their luxury emissions and contribute to international climate justice.

It is therefore necessary to also pay attention to environmental justice when monitoring planetary boundaries, whereby ecological sustainability goes hand in hand with social equality. Policy measures should take into account historical emissions, unequal access to raw materials or resources, and differences in economic capacity. In this way, planetary boundaries can be respected in a socially just manner.

Don't undershoot

Until now, the focus has been on not overshooting the outer limits of the planet. But an additional school of thought also advocates not falling below social foundations. In this regard, Kate Raworth's *Doughnut Economy*[10] (2017) plays an undeniable role. The economy must be organised according to an inner ring that represents the social foundation – the basic necessities of life such as food, water, housing, education, etc. – and an outer ring that forms the ecological ceiling – the planetary boundaries. Between these two rings lies the safe and just space for humanity. By combining the SDGs[11] with planetary boundaries, she arrives at the economy of the 21st century. This concept has already been implemented in a number of cities around the world. Amsterdam was the first city to officially adopt this concept in 2020.[12]

In 2025, an update of the global *Doughnut* was published (Raworth & Fanning, 2025). This update highlighted global inequalities in terms of shortfalls and overshoots. The poorest 40% of countries mainly fall short in terms of human lower limits, while the richest 20% of countries overshoot more planetary boundaries. We see that the social deficit improves and the ecological surplus worsens as income levels rise. An earlier study by Fanning et al. (2022) already showed that countries cross planetary boundaries faster than they contribute to social indicators.



a, Poorest 40% countries. **b**, Middle 40% countries. **c**, Richest 20% countries. Red areas indicate a deficit below the social foundation or an overshoot of the ecological ceiling. Kate Raworth & Andrew Fanning (2025).

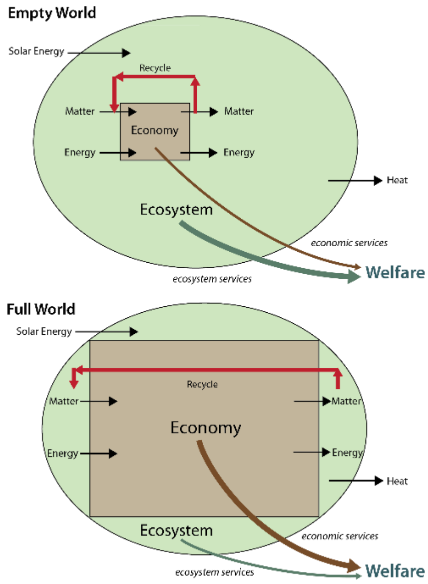
Ensor and Hoddy (2021) further advocate a human rights perspective as a useful addition by drawing attention to the social contexts, power relations, and structural problems that influence environmental management. One solution lies in *adaptive governance* and rights-based approaches. These recognise that human rights are not just legal frameworks, but also powerful tools for oppressed groups to claim resources, participation and self-determination. Bottom-up processes in particular – such as grassroots activism, social movements and local NGOs – are considered crucial. Human rights can thus form a bridge between local struggles and global environmental goals.

In addition, Chang (2003) draws attention to the phenomenon of 'kicking away the ladder'. This idea posits that rich countries that became economically successful through active government policy in the 1970s are now advocating other strategies, such as free trade. In doing so, they are preventing poorer countries from using the same strategies that worked for them in the past. They are kicking away the ladder they themselves climbed, so that others can no longer use it. By analogy with Chang, it is advisable not to follow the same path when it comes to the sustainability transition. Developing countries are often pressured to reduce their emissions immediately, without ever having had the same development opportunities as developed countries. Developing countries are expected to avoid fossil fuels and switch immediately to renewable sources, but often without sufficient financial and technological support or access. Here, it is more a case of kicking away the green ladder, which must be avoided.

Decoupling

In summary, the action to be taken can be traced back to the discussion surrounding Gross Domestic Product (GDP). In order to remain within planetary boundaries and guarantee a dignified life for everyone, we must move away from the idea of economic growth in terms of GDP. This idea comes from post-growth thinkers such as Kallis and Hickel (2025). This is not a new, revolutionary idea, as a report to the Club of Rome already noted in 1972 that there are limits to growth.

According to Herman Daly (2015), infinite growth is not possible in a world with finite resources. He illustrates this with his 'full world' and 'empty world' concepts. He points out that the economy is a subsystem of the ecosphere and not the other way around. The problem, according to him, is that many people today still believe that we live in an ‘empty world’, which means that we can and must allow the economy to grow while protecting the environment at the same time.



Full world vs. empty world, Daly (2015)

This brings us to the idea of decoupling. According to the OECD definition (OECD, 2006), decoupling should be understood as breaking the link between “environmental damage” and “economic goods”. This can happen in two ways: on the one hand, relatively, whereby both economic growth and environmental damage increase, but not at the same rate (growth is higher than environmental damage); on the other hand, absolutely, whereby the economy grows while environmental damage nevertheless decreases.

Ritchie (2021) argues that over the past thirty years, an absolute decoupling seems to have occurred between CO_2 emissions and GDP. However, this idea was refuted by the European Environment Agency (Parrique et al., 2019). The strongest evidence against decoupling can be found in raw materials.

Energy and raw materials are crucial to the functioning of an economy, and even more so to a growing economy. Available data indicate that the costs of extracting both energy sources and raw materials are rising (Discovery Alert, 2025; McKinsey&Company, 2015). This is due to the need to compensate for declining raw material quality. If economic growth requires more energy and materials, and more and more energy and materials are needed to extract the same amount of resources, then this increasing energy consumption limits growth and hinders decoupling. Take the increasing demand for critical raw materials such as cobalt and lithium as an illustration. According to estimates, global demand for these materials will increase by 500% by 2050 (World Bank Group, 2020). This is not a consequence of the energy transition, but rather the result of economic logic based on growth. It therefore makes more sense to reverse the reasoning: it is not our demand that determines how much we use, but rather the available quantity that determines what is possible. This means a shift from a model based on efficiency to one based on sufficiency. Green growth is therefore not possible globally (Nathan et al., 2024).

The IPCC also considers sufficiency to be a fully-fledged sustainability strategy. The SER framework used for this purpose distinguishes between three strategies that are linked in a hierarchical structure. The first step is sufficiency: behavioural and systemic changes that ensure we need less energy and raw materials. This is followed by efficiency, whereby the available energy is used as optimally as possible. Only in the third step does renewable energy come into play: the remaining energy needs are then met with renewable sources (Buildings and Cities, 2021; IPCC, 2022).

Traditional economic theories do not allow for determining whether a market transaction is fair or not. Hornborg (1998) proposes understanding unequal exchange through the flow of energy and materials. Poorer countries supply raw materials with high productive value, while richer countries supply products in which a lot of energy has already been wasted. Paradoxically, this wasted energy increases the economic value of a product, causing resources to continue to flow into production that is actually destructive. This exacerbates ecological damage and global inequality. Nevertheless, there is a possibility to break out of this system of dependency. It is often warned that there is no ecological space for Africa to start industrialising on a large scale. According to Millward-Hopkins et al. (2025), there is. The world already uses 2.5 times as much energy and raw materials to provide everyone – both now and in the future – with a decent minimum standard of living. Nevertheless, the authors note that about half of the countries are struggling with energy and material shortages, while the countries with surpluses are growing four times as fast. They conclude that the countries with surpluses should reduce them to a sustainable level in order to make room for countries with shortages to increase their consumption to an adequate level.

5. Strengths and limitations

Strengths

The planetary boundaries framework provides a scientifically based framework for analysing the sustainability of human activities within the carrying capacity of the planet. One of its greatest strengths is that it is based on interdisciplinary research, bringing together insights from climate science, ecology, chemistry and geology, among other fields. This makes the model a solid scientific basis for environmental policy and sustainability strategies.

A second important strength is the systems thinking that underlies the concept. Instead of viewing environmental problems as separate elements, the model recognises that the Earth is a coherent system in which disturbances in one component (such as biodiversity) also affect other components (such as climate and food security). This makes it possible to gain insight into complexity.

In addition, the concept functions as a warning system. By visually and quantitatively displaying the crossed boundaries with the radar chart, it becomes clear which environmental limits have already been exceeded and which are still within safe margins. This can increase the urgency and stimulate action among policymakers and citizens.

The model also has communicative power. The term *planetary boundaries* appeals to the imagination and helps to make abstract environmental problems concrete. It can connect humanity by presenting a common goal.

Finally, the model is policy-relevant: it is recognised by international organisations such as the United Nations and the European Union and forms the basis for their respective sustainability objectives, such as the Sustainable Development Goals (SDGs) and the 8th Environment Action Programme. In this way, it bridges the gap between science and policy.

Limitations

Despite the scientific and policy value of the model, the concept of planetary boundaries also has clear limitations. The first and most important limitation is scientific uncertainty. Determining the exact thresholds for some boundaries, such as biodiversity loss or nitrogen pollution, is difficult. Some boundaries are based on estimates with large margins of uncertainty. This makes it difficult to make concrete policy choices. Because the boundaries are defined globally, it is not obvious to convert the global environmental impact into national or regional thresholds. In addition, the limited quantification also poses a problem. Not all boundaries are well quantified. Consider, for example, the ‘novel entities’ boundary, which is difficult to measure. For some boundaries, there is also debate about which indicator is most suitable for measuring the threshold value. In the case of biodiversity loss, one can look at the rate of extinction on the one hand or at ecosystem function on the other.

Secondly, criticism has been levelled that the planetary boundaries take too little account of social justice. Although the original framework from 2009 was ecologically oriented, it has been expanded in recent years to include a social dimension. Johan Rockström and his colleagues (2023; 2024) have actively contributed to this process through the concept of *Safe and Just Operating Spaces* – inspired by Kate Raworth's doughnut economy – which focuses not only on preserving the biosphere and stability, but also on social justice and human dignity. A nitrogen limit that is ecologically safe at the global level may be socially unjust at the local level. A ‘safe and just’ approach therefore requires stricter limits in places where people suffer disproportionately from the effects of nitrogen pollution, even if the global standard has not yet been formally exceeded.

Thirdly, questions are sometimes raised about the political feasibility of the framework. This is not entirely unjustified, but although the planetary boundaries framework is global and abstract in nature, that does not mean it cannot be translated into practical policy. The example of fish quotas based on the regenerative capacity of marine ecosystems shows that policy measures are indeed possible if ecological carrying capacity is taken as the starting point, limits are translated into measurable indicators at the ecosystem level, and there is a willingness to adapt human activity accordingly.

Finally, the model rightly focuses on crossing planetary boundaries, but once a boundary has been crossed, there is no turning back. And that is true to a certain extent. If a planetary boundary is crossed that also activates one or more tipping points, the consequences are disastrous. Scientists have identified 25 tipping points in the Earth system, and five of these are already at risk of being reached at the current rate of warming (University of Exeter, 2023). However, no one knows exactly at what temperature increase these tipping points will be reached. But once they are reached, it is out of our hands. Mitigation efforts are being undermined by feedback loops such as the release of methane gas from permafrost. Biodiversity efforts are being undermined by the desertification of the Amazon rainforest and the death of coral reefs.

However, this does not have to be a one-way street. There are also positive tipping points that can turn the tide. But this requires political will. For example, the 1987 *Montreal Protocol* decided to stop using substances that deplete the ozone layer in order to combat ozone depletion (Ozone Secretariat, 2019). This is a prime example that shows that progress can be made with regulatory environmental policy. An important caveat here is that this will not undermine the underlying system. It is a correction that does not call today's economic model into question. In order to reverse the direction in which we are evolving to the ecological and social advantage, it is necessary to organise our economic system according to those principles as well.

Strengths	Limitations (nuanced)
Scientifically substantiated: based on interdisciplinary research	Scientific uncertainty and quantification problems
Systems thinking: approaches the Earth as a coherent whole	
Warning system: shows where critical thresholds are being exceeded	Social dimension absent in initial publication, later supplemented with 'safe and just' principles
Communicates urgency: makes environmental problems tangible and concrete	Political feasibility subject to conditions
Supports sustainable policy: aligns with SDGs and policy strategies	Transgressing planetary boundaries is not necessarily a one-way street

Strengths and limitations of planetary boundaries framework, summary

6. Summary

The concept of planetary boundaries, developed by the *Stockholm Resilience Centre* (Rockström et al., 2009), provides a scientific framework for assessing the stability of the Earth system. It identifies nine critical processes that determine the Earth's habitable equilibrium, including climate change, biodiversity, nitrogen and phosphorus cycles, land use, freshwater consumption, ocean acidification, ozone depletion, aerosols and chemicals. The boundaries have been deliberately set below the thresholds of irreversible change in order to create a safety margin. However, the most recent *Planetary Health Check* (2025) shows that seven of the nine boundaries have been crossed globally. Only ozone depletion and aerosols remain within the safe zone. The CO_2 concentration of 423 ppm illustrates that we are already deep in the danger zone.

Although the framework was developed at the global level, there is a growing consensus that planetary boundaries must also be translated fairly to countries and regions. After all, not every country contributes equally to environmental pressure or has the same development needs. That is why the principle of *Earth System Justice* is essential: striving for a balance that respects ecological boundaries without losing sight of social justice.

Translating planetary boundaries into national indicators is complex and highly politicised. There is no single method. Six distribution principles can be applied to contextualise these boundaries at the national level:

Equality – Needs – Right to development – Sovereignty – Capacity – Responsibility

These principles range from progressive (*right to development*) to conservative (*sovereignty*) and influence when a boundary is considered to have been crossed.

Furthermore, environmental pressure can be calculated in three ways: through production (impact of domestic production), consumption (impact of domestic consumption, including imports) or territorial emissions (impact within national borders).

Belgium overshoots almost all planetary boundaries, both in terms of production and consumption. The overshoot is particularly serious for air quality, nitrogen and phosphorus pollution, biodiversity loss, climate change and land use. Only freshwater use remains slightly within planetary boundaries, although there is local pressure on water resources. Addressing this overshoot requires fundamental changes in the use of resources, energy, nature and food.

These results make it clear that Belgium's ecological footprint is mainly determined by consumption patterns. An integrated policy that reforms both production and consumption is therefore necessary. Within this framework, the agricultural sector is a key element. Current agricultural practices contribute significantly to nitrogen pollution and biodiversity loss and require a fundamental transition to sustainability. Belgium must commit to an agricultural model that is less dependent on pesticides and artificial fertilisers, with stricter nitrogen standards in the vicinity of nature reserves. At the same time, there is a need for a well-thought-out transition plan that reduces livestock numbers, optimises land use and guarantees the economic viability of farmers.

These insights emphasise that climate, agriculture, biodiversity and health are inextricably linked. Measures that focus on one boundary often affect other boundaries. A systems approach is therefore necessary: climate policy must go hand in hand with nature restoration, circular agriculture, reducing food waste and promoting sustainable consumption.

The principle of *safe and just operating space* provides a guiding framework for this. It combines ecological boundaries (safe) with social foundations (just), so that justice and well-being are also guaranteed. Rich countries such as Belgium bear historical responsibility and have the means to become sustainable more quickly. A distinction must be made between ‘survival emissions’, which are necessary for basic needs, and ‘luxury emissions’, which result from overconsumption.

This way of thinking is in line with Raworth's *Doughnut Economy* (2017, 2025), which defines a safe and just space between a social foundation and an ecological ceiling. While poorer countries often remain below the social minimum, rich countries systematically overshoot ecological limits. This calls for a redistribution of resources, technology and knowledge, and a reorientation of economic growth.

The idea that ‘green growth’ is sufficient is increasingly being questioned. Empirical evidence shows that absolute decoupling between economic growth and environmental pressure rarely occurs (Parrique et al., 2019). Therefore, a shift from efficiency to sufficiency is needed: first, limiting demand and adjusting consumption patterns, then producing efficiently, and finally focusing on renewable energy (IPCC, 2022). Today, the world uses 2.5 times more energy and raw materials than is sustainable (Millward-Hopkins et al., 2025).

Despite its limitations — uncertainties in thresholds and difficulties in national translation — the concept of planetary boundaries has a major merit: it offers a clear and scientifically based compass. It makes the ecological urgency tangible and shows that sustainability is not merely an environmental goal, but a prerequisite for social well-being.

For Belgium, this means a clear call to action: the current overshoot of almost all planetary boundaries is not inevitable. With targeted policy measures, a transition to sustainable land use and food production, and a societal shift towards sufficiency, our country can contribute to a future within the safe and just boundaries of the Earth.

7. Sources

Agarwal, A., & Narain, S. (1991). *Global warming in an unequal world* (p. 81).

Buildings and Cities. (2021, 10 October). *COP26: Sufficiency Should be First.*

CERAC. (2024). *Is Belgium living within its safe operating space?* Final report.

Chang, H. J. (2003). Kicking away the ladder: Infant industry promotion in historical perspective. *Oxford Development Studies, 31*(1), 21-32.

Daly, H. E. (2015). Economics for a full world. *Great Transition Initiative*.

Departement Omgeving. (2024). *Leeft Vlaanderen binnen de grenzen van onze planeet? Een analyse van de indicatoren voor Vlaanderen in relatie tot de planetaire grenzen.*

Discovery Alert. (2025). *Energy Transition's Profound Impact on Mining Economics.*

EEA, FOEN. (2020). Is *Europe living within the limits of our planet? An assessment of Europe's environmental footprints in relation to planetary boundaries.* Publications Office, Copenhagen Denmark.

Ensor, J., & Hoddy, E. (2021). Securing the social foundation: A rights-based approach to planetary boundaries. *Earth System Governance*, 7.

European Commission. (2023). *Nitrogen pollution reduction targets: a more plant-based diet is key.*

European Commission. (2025). *Environment action programme to 2030.*

Fanning, A., et al. (2022). The social shortfall and ecological overshoot of nations. *Nature sustainability*, *5*(1), 26-36.

Fanning, A., & Raworth, K. (2025). Doughnut of social and planetary boundaries monitors a world out of balance. *Nature*, 646, 47–56.

Findlay, H. S., et al. (2025). Ocean acidification: another planetary boundary crossed. *Global Change Biology*, 2025, *31*(6).

Gupta, J., Bai, X., Rockström, J. (2024). A just world on a safe planet: a Lancet Planetary Health–Earth Commission report on Earth-system boundaries, translations, and transformations. *The Lancet Planetary Health, 8*(10), e813-e873.

Gupta, J., et al. (2023). Earth system justice needed to identify and live within Earth system boundaries. *Nature Sustainability, 6*(6), 630-638.

Hornborg, A. (1998). Towards an ecological theory of unequal exchange: articulating world system theory and ecological economics. *Ecological economics, 25*(1), 127-136.

IPCC. (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Kallis, G., Hickel, J., O'Neill, D. W. (2025). Post-growth: the science of wellbeing within planetary boundaries. *The Lancet Planetary Health, 9*(1), e62-e78.

Kersten, K., et al. (2025), *Naar een raamwerk voor het meten van de impact van de Nederlandse economie op de planetaire grenzen*. Den Haag: Centraal Bureau voor de Statistiek. Bilthoven: Rijksinstituut voor volksgezondheid en milieu (RIVM), 50pp

Li, C., Pradhan, P., Wu, X., et al. (2024). Livestock sector can threaten planetary boundaries without regionally differentiated strategies. *Journal of Environmental Management*, *370*.

McKinsey&Company. (2015). *Productivity in mining operations: Reversing the downward trend.*

Millward-Hopkins, J., Hickel, J., & Nag, S. (2025). Is growth in consumption occurring where it is most needed? An empirical analysis of current energy and material trends. *The Lancet Planetary Health, 9*(6), e503-e510.

Nathan, H. S. K., et al. (2024). Guest editorial: Towards operationalizing sufficiency. *Journal of Indian Business Research*, *16*(1), 1-7.

OESO. (2006). *Decoupling the Environmental Impacts of Transport from Economic Growth*.

Ozone Secretariat. (2019). *The Montreal Protocol on Substances that Deplete the Ozone Layer*.

Parrique T., Barth J., Briens F., C. (2019). Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability. *European Environmental Bureau.*

Planetary Boundaries Science (PBScience). (2025). *Planetary Health Check 2025*. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany.

Planetary Health Check. (2024). *Our planet's vital signs are flashing red.*

Planetary Boundaries Science (2025). Planetary Health Check 2025. *Potsdam Institute for Climate Impact Research (PIK).*

Raworth, K. (2017). *Doughnut economics: Seven ways to think like a 21st century economist*. Chelsea Green Publishing.

Richardson, K., et al. (2023). Earth beyond six of nine planetary boundaries. *Science advances*, *9*(37).

Rijksinstituut voor volksgezondheid en milieu. (2025). Naar een raamwerk voor het meten van de impact van de Nederlandse economie op de planetaire grenzen. *Centraal Bureau voor de Statistiek*., 50pp.

Ritchie, H. (2021). Many countries have decoupled economic growth from CO2 emissions, even if we take offshored production into account. *Our World in Data*.

Rockström, J., Steffen, W., Noone, K., et al. (2009). A safe operating space for humanity. *Nature* 461, 472–475.

Rockström, J., Thilsted, S. H., Willett, W. C., et al. (2025). The EAT–Lancet Commission on healthy, sustainable, and just food systems. *The Lancet*.

Rockström, J., Gupta, J., Qin, D., et al. (2023). Safe and just Earth system boundaries. *Nature, 619*(7968), 102-111.

Statistical Data and Studies Departement. (2019). *France and the nine planetary boundaries.*

Steffen, W., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *science*, *347*(6223).

Stockholm Resilience Centre. (2025). *Planetary boundaries*.

Swedish Environmental Protection Agency. (2022). *Living within the limits of our planet – a Swedish perspective.*

University of Exeter. (2023). *Global Tipping Points Report*. Summary Report 2023.

van Vuuren, D. P., Doelman, J. C., Schmidt Tagomori, I. et al. (2025). Exploring pathways for world development within planetary boundaries. *Nature, 641*(8064), 910-916.

World Bank Group. (2020). *Mineral Production to Soar as Demand for Clean Energy Increases*.

Zenodo. (2023). *Appetite for Change: Food system options for nitrogen, environment & health. 2nd European Nitrogen Assessment Special Report on Nitrogen & Food*

Zero Waste Europe. (2025). Towards resource autonomy: Proposals for a Circular Economy Act.

Mentioned institutions
[1] https://www.stockholmresilience.org/
[2] https://www.planetaryhealthcheck.org/
[3] https://www.pik-potsdam.de/en
[4] https://pml.ac.uk/
[5] https://www.eea.europa.eu/en
[6] https://www.bafu.admin.ch/bafu/en/home.html
[7] https://www.cerac.be/en
[8] https://www.cbs.nl/en-gb/
[9] https://www.rivm.nl/en
[10] https://doughnuteconomics.org/about-doughnut-economics
[11] https://sdgs.un.org/
[12] https://amsterdamdonutcoalitie.nl/