Applying Planetary Boundaries

Effective Risk Management and Value Creation

June 2026

First Sentier MUFG
Sustainable Investment Institute

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The Institute commissions research on Environmental, Societal and Governance issues, looking in detail at a specific topic from different viewpoints. The Institute recognises that investors are now looking in far greater depth, and with far greater focus, at issues relating to sustainability and sustainable investing. These issues are often complex and require deep analysis to break down the contributing factors. If, as investors, we can better understand these factors, we will be better placed to consider our investment decisions and use our influence to drive positive change for the benefit of the environment and society.

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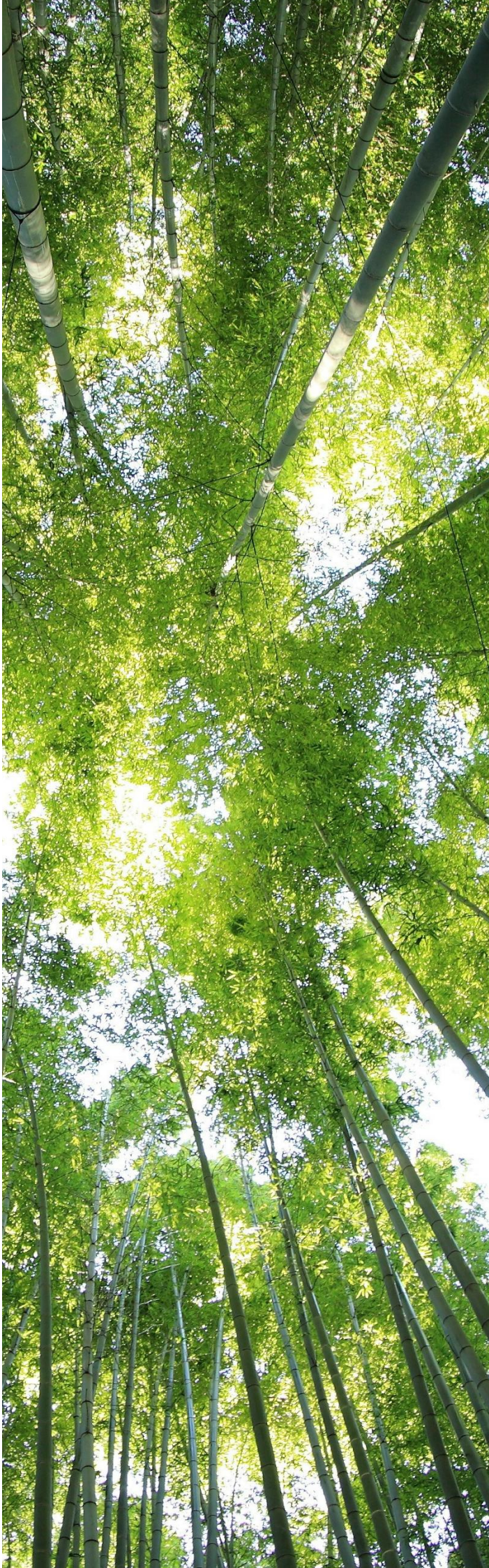


How to read this report

The aim of this report is to help readers understand how Earth systems and planetary boundaries impact global markets.

It equips corporate leaders and investors with a conceptual understanding of the science-based frameworks, as well as actionable insights to navigate emerging environmental risks, anticipate regulatory shifts, and unlock avenues for resilient, long-term value creation.

It is our hope that readers will find the full report useful and intellectually stimulating. For those readers more pressed for time, however, the below summary overview should act as a useful guide in navigating this report.

Chapter	What the chapter covers	Most relevant for
Executive summary	The planetary boundaries framework, systemic risks, and the opportunities for Earth-system-aligned value creation.	All readers, particularly: • C-suite executives • Board members • Senior investment leaders
1. Introduction	The foundational science of the safe operating space and the core strategic questions this report answers.	All readers seeking a high-level baseline understanding of the planetary boundaries topic
2. The Science and interconnections	The nine critical global processes, their trajectories to 2050, and their cascading interdependencies and tipping points.	• ESG investment analysts • Corporate risk officers • Sustainability directors
3. Implications and risks for business, investors, and society	How ecological deterioration translates into material risk, across geographic, sectoral, and temporal lenses.	• Asset allocators • Portfolio managers • Corporate strategists • Corporate risk managers
4. Regulatory and policy landscape	Overview of global disclosure frameworks and regional regulations in the EU, UK, and APAC.	• Investor ESG reporting leads • Corporate compliance officers • Corporate legal teams
5. Opportunities for value creation	How planetary boundary alignment drives market share growth, builds operational resilience, and secures improved financing.	• Growth-focused investors • Corporate strategy leads • Operations directors
6. Tools and methodologies to unlock growth and resilience	Analytical frameworks and models that translate macro-ecological limits into precise corporate and investment metrics.	• Investment analysts • Quantitative modellers • Corporate sustainability teams
7. The critical role of investors	Principles for capital deployment and stakeholder engagement plan to drive value and systemic market change.	• Asset owners • Institutional investors • Stewardship / engagement teams
Appendix	Additional analytical content, e.g. on boundary interdependencies, double-materiality analysis, regulatory factsheets.	All readers seeking more in-depth contextual understanding and analytical outputs

Executive summary

Global markets are being reshaped by a deeper ecological realignment. While the world's attention has been on the immediate threats of climate change, broader changes to Earth's critical global processes are creating wider systemic risks alongside new multi-trillion-dollar opportunities. Investors and corporates best positioned to succeed will be those who anticipate, adapt, and act.

1. **Resilience and long-term growth prospects of the global economy rely intrinsically on the stability and health of our planet.** To date, understanding the ecological changes that threaten this stability has been assessed through the lens of climate change and greenhouse gas (GHG) emissions. However, there exist another eight critical global processes that are far less widely translated into corporate and investment decision-making.
2. **Damage to these wider global processes is already causing significant risk and harm**. For example:
    - $58tn of annual global economic value (>50% of the world's GDP) is dependent on natural ecosystems, many of which are at risk today.[1]
    - $320bn in global physical damages were caused by natural disasters in 2024 alone, while economic losses associated with air pollution accounting for nearly 7% of global GDP.[2]
    - Up to 1.2bn people are projected to be displaced by 2050 due to severe ecological threats, natural instability, and scarcity.[3]
3. In 2009, the Stockholm Resilience Centre developed a science-based framework outlining the **nine critical global processes** that regulate the stability and resilience of our planet. Crucially, the "Planetary Boundaries Framework" also defines the quantitative **planetary boundary (PB) thresholds**. Ultimately, if these boundaries are crossed, they would **increase the likelihood of crossing Earth-system tipping points that would trigger unacceptable and non-linear environmental change**, causing irreversible damage to the Earth.

Figure 1. Current global status of the nine planetary boundaries[4]

Climate Change	High risk	Ocean Acidification	Increasing risk
Biosphere Integrity	Critical	Atmospheric Aerosol Loading	Within safe operating space
Land-System Change	High risk	Stratospheric Ozone Depletion	Within safe operating space
Freshwater Change	High risk	Novel Entities	Critical
Biogeochemical Flows	Critical		

[1] "Living Planet Report", WWF (2024).
[2] "Natural Disaster Figures", Munich Re (2025); "Accelerating Access to Clean Air for a Livable Planet", World Bank (2025).
[3] "Nature Risk Analysis", WWF (2025).
[4] "Seven of nine planetary boundaries now breached – ocean acidification joins the danger zone", Potsdam Institute for Climate Impact Research (2025).

4. **The scientific consensus establishes that seven of the nine planetary boundaries have already been breached.**[5] This is causing an increased risk of irreversible damage, amplified by the profound interconnectedness of critical global processes. Deterioration of one process has immediate negative implications for others. For instance, **Land-System Change** (driven by rapid deforestation) directly exacerbates **Climate Change** by releasing stored carbon. This influx of emissions intensifies **Freshwater Change** by disrupting global precipitation patterns, which subsequently degrades **Biosphere Integrity**, creating a dangerous feedback loop that further weakens the planet's baseline resilience.

5. **The deterioration of critical global processes and planetary boundaries brings existential risks to entire markets and segments of economic activity**. Understanding the impacts of these acute risks requires planetary boundary assessments to be:

    - **Location-specific:** Global averages mask acute regional transgressions. For example, while **Atmospheric Aerosol Loading** is globally within safe limits, severe air pollution in urban areas across Southeast Asia creates localised hotspots of significant risk.
    - **Sector- and asset-based:** Boundaries exhibit distinct 'double materiality' across industries. For instance, the Fisheries sector is existentially threatened by **Ocean Acidification**, even if it barely contributes to the reduction of oceanic pH levels. Similarly, the Transportation sector has little impact on **Freshwater Change**, yet inland shipping can be substantially affected by low river and canal levels, causing high financial materiality exposure.
    - **Time-dependent:** Not all boundaries degrade at the same speed. For example, **Freshwater Change** can create near-term operational risks where drought or water restrictions halt production, constrain hydropower, or disrupt inland shipping, while **Novel Entities** (e.g. PFAS) can build gradually over many years, before turning rapidly into material financial exposure through litigation, clean-up costs, product bans, or tighter regulation.

6. **Companies and investors face interconnected planetary boundary risks that can disrupt cash flows, operations, valuations, and access to capital**. Yet these risks are still not consistently priced by markets, partly because environmental costs remain externalised and decision-useful data is limited. Our shareholder returns analysis found no clear evidence that companies actively mitigating planetary boundary risks outperformed more exposed peers. In some cases, they underperformed the MSCI ACWI benchmark, suggesting public markets do not yet consistently reward companies that are better insulated to Earth system shocks.

7. **From a regulatory perspective, encouragingly, both global frameworks and local legislation are beginning to capture a wider range of critical global processes. However, while improved reporting is an essential tool in advancing the understanding of planetary boundary risks, the regulatory landscape remains fragmented, placing the ball in investors' and corporates' courts to examine their exposures.** This divergence undermines the transition toward transparent and comparable disclosures across jurisdictions. Essentially, until these new PB-aligned regulatory frameworks gain critical mass and establish consistent and comparable market standards, analogous to carbon budgets and well-functioning carbon markets, it remains within investors' and corporates' purview to proactively assess their own planetary boundary exposures and identify related opportunities.

8. **For those able to effectively introduce planetary boundary considerations into their strategic processes and operations, the rewards span well beyond simply improving risk management and mitigating the adverse impacts of environmental deterioration.** Increased value creation, more resilient operations, and improved financing conditions await those who are best able to anticipate, adapt, and act. For example:

[5] "Seven of nine planetary boundaries now breached", Potsdam Institute for Climate Impact Research (2025).

- **The size of the prize:** $10tn in annual business value is expected from transitioning the global economy to a 'nature-positive' state.[6]
- **Sectoral upside:** $4.5tn economic opportunity in the transition to a circular economy.[7]

9. **A growing range of public frameworks and open-source datasets exist to help corporates and investors navigate this transition and achieve a better understanding of planetary boundaries.** Crucially, some of these technical frameworks are free to access and help fill the precise analytical gaps that current regulation is unable to address. By leveraging mechanisms like the Earth System Impact (ESI) Score or NGFS scenarios, investors can translate abstract macro-ecological limits into highly precise, actionable investment metrics. It is in this context that we are also seeing proprietary approaches from investors and corporates emerge to integrate planetary-boundary considerations into investment processes, portfolio construction, risk management, stewardship activities, and capital-allocation decisions. This empowers asset owners and asset managers to benchmark the true biophysical intensity of different investments, structurally identifying those companies and assets driving critical boundary transgressions versus solution providers and transition leaders operating within the Earth's carrying capacity.

10. **While the scale of the challenge ahead is unprecedented, governing our return to a safe operating space remains fundamentally possible.** The 1987 Montreal Protocol stands as the ultimate proof: combining unequivocal science with decisive global policy and industrial innovation, we successfully placed a critical planetary boundary, **Stratospheric Ozone Depletion**, on the path to recovery. By embracing planetary boundaries science, and integrating it into strategic and operational decision-making, corporates and investors can transition from managing existential risks to leading the multi-trillion-dollar realignment toward a more resilient, nature-positive global economy.

Recommendations for investors

The investor community has a vital role to play in this global realignment. Investors can adopt a multi-faceted approach to capitalise on opportunities by:

1. **Building capability** through tools, data, and cross-disciplinary expertise to translate planetary boundary science into investment insights and improved understanding of market demand shifts.
2. **Mapping exposure** across planetary boundaries, geographies, sectors, assets, and time horizons to identify material risks and opportunities.
3. **Assessing and pricing risks and opportunities** by embedding planetary boundary exposures into valuations, scenario analysis, funding decisions, and performance metrics.
4. **Shaping portfolio strategy** through asset allocation, portfolio construction, and risk management aligned to Earth system resilience.
5. **Engaging portfolio companies** to strengthen disclosure, governance, operational resilience, and strategic decision-making.
6. **Influencing the wider system** through policy engagement, market signalling, collaboration, and thought leadership, and by supporting the scaling of transition and adaptation technologies.

[6] "How to unlock $10.1 trillion from the nature-positive transition", World Economic Forum (2024).
[7] "Circular Economy and Sustainability", Cardiff School of Management, WBCSD (2022).

1 Introduction

1.1 What are planetary boundaries and why do they matter?

At least $58tn of global economic value generation is at risk from planetary boundary breaches. Corporates and investors need to adopt a more holistic methodology to understand planetary health and environmental risks beyond GHG emissions alone.

Resilience and long-term growth prospects of the global economy rely on the stability and health of our planet. In 2009, the **Stockholm Resilience Centre**, led by Johan Rockström, introduced the **Planetary Boundaries Framework**, which constitutes a paradigm shift in how we understand environmental risks and the various interdependencies in Earth's complex and deeply intertwined systems. The framework moves beyond general sustainability concepts to provide a science-based, quantitative assessment of the "safe operating space" for humanity. It identifies nine critical global processes that regulate the stability and resilience of our planet, defining the thresholds which, if crossed, could generate unacceptable environmental change.

For investors and corporates, the nine critical global processes and their planetary boundaries constitute a critical evolution in how environmental risks must be assessed and value creation opportunities realised in a global market that is increasingly volatile and challenging to predict.

Figure 2. The nine critical global processes (2025)[8]

Primary scale of impact / System type	Local *Site-specific operational risks*	Regional *Localised supply chain risks*	Global *Macrostrategic risks*
Physical Base *Land & water*	Land-System Change *Deforestation, site footprint*	Freshwater Change *Water scarcity, watershed health*	Biosphere Integrity *Genetic diversity loss, Extinction*
Chemical Flows *Inputs & waste*	Novel Entities *Microplastics, toxins, forever chemicals (PFAS)*	Biogeochemical Flows *Nitrogen & Phosphorus*	Ocean Acidification *Global marine chemistry shift*
Planetary Shield *Air & atmospheric layers*	Atmospheric Aerosols *Smog, haze, air quality*	Stratospheric Ozone *UV radiation shield*	Climate Change *Global warming, atmospheric heat trapping*

The nine critical global processes are inherently interconnected (see Chapter 2) and can be broadly categorised based on (a) their system type (physical base, chemical flows, planetary shield), and (b) their most prominent geospatial impact scale (local, regional, global). Figure 2 above sets out the nine global processes within these categories. It is important to note the above constitutes merely a simplified overview for the purpose of intuitive basic understanding of the critical global processes. For instance, while Novel Entities do indeed predominantly affect the ecosystem at a local level, plastic pollution often has more widespread effects, as materials and toxins spread regionally (even globally) through freshwater and oceanic

channels.

[8] Baringa analysis based on Stockholm Resilience Centre and Potsdam Institute for Climate Impact Research (2025).

While the global focus on Net Zero remains essential, a mere focus on carbon emissions risks obscuring broader systemic threats. The Planetary Boundaries Framework demonstrates that climate stability cannot be achieved if other boundaries, such as Biosphere Integrity or Land-System Change, are breached.

Therefore, to avoid the underestimation and misrepresentation of risks, meaningful environmental assessments must go beyond greenhouse gas emissions. Furthermore, data needs to be examined through a geographic and sector-specific lens, as planetary-boundary-based risks and their implications are likely to manifest differently across different locations and economic activities. Without the consideration of these factors, decisions on strategy, operations, and capital allocation are made with an incomplete picture of physical and transition risks. Ultimately, these can lead to significant risks and damages to our planet, societies, and businesses (see Figure 3).

Figure 3. Risks and damages caused by deteriorating planetary boundaries[9]

Impacted area	Manifested risks *(non-exhaustive)*		Example impact
Planet	• Extreme weather events (floods, droughts, etc.) • Ocean acidification	• Biodiversity loss • Air pollution • Plastic pollution	**$320bn** – global physical damages caused by natural disasters in 2024 **6% of global GDP** – global annual health damages associated with air pollution
People	• Mass migration • Health crises • Social & political unrest	• Inequality amplification • Labour & productivity loss	**up to 1.2bn people** – displaced globally by 2050 due to ecological threats & instability **500bn labour hours** – lost globally in 2022 due to heat exposure (est.)
Businesses	• Supply shocks • Commodity volatility • Regulatory uncertainty	• Stranded assets & capital flight • Climate litigation	**$550bn** – direct economic losses caused by floods and droughts in 2024 **50% of global GDP** – at risk from planetary boundary breaches

Addressing planetary boundary risks requires a shift in analytical resolution. High-level averages often ignore or misrepresent specificities in given place-based or economic activity contexts. To effectively address risks and opportunities, corporates and investors need to assess exposure in a location-specific manner, at the sector and asset level, and by paying specific attention to the most acute and time-critical factors.

Figure 4. Key requirements for effective exposure assessment of planetary boundary risks[10]

Location-specific	Sector- and asset-based	Time-dependent
Understanding and mitigating against planetary boundary risks needs consideration of local conditions	*Estimating influence on and exposure to planetary boundary risks requires looking at the specific sectors of operation and activities carried out*	*Ensuring long-term resilience and value generation requires mitigation of the most acute planetary boundary risks first*
✓	✓	✓

[9] "Global Water Monitor", Australian National University (2025); "Nature Risk Analysis", WWF et al. (2025); "Natural Disaster Figures", Munich Re (2025); "Global Burden of Disease", World Bank (2023); "Ecological Threat Register", Institute for Economics & Peace (2020); "Countdown on Health and Climate Change", The Lancet (2023).

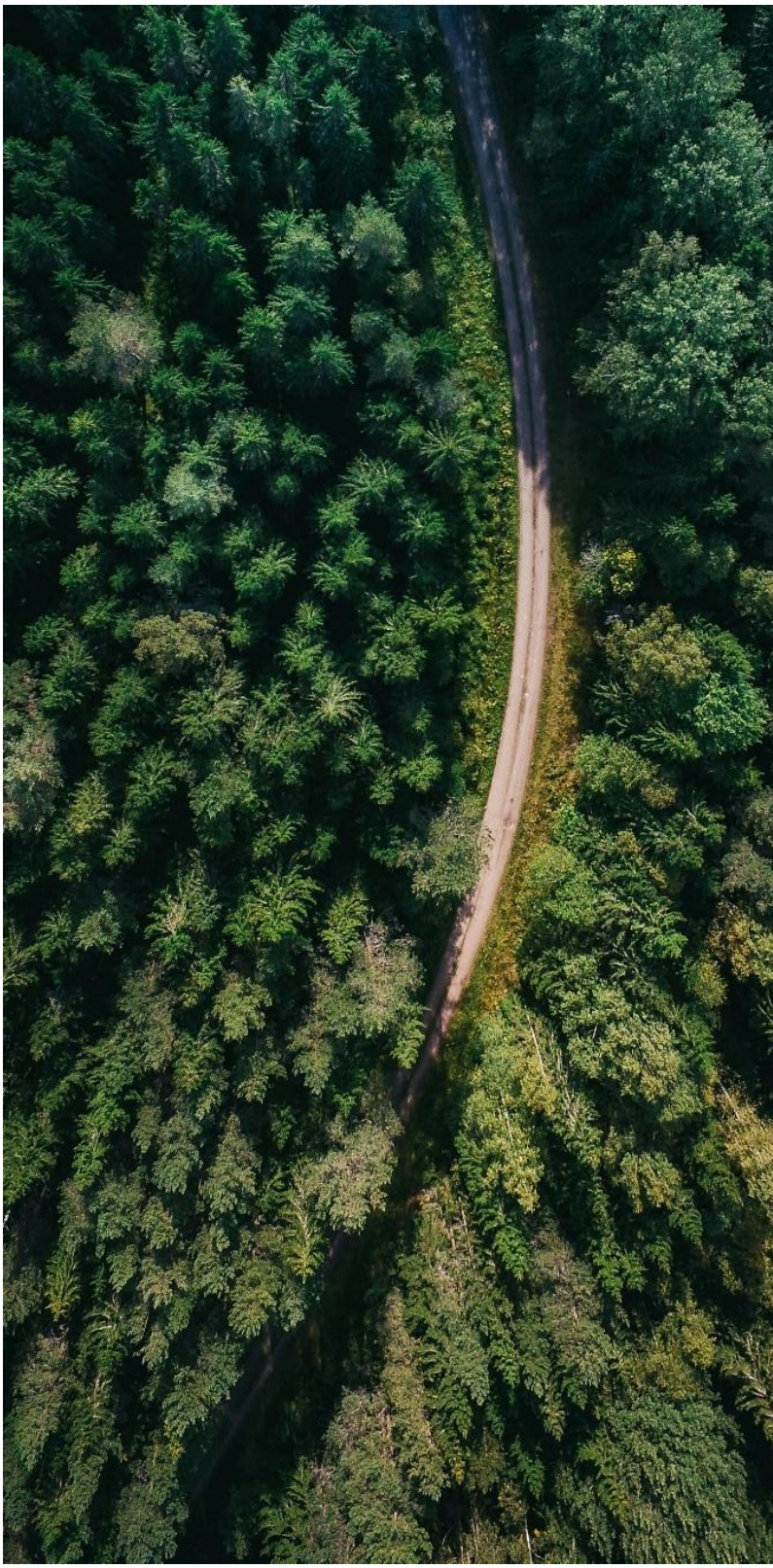
[10] "Doing business with Planetary Boundaries", Stockholm Resilience Centre (2024); Baringa analysis.

1.2 About this report

The purpose of this report is to highlight how companies and investors can use the Planetary Boundaries Framework for strategic foresight, effective risk management, and improved and resilient long-term value creation.

Understanding planetary boundaries is no longer an academic exercise, but a core prerequisite for effective risk management, strategic decision-making, and resilient, long-term value creation. To help corporates and investors navigate this increasingly complex environment, this report focuses on three questions:

1. **What is the Planetary Boundaries Framework?**
    i. What are the nine critical global processes, how do they work, and what are their planetary boundaries?
    ii. How are the severity and materiality of planetary boundaries dependent on location, sector, and temporal factors?
2. **Where are planetary boundaries useful?**
    i. What are examples of acute and chronic risks faced by businesses, investors, and society?
    ii. How are planetary boundaries covered under existing or evolving rules and regulations?
    iii. What do businesses stand to gain from better integrating planetary boundaries into their strategies and decision-making processes?
3. **What should corporates and investors do?**
    i. What tools and methodologies exist to help businesses unlock value from better planetary boundary integration?
    ii. What role should investors play to support their portfolios and drive greater ecosystem change?



2 The science and interconnections

2.1 The nine planetary boundaries and their trajectory to 2050

The health of our planet depends on the status of the nine critical global processes, seven of which have crossed their safe operating space. Further deterioration is likely unless decisive action is taken to avoid irreversible damage to our planet, people and businesses.

The nine planetary boundaries

The Planetary Boundaries Framework, first introduced in 2009 by the Stockholm Resilience Centre, outlines quantitative thresholds for nine critical global processes important to sustain human social and economic prosperity. These boundaries demarcate the "safe operating space" for humanity and are based on the intrinsic biophysical processes that regulate the stability of the Earth system.

As a baseline, the framework aims to ensure the Earth stays in alignment with the same planetary conditions during the Holocene epoch. This is the interglacial period of the last ~12,000 years, which constitutes the only environmental state we know that can support contemporary civilisation.

More recently, driven by intensifying industrial activity, accelerating resource consumption, and rapid population growth, humanity's role has shifted from a mere inhabitant to the dominant geological and biological force shaping the Earth system. This new "Anthropocene" era is frequently described as the end of the stable Holocene and the beginning of a new, likely less stable planetary state.

The Planetary Boundaries Framework analyses the nine global change processes where human activities affect Earth system functioning. Figure 5 below outlines the description for each of these systems, as well as the key measurements by which their boundaries are assessed.

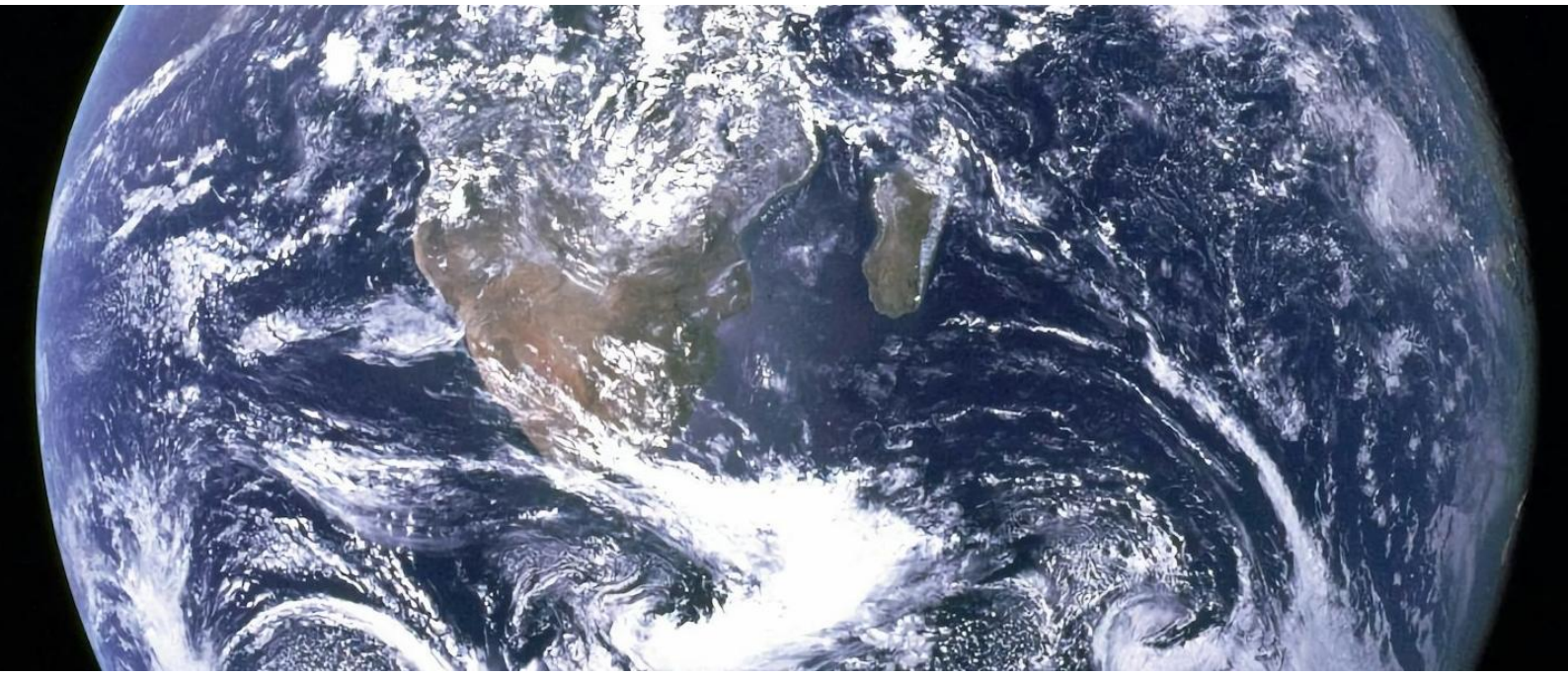


Figure 5. The 9 planetary boundaries: Critical global process descriptions and planetary boundary measurements[11]

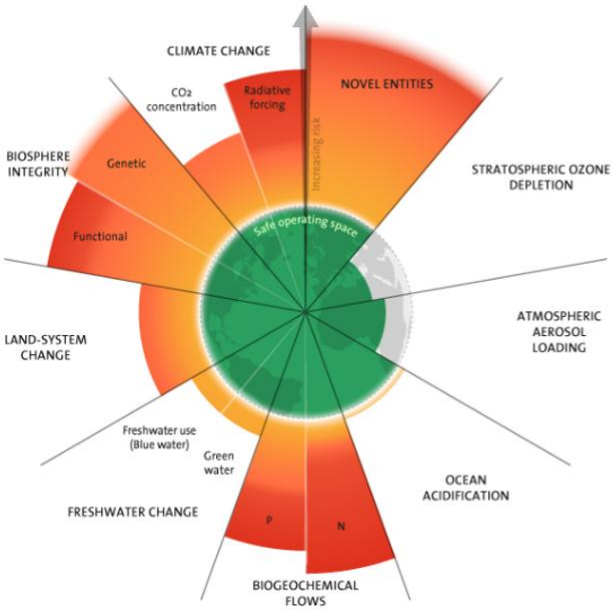
Process	Description	Planetary boundary control variables
 Climate Change	Human activities that disrupt Earth's energy balance, primarily through greenhouse gas emissions	• Concentration of CO_2 in the atmosphere • Extra amount of the sun's heat that is trapped because of human activities
 Biosphere Integrity	The loss of species, ecosystems, and ecological functions that sustain and regulate the overall state of the Earth	• Rate at which species are going extinct (genetic diversity) • Energy extracted from nature through harvesting, hunting and fishing (functional integrity)
 Land-System Change	The transformation of forests, grasslands, and other natural areas through land use and other human actions	• Share of original forest cover remaining across global, tropical, temperate, and boreal biomes
 Freshwater Change	The alteration of the freshwater dynamics that regulate climate, maintain ecosystems, and support fundamental living conditions	• Land area experiencing deviations in streamflow from pre-industrial baseline (blue water) • Root zone soil moisture deviation from pre-industrial baseline (green water)
 Biogeochemical Flows	The disruption of nutrient cycles, particularly Phosphorus (P) and Nitrogen (N), that regulate soil fertility water ecosystem health	• Amount of P flowing from land into freshwater systems and oceans • Amount of N introduced by humans, e.g. in fertilizers and through fossil fuel combustion
 Ocean Acidification	The reduction in ocean pH levels caused by increasing carbon dioxide absorption	• Aragonite saturation state of surface seawater, a measure of how easily marine organisms can build shells and skeletons from calcium carbonate
 Atmospheric Aerosol Loading	The concentration of fine particles (like soot, dust, and sulphates) suspended in the air that affect climate and human health	• Difference in Aerosol Optical Depth (measuring how much sunlight is scattered or absorbed by particles in the atmosphere) between Northern and Southern hemispheres
 Stratospheric Ozone Depletion	The thinning of the protective ozone layer that shields the Earth from harmful ultraviolet radiation	• Global mean stratospheric ozone concentration (O_3) in the upper atmosphere
 Novel Entities	The introduction of synthetic chemicals, plastics, and other human-made materials into Earth's systems	• Percentage of untested chemicals in use worldwide

[11] Stockholm Resilience Centre (2025).

Current status of the planetary boundaries

As of 2025, seven of the nine boundaries have crossed their safe operating space threshold. Only Ozone Depletion and Aerosol Loading are considered safe on a global level, although it is worth pointing out that regional divergences in these measures exist, meaning that even safe boundaries like Aerosol Loading can pose considerable risks on a local level, e.g. as a result of high air pollution in urban areas in South-East Asia *(see chapter 3 for more detail)*.

Figure 6. The 9 planetary boundaries: Current status[12]



Boundary	Global status *(as of 2025)*
Climate Change	High risk
Biosphere Integrity	Critical
Land-System Change	High risk
Freshwater Change	High risk
Biogeochemical Flows	Critical
Ocean Acidification	Increasing risk
Atmospheric Aerosol Loading	Within safe operating space
Stratospheric Ozone Depletion	Within safe operating space
Novel Entities	Critical

Key

- **Within safe operating space:** The boundary is within the Holocene-like baseline, with low risk of systemic feedback.
- **Increasing risk:** The boundary has breached the safe limit, with growing negative impacts across the ecosystem.
- **High risk:** The boundary is significantly transgressed, increasing the likelihood of triggering irreversible tipping points.
- **Critical:** The boundary is fundamentally destabilised on a global level, posing a high risk of tipping point breaches.

While this high-level overview presents a stark picture on its own, it is worthwhile having a closer look at specific examples of real-life impacts and implications of the transgressed status of various planetary boundaries.

- **Climate Change:** At the rate of current policies and climate action, Earth is on a trajectory for a temperature increase of 2.5°C by the end of the century, far exceeding the 1.5°C limit aspired by the Paris Agreement to avoid the most catastrophic climate consequences.[13] Such increases in temperature would likely melt the West Antarctic and Greenland ice sheets, potentially causing sea levels to rise by several meters and placing land currently home to **300 million people below the annual flood line** by 2050.[14]
- **Biosphere Integrity:** In Europe, nearly 80% of natural habitats are currently in "poor" or "bad" condition, and 1 in 10 species of bees and butterflies is threatened with extinction, **endangering ~€22bn**

[12] Stockholm Resilience Centre (2025).
[13] "Baringa Base Case", Baringa (2024). This considers full Greenhouse Gas emissions from energy, industry, agriculture, and land use change & forestry, and is informed by the outcome of the latest climate policies, pledges, and their deliverability.
[14] Climate Action Tracker Emissions Pathways (2025); AR6 Synthesis Report, IPCC (2023).

in annual economic value provided by insect pollination to European agriculture alone.[15]

- **Land-System Change:** 10 million hectares of forest cover is lost annually (roughly equivalent to the size of South Korea), acting as the primary driver of **1 million animals and plant species being threatened with extinction**.[16]
- **Freshwater Change:** More than 170 million hectares of irrigated cropland - nearly five times the land area of Japan - are under "high" or "very high" water stress, and economic damage from land degradation, groundwater depletion and climate change amounts to more than $300bn a year worldwide.[17]
- **Biogeochemical Flows:** Over **$200bn is lost annually in potential crop value** due to the inefficient use of Nitrogen, while nutrient runoff has created over 400 "dead zones" globally, covering a combined area larger than the United Kingdom.[18]
- **Ocean Acidification:** Since the beginning of industrialisation, the acidity of surface ocean waters has increased by 30%, a rate of change 10 times faster than any seen in the last 65 million years, **threatening the global shellfish industry and food security of ~3bn people** who rely on fish as their primary source of protein.[19]
- **Atmospheric Aerosol Loading:** Despite being within safe operating space, air pollution is now the **world's leading environmental health risk**, **with an estimated economic cost of $8.1tn annually**. In South Asia, for instance, aerosol clouds can reduce sunlight reaching the surface by up to 15%, significantly cutting agricultural yields.[20]
- **Stratospheric Ozone Depletion:** While the ozone layer is on track to recover by 2066 thanks to unprecedented global cooperation under the Montreal Protocol in 1987, a failure to maintain this boundary would have resulted in an estimated **2 million additional cases of skin cancer** globally every year.[21]
- **Novel Entities:** It is estimated that **19-23 million tonnes of plastic waste** (the equivalent of over 700,000 garbage truck loads) leaks into aquatic ecosystems on an annual basis, polluting lakes, rivers and seas.[22]

[15] Nature Restoration Regulation Factsheet, European Commission (2024).
[16] "For the Forests", Earthworm Foundation & UN FAO Forestry Data (2025).
[17] "Global Water Bankruptcy", United Nations Institute for Water, Environment, and Health (2026).
[18] "Keeping Track of Ocean Health and Services", UNESCO Intergovernmental Oceanographic Commission (2024).
[19] US National Oceanic and Atmospheric Administration (2025, 2019).
[20] "The Cost of Air Pollution", World Bank (2022).
[21] "Scientific Assessment of Ozone Depletion", World Meteorological Institute (2022); "Skin Cancer Risks Avoided by the Montreal Protocol", Van Dijk et al, Photochemistry and Photobiology (2013).
[22] "Statistics of plastic pollution", UN Environment Programme (2022).

Info box: Physical tipping points[23]

Defining the point of no return: Physical tipping points are critical thresholds within our planetary system where a relatively small change in external conditions (such as a slight temperature increase) can trigger a large, non-linear, and often irreversible shift in the state of the system. Unlike gradual changes in climate, which scale roughly linearly with emissions, tipping points represent a structural reorganisation of an entire system. Once a tipping point is crossed, the system enters a self-perpetuating feedback loop that drives the change independently of the original human driver.

For example, as **Arctic permafrost** thaws, it releases methane, causing further warming and thawing, thus creating a cycle that persists even if human-caused GHG emissions were to stop immediately.

Consequences of crossing thresholds: When a tipping point is breached, the impacts are often abrupt and cascading. "Tipping elements" - large-scale components of the Earth system like the **Amazon rainforest**, the **West Antarctic Ice Sheet**, or the **Atlantic Meridional Overturning Circulation** (AMOC) - can shift from acting as climate stabilisers to becoming destabilisers. Furthermore, the crossing of one tipping point increases the likelihood of others being triggered, potentially causing a "tipping cascade".

For instance, the rapid melting of **Greenland's ice sheet** injects additional water into the North Atlantic, which can slow down the AMOC. This slowdown, in turn, can alter rainfall patterns over the Amazon, pushing the rainforest closer to its own tipping point. Such cascades threaten to move the Earth system out of the stable Holocene state and risk causing irreversible systemic damage to planet, people, and businesses.

Relation to planetary boundaries: Tipping points are intimately linked to the Planetary Boundaries Framework. The boundaries themselves scientifically establish the safe operating space, defined to keep humanity in a state of low risk of negative systemic feedback. Once a boundary is transgressed – e.g. the current breach of the Climate Change boundary (at ~420 ppm CO_2 vs. the safe limit of 350 ppm) – it significantly increases the risk of activating tipping elements.

Recent assessments indicate that at current warming levels (~1.2°C to 1.4°C), we are already entering the high-risk zone for five major tipping points, including the collapse of **warm-water coral reefs**, the abrupt thaw of **boreal permafrost**, the Greenland and West Atlantic ice sheets collapse, and the Labrador Sea and Subpolar Gyre Circulation collapse The further we push beyond the planetary boundaries, the higher the probability of triggering these irreversible shifts, effectively handing over control of the planet's future climate from human hands to natural feedback mechanisms.

Aftermath of a wildfire in Colorado, USA

Future scenarios

Scenario analysis conducted in 2025[24] indicates the further degradation of seven of the eight assessed planetary boundaries by 2050 in a base case scenario, assuming no considerable changes from current societal trends. An alternative, adverse case scenario, with increasing regional competition and slowing economic growth and technological development, results in further transgression for most indicators. Only in an improved scenario, entailing higher resource efficiency, lower population growth, and improved technological development, can the expected degradation of most planetary boundaries be counteracted.

[23] "Planetary Health Check 2025" and "Planetary Health Check 2024" (main reports and supplementary materials), Potsdam Institute for Climate Impact Research (2025, 2024); "Earth Beyond Six of Nine Planetary Boundaries", Richardson et al., Science Advances (2023).
[24] "Exploring pathways for world development within planetary boundaries", Van Vuuren et al., Nature (2025).

Figure 7. The 9 planetary boundaries: Future scenarios for 2050[25]

Boundary	2025: Current status	2050: Adverse case	2050: Base case	2050: Improved case
Climate Change	High risk	Substantial transgression, driven by regional rivalry and fossil reliance	Further transgression, due to insufficient decarbonisation and inertia	Slight improvements, but continued transgression due to system inertia
Biosphere Integrity	Critical	Severe decline due to rapid deforestation and fragmented protection	Further deterioration as land use and climate pressures intensify	Remains transgressed despite restoration, given lag effects
Land-System Change	High risk	Significant deterioration driven by food insecurity and clearing	Worsened status due to agricultural expansion and bioenergy demand	Improvements to at least 2015 levels thanks to dietary shifts
Freshwater Change	High risk	Severe water scarcity driven by inefficiency and lack of cooperation	Global deterioration due to rising demand and climate shifts	Rapid improvement via water efficiency and waste reduction
Biogeochemical Flows	Critical	Continued worsening as inefficient agriculture drives critical nutrient runoff	Remains in critical-risk zone due to fertilizer overuse	Remains transgressed, as efficiency gains are offset by legacy loads
Ocean Acidification	Increasing risk	Severe deterioration as high emissions remain unaddressed by global policy	Worsening in lockstep with rising atmospheric CO_2 concentrations	Some stabilisation amid continued risk due to slow ocean response
Atmospheric Aerosol Loading	Within safe operating space	Regional pollution spikes due to weak environmental regulation	Global improvements thanks to combustion engines and coal phase-outs	Further improvement from clean energy and air quality mandates
Stratospheric Ozone Depletion	Within safe operating space	Relative stability as Montreal Protocol largely holds	Continued recovery thanks to effective Montreal Protocol implementation	Enhanced recovery path towards full restoration
Novel Entities	Critical	*Not assessed*		

Notes on 2050 scenarios

The scenarios are built based on three of the "Shared Socioeconomic Pathways" (SSP) scenarios from the IPCC's Sixth Assessment Report, with supplementary policy assumptions included under the improved case.

- **Base case:** Based on SSP2, this scenario assumes current socio-economic trends continue with moderate population growth and uneven development, leading to a worsening of most environmental pressures by 2050 due to insufficient structural change.
- **Adverse case:** Based on SSP3, this scenario anticipates a resurgence of nationalism and conflict where countries prioritise security over sustainability, resulting in substantial environmental degradation and the critical transgression of multiple boundaries.
- **Improved case:** Based on SSP1 and additional policy action, this scenario combines ambitious interventions (e.g. improved health diets, 50% reduction in food waste, and improving water efficiency) to achieve a return of several boundaries to 2015 levels or better.

Seven of the nine planetary boundaries have already transgressed their safe operating space, with scenario analysis projecting further degradation by 2050 under current trends, unless decisive and coordinated action is taken. This trajectory poses inevitable physical and transition risks for corporates and investors, as the environmental stability that underpins the global economy is increasingly compromised, and is likely to cause political, social, and economic disruptions. Even in the improved case scenario, planetary boundary risks persist, and – irrespective of the future case – these risks do not manifest in isolation; the deterioration of one boundary frequently accelerates the breach of others, creating complex webs of interdependency that define the true scale of the challenge, as the next section outlines.

[25] Baringa analysis of Stockholm Resilience Centre (2025), PIK Potsdam (2025), and "Exploring pathways for world development within planetary boundaries", Van Vuuren et al., Nature (2025).

2.2 Planetary boundary interdependencies

Earth systems are intricately interlinked through their various processes. This makes it essential to take a full systems view when assessing business and investment implications.

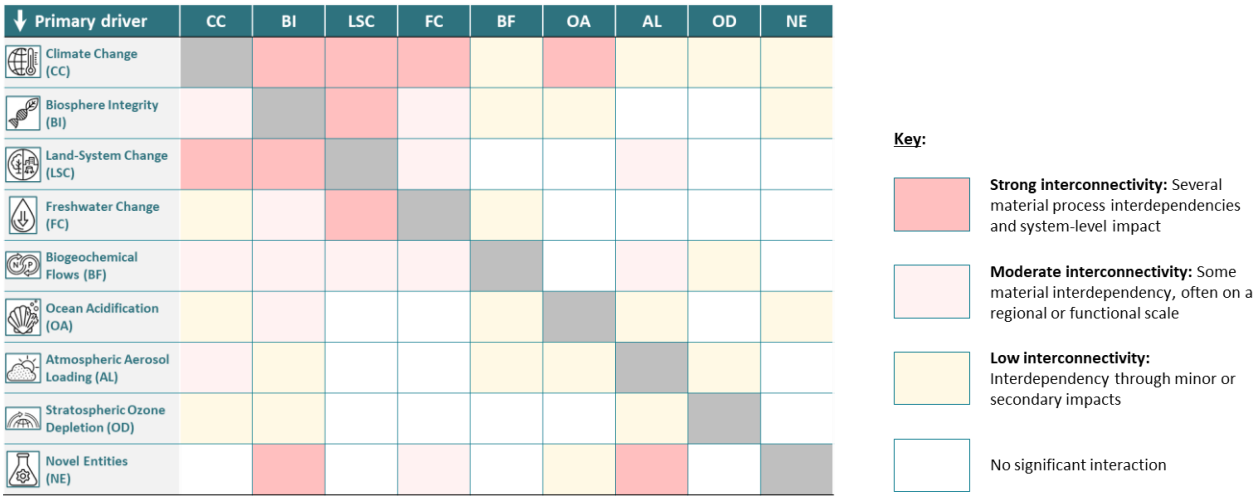
The Planetary Boundaries Framework reveals that environmental risks are rarely isolated events. Instead, they operate as a complex and interconnected web where the transgression of one boundary frequently accelerates the destabilisation of others.

For instance, Land-System Change (e.g. through deforestation) directly exacerbates Climate Change by releasing stored carbon, which in turn intensifies Freshwater Change by disrupting precipitation patterns. This hydrological instability can then degrade Biosphere Integrity, creating a feedback loop that further weakens the planet's resilience.

Another example of critical Earth system interactions is the connection between Climate Change, Ocean Acidification, and Biosphere Integrity: As the oceans absorb approximately 25% of all anthropogenic CO_2 emissions, the resulting chemical shift reduces the seawater's pH and carbonate ion levels. This process fundamentally compromises Biosphere Integrity by impairing the ability of calcifying organisms (e.g. corals and shellfish) to form skeletons, thereby endangering the health of coral reef ecosystems that support an estimated 25% of all marine species.

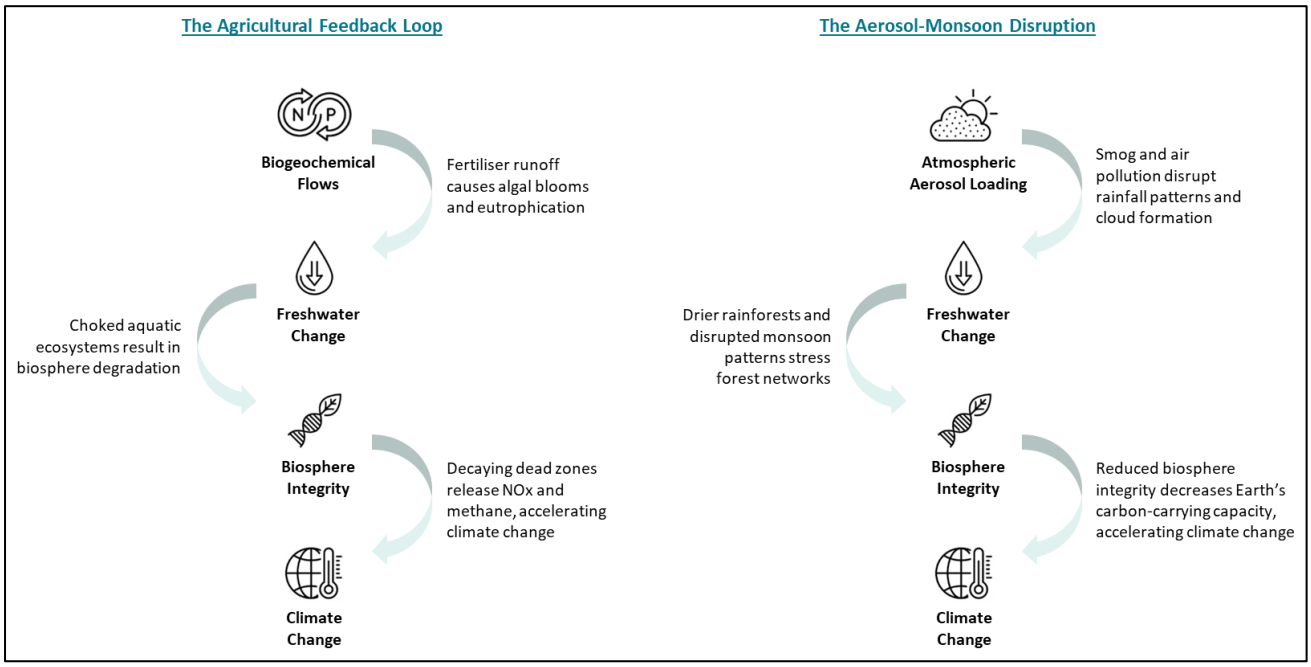
For investors and corporates, this means that risk assessments have to be multi-system focused, taking note of the various interdependencies (i.e. consider water, carbon, and biodiversity as interconnected issues). A failure to recognise these cascading effects can lead to significant underestimations of material risk, with operational disruptions in one area often risking knock-on impacts (e.g. price shocks, supply chain collapses, or regulatory interventions) in another. Figure 8 illustrates the scale of interconnectivity across these systems with the Appendix offering further detail.

Figure 8. Earth systems interconnectivity[26]



[26] Baringa analysis of "Planetary Health Check 2025" (supplementary materials), Potsdam Institute for Climate Impact Research (2025).

Figure 9. Other examples of prominent planetary boundary interdependencies[27]



Case study 1. The Amazon tipping point

The deforestation of the Amazon rainforest serves as a critical example of how Land-System Change drives Climate Change and Freshwater Change, with immediate economic repercussions for global agriculture. As trees are cleared for cattle and soy, the region loses its ability to recycle water, leading to severe droughts that impact agricultural output far beyond the rainforest itself.

In 2023-2024, a combination of deforestation-induced regional climate shifts and El Niño caused a historic drought in the Amazon, rendering major rivers unnavigable and disrupting logistics for months. This caused an immediate economic toll: Soy yields in affected areas dropped significantly, with research indicating that deforestation-driven heat and drought caused an estimated $1 billion in losses for Brazilian soy and corn industries between 2006 and 2019 alone.[28] Furthermore, these extreme weather conditions contributed to global price spikes in coffee, a crop for which Brazil is the world's largest supplier, demonstrating how local ecological tipping points can trigger volatility in global commodity markets.[29]


Forest clearing in the Amazon, Brazil

[27] Baringa analysis of "Planetary Health Check 2025" (supplementary materials), Potsdam Institute for Climate Impact Research (2025), King's Centre for Visualization in Science.

[28] "Agricultural yield losses from deforestation-induced heat-stress", Nature (2020).

[29] "Drought in the Amazon", World Resources Institute (2024).

Case study 2. The Sichuan power crunch

The 2022 drought in the Southern Chinese region of Sichuan illustrates the direct relation between Climate Change, Freshwater Change, and industrial stability. Given Sichuan's reliance on hydropower for over 80% of its electricity, its energy grid is highly vulnerable to hydrological shifts.[30]

In the summer of 2022, an extreme heatwave combined with the lowest rainfall levels in 60 years caused hydropower generation to decrease by 50%. To prevent grid collapse, authorities enforced a six-day industrial power cut, forcing major local manufacturers to suspend operations.[31] This event highlighted a critical 'hidden dependency': Global supply chains for electric vehicles and electronics were negatively impacted not by a lack of raw materials, but by a failure of the local freshwater boundary. The disruption rippled through the economy, with the lack of power affecting everything from aluminium smelting to solar panel production, serving as a stark warning of how water scarcity can abruptly strand industrial assets.

Case study 3. The Caribbean sargassum crisis

The massive influx of sargassum seaweed on Caribbean coastlines is a direct effect of disrupted Biogeochemical Flows (through nutrient pollution) interacting with system change in oceans. While complex factors are at play, nutrient runoff from agricultural intensification in major river basins, like the Amazon and Mississippi, is considered a key driver, feeding algal blooms that are then transported by ocean currents.

The seaweed influx has had a damaging economic impact on the tourism-dependent Caribbean. In 2018 alone, the cost to clean up rotting seaweed from beaches across the region was estimated at $120 million.[32] In Mexico's Quintana Roo state, the arrival of sargassum was linked to an 11.6% decrease in gross local product related to tourism between 2016 and 2019.[33] Beyond tourism, the crisis affects nearshore fisheries and damages seagrass habitats, threatening the "blue economy" that supports millions of livelihoods. This case demonstrates how excess fertilizer use in terrestrial agriculture activities in one country can destroy value in an entirely different sector (marine tourism) in other countries.

Seaweed build-up on a Caribbean beach

[30] "Australia's Global Climate Reset", Climate Council of Australia & S&P Global Commodity Insights (2022).
[31] "The Cost of Inaction", World Economic Forum (2024).
[32] "After record Sargassum influx, CRFM initiates fact-finding study in CARICOM States with support from Japan", UNEP (2019).
[33] "The Economic Impact of Sargassum", Inter-American Development Bank (2022).

3 Implications for business, investors, and society

3.1 Geographic, sectoral, and temporal considerations

Since not all Earth system impacts are equal, corporates and investors need to assess planetary boundary risks across geographic, sectoral, and temporal dimensions to fully understand their exposure and requirements for action.

Geographic considerations

While the nine planetary boundaries (PBs) provide a critical framework for global stability, relying solely on global averages can be dangerously misleading for investors and corporates. Many boundaries, specifically Freshwater Change, Biosphere Integrity, Land-System Change, and Biogeochemical Flows, do not operate uniformly across the planet.

A global average might suggest a boundary is "safe" at a macro level, masking acute regional transgressions at a local level that poses immediate operational risks. For instance, while Atmospheric Aerosol Loading is globally within safe limits, urban pollution over significant parts of Asia and Africa tell a different story, creating acute risk hotspots that the global status does not capture.

Understanding this geographic nuance is essential: A company's exposure is defined not by the global state of the Earth system, but by the specific health of the local ecosystems and markets where its assets and suppliers operate.

Figure 10 below illustrates the stark regional divergences in boundary transgression. While Climate Change and Ocean Acidification are systemic risks that impact the entire planet relatively evenly (a ton of CO_2e emissions in London has the same atmospheric effect as one in Beijing), other boundaries show distinct regional patterns. Freshwater Change, for example, constitutes a moderate materiality impact in Europe with summer drought risks causing, amongst others, water stress in agriculture, but has a critical impact in North Africa and the Middle East, where severe water scarcity and hydro power challenges pose significant risks. Similarly, Biogeochemical Flows are heavily concentrated in the intensive agricultural zones of the Northern Hemisphere (specifically in the US, Europe, China, and India), creating large-scale coastal dead zones, while large parts of Africa remain nutrient-deficient.

- **Asia-Pacific:** APAC faces the most complex convergence of planetary boundary transgressions. Rapid industrialisation and intensive agriculture have driven Atmospheric Aerosol Loading and Biogeochemical Flows into high-risk zones, particularly in India and China. Freshwater Change is critical, with ice sheets in the Himalayas melting and major river systems, such as the Mekong, Ganges, and Yangtze, facing severe stress. Additionally, the region is a hotspot for Novel Entities via plastic pollution in marine environments, creating acute regulatory and reputational risks for supply chains.
- **Africa & Middle East:** The primary risk here is Climate Change vulnerability as a result of extreme heat. This also exacerbates Freshwater Change issues, with the Middle East and North Africa the most water-stressed region globally[34], threatening operational viability for water-intensive industries. Across Africa, Land-System Change is accelerating due to agricultural expansion and population growth, increasing the risk of desertification of the Sahel, as well as biodiversity loss, while Aerosol Loading from biomass burning remains a growing regional concern, especially in urban areas.

[34] "Middle East and North Africa", International Water Management Institute (2026).

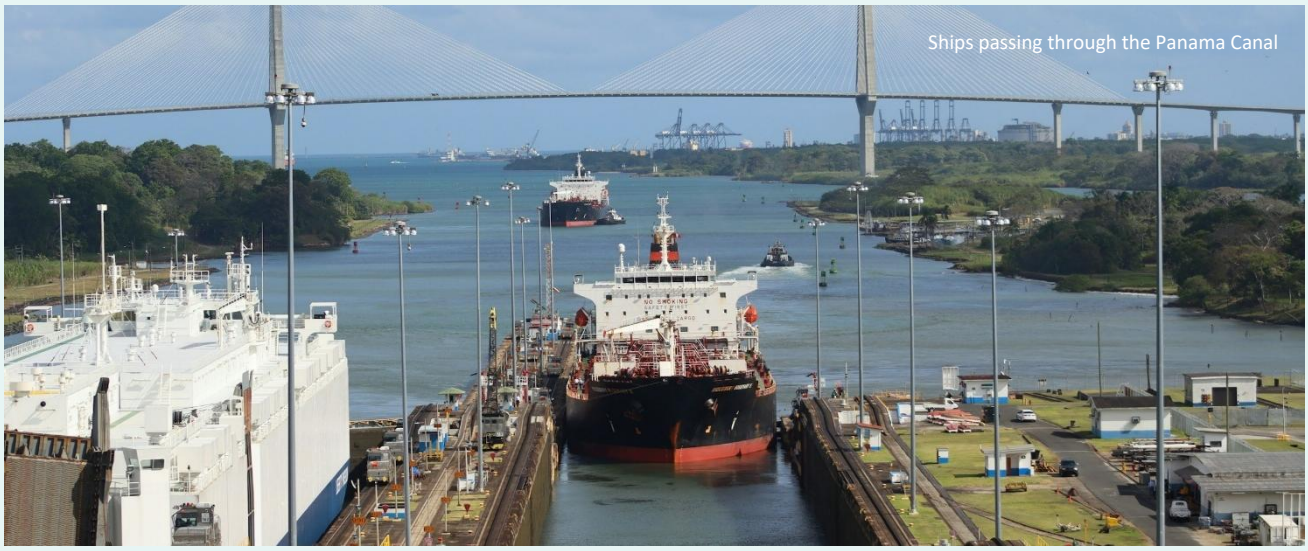
- **Europe and North America:** These regions bear the historical weight of Climate Change (through cumulative, historic emissions) and Novel Entities (chemical production). The primary local transgression is Biogeochemical Flows, where decades of intensive fertilizer use have saturated soils and waterways, leading to strict regulatory crackdowns, economic losses, as well as political and social tension, arguably most aptly exemplified by the Dutch "nitrogen crisis"[35]. While Aerosol Loading and Ozone Depletion are largely managed, Biosphere Integrity remains degraded due to long-standing land conversion and urbanisation.
- **Central & South America:** This region is central to global Biosphere Integrity and Land-System Change. Most crucially, the Amazon Rainforest is approaching a critical tipping point where deforestation and climate change could trigger a dieback, shifting the biome from a carbon sink to a source. This poses one of the most material systemic risks to global climate stability and a direct physical risk to regional agriculture (e.g. via altered rainfall patterns). Extractive industries also face high risks related to Freshwater Change and Novel Entities in numerous sensitive biodiversity hotspots.

Case study 4. The Panama Canal drought

In 2023-2024, the Panama Canal Authority faced its worst drought since records began in 1950.[36] Triggered by El Niño and exacerbated by long-term Climate Change and shifting rainfall patterns, the water levels in Gatun Lake, which feeds the canal's locks, dropped to critical levels.

The Authority was forced to slash daily transits by nearly 40% (from ~36 to ~24 vessels per day) and impose strict draft restrictions, forcing ships to carry less cargo. In addition to the material financial implications for the Panama Canal Authority, with an **estimated revenue loss of between $500m-700m** for FY 2024, the incident created a global shipping bottleneck. Ultimately, this **delayed billions of dollars in goods and forced vessels to take longer, more carbon-intensive routes** around Cape Horn or Suez. [37]

The Panama Canal drought thus illustrates the material collision of Freshwater Change (local scarcity) and Climate Change (global driver), and demonstrates how the transgression of a local boundary (freshwater availability in Panama) can instantly cascade into a macro-economic shock for global trade infrastructure.



Ships passing through the Panama Canal

[35] "Nitrogen Wars: How the Netherlands Hit the Limits to Growth", Green European Journal (2023).
[36] "Drought could make the Panama Canal impassable", World Economic Forum (2023).
[37] "Drought will cut Panama Canal revenue by up to $700 million," Newsroom Panama (2023).

Figure 10. Geographic overview of Planetary boundary materiality[38]

Planetary Boundary	Asia-Pacific	Africa & Middle East	Europe	North America	Central & South America
Climate Change	Extreme typhoons, rising sea levels threatening megacities, and heat stress	Extreme drought, desertification, and unliveable heat thresholds	Heatwaves affecting health/productivity; flood risks in Northern/Central regions	Increasing frequency of wildfires, hurricanes (Gulf Coast), and heat domes	Glacial retreat (Andes), changing rain patterns affecting agriculture
Biosphere Integrity	Habitat loss in SE Asia (palm oil/logging); coral reef collapse	Poaching threats; loss of megafauna habitat; desertification	High loss of farmland biodiversity; intensive land use reducing wild spaces	Habitat fragmentation due to urbanisation; loss of insect populations	Rapid loss in the Amazon and Cerrado; highest global decline in species
Land-System Change	Rapid conversion of forests to agricultural land and expanding urban footprints	Expansion of agriculture into savannahs and forests; soil degradation.	Land effectively "locked in"; focus on restoration / rewilding	Urban sprawl consuming arable land; forestry management issues	Deforestation of the Amazon rainforest (global tipping point)
Freshwater Change	Groundwater depletion in India/China; pollution of major river systems	Severe physical water scarcity in MENA region; drought affecting hydro power	Summer droughts increasing in Southern/Western Europe; water stress in agriculture	Critical scarcity in Western US (Colorado River); groundwater depletion in aquifers	Generally abundant, but localized scarcity (e.g., Chile, Mexico) and pollution
Biogeochemical Flows	Massive fertilizer overuse in intensive agriculture (China/India) causing water pollution	Generally nutrient-poor soils; lack of access to fertilizers in many areas	Historic oversaturation of soils; strict regulation now attempting to reverse damage	Nutrient runoff creating "Dead Zones" (e.g. in Gulf of Mexico); algal blooms	Increasing fertilizer use for export crops (soy) affecting river basins.
Ocean Acidification	Destruction of coral reefs (Coral Triangle, Great Barrier Reef) affecting tourism/fishing	Impact on Red Sea reefs and coastal fisheries dependent on calcifying organisms.	North Atlantic ecosystems shifting; threat to cold-water corals.	Shellfish industry threatened in Pacific Northwest; impact on cold-water ecosystems.	Impact on Caribbean reefs and fisheries; Southern Ocean saturation.
Atmospheric Aerosol Loading	Strong pollution over South and East Asia (India/China) affecting monsoons and health	Dust storms combined with urban pollution (Cairo, Lagos); biomass burning	Generally good, though some urban centres in Eastern Europe struggle with smog	Generally good air quality due to regulation; seasonal spikes from wildfire smoke	Urban smog in megacities (Mexico City, São Paulo); biomass burning smoke
Stratospheric Ozone Depletion	Safe	Safe	Safe (monitoring ongoing but no immediate crisis)	Safe	Southern tip (Chile/Argentina) still periodically affected by the Antarctic ozone hole
Novel Entities	Major source of ocean plastic leakage; rapid industrialisation with limited regulation	E-waste dumping ground; lack of infrastructure to manage imported plastic/chemical waste	High chemical production but strictest global regulations (REACH); export of waste issues	High per-capita plastic waste generation; PFAS contamination	Pesticide usage in agriculture; waste management infrastructure gaps

Key: Low risk / impact: Within safe operating space or improving. | High risk / impact: Significant pressure; visible negative economic and social impacts. | Moderate risk / impact: Issues exist but are managed or localised. | Critical risk / impact: Boundary is transgressed, leading to immediate systemic feedback or failure.

[38] Baringa analysis of numerous scientific and thematic resources and organisations, e.g. Basel Action Network, Food and Agriculture Organization of the United Nations, Intergovernmental Panel on Climate Change, UN Convention to Combat Desertification, UN Environmental Programme, World Bank, World Health Organization, World Meteorological Organization, World Resources Institute, WWF – see Bibliography for a full list of sources.

Info box: Implications for global businesses

For corporates with a multinational footprint, the geographic considerations of planetary boundaries create three distinct challenges.

1. **Operational discontinuity:** For example, a factory in a water-stressed basin (e.g. Mexico City or Chennai) faces physical shutdown risks that a competitor in a water-rich region does not, even if both operate in the same sector.
2. **Supply chain choke points:** Many commodities are sourced from specific hotspots. For example, 80% of the world's almonds are grown in drought-prone California (subject to Freshwater Change risks), and significant semiconductor manufacturing is concentrated in water-stressed Taiwan, creating single points of failure for global value chains.
3. **Regulatory fragmentation:** Companies must navigate a patchwork of environmental laws. For instance, a chemical banned as a "Novel Entity" in the EU might be legal in Asia, creating compliance complexity in present times, and liability risks as global standards tighten and regulatory harmonisation accelerates in the future.

Reminder: Key requirements for effective exposure assessment of planetary boundary risks

Location-specific	Sector- and asset-based	Time-dependent
Understanding and mitigating against planetary boundary risks needs consideration of local conditions	*Estimating influence on and exposure to planetary boundary risks requires looking at the specific sectors of operation and activities carried out*	*Ensuring long-term resilience and value generation requires mitigation of the most acute planetary boundary risks first*
✓	✓	✓

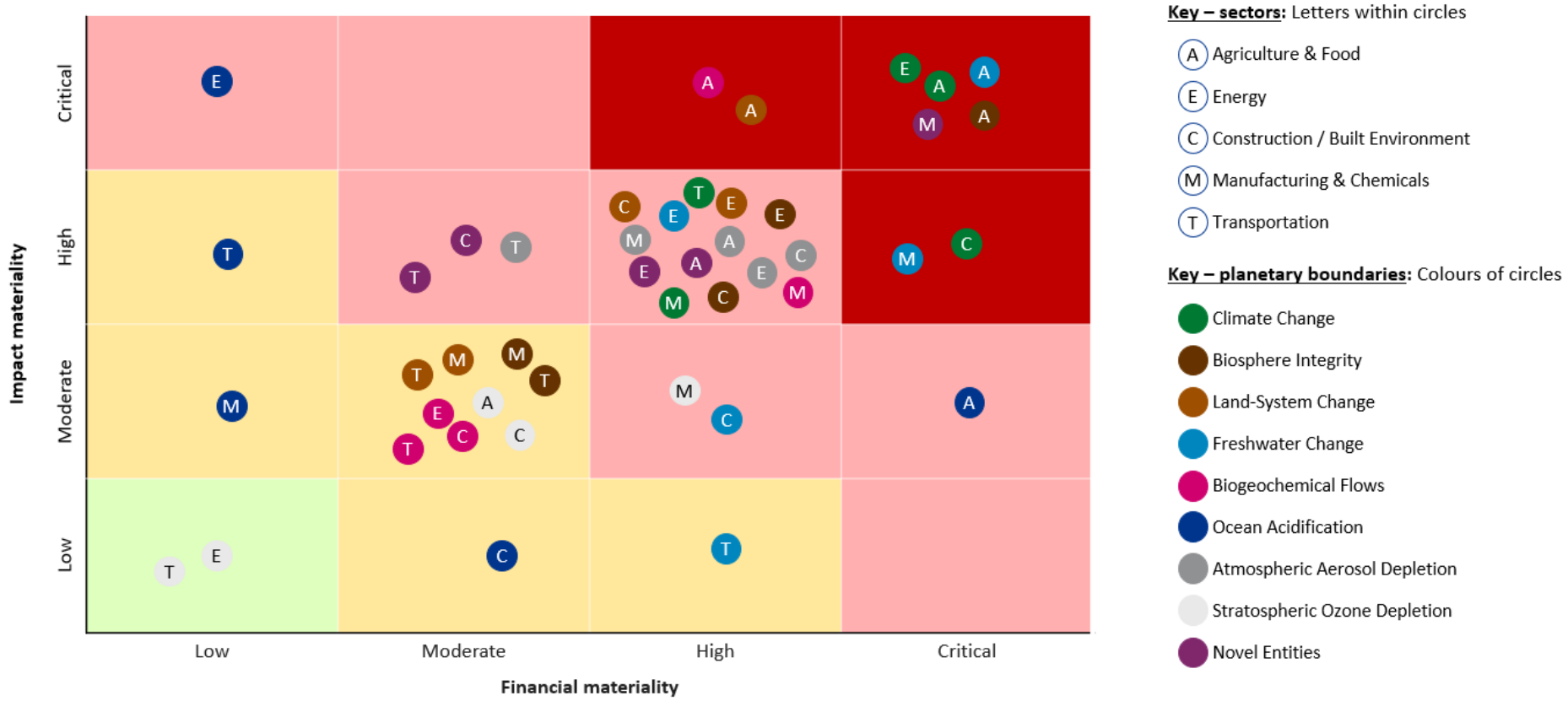
Sectoral & business activity considerations

While the nine planetary boundaries represent a single, interconnected system, their relevance to business is far from uniform. Different economic activities act as primary drivers for different boundary transgressions, just as they face unique risks from those same boundaries. For instance, the Energy sector is the primary driver of Climate Change (via combustion) but has a negligible direct impact on Biogeochemical Flows. Conversely, the Agriculture sector is the dominant driver of Biosphere Integrity loss and Freshwater Change but is less central to Novel Entities compared to the Manufacturing and Chemicals industries.

Understanding this "double materiality" - how a sector impacts the planet (impact materiality) and how the planet impacts the sector (financial materiality) - is critical for investors and corporates. A one-size-fits-all sustainability approach that (a) focusses solely on carbon emissions, and (b) assumes all sectors are uniformly exposed to planetary boundaries, is likely to fail to capture specific materiality vulnerabilities, e.g. critical water risks in semiconductor manufacturing or biodiversity risks in the fashion supply chain.

As chapter 4 further below lays out, double materiality assessments (DMAs) are central requirements under existing regulations (most notably EU CSRD and SFDR 'Principal Adverse Impacts'), and likely to feature in other sustainability regulations in the future

Figure 11. Double materiality assessment per planetary boundary and sector[39]



[39] Baringa analysis of numerous scientific and thematic resources and organisations, including BloombergNEF, Carbon Tracker Initiative, Chatham House, ClientEarth, European Environment Agency, Food and Agriculture Policy Research Institute, Intergovernmental Panel on Climate Change, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, International Energy Agency, International Maritime Organization, Stockholm Resilience Centre, Swiss Re Institute, UN Environmental Programme, World Economic Forum – see Bibliography for a full list of sources.

Figure 11 above maps five key sectors against the nine planetary boundaries. The y-axis represents impact materiality (how much the sector contributes to the problem), while the x-axis represents financial materiality (how much the problem threatens the sector's financial viability). The circles within the matrix denote the double materiality exposure of the sectors against the Earth systems and planetary boundaries – letters within circles specify the sector, whilst the colours of the circles indicate the planetary boundary.[40]

For example, the positioning of the dark blue "C" circle means that the Construction / Built Environment sector is moderately affected by Ocean Acidification (since coastal erosion threatens property value and the effective functioning of the Real Estate insurance market), but has a low impact on this particular Earth system. Overall, the analysis uncovers a number of interesting findings.

- **Bottom-left segments** (low-moderate impact materiality / low-moderate financial materiality): Some boundaries are less relevant for certain sectors. For example, Stratospheric Ozone Depletion is a low risk for Transportation and Energy because these sectors do not rely on ozone-depleting substances like refrigerants, nor do they face direct losses from a thinner ozone layer.
- **Bottom-right segments** (low-moderate impact materiality / high-critical financial materiality): In some cases, a sector may be highly financially exposed to a boundary it does not directly impact. For example, Freshwater Change is a critical financial risk for the Transportation sector, for example due to low river levels halting inland freight on major waterways like the Rhine or Mississippi, even though the sector's direct consumptive use of water is minimal compared to Agriculture & Food.
- **Top-left segments** (high-critical impact materiality / low-moderate financial materiality): Conversely, a sector may drive a problem without facing immediate financial blowback. Ocean Acidification is driven largely by CO_2 emissions from the Energy sector, yet energy companies face minimal direct financial loss from dying coral reefs.
- **Top-right segments** (high-critical impact materiality / high-critical financial materiality): These are the systemic risks where a sector is both substantially exposed and having a major impact on boundary transgression. The clearest example is the Agriculture & Food sector across Climate Change, Freshwater Change, and Biosphere Integrity. The sector drives these transgressions through land use and emissions, while concurrently its financial model is existentially threatened by heat stress, droughts, and pollinator collapse.

  From a sectoral lens, 7 / 9 planetary boundaries fall within these high-risk segments for Agriculture & Food, 6 / 9 for the Energy sector, and 5 / 9 for Manufacturing & Chemicals.

  From a planetary boundary point of view, four Earth systems appear in the critical/critical segment, and frequently in the other high-risk zones:

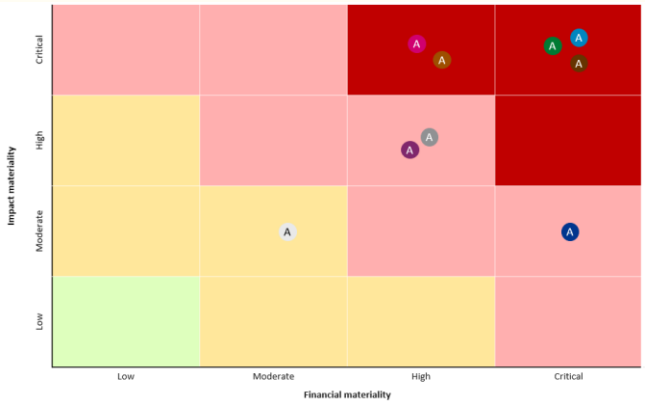
  i. Climate Change (green circles): A high-critical financial and impact issue for all five sectors, reflecting its systemic nature.
  ii. Freshwater Change (light blue circles): A high-critical materiality for three out of five sectors, driven by operational dependencies on water for cooling, cleaning, and irrigation.
  iii. Biosphere Integrity (dark brown circles): High-critical materiality for three sectors, e.g. for Agriculture and Construction, reflecting the physical dependency on healthy ecosystems for land and raw materials.
  iv. Novel Entities (purple circles): High double materiality exposure for Energy and Agriculture & Food, and critical financial and impact materiality for Manufacturing & Chemicals, which produces the vast majority of plastics and synthetic chemicals that are now ubiquitous in the environment.

[40] Please refer to Appendix for supporting commentary on the assessment of each circle in the DMA matrix, as well as current state and potential 2050 outcomes for each of the principal sectors assessed.

Info box: Agriculture & Food sector exposure – current state and potential 2050 outcomes

In the **current state**, the Agriculture & Food sector faces unique double materiality exposure, with the highest number of Earth systems assessed as "critical" across impact and financial materiality.

Agriculture & Food DMA – current state

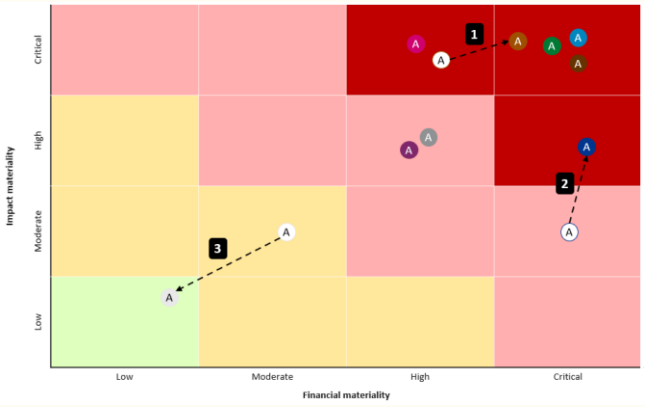


Agriculture & Food acts as a primary driver (critical impact) for 5 of 9 planetary boundaries: Climate Change, Biosphere Integrity, Land-System Change, Freshwater Change, and Biogeochemical Flows.

Its profound dependency on nature also makes it the most financially exposed, with critical financial materiality for 4 of 9 systems: Climate Change, Biosphere Integrity, Freshwater Change, and Ocean Acidification.

While the current state raises sufficient cause for alarm on its own, circumstances are likely to worsen in the **2050 base case scenario** (revisit Figure 7 above for more detail), most importantly for Land-System Change and Ocean Acidification.

Agriculture & Food DMA – 2050 base case

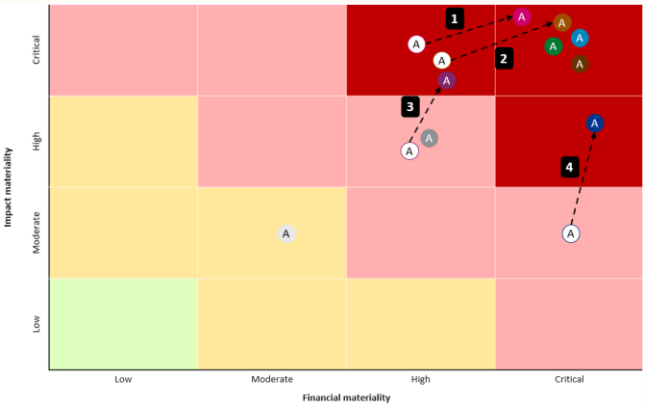


Major materiality movements:

1. Deteriorating financial materiality for Land-System Change as agricultural expansion increases asset and land scarcity risks
2. Worsening impact materiality on Ocean Acidification in lockstep with CO_2 emissions; growing financial risks for fisheries industry
3. Continued ozone recovery reducing phase-out costs for fumigants

In the **adverse case scenario**, dominated by regional rivalry, the sector faces numerous existential threats, as deregulated chemical use destroys soil fertility and Freshwater Change halts production in key breadbaskets.

Agriculture & Food DMA – 2050 adverse case



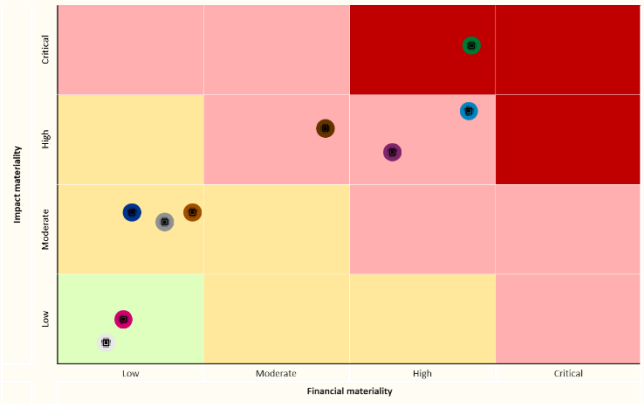
Major materiality movements:

1. Unregulated fertilizer overuse creates dead zones; financial risk increases due to soil toxicity and Phosphorus scarcity.
2. Aggressive expansion for food security, land scarcity and degradation drive asset volatility.
3. Heavy pesticide use pests leads to toxic soil and increased risks on litigation & market bans.
4. Continued CO_2 absorption causes fisheries collapse and critically erodes value for seafood sub-sector.

Info box: Double materiality exposure of the Big Tech firms

Big Tech is currently driving one of the fastest expansions of infrastructure in human history, fuelled by the boom of Artificial Intelligence and Machine Learning. While these companies are leaders in renewable energy procurement, their absolute demand for energy, freshwater (for cooling), and critical minerals (for hardware and batteries) places intense localised pressure on specific planetary boundaries.

Big Tech DMA – current state



Big Tech firms' double materiality exposure is currently most pronounced across four planetary boundaries:

- **Climate Change:** While the Magnificent 7 are leaders in renewable energy PPAs (Scope 2), their Scope 3 emissions (hardware manufacturing and logistics) and the exponential growth in power required for AI model training keep their absolute carbon footprint highly material.
- **Freshwater Change:** Hyper-scalers require millions of litres of water for cooling, and are often located in water-stressed regions (e.g. Arizona, Spain). Semiconductor manufacturing (critical for Nvidia, Apple, Tesla) is extraordinarily water-intensive.
- **Novel Entities:** Tech hardware, batteries, and semiconductor fabrication rely heavily on PFAS, toxic solvents, and heavy metals. Furthermore, server racks create considerable global e-waste.
- **Biosphere Integrity:** The indirect impact is highly material. The hardware required relies on intensive mining for critical minerals (lithium, cobalt, copper, rare earths), often driving stark habitat destruction and biodiversity loss in vulnerable ecosystems.

Big Tech DMA – future scenarios

In the 2050 base case, the Big Tech sector can be expected to successfully navigate the massive resource demands of the AI boom through aggressive innovation and regulatory alignment. To sustain exponential compute requirements, companies need to drive historic investments into next-generation clean baseload power, such as advanced geothermal and small modular nuclear reactors, largely insulating themselves from carbon pricing penalties. While absolute freshwater demand will remain high, the widespread adoption of closed-loop and waterless cooling technologies for hyper-scale data centres should prevent critical regional rationing. Furthermore, tightening global regulations can be expected to successfully force the phase-out of highly toxic PFAS in semiconductor fabrication, replacing them with circular economy models that aggressively recycle battery materials and server racks. Although transition risks and immense capital expenditures are likely to persist, coordinated sustainability strategies should allow the Magnificent 7 to maintain operational resilience and secure uninterrupted global supply chains.

The 2050 adverse case scenario envisions a severely fragmented operating environment where unchecked ecological deterioration would structurally break Big Tech's physical networks. As fragmented power grids fail to support hyper-scale AI energy demands, it is likely that extreme weather events trigger catastrophic, systemic blackouts across critical data centre nodes. Concurrently, chronic and severe regional water scarcity would force local governments to permanently ration industrial water use, paralysing both water-dependent semiconductor fabrication hubs and data centre cooling systems. Furthermore, a lack of cohesive global regulation would likely result in rampant e-waste dumping and unregulated chemical pollution, exposing major hardware and battery manufacturers to multi-billion-dollar retroactive litigation. Ultimately, geopolitical fragmentation would probably drive destructive, uncoordinated mining for critical minerals, triggering localised habitat collapses and draconian urban logistical bans that transform environmental failures into existential financial risks, permanently stranding vital technology assets.

Info box: Implications for global businesses

Corporates with complex value chains and/or material business activity across multiple sectors and business activities must review their exposure at a sector- and asset-specific level, in addition to factoring in geographic considerations of planetary boundaries.

For example, a textile company's impact on Biosphere Integrity and Land-System Change varies wildly depending on whether it sources leather (high land footprint and methane emissions) or synthetic fibres (high Novel Entities risk due to microplastics).

This is in addition to the already established geographic factor: A semiconductor plant faces critical Freshwater Change risks in arid regions, but only moderate risks in water-abundant regions.

Reminder: Key requirements for effective exposure assessment of planetary boundary risks

Location-specific	Sector- and asset-based	Time-dependent
Understanding and mitigating against planetary boundary risks needs consideration of local conditions	*Estimating influence on and exposure to planetary boundary risks requires looking at the specific sectors of operation and activities carried out*	*Ensuring long-term resilience and value generation requires mitigation of the most acute planetary boundary risks first*
✓	✓	✓

Case study 5. Material liabilities in 'forever chemicals'[41]

In addition to the damages they cause to the planet, Novel Entities also poses a critical, latent financial risk. For decades, Chemicals manufacturers produced PFAS ('forever chemicals') in significant quantities, given their mass use in everything from non-stick pans to firefighting foam.

Regulatory and legal action in the area of PFAS has considerably increased in recent years. In 2023, one of the largest global Manufacturing businesses agreed to **pay over $10 billion to settle lawsuits** claiming its chemicals contaminated public drinking water systems across the US. The settlement did not cover personal injury claims or international liabilities, suggesting the final legal costs could be higher.

This case illustrates how the impact materiality on Novel Entities can transform into a substantial financial materiality event (e.g. via litigation and fines), even decades after the pollution has occurred. It serves as a warning for sectors like Manufacturing & Chemicals that the allegedly "safe" release of new substances can serve as only a temporary illusion if safety thresholds are crossed.

[41] "3M Incurs $10.5 Billion Liability for Polluting Waterways with 'Forever Chemicals", TNFD & BloombergNEF (2024).

Temporal considerations

While geographic and sectoral lenses reveal *where* and *how* planetary boundary risks manifest, a temporal lens reveals *when* these risks will become critical or irreversible.

Not all boundaries are deteriorating at the same speed. Climate Change is accelerating, with the 1.5°C threshold likely to be crossed in the early 2030s, making this the "critical decade" for action. Land System Change is also moving towards significant deterioration with critical ecosystems approaching their tipping point. Even more acutely, Freshwater Change, Biosphere Integrity, and Novel Entities have moved beyond high risk to immediate systemic crises, with accelerating deterioration and the highest urgency for action. In contrast, Stratospheric Ozone Depletion is on a path to full recovery by ~2066, proving that coordinated global governance can reverse even severe transgressions.

For investors and corporates, this distinction is vital. Some risks are slow(er)-moving "chronic" issues (such as Ocean Acidification), while others (Novel Entities, for instance) are accelerating strongly, requiring urgent mitigation strategies today to avoid unmanageable liabilities in the near-to-medium term.

Figure 12 below categorises the nine boundaries by their speed of deterioration (trend and direction of travel) and time criticality (urgency of action required).

Figure 12. Planetary boundary temporal considerations[42]

Boundary	Deterioration speed *(trend)*	Time criticality *(urgency)*	Supporting commentary
Climate Change	Accelerating	Shorter-term	Delays in decarbonisation rates causing rapid transgression. With CO_2 levels at ~420 ppm, the 1.5°C threshold is expected to be crossed in the early 2030s, making this the decisive decade for avoiding irreversible feedbacks.
Biosphere Integrity	Accelerating	Immediate	Severe decline of functional and genetic diversity, with extinction rates at 100-1,000 times higher than reference ("background") rates, indicating the system is already losing functional redundancy.
Land-System Change	Worsening	Shorter-term	Moving toward significant deterioration as a result of food insecurity. Critical ecosystems like the Amazon are approaching their tipping point (20-25% deforestation), requiring concerted and coordinated intervention.
Freshwater Change	Accelerating	Immediate	Global deterioration has turned into a systemic risk in need of immediate intervention, with current transgression 2.9x the safe limit for blue water and 3.0x for green water.
Biogeochemical Flows	Persistent	Shorter-term	Remains in critical-risk zone, as the absolute load of Nitrogen & Phosphorus in circulation has already created dead zones that will persist for decades due to legacy accumulation in soils.
Ocean Acidification	Worsening	Medium-term	Deteriorating in lockstep with atmospheric CO_2. While acute now for some species, the widespread collapse of aragonite saturation (dissolving shells) is a mid-century risk if emissions continue increasing.
Atmospheric Aerosol Loading	Improving	Safe (managed at global level)	Showing improvements at global level due to phase-outs of emissions-intensive industrial practices (e.g. coal). Local regional pollution spikes remain an immediate health risk in specific areas (see section above).
Stratospheric Ozone Depletion	Improving	Safe	Showing continued recovery. The ozone hole over Antarctica is stabilising, with full recovery projected for ~2066, demonstrating effective governance and progress under the Montreal Protocol.
Novel Entities	Accelerating (strongly)	Immediate	Production of plastics and chemicals is outpacing assessment capabilities. Given the unclear future boundaries but high current impact, the risk is immediate due to the irreversible persistence of "forever chemicals" (PFAS).

Key – speed of deterioration

- **Accelerating:** Deterioration is speeding up
- **Worsening:** Steady, (near-)linear decline
- **Persistent:** High risk but (relatively) static transgression
- **Improving:** Moving towards/further within safe operating zone

Key – time criticality

- **Immediate:** Tipping point imminent or buffer already exhausted
- **Shorter-term:** Key irreversible thresholds likely to be breached within ~10 years
- **Medium-term:** Critical risks manifesting beyond 10-year timeframe
- **Safe:** Risks are (broadly) contained

[42] "Planetary Health Check 2025" and "Planetary Health Check 2024" (main reports and supplementary materials), Potsdam Institute for Climate Impact Research (2025, 2024); "Earth Beyond Six of Nine Planetary Boundaries", Richardson et al., Science Advances (2023); Baringa analysis.

Info box: Implications for global businesses

The temporal considerations of planetary boundaries create a "time value of action" for corporates.

1. **Stranded asset risk:** Investments in water-intensive assets (e.g., mines, data centres) in regions with accelerating Freshwater Change face a high risk of becoming stranded within the decade, not just in the distant future.
2. **Regulatory whiplash:** For rapidly deteriorating boundaries like Novel Entities, regulation often lags behind reality but can catch up abruptly. Companies relying on PFAS or single-use plastics face a cliff edge of sudden bans or litigation, as seen with the $10bn+ PFAS settlements in the US (see case study 5 above).
3. **First-mover advantages:** Conversely, businesses that align with recovering boundaries (e.g. alternatives to ozone-depleting substances) or solve immediate crises (e.g. water recycling / circular water technology) can position themselves to capture market share as competitors scramble to adapt - see chapter 5 below for more detail on value creation opportunities.

Ultimately, only investors and corporates who assess their planetary boundary exposure in a manner that covers geographic, sectoral, as well as temporal considerations, are able to establish a comprehensive picture of risks and opportunities.

Reminder: Key requirements for effective exposure assessment of planetary boundary risks

Location-specific	Sector- and asset-based	Time-dependent
Understanding and mitigating against planetary boundary risks needs consideration of local conditions	*Estimating influence on and exposure to planetary boundary risks requires looking at the specific sectors of operation and activities carried out*	*Ensuring long-term resilience and value generation requires mitigation of the most acute planetary boundary risks first*
✓	✓	✓

Case study 6. Critical time in the Amazon Rainforest

The Amazon Rainforest is racing against a ticking clock. Scientists estimate that if 20-25% of the forest is lost, it will cross an irreversible "tipping point" where it can no longer generate its own rainfall, causing it to die back into a savannah. Recently, the rate of deforestation stood at ~17%.[43]

Consequently, this is not a distant theoretical risk, but a critical materiality exposure that is already causing harm at large scale. As outlined in case study 1, deforestation-driven heat and drought in the Amazon caused an estimated $1bn in losses in the corn and soy industries from 2006-2019. More recently, in 2023-2024 a historic drought driven by the interaction of deforestation and climate change rendered major Amazonian rivers unnavigable, **disrupting billions of dollars in soy and corn logistics**. The drought stranded communities and stalled industrial logistics in the Manaus Free Trade Zone, where companies faced a nearly **20% drop in economic output and a 300% increase in logistics costs** due to delays and rerouting.[44] On a macro scale, studies estimate that crossing the Amazon tipping point could cost the region **up to $256 billion in lost GDP by 2050** due to the collapse of ecosystem services like rain-fed agriculture.[45]

The Amazon exemplifies the convergence of Land-System Change (via deforestation), Freshwater Change (regional drought), and Climate Change (carbon sink loss). For investors, the "Amazon Tipping Point" is a material financial deadline: assets linked to local agriculture face imminent systemic devaluation if this temporal threshold is crossed.

[43] "Critical transitions in the Amazon forest system", Nature (2024).
[44] "After historic 2023 drought, Amazon communities brace for more in Brazil", Mongabay (2024).
[45] "An Amazon Tipping Point: The Economic and Environmental Fallout", IDB Group (2021).

3.2 Financial impacts, risks, and failures caused by PB breaches

Companies are required to navigate a multitude of material risks as a result of planetary boundary deterioration; managing these risks is further complicated by a set of market failures which cause systemic vulnerability.

As demonstrated by the regional vulnerabilities and sectoral risks outlined in chapter 3.1, corporates and investors are highly exposed to the deterioration of Earth's natural systems. It is therefore imperative that businesses identify and manage these planetary boundary risks to mitigate negative exposure and adverse impacts. Even more worryingly, as chapter 2.2 above shows, transgressing Earth system processes cause these environmental risks to become increasingly intertwined, creating expanding feedback loops that amplify business disruptions. The 2026 World Economic Forum Global Risks Report underscores this importance, with its Global Risks Perception Survey (which represents perspectives from over 1,300 experts) classifying environmental risks as the most severe in the next 10 years.[46]

The breach of planetary boundaries translates directly into material financial risks that undermine the fundamental drivers of corporate value. When natural systems destabilise and companies are affected (or seen as ill-prepared to protect themselves), the economic implications permeate through income statements, balance sheets, valuations, and funding costs. In essence, unpriced planetary-boundary-related risks can severely impact corporate financials across several key dimensions:

- **Cashflows:** Disruptions to natural inputs (e.g. water scarcity, soil degradation) and extreme weather events lead to direct operational stoppages and supply chain shocks. This drives up the cost of goods sold through commodity price volatility and depresses revenue streams. According to a recent report by Ceres, land and sea use change and overexploitation of natural resources alone could pose multi-billion-dollar threats to the cash flows of major FMCG companies.[47]
- **Valuations:** Companies with high exposure to deteriorating planetary boundaries face significant asset write-downs. Infrastructure, manufacturing plants, or real estate located in high-risk zones (such as flood plains or wildfire corridors) face the immediate threat of becoming stranded assets, destroying book value and compressing future earnings multiples.
- **Funding costs:** As investors, credit rating agencies, and insurers increasingly price in physical and transition risks associated with Earth system deterioration and planetary boundary breaches, exposed corporates face higher risk premia and hedging costs. Companies failing to manage planetary boundary risks thus face elevated borrowing costs and restricted access to debt and equity markets, especially as capital providers actively price in the probability of environmental liabilities.

[46] "Global Risks Report 2026", World Economic Forum (2026) – While environmental concerns are deprioritised in the short term, half of the top 10 identified risks over the next 10-year period are environmental in nature, with extreme weather events ranked as the no. 1 risk.
[47] "Nature's Price Tag", Ceres (2025).

Case study 7. Infrastructure failure and social catastrophe in Paradise, California[48]

The interplay of Climate Change (manifesting as severe drought and extreme heat) and Land-System Change (poor land management and dry vegetation accumulation) created a highly combustible environment in Northern California.

In 2018, faulty transmission infrastructure ignited the deadliest and most destructive wildfire in California history, which rapidly engulfed the town of Paradise, and resulted in 85 deaths, the destruction of nearly 19,000 structures, and the massive displacement of over 50,000 people. It is estimated that the fire, which lasted for 17 days, caused damages exceeding $16.5bn.

This event exemplifies how the transgression of local and global environmental boundaries can accentuate the impacts of infrastructure failure and lead to social catastrophe, especially when affected businesses fail to identify and effectively mitigate against such risks. The transmission infrastructure operator, one of the largest US utilities, faced crippling financial consequences as a result of equipment maintenance failure, including a $3 billion liability specifically for social and environmental damages, ultimately forcing the utility to file for Chapter 11 bankruptcy.

Burned vehicles following the 2018 wildfire in Paradise, California

Case study 8. **Market collapse of California's property insurance sector**

As Climate Change and Land-System Change accelerate, the frequency and severity of wildfires in California have surged beyond historical predictive models.

In response to escalating and increasingly unpredictable physical risks, many major US insurers have stopped writing new property and casualty policies in California. This withdrawal has created a considerable insurability gap, with private homeowners facing an **estimated coverage shortfall of $1.3-2.0tn**.[49] While State support exists through the California FAIR Plan, ca. **100,000 households remain uninsured**, with the remainder facing **premiums doubling or tripling** in high-risk zones.[50]

This represents a systemic market failure where the financial sector can no longer price the risks associated with destabilised Earth systems. Without access to insurance, the Construction & Built Environment sector cannot secure financing for new projects, and existing Real Estate market values are severely threatened, illustrating how environmental tipping points can trigger immediate financial market contraction.

Wildfire smog over Los Angeles, California

[48] "The economics of climate change: no action not an option", Swiss Re Institute (2021).

[49] "Economic impact of the Los Angeles wildfire", Zhiyun Li and William Yu, University of California (2025).

[50] "Thousands of Los Angeles homeowners were dropped by their insurers before the Palisades Fire", CBS News (2025); "California's Insurance Crisis: How Homeowners Pay More for Less While Insurers Profit", Unlocking America's Future (2025).

At a more systemic level, planetary boundary risks extend beyond the idiosyncratic exposures faced by corporates and investors.

As Earth system processes deteriorate, they redefine the physical and operational parameters companies do business in, and in doing so cause or enhance market failures which further exacerbate the risks corporates and investors are exposed to. Figure 13 below shows the main market failures caused and/or amplified by planetary boundaries, and how they affect businesses.

Figure 13. Market failures driven by planetary boundary breaches[51]

Market failure	Description	Manifested impact	Relevant examples
 **Externalities**	Costs of environmental degradation are not reflected in the price of goods, passing the economic burden to society.	• Misallocation of capital towards destructive activities • Burden of cleanup falls on taxpayers and the public • Lack of financial incentive to reduce supply chain pollution	• Air pollution claims roughly 5.7 million lives annually and accounts for economic losses of nearly 5% of global GDP
 **Information asymmetry**	Investors lack accurate, standardised data on companies' true exposure to earth-system-related risks and dependencies.	• Structurally mispriced risk and overvaluation / insufficient discounting of vulnerable companies • Capital flowing without sufficient restriction into high-risk, unmonitored supply chains • Sudden valuation crashes when hidden environmental risks materialise	• Only 4/10 companies report on supply chain emissions, although supply chain impacts are on average >10x higher than direct emissions • 70% of companies do not assess the impact of their value chains on biodiversity
 **Public goods**	Non-excludable earth systems (e.g. atmosphere, oceans) are overexploited because no single entity governs or protects them.	• Accelerated depletion of shared, vital resources • Free-rider problem of companies benefitting from extraction without ensuring maintenance and sustainability of resources • Systemic collapse of ecosystems that provide free baseline stability	• Global ocean economy generates ~$1.5tn/year; declining ocean health threatens up to $8.4tn of value across global listed companies over the next 15 years
 **Time horizon misalignment**	Financial markets prioritise short-term returns over long-term environmental stability, delaying necessary capital allocation.	• Chronic underinvestment in resilience and adaptation infrastructure • Capital misdirected to high-yield, short-term activities with low/no long-term financial and societal value • Future systemic risks heavily discounted in current valuations	• $7.3tn of finance flows into "nature-negative" activities in 2023, dwarfing investment for nature-based solutions of $220bn
 **Missing markets**	Critical natural services have no market price, with their degradation carrying no immediate accounting cost.	• No financial incentive to protect foundational ecosystem services • Total loss of agricultural yield when natural subsidies disappear • Corporate balance sheets treating natural capital as perpetual	• $235bn - $577bn worth of annual global food production and 75% of global food crops relying directly on insect pollination
 **Systemic risk (network externalities)**	Highly interconnected supply chains cause local ecological failures to trigger cascading global economic shocks	• Geographically distant investors suffer sudden, unpredicted losses • Single points of environmental failure halt global production lines • Insurance markets fail or withdraw due to correlated risks or inability to effectively model exposure and materiality	• 2011 Thailand floods caused $46.5bn in total economic damages, crippling global supply chains and forcing a 25% global price increase in hard disk drives

[51] World Bank Group Cleaner Air Report (2025); CDP Global Supply Chain Report (2022); UNEP Ocean Panel Report (2022); WWF "Value at Risk in the Global Blue Economy" (2026); UNEP "State of Finance for Nature" (2026); IPBES "Assessment Report on Pollinators, Pollination and Food Production" (2017); World Bank Group Impact Assessment Report (2012); Baringa analysis.

How financial markets price in planetary boundary exposures at company level

In light of the current gaps in planetary boundary understanding, accentuated by the systemic market failures outlined above, financial markets' ability to effectively price in planetary boundary risks and exposures is worth a closer examination.

Figure 14 and Figure 15 show the shareholder return performance of two portfolios from 2015 to 2025, both market-cap-weighted and equal-weighted, compared against their respective benchmark MSCI ACWI indexes. The first was composed of firms with higher exposure to planetary boundary risks ('**PB-exposed**'), and the second was made up of firms that appear better positioned to manage, mitigate, or adapt to planetary boundary exposures ('**PB-mitigated**').[52]

Notwithstanding these fundamental differences in composition, to ensure overall comparability, both portfolios are constructed using the same criteria:

- Sector focus: The portfolios are composed of firms operating in three sectors that are inherently vulnerable to planetary boundary movements – Agriculture & Food; Manufacturing with intensive water use[53]; and Power & Utilities.
- Geographic footprint: The portfolios contain firms from both developed and emerging markets to capture differing risk profiles, growth trajectories, and regional exposures.
- Market listing: All firms trade on the MSCI All Countries World Index (ACWI).
- Market cap: Only firms with a market capitalisation of $5bn+ are included, to minimise liquidity premium and company-size volatility factors.

Figure 14. Total shareholder returns – market-cap-weighted (2015-2025)[54]

	5-year growth rate	10-year growth rate
PB-mitigated	69%	166%
PB-exposed	54%	135%
MSCI ACWI	57%	140%

In Figure 14, for the market-cap-weighted analysis, the PB-mitigated and PB-exposed portfolios move in relative lockstep, albeit with the PB-mitigated portfolio showing higher returns for a five- and ten-year investment horizon (69% vs 54% five-year returns, and 166% vs 135% ten-year returns, respectively). Furthermore, the PB-exposed portfolio shows returns aligned with the broader MSCI All Country World Index (ACWI), while the PB-mitigated portfolio outperforms the broader index (mostly driven by strong shareholder returns from several large Manufacturing companies). This indicates that a limited market premium might exist for companies that are better calibrated to withstand planetary boundary deterioration over the long-term.

[52] To determine portfolio allocation, companies were assessed against four criteria: Geographic concentration (firms with a more concentrated operational footprint across environmental hotspot regions scoring highly on PB exposure), nature dependence (firm with a high proportion of revenues reliant on inputs such as mining or water scoring highly on PB exposure), mitigation strategy (firms with minimal evidence of proactive risk management scoring highly on PB exposure), and disruption track record (firms with history of environmental disruption scoring highly on exposure).

[53] e.g. Textiles, Automotive, Steel, Chemical Manufacturing, Semiconductor Manufacturing.

[54] Data baselined to 100 at end of Q1 2015; Sources: MSCI; Invesco; Investing.com; ETFreplay; Baringa analysis of 90 MSCI ACWI-quoted corporates.

Figure 15. Total shareholder returns – equal-weighted (2015-2025)[45]

	5-year growth rate	10-year growth rate
PB-mitigated	-7%	52%
PB-exposed	18%	43%
MSCI ACWI	35%	87%

However, the equal-weighted analysis in Figure 15 is unable to corroborate this. While the PB-mitigated portfolio still outperforms the PB-exposed one (52% vs 43% over a ten-year horizon), that delta substantially narrows over the last five years, when the PB-mitigated basket actually recorded negative growth (-7%), while the PB-exposed portfolio grew by 18%. Crucially, both portfolios underperform versus the wider MSCI ACWI (equal-weight) index, suggesting that the strong growth of a number of firms with high market capitalisation in both portfolios drive the high returns in the market-cap-weighted portfolios.

Key takeaways and analytical limitations

Overall, based on the analysis conducted, the data does not clearly indicate whether discernible differences exist in performance between firms that are actively mitigating against planetary boundary risks versus those that do not and/or are more exposed. While the market-cap-weighted PB-mitigated portfolio suggests some outperformance vs the PB-exposed portfolio and the wider MSCI ACWI index, similar conclusions cannot be drawn from the performance of the equal-weighted portfolios.

It is equally important to note that the analysis carried out contains several limitations, and serves primarily as a means to stimulate discussion and further investigation. Substantially more in-depth work and complex multi-variate regression analysis is necessary in order to gain a better understanding of whether and how planetary boundary exposure is truly incorporated in capital markets pricing and investment decision-making, while limiting selection randomness and bias, and establishing causation rather than correlation between different parameters.

4 Regulatory and policy landscape

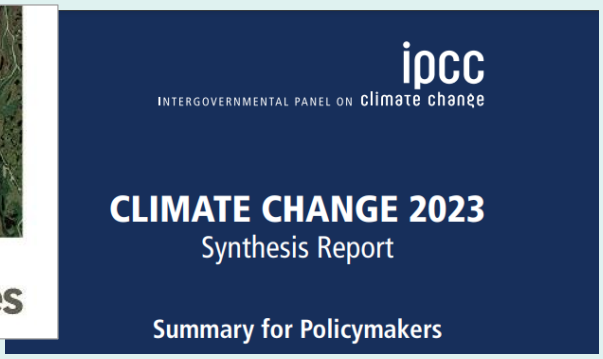
4.1 Global standards and frameworks

Global standards like TNFD, ISSB, and GRI are moving beyond climate to create an interoperable baseline for comprehensive planetary boundary reporting.

Over the past decade, the regulatory and policy landscape governing corporate sustainability has undergone a profound evolution. Historically, environmental regulation and corporate disclosures were almost exclusively focussed on greenhouse gas emissions, driven by the urgency of climate change. More recently, there has been an accelerating shift toward a more comprehensive approach that encompasses a more expansive spectrum covering other planetary boundaries beyond Climate Change.

This pivot is firmly rooted in the strong scientific foundations established by the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The IPCC provides the world's most authoritative scientific assessments on climate change, detailing its physical science basis, impacts, and mitigation pathways. Concurrently, IPBES serves a similar role for nature, assessing the state of biodiversity and the ecosystem services it provides to society. Together, these bodies have scientifically demonstrated that climate change and nature loss are inextricably linked, where one cannot be solved without addressing the other. Building on this consensus, policymakers are increasingly integrating Earth system sciences into financial and corporate regulations.

This chapter explores this shifting paradigm in more detail. It first examines how global standards and frameworks are evolving to cover Earth systems and planetary boundaries, before diving into the specific, rapidly developing regulatory requirements across several key jurisdictions (the EU, UK, Australia, Japan, and Singapore).



Over the last years, the global reporting landscape has matured from a fragmented array of voluntary, single-issue initiatives into a more consolidated and increasingly mandatory baseline. 10 years ago, frameworks largely siloed environmental issues, with climate dominating the agenda via the Task Force on Climate-related Financial Disclosures (TCFD). Today, the landscape is pivoting to embrace the inter-connectedness of the planetary boundaries framework. Major standard-setters are expanding their scope to require comprehensive disclosures on water, biodiversity, land use, and pollution, reflecting a dual focus on how environmental degradation threatens enterprise value and how corporate activities impact the planet. Figure 16 below sets out, at a high level, how the principal global standards and frameworks currently address the nine planetary boundaries.[55]

[55] The Appendix contains detailed factsheets on all 21 global standards and regional/national regulatory frameworks assessed, comprising amongst others what the regulations aim to achieve, how they are aligned with other reporting requirements, and how planetary boundaries are covered.

Figure 16. Coverage of planetary boundaries by key global regulatory standards

Standard / framework	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
TNFD (Taskforce on Nature-Related Financial Disclosures)	●	●	●	●	●	●	●	○	●
IFRS S1 & S2 (International Sustainability Standards Board)	●	◐	◐	◐	◐	◐	◐	◐	◐
GRI (Global Reporting Initiative)	●	●	●	●	●	◐	●	●	●
SBTN (Science Based Targets Network)	●	●	●	●	●	◐	○	○	○
NGFS (Network for Greening the Financial System)	◐	◐	◐	◐	◐	◐	◐	◐	◐

Key – coverage of planetary boundaries:

● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary

◐ Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered systemically as part of wider macro assessment

○ No coverage

The current web of global standards exhibits both strong alignments and differing levels of maturity across the nine planetary boundaries. A major alignment is the deliberate 'building block' interoperability between the ISSB's financial materiality baseline and GRI's impact materiality standards, which together allow corporates to construct a comprehensive double materiality disclosure. Furthermore, TNFD explicitly builds on the architecture of TCFD (now subsumed by ISSB), creating a cohesive structural approach for reporting both climate and nature risks.

However, while the frameworks are fairly comprehensive in aggregate, the maturity of guidance varies by boundary. For example, while there is no standalone standard for Novel Entities comparable to IFRS S2 for climate, the boundary is increasingly being operationalised through TNFD's pollution metrics, GRI's waste standards, and SBTN's upcoming methodology for toxic chemicals. Furthermore, the handling of complex systemic boundaries like Atmospheric Aerosol Loading and Ocean Acidification reveals a distinct gap between reporting and target-setting. While both boundaries are effectively captured in global disclosure frameworks (e.g. through GRI and TNFD mandates on localised air pollutants), they currently lack dedicated, science-aligned target methodologies under SBTN, leaving companies without the precise quantitative blueprints that are already available for other boundaries like land and freshwater.

Despite these discrepancies, it is reasonable to conclude that the time of "climate-only" sustainability reporting is coming to an end. Investors now possess the frameworks to demand more comprehensive Earth system disclosures. Going forward, best practice shows that corporates may proactively adopt double materiality assessments even where not strictly mandated, as the interoperability of ISSB, TNFD, and GRI creates a de facto global expectation. Navigating this successfully requires moving from siloed compliance and regulatory box-ticking towards integrating planetary boundary data and decision-making directly into core strategic and financial planning processes.

4.2 EU and UK regulations

The EU leads with a strict double-materiality mandate, while the UK pursues a pragmatic, disclosure-led approach prioritising single financial materiality.

European Union

The European Union has historically been the clear global frontrunner in translating Earth system science and voluntary frameworks into mandatory regulatory requirements. At the core of the EU's approach is the double materiality mandate, which requires companies to report not just on how environmental degradation threatens their enterprise value, but also how their operations physically impact the planet. Consequently, the EU has engineered a comprehensive architecture that absorbed TCFD, aligned with TNFD, and integrated planetary limits into a standardised scientific classification system via the Corporate Sustainability Reporting Directive (CSRD), the Corporate Sustainability Due Diligence Directive (CSDDD), and the EU Taxonomy.

However, recent developments highlight an inherent and growing tension between progressive sustainability regulation and global economic competitiveness. Facing substantial political and industry pushback over administrative burdens, the EU advanced the "Omnibus I" package in late 2025, significantly recalibrating its sustainability ambitions to protect the competitiveness of the European marketplace. This regulatory simplification package drastically narrowed the scope of both the CSRD and CSDDD, exempting thousands of previously targeted companies to reduce administrative and operational costs; it also pushed back the deadline for transposition into national legal frameworks to give companies more time to prepare for compliance. Similarly, the enforcement of the landmark EU Deforestation Regulation (EUDR) was officially delayed by a full year to late 2026 to allow global supply chains and IT systems more time to adapt. While the EU remains the most advanced jurisdiction for planetary boundary codification, this recent wave of pushbacks signals a pragmatic shift, prioritising targeted enforcement on the largest multinationals rather than blanket market coverage. As such, for global corporates the European landscape remains a rigorous compliance exercise, albeit one with a newly narrowed focus on the most systemically significant players.

Figure 17. Coverage of planetary boundaries by key EU regulatory standards

Regulation	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
CSRD (Corporate Sustainability Reporting Directive)	●	●	●	●	●	●	●	●	●
EU Taxonomy	●	●	●	●	●	●	●	●	●
CSDDD (Corporate Sustainability Due Diligence Directive)	●	●	●	●	●	●	●	●	●
EUDR (EU Deforestation Regulation)	○	●	●	○	○	○	○	○	○
SFDR (Sustainable Finance Disclosure Regulation)	●	●	●	●	●	●	●	○	●

Key – coverage of planetary boundaries:

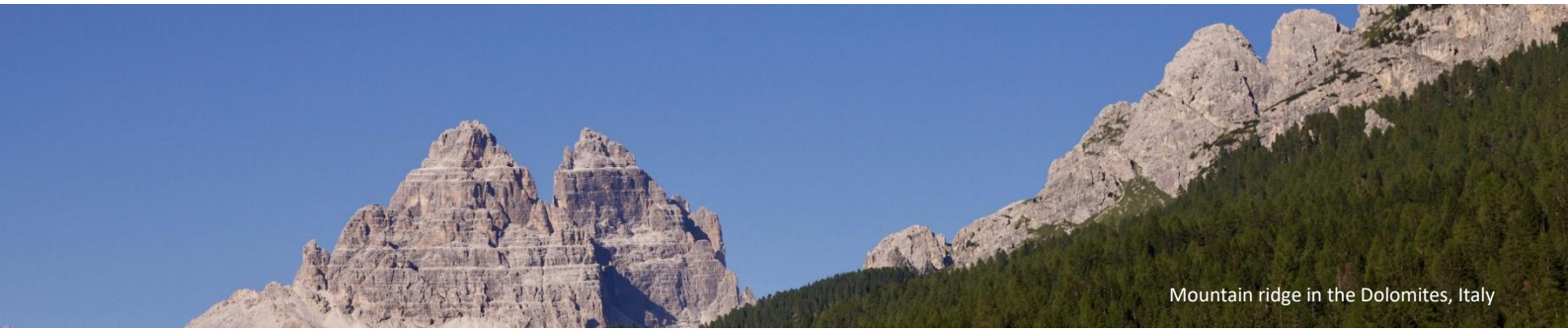
- ● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary
- ● Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered systemically as part of wider macro assessment
- ○ No coverage

Given the strong alignment efforts undertaken at EU level, it is better to see the EU landscape not as a separate set of rules, but as a translation mechanism. The EU has engineered its directives to convert relatively abstract global planetary boundary concepts into specific compliance mechanisms. For example:

- **From 'Safe Operating Space' to 'Do no significant harm' (DNSH):** The scientific concept of Earth's safe operating space is translated by the EU Taxonomy into the legally binding DNSH principle. An economic activity cannot be classified as sustainable if its positive contribution to one boundary (e.g. building a wind farm) breaches another (e.g. destroying Biosphere Integrity).
- **From TNFD 'Locate' to CSDDD 'Liability':** The TNFD's voluntary LEAP approach asks companies to locate their interfaces with nature. The CSDDD translates this exercise into a legal mandate. Essentially, if a company locates a planetary boundary breach in its supply chain, CSDDD can create obligations and liability exposure for mitigating that breach, moving the market from passive disclosure to active intervention.

Ultimately, the EU's regulatory architecture represents the most advanced jurisdictional attempt globally to codify the planetary boundaries framework into actionable law. The EU Taxonomy's six environmental objectives effectively mirror the critical global processes, creating a legally binding definition of what constitutes a safe operating space for economic activity.

However, the primary consideration for global corporates and investors today lies in navigating the volatility of the EU's deregulation wave. As the EU pushes ahead with a simplified CSRD and a narrowed CSDDD, multinational companies must adapt to shifting timelines while managing the divergence between the EU's strict double materiality mandate and the single-materiality ISSB baseline adopted by most other jurisdictions. Consequently, companies operating within or exporting to the EU must treat the European standards as their highest common denominator, utilising the CSRD and the EU Taxonomy as the foundational blueprint for their global Earth systems data and compliance strategy.



Mountain ridge in the Dolomites, Italy

United Kingdom

While the EU has pursued a highly prescriptive, double-materiality framework, the United Kingdom has set out on a distinctly different course. Emphasising its role as a global financial hub, the UK has adopted a pragmatic, disclosure-led approach rooted firmly in financial materiality. Instead of mandating complex, cross-boundary activity classifications, as evidenced by the official shelving of the UK Green Taxonomy in 2025[56], the UK relies heavily on global baselines like the ISSB to ensure interoperability and protect corporate competitiveness.

In areas where the UK does set out more prescriptive requirements, however, such as the Biodiversity Net Gain, it does so with targeted local mechanisms rather than more demanding global supply chain liabilities.

The most prominent regulatory focus point for 2026 is the rollout of the UK Sustainability Reporting Standards (UK SRS), which aligns very strongly with IFRS / ISSB, and constitutes a strong regulatory push on credible climate transition plans, as well as an ongoing calibration of anti-greenwashing measures for financial markets.

[56] The UK Green Taxonomy was abandoned in July 2025 following a government consultation which revealed only 45% of respondents expressed positive views about the regulation given the resource-intensiveness of regulatory adherence. – source: HM Treasury (2025).

Figure 18. Coverage of planetary boundaries by key UK regulatory standards

Regulation	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
UK SRS (Sustainability Reporting Standards)	●	●	●	●	●	●	●	●	●
TPT (Transition Plan Taskforce)	●	●	●	○	○	○	○	○	○
BNG (Biodiversity Net Gain)	○	●	●	●	○	○	○	○	○
Forest Risk Commodities	○	●	●	○	○	○	○	○	○
SDR (Sustainability Disclosure Requirements)	●	●	●	●	●	●	●	●	●

Key – coverage of planetary boundaries:

- ● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary
- ● Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered if reporting companies are exposed to materials risks
- ○ No coverage

As outlined further above, the UK's regulatory architecture presents a stark contrast to the EU, defined by its predominant focus on financial materiality rather than double materiality under UK SRS and TPT. Assessed against the planetary boundaries, this yields a less exhaustive landscape of coverage. On the plus side, the UK excels in its structural approach to Climate Change: By endorsing the ISSB baseline via UK SRS S2, alongside the strategic requirements of the Transition Plan Taskforce (TPT), the UK ensures corporate decarbonisation pathways yield highly comparable data. Furthermore, domestic regulations like Biodiversity Net Gain (BNG) provide stringent, legally binding protections for localised Biosphere Integrity and Land-System Change.

However, significant omissions emerge across the remaining boundaries. Unlike the EU's ESRS, the UK framework lacks prescriptive, standalone metrics for Freshwater Change, Biogeochemical Flows, Ocean Acidification, Atmospheric Aerosols, and Novel Entities. Instead, these boundaries are relegated to the "catch-all" provisions of UK SRS S1, and must only be considered and reported against in the case of material risks. Consequently, a UK-listed company is only required to disclose its impact on, for example, plastic pollution or nutrient runoff if that specific boundary breach poses a quantifiable financial risk to its enterprise value.

For global investors, this creates a distinct discrepancy. While the UK framework protects corporate competitiveness and reduces administrative burden through a climate-first transition relief, capital markets may remain largely uninformed about broader planetary impacts, unless those impacts cross the threshold into immediate financial liability.

4.3 APAC regulations

APAC jurisdictions align with the ISSB baseline for climate risk while deploying distinct local taxonomies and targeted nature laws to manage broader impacts.

Australia

Australia's regulatory approach is heavily influenced by its dual identity as a major fossil fuel exporter on one side, and one of the world's most diverse, climate-vulnerable continents on the other. Historically a laggard in mandatory reporting, the country has rapidly transformed into a fast follower. To ensure interoperability for its capital markets, the government is eschewing bespoke frameworks in favour of global baselines. Crucially, the Australian Treasury is currently developing a Sustainable Finance Taxonomy, designed as a voluntary, interoperable classification system to mobilise private capital toward both green and transition activities. While this taxonomy matures, the immediate regulatory landscape is dominated by the hard mandate of the Australian Sustainability Reporting Standards (ASRS) and the complex, ongoing political debate to overhaul the nation's foundational environmental laws through the "Nature Positive" plan.

Figure 19. Coverage of planetary boundaries by key Australian regulatory standards

Regulation	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
ASRS (Australian Sustainability Reporting Standards)	●	○	○	○	○	●	○	○	○
Nature Positive Plan (EPBC Act Reform)	○	●	●	●	●	○	○	○	○

Key – coverage of planetary boundaries:

- ● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary
- ● Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered if reporting companies are exposed to materials risks
- ○ No coverage

Australia provides a textbook example of a bifurcated regulatory landscape. For Climate Change, the ASRS mandate provides investors with exceptional, ISSB-aligned financial transparency regarding enterprise transition risks. However, by explicitly stripping broader sustainability requirements (IFRS S1) from the immediate mandate, the Australian reporting framework leaves capital markets exposed to the financial risks associated with the remaining boundaries. Conversely, on the impact materiality side, the Nature Positive Plan places a strong focus on Biosphere Integrity and Land-System Change, reflecting the continent's reliance on land-intensive industries like mining and agriculture. The challenges faced by Australian regulation to cover planetary boundaries more comprehensively are further exacerbated by the delay and lack of clarity on go-live date of the Nature Positive Plan.

The resulting gap between climate transparency and nature regulation creates a disjointed environment where corporates are not incentivised or mandated to holistically connect their carbon reporting with wider on-the-ground ecological compliance and risks.

Japan

Japan's regulatory architecture is rapidly evolving to bridge the expectations of global capital markets with its unique domestic environmental priorities. Recognising the need to remain highly competitive for foreign investment, Japan is actively harmonising its corporate disclosure regime with global financial baselines through the Sustainability Standards Board of Japan (SSBJ). Simultaneously, Japan has pioneered a unique legislative approach to nature conservation: Rather than relying solely on punitive regulations, it is creating formal certification systems that allow its large industrial conglomerates to leverage their privately owned lands (such as factory buffer zones and corporate forests) as officially recognised contributions to global biodiversity targets.

Figure 20. Coverage of planetary boundaries by key Japanese regulatory standards

Regulation	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
SSBJ (Sustainability Standards Board of Japan)	●	●	●	●	●	●	●	●	●
Act on Promoting Activities to Enhance Regional Biodiversity	●	●	●	●	○	○	○	○	○

Key – coverage of planetary boundaries:

- ● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary
- ● Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered if reporting companies are exposed to materials risks
- ○ No coverage

Assessed against the nine planetary boundaries, the Japanese framework reveals a distinct split between strict climate mandates and voluntary nature initiatives. On Climate Change, the SSBJ successfully delivers what international markets demand: Highly comparable, ISSB-aligned transparency regarding transition risks. However, because this reporting is anchored exclusively to single financial materiality, it inherently creates a systemic blind spot for broader ecological impacts.

To counterbalance this, the Act on Promoting Activities to Enhance Regional Biodiversity cleverly utilises corporate real estate to defend Biosphere Integrity and halt Land-System Change. Yet, because this certification is voluntary, it does not establish a market-wide regulatory floor. Consequently, the national architecture lacks comprehensive, mandatory mechanisms for the remaining Earth systems. Relying heavily on the SSBJ's 'catch-all' reporting provisions means critical systemic drivers, such as Freshwater Change (vital to Japan's semiconductor industry) or Novel Entities (central to its advanced chemical sector), will remain financially obscured unless a company formally determines they pose an immediate, quantifiable threat to its enterprise value.

Farmhouses in Shirakawa-go, Japan

Singapore

As the premier financial hub of Southeast Asia, Singapore exerts regulatory influence far beyond its borders. The Monetary Authority of Singapore (MAS) and the national exchange (SGX) are actively positioning the city-state as the benchmark for sustainable finance in the region. Acknowledging that much of Asia relies on hard-to-abate sectors, Singapore's regulatory setup and architecture are designed not to exclude carbon-intensive industries, but to rigorously manage their transition. It achieves this by rapidly mandating the ISSB baseline across the economy and pioneering a nuanced, multi-objective taxonomy that addresses multiple Earth systems simultaneously.

Figure 21. Coverage of planetary boundaries by key Singaporean regulatory standards

Regulation	Climate Change	Biosphere Integrity	Land-System Change	Freshwater Change	Biogeo-chemical Flows	Ocean Acidification	Atmospheric Aerosol Loading	Stratospheric Ozone Depletion	Novel Entities
SGX / ACRA (Mandatory Climate Reporting)	●	●	●	●	●	●	●	●	●
SAT (Singapore-Asia Taxonomy for Sustainable Finance)	●	●	●	●	●	●	●	●	●

Key – coverage of planetary boundaries:

- ● Comprehensive coverage – explicit reporting metrics aligned with the relevant Earth system / planetary boundary
- ● Partial coverage – either (a) reporting metrics not explicitly linked to specific Earth system / planetary boundary, (b) metrics/scope covering only parts of the Earth system, or (c) planetary boundary only covered if reporting companies are exposed to materials risks
- ● No coverage

Singapore's framework is arguably the most pragmatic and holistic in the APAC region. While its mandatory reporting (SGX/ACRA) mirrors Australia and Japan by focusing on the financial materiality of Climate Change via the ISSB baseline, its Taxonomy sets a much broader standard. The Singapore-Asia Taxonomy effectively captures almost the entirety of the Planetary boundaries framework, including Freshwater Change, Biosphere Integrity, and Novel Entities (via pollution), while employing a 'traffic light' system that bridges the high ambition of the EU with the industrial realities of Asia. For investors, this dual approach ensures rigorous financial visibility on climate risk, while providing a clear, scientifically backed mechanism to safely deploy capital into companies transitioning their broader Earth system impacts across the ASEAN block.

Aerial view of Gardens by the Bay, Singapore

4.4 The regulatory path ahead

As global regulations consolidate, corporates will need to look beyond fragmented compliance and use tools to actively manage interconnected Earth system risks.

The recent regulatory evolution: Ambition versus pragmatism

The global regulatory environment has undeniably expanded its horizons over the last five years. Frameworks such as the Taskforce on Nature-related Financial Disclosures (TNFD), the Science Based Targets Network (SBTN), and the general financial materiality provisions of IFRS S1 have officially pushed the sustainability narrative beyond the single lens of Climate Change. By bringing wider planetary boundaries, such as Biosphere Integrity, Freshwater Change, and Novel Entities into reporting processes, these standards have laid the groundwork for a more informed understanding of Earth system risks.

However, the translation of these voluntary global frameworks into mandatory domestic laws has encountered challenges. A recurring theme across recent legislative cycles is the clash between ecological ambition and economic competitiveness.

This tension has resulted in a marked wave of pragmatism, and in some cases, active legislative pushback, as demonstrated by the EU Omnibus package. Concurrently, this evolution has cemented a highly fragmented approach to corporate materiality across different jurisdictions. Double materiality requirements remain the exception rather than the global norm, with the UK, Australia, Japan, and Singapore having anchored their mandates almost exclusively to the single financial materiality baseline of the ISSB.

For global investors and multinational corporates, the resulting picture is profoundly complex. Companies are forced to navigate a patchwork of regulations where they must decouple their climate reporting from their broader ecological impacts, reporting against divergent standards depending on the jurisdiction.

Looking ahead: Expected developments over the next 5-10 years

Notwithstanding any major disruptions, the global regulatory landscape is likely to undergo a period of gradual consolidation and harmonisation, driven more by investor demand for comparable data rather than unified global political will. ISSB should cement its position as the dominant standard for financial materiality, with IFRS S1's broader sustainability requirements transitioning from catch-all guidelines to strictly enforced mandates. As spatial mapping data and supply chain traceability capabilities improve, TNFD-aligned nature disclosures can be expected to shift from voluntary best practice to mandatory requirements across leading financial hubs.

Regionally, the trajectories are likely to remain distinct based on local priorities:

- **The EU** will likely spend the next five years on operationalising its current wave of regulations. Having weathered the political pushbacks of 2025/2026, the focus may shift from expanding the legislative scope to ensuring rigorous enforcement, standardising double materiality data from the market's largest multinationals, and refining the EU Taxonomy to improve coverage of complex transition activities.
- **The UK** will likely be defined by the formal integration of the Transition Plan Taskforce (TPT) requirements into law and the eventual mandatory rollout of the UK SRS for listed companies. Substantial tightening of anti-greenwashing rules and a phased expansion of mandatory Biodiversity Net Gain metrics to cover broader infrastructure and corporate footprints can also be expected.
- **APAC** will most likely remain focussed on a pragmatic and financialised transition. Japan and Australia can be expected to operationalise their respective ISSB-aligned standards (SSBJ and ASRS), while increasingly tying corporate landholdings to national biodiversity targets via domestic nature laws. Meanwhile, Singapore is unlikely to lose its role as the regional benchmark, iterating on its Taxonomy to direct transition finance toward hard-to-abate sectors across the ASEAN block.

What this means for effectiveness of planetary boundary exposure assessments

When projecting this regulatory path against the framework for effective planetary boundary risk assessment, which demands location-specific, sector-based, and time-dependent analysis (see chapter 3), the likelihood of achieving a universally adopted, comprehensive, yet streamlined standard remains low. Consequently, corporates and investors must prepare to operate within an imperfect, evolving ecosystem of disclosures defined by distinct regulatory gaps.

- **Location-specific gaps:** While frameworks like TNFD and SBTN heavily emphasise the geospatial realities of nature, translating this into mandatory corporate reporting remains exceptionally challenging. Regulations currently struggle to mandate the highly localised, basin-level or biome-specific data required to accurately assess Freshwater Change or Land-System Change without imposing crippling administrative burdens on complex, multi-tier global supply chains.
- **Sector- and asset-based gaps:** Standardisation is improving, primarily through the ISSB's industry-based requirements and targeted mechanisms like the EU Taxonomy. However, regulations tied strictly to single financial materiality are likely to continue to under-report sector-specific impacts that do not immediately threaten a company's enterprise value, such as the agricultural sector's immense contribution to Biogeochemical Flows or the manufacturing sector's release of Novel Entities.
- **Time-dependent gaps:** Regulatory frameworks inherently lag behind the speed of planetary boundary deterioration. While Climate Change mandates increasingly require forward-looking, time-bound transition plans, other critical boundaries lack similar urgency. The immediate, accelerating crises of Biosphere Integrity and Novel Entities are often treated as static compliance exercises rather than time-critical strategic risks.

Ultimately, while the global regulatory floor is rising, compliance alone will remain insufficient to capture the full spectrum of Earth system vulnerabilities.

Figure 22. Key characteristics for effective exposure assessment of PB risks: Expected regulatory coverage

Location-specific	Sector- and asset-based	Time-dependent
Understanding and mitigating against planetary boundary risks needs consideration of local conditions	*Estimating influence on and exposure to planetary boundary risks requires looking at the specific sectors of operation and activities carried out*	*Ensuring long-term resilience and value generation requires mitigation of the most acute planetary boundary risks first*
Challenges in mandating location-specific assessments without imposing significant operational burden	Improving sectoral standardisation, but predominant focus on financial materiality	Static approach and lack of time-criticality prioritisation for acute systemic Earth system and PB risks

The need for international cooperation and implications for corporates and investors

It is crucial to recognise that establishing regulatory standards, reporting requirements and financial taxonomies is only one piece of the puzzle. Corporate disclosure alone does not halt ecological degradation.

Effective systemic change requires coordinated cooperation that actively phases out harmful activities and incentivises sustainable alternatives at a macro level. Ultimately, the core objective should not merely be to map out transgression of planetary boundaries, but to set out a path and govern the return to a safe operating space. This level of decisive, cross-border intervention is not without precedent. As demonstrated by historical environmental successes, when international scientific consensus is paired with binding global policy and targeted industry cooperation, even critical Earth system boundaries can be stabilised and reversed, as evidenced by the Montreal Protocol.

For corporates and investors, the imperative is clear: Waiting for a perfectly harmonised, globally unified regulatory framework is a flawed approach. As compliance mandates will continually trail the physical reality of planetary boundary deterioration, businesses must proactively adopt a systems-thinking approach to risk management and value creation. Rather than treating reporting as a backwards-looking compliance exercise, forward-thinking business leaders are advised to integrate Earth system science directly into their core strategy formulation. To bridge the gap between fragmented regulations and true ecological resilience, market participants can make use of existing advanced tools and methodologies, such as the bespoke scenario modelling and integrated assessment frameworks detailed in chapter 6, to proactively identify hidden vulnerabilities, unlock nature-positive market opportunities, and secure long-term financial stability.

Case study 9. The success of the Montreal Protocol[57]

In the mid-1980s, the scientific discovery of a rapidly expanding hole in the ozone layer over Antarctica triggered unprecedented global alarm. The primary culprits were identified as chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODS), which were ubiquitous in everyday global manufacturing, heavily utilised in refrigeration, aerosol sprays, and industrial cleaning.

In response, the international community convened to draft the **1987 Montreal Protocol**, an environmental agreement explicitly designed to phase out the production and consumption of ODS. Its profound success, returning the stratospheric ozone layer to a safe operating space, stemmed from three critical factors.

First, it was grounded in unequivocal, universally accepted science. Second, it employed a pragmatic, phased approach, offering differentiated timelines and establishing a dedicated multilateral fund to help developing nations transition without crippling their emerging economies. Finally, it secured total industry buy-in; chemical manufacturers, faced with unified, inescapable global regulation, rapidly innovated and scaled viable, non-depleting technological alternatives.

The Montreal Protocol remains the gold standard for global environmental governance. It proves that targeted policy can course-correct human impacts on Earth systems, providing a blueprint for addressing today's accelerating crises.

Case study 10. The EU Common Agricultural Policy exacerbating terrestrial biodiversity loss[58]

Recognising the profound impact of agricultural financing on the Earth system, recent analysis highlights how specific government subsidies can actively undermine planetary boundaries. In the European Union, roughly €32 billion of the annual Common Agricultural Policy (CAP) budget is directed toward activities considered actively harmful to biodiversity.

By providing direct financial support that unintentionally incentivises the degradation of species and habitats, these funds severely strain the **Biosphere Integrity** and **Land-System Change** boundaries. This issue is further compounded by decentralised national approaches, such as the €15 billion allocated by Member States to biomass energy in 2022, which encourages nature-harming land use.

Ultimately, repurposing these vast agricultural subsidies is imperative for the transition to a nature-positive economy, closing the biodiversity financing gap and protecting critical ecosystem resilience.


A tractor towing a fertilizer applicator, UK

[57] "About Montreal Protocol", UNEP (2026); "32 years ago the world pledged to fix the ozone layer. And it worked.", World Economic Forum (2017); "Atmospheric science: Fixing the sky", Nature (2009); Baringa analysis.

[58] "Can Your Money Do Better", WWF (2024); "Environment and the common agricultural policy", European Parliament briefing paper (2024), Baringa analysis.

5 Opportunities for value creation

5.1 What corporates stand to gain

Corporates and investors need to move beyond reactive risk management and reporting to realise the vast opportunities for Earth-system-aligned value creation.

While this report has thus far focussed mostly on the risks and reporting requirements related to Earth system changes and planetary boundaries, it is equally important to assess the vast opportunity space stakeholders can access from incorporating planetary boundaries more effectively in strategy formulation and commercial decision-making. Ultimately, treating Earth system dynamics merely as a compliance exercise or a risk mitigation checklist fundamentally misunderstands the scale of the transition underway. Chapter 5 thus turns the attention from reactive mechanisms towards proactive value creation opportunities.

The transition toward a sustainable, Earth-systems-aligned global economy represents arguably the largest commercial reallocation of capital in modern history. As planetary limits are breached, the linear, extractive economic models of the 20th century are becoming increasingly unviable. In their place, circular, regenerative, and resource-efficient business models are rapidly gaining structural advantages. The opportunity is indeed substantial. According to research by the World Economic Forum (WEF), transitioning the global economy to a "nature-positive" state could generate up to $10.1 trillion in annual business value and create 395 million new jobs by 2030.[59]

For investors, this marks a profound shift in capital allocation strategies. The focus is moving beyond simple exclusionary screening (avoiding the worst polluters) toward active, solutions-oriented allocation. Investors are seeking out the companies that hold the intellectual property, infrastructure, and innovative business models required to solve Earth system crises. These solutions providers are uniquely positioned to benefit from regulatory tailwinds, shifting consumer preferences, and the influx of sustainable capital.

The five key sectors analysed in chapter 3 (Agriculture & Food, Energy, Construction & Built Environment, Manufacturing & Chemicals, and Transportation) stand at the nexus of planetary impact and commercial upside. While these sectors are responsible for the vast majority of current Earth system degradation, they simultaneously hold tremendous potential for value creation through transformation. Figure 23 below outlines high-level opportunities across these core sectors, alongside the estimated macroeconomic 'size of the prize' for successfully executing these transitions.

[59] "How to unlock $10.1 trillion from the nature-positive transition", World Economic Forum (2024).

Figure 23. Macro value creation opportunities by sector[60]

Sector	Examples of PB-aligned opportunities	Size of the opportunity
Agriculture & Food	• Precision agriculture • Regenerative soil management • Alternative proteins • Zero-conversion supply chains	**$5-10tn** in annual economic benefits by transforming food systems to be environmentally sustainable and health-enhancing
Energy	• Expansion of renewable baseloads • Long-duration energy storage • Smart-grid infrastructure	**$2.0tn** in annual capital investment flowing directly into clean energy technologies in 2024, double the amount invested into fossil fuels
Construction / Built Environment	• Circular building materials • Green steel • Low carbon cement • Water-efficient urban design	**$1.3tn** of projected market value for the global sustainable construction and green buildings sector by 2033
Manufacturing & Chemicals	• Closed-loop manufacturing • Green chemistry (reduced novel entities) • Industrial symbiosis	**$4.5tn** in annual economic output generated by 2030 through global adoption of circular economy models and reduced raw material dependency
Transportation	• EV fleet management • Circular battery recycling • Sustainable Aviation Fuels	**$1.0tn+** in annual revenue pools expected by 2030 across the EV value chain, as well as from battery recycling and charging infrastructure income

Aerial view of a solar farm near Milton Keynes, UK

[60] "The Economics of the Food System Transformation", Food System Economics Commission (2024); "World Energy Investment 2024", International Energy Agency (2024); "Sustainable Construction Market Size & Growth Projections", Precedence Research (2024); "Circular Economy as an Enabler for Responsible Banking", UNEP Finance Initiative (2024); "Mobility's net-zero transition: A look at opportunities and risks", McKinsey & Company (2023); Baringa analysis.

5.2 Unlocked market growth

Corporates able to translate how Earth system changes and planetary boundaries are affecting markets and buyers can displace incumbents and reap early-mover advantages that others fail to see.

Unlocking opportunities for value creation necessitates informed decision-making and foresight in most if not all strategic environments. Due to the complexity and interconnectedness of planetary boundary interactions, and their wide-ranging implications on global markets, it is even more indispensable in the current context.

Earth system changes are fundamentally altering global demand dynamics. As planetary boundaries transgress, they recalibrate local physical, social and economic realities, and thus alter consumer demands, reshape supply feasibilities and constraints, and trigger consequential regulatory interventions. Companies that actively integrate planetary boundary frameworks and datasets into their strategic planning can better predict how markets will shift in response to these changes, allowing them to proactively position their products and services ahead of the curve.

For example, as the Freshwater Change boundary is increasingly breached, demand for water-intensive products in arid regions will likely falter due to regulatory rationing and prohibitive pricing. Conversely, the market for drought-resistant agricultural inputs, closed-loop water recycling technologies, and hyper-efficient appliances will experience exponential growth. Companies that foresee these shifts can pivot their capital expenditure away from increasingly at-risk demand centres and into new high-growth markets.

Relatedly, and crucially, integrating planetary boundary data provides a powerful mechanism for competitor displacement. In every sector, incumbent firms that fail to adapt to Earth system shifts will inevitably face shrinking addressable markets, stranded assets, and severe margin compression risks.

Forward-looking companies can exploit these vulnerabilities to gain market share within the existing market space. For instance, when a product line is taxed or regulated out of existence or viability due to its heavy reliance on Novel Entities (e.g. PFAS chemicals) or destructive Land-System Change (e.g. uncertified deforestation), a PB-aligned company can immediately step in to capture the unserved demand. In this manner, PB alignment unlocks growth without necessarily requiring the overall market size to expand; it simply accelerates the transfer of market share from the rigid to the resilient.

Finally, moving early to address these planetary shifts establishes deep brand loyalty and formidable technological moats. First movers in nature-positive product categories often are able to define the industry standards, secure the most lucrative green procurement contracts from governments, and lock in the most sustainably conscious consumer demographics.

Sprinkler irrigation system in the Salinas Valley, USA

Figure 24. Expected market shifts and emerging demand centres[61]

Sector	Expected shifts in current market characteristics	Emerging market characteristics and demand centres	Relevant opportunity areas
Agriculture & Food	• LSC / BI / FC: Decline of high-yield, water-intensive monocultures • LSC / BI: Rejection of supply chains linked to deforestation	• Surge in drought-resistant seed varieties, precision micro-irrigation, and verified zero-conversion commodities	Displacement of rigid incumbents across the **$10tn global agrifood market** as market share of climate-resilient models rises
Energy	• CC / OA / BF: Phase-out of fossil baseloads • FC / BI / CC: Margin compression for unabated thermal energy through carbon pricing	• Significant demand for solar and wind, utility-scale battery storage, and grid-enhancing technologies	Capturing growing market share in the **$2tn current annual investments in the clean energy transition**
Construction / Built Environment	• CC / FC / BI / NE: Decline in commercial viability of traditional cement and virgin steel through levies and tariffs (e.g. CBAM)	• Premium pricing for low-embodied-carbon materials (green steel) and modular, reusable building components	Scaling dominance in a **global green building and sustainable infrastructure market projected to reach $1.3tn** by the early 2030s
Manufacturing & Chemicals	• NE / BI: Phase-out of virgin, single-use plastics and hazardous chemical compounds (e.g. PFAS) due to stricter Novel Entity bans	• Rapid transition to bio-based packaging, chemical recycling infrastructure, and non-toxic industrial solvents	Disruption and displacement within the **~$5tn global chemicals and advanced materials sector**
Transportation	• CC / AL: Phase-out of internal combustion engine vehicles and fragmented fossil-fuel supply chains	• Dominance of vertically integrated EV fleet services and localised, circular battery recycling hubs	Growing market share in the **$3tn global automotive sector**, driven by **$600bn+ in annual electrified transport spending**

Key: CC = Climate Change, BI = Biosphere Integrity, LSC = Land-System Change, FC = Freshwater Change, BF = Biogeochemical Flows, OA = Ocean Acidification, AL = Atmospheric Aerosol Loading, NE = Novel Entities

Case study 11. Ørsted's anticipation of the global energy shift[62]

In the mid-2000s, Ørsted, then called Danish Oil and Natural Gas (DONG Energy), was one of the most coal-intensive utilities in Europe, with 85% of its energy generation based on fossil fuels. Recognising the unsustainable trajectory of global climate change, anticipating the inevitable regulatory shift against carbon, and seeing the business opportunity in renewable energy, Ørsted initiated a radical pivot.

The company divested its legacy oil and gas assets entirely, rebranded as Ørsted in 2017, and deployed its capital into pioneering offshore wind technology, reaching a 99% renewable energy share in 2025. By predicting the market shift away from carbon-intensive demand centres, Ørsted successfully displaced lagging competitors to become the world's foremost leader in offshore wind.

This PB-aligned transformation unlocked substantial shareholder value. Since its IPO in 2016, Ørsted's market capitalisation surged by over 314% at its peak, outperforming traditional fossil fuel majors. Today, having secured a massive technological moat in Climate Change mitigation, Ørsted is expanding its planetary-boundary-aligned focus, having committed to a net-positive biodiversity impact for all new renewable energy projects commissioned from 2030 onward. To guide the company in achieving this, Ørsted developed a bespoke Biodiversity Measurement Framework – an eight-step process that unites diverse global standards into a single practical tool for projects on- and offshore. Ørsted also issued a Blue Bond, with proceeds channelled into marine ecosystem and biodiversity initiatives.

[61] "The Economics of the Food System Transformation, Food System Economic Commission (2024); "World Energy Investment 2024", International Energy Agency (2024); "Green Building Materials Market Size, Share & Industry Analysis", Fortune Business Insights (2024); "Global Chemical Industry Revenue", Statista / UNEP (2024); "Energy Transition Investment Trends 2024", BloombergNEF (2024); Baringa analysis.

[62] Ørsted website (2026); "From Dong to Orsted: A Leading Utility's Green Energy Transition", Institute for Energy Economics and Financial Analysis (2021); Baringa analysis.

5.3 Enhanced operational resilience

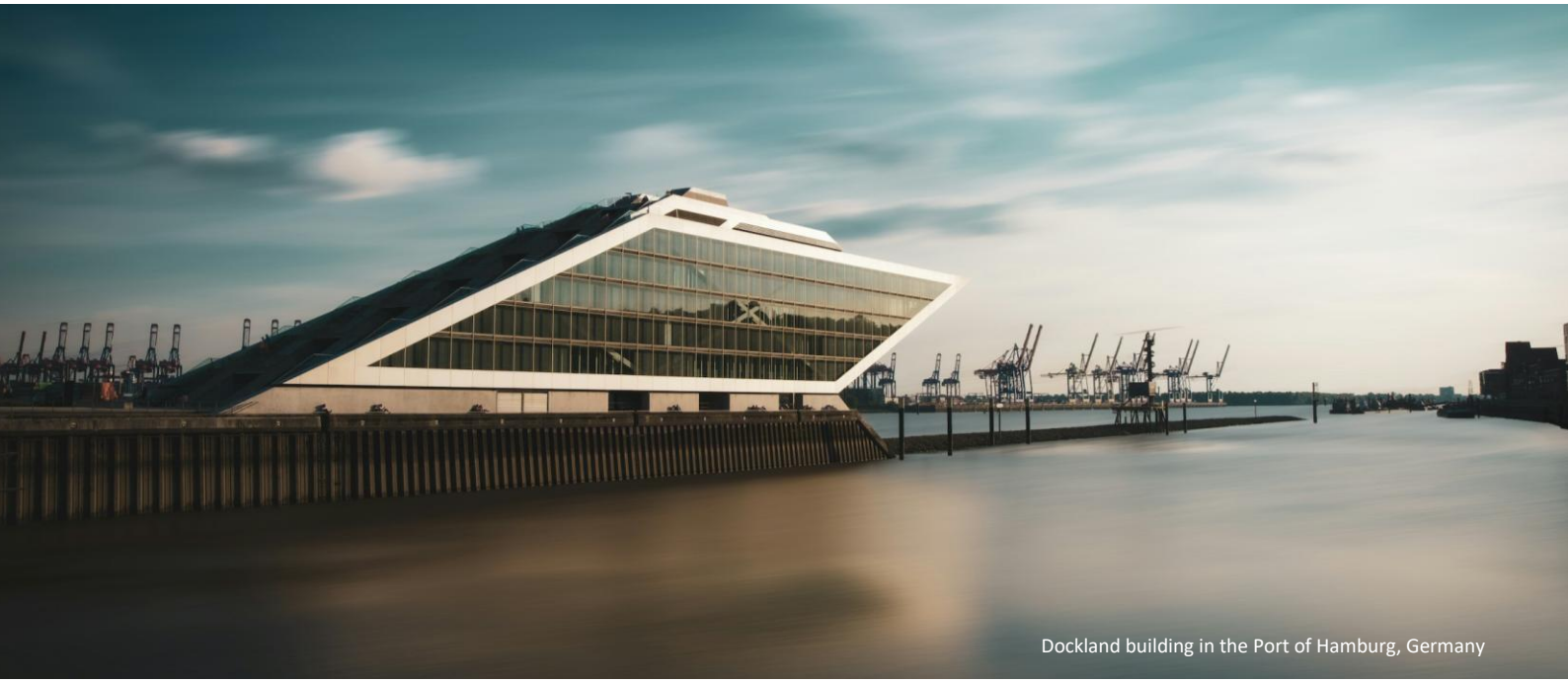
In the increasingly complex ecological environment of today, companies that integrate Earth system and planetary boundary concepts in their decision-making are able to build vital protection against systemic risks and macro disruptions.

Having looked at the top-line benefits of market growth in the previous sub-chapter, it is just as important to consider how integrating planetary boundaries can help with protecting the bottom line through enhanced operational resilience. In recent decades, global supply chains have been optimised for cost and speed (e.g. through just-in-time manufacturing), leaving them exposed to physical Earth system shocks. As planetary boundaries are breached, the frequency of these shocks, ranging from historic droughts and unprecedented floods to localised ecosystem collapses, is accelerating at an increasing materiality exposure.

For corporations, as already set out in chapter 3, these are not abstract environmental issues. They represent severe operational disruptions that cause factory downtime, logistics failures, and raw material shortages. By actively managing their planetary boundary impacts and dependencies, companies can fundamentally decouple their production capacity from localised ecological constraints. Amongst other things, enhancing operational resilience means building strategic buffers, transitioning to circular supply chains to reduce reliance on virgin resource extraction, and investing in local natural capital.

The transition to a circular economy is one of the most powerful levers for ensuring operational resilience. By designing out waste and keeping materials in continuous use, companies insulate themselves from the growing price volatility and geopolitical supply chain bottlenecks associated with raw material extraction. As noted further above, this transition alone can unlock $4.5 trillion in economic benefits by 2030 by promoting the persistent, safe (re)use of natural resources.

Crucially, operational resilience acts as a massive competitive advantage during systemic crises. When a planetary-boundary-driven shock hits an industry, e.g. a regional drought halting semiconductor production, or a severe blight wiping out a commodity crop, resilient companies do not merely survive; they maintain their production lines, honour their contracts, and – crucially – capture the unmet demand left behind by less resilient competitors. Consequently, in an era of Earth system instability, resilience is synonymous with profitability.



Dockland building in the Port of Hamburg, Germany

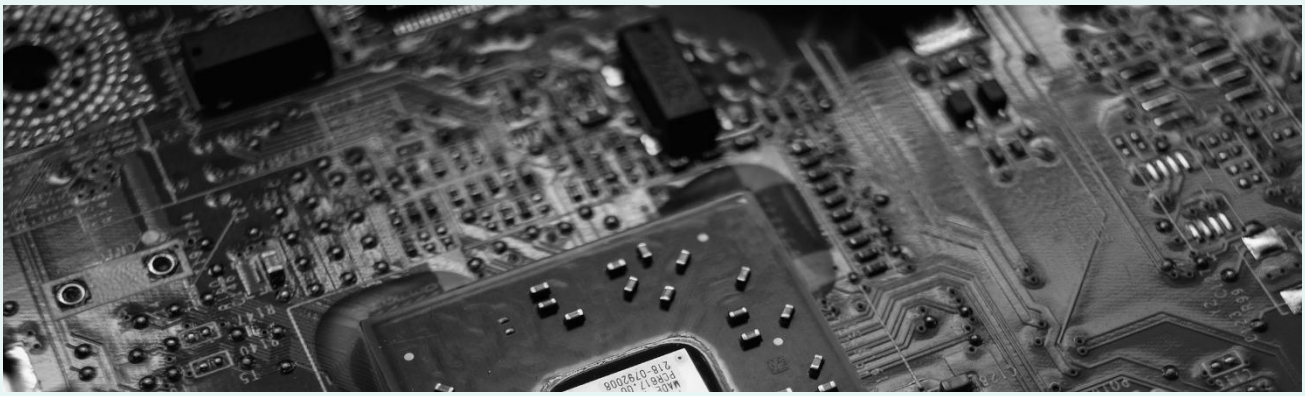
Figure 25. Operational resilience use case examples linked to planetary boundaries[63]

Sector	Operational resilience example use cases	Impact and value drivers
Agriculture & Food	**Regenerative Soil Management:** Transitioning away from synthetic fertilisers to cover cropping and localised organic matter retention	Restores Biosphere Integrity and Biogeochemical Flows while making crops highly resilient to extreme flood and drought cycles, ensuring stable yields
Energy	**Decentralised Microgrids & Co-Location:** Deploying localised renewable generation coupled with commercial battery storage at key industrial hubs	Mitigates Climate Change risks by ensuring uninterruptible power supply during extreme-weather-induced grid failures and rolling blackouts
Construction / Built Environment	**Closed-Loop Water & Cooling Systems:** Integrating advanced wastewater treatment and recirculation into major real estate and infrastructure assets	Reduces exposure to Freshwater Change boundaries, ensuring operational continuity even during severe municipal water rationing mandates
Manufacturing & Chemicals	**Circular Raw Material Sourcing:** Re-engineering product lines to utilise 100% recovered or remanufactured inputs (e.g. recycled metals and plastics)	Dramatically lowers exposure to raw material price volatility and reduces the generation of Novel Entities and hazardous industrial waste
Transportation	**Climate-Fortified Port Infrastructure:** Upgrading coastal logistics hubs with advanced physical barriers and restored mangrove buffers	Protects critical supply chain nodes from sea-level rise and extreme storm surges, preventing catastrophic logistics downtime

Case study 12. Futureproofing operations against freshwater risks[64]

Semiconductor manufacturing is an incredibly water-intensive process, requiring millions of gallons of ultrapure water daily to clean silicon wafers. Taiwan Semiconductor Manufacturing Co. (TSMC), the world's largest contract chipmaker, operates heavily in regions increasingly threatened by the Freshwater Change boundary. In 2021, Taiwan faced its worst drought in 56 years, forcing the government to impose severe water rationing that threatened global tech supply chains.

Anticipating these physical risks, TSMC heavily invested in operational resilience. The company collaborated with the government to build the world's first industrial reclaimed water plant at the Southern Taiwan Science Park. By utilising advanced treatment technologies, TSMC achieved a process water recycling rate of over 90%, versus a historical baseline figure of roughly 60%. This massive decoupling from the local municipal water supply allowed TSMC to maintain uninterrupted production during historic droughts, protecting billions of dollars in revenue while other local firms scrambled for emergency water supply.



[63] Baringa analysis.

[64] TSMC website (2026); "TSMC S.T.S.P. Reclaimed Water Plant Commences Operation", TSMC Sustainability (2022); Baringa analysis.

5.4 Strengthened financial position

Companies that combine increased value creation potential and improved operational resilience through planetary boundary analysis can also benefit from more and improved funding conditions, as well as higher valuation upsides.

In any relevant operating context, predictive market growth and robust operational resilience supports a strengthened financial position. From an investment standpoint, companies that effectively integrate planetary boundary assessments have a higher potential to generate better risk-adjusted returns and exhibit much lower volatility during systemic market shocks. By anticipating regulatory shifts and insulating supply chains from physical climate and nature risks, PB-aligned companies will be better able to mitigate the tail risks that routinely destroy shareholder value.

Financial markets should become increasingly efficient at pricing in these risks, meaning that companies that proactively manage their Earth system impacts will be able to benefit from a lower cost of equity and cheaper debt financing. Lenders and asset managers are actively rewarding corporate resilience, allocating premium valuations to firms that can prove long-term viability in a more volatile and resource-constrained world.

Nowhere is this financial upside more evident than in the growth of the sustainable finance market. While early iterations of green finance focused almost exclusively on carbon mitigation, the fixed-income market has rapidly evolved to encompass planetary boundaries beyond Climate Change. Nowadays, corporates have access to a sophisticated suite of instruments, including, among others, green bonds, blue bonds, and Sustainability-Linked Bonds (SLBs).

SLBs are particularly powerful tools for value creation. Unlike traditional green bonds, which ring-fence funds for specific projects, SLBs provide general corporate purpose funding where the cost of the debt is tied directly to the achievement of overarching sustainability targets. By linking coupon rates directly to planetary boundary metrics, such as reducing freshwater consumption, or preserving biodiversity, firms can lock in cheaper funding while signalling strategic robustness to the market. For institutional investors, allocating capital to these PB-aligned instruments serves as a vital hedge against systemic Earth system risks, protecting long-term portfolio value while driving measurable positive impacts across the biosphere.

To capitalise on the transition toward a nature-positive economy, investors can deploy a range of additional financial instruments tailored to specific risk-return profiles and planetary-boundary-aligned objectives.

Figure 26. Financial instruments suitable for capturing planetary boundary value *(non-exhaustive)*

Financial instruments	Description	Most suitable for	How they work
Green & Blue Bonds	Fixed-income instruments funding specific, targeted environmental projects	**Direct impact generation**	• Capital is strictly ring-fenced for projects that directly mitigate boundary breaches (e.g. water infrastructure or marine conservation) • Provides investors with predictable yields while funding measurable, location-specific ecological restoration
Nature-based Venture Capital & Private Equity	Equity investments in private companies restoring or protecting natural capital	**Long-term value creation**	• Provides high-conviction growth capital to scalable, innovative nature-positive businesses (e.g. regenerative agriculture technologies) • Captures high upside return potential from rapidly emerging environmental markets and biodiversity credits
Parametric Catastrophe Bonds	Debt instruments triggered automatically by predefined biophysical or environmental events	**Acute downside protection**	• Pays out automatically when specific physical thresholds (e.g. hurricane wind speed, regional drought levels) are crossed • Provides immediate liquidity to recover from acute physical risks without lengthy loss-adjustment processes
Blended Finance Vehicles	Public-private structures absorbing initial risk to attract commercial capital	**Frontier market development**	• Uses concessional public or philanthropic capital to de-risk investments in novel or untested ecological solutions • Unlocks large-scale institutional funding for complex, capital-intensive boundary challenges like large-scale reef restoration

Case study 13. Pioneering the Biodiversity Sustainability-Linked Bond[65]

In January 2021, Klabin, Brazil's largest paper and packaging producer, demonstrated how planetary boundaries beyond carbon can be leveraged to secure financial advantages. The company issued a landmark $500 million Sustainability-Linked Bond (SLB) tied explicitly to a diverse set of planetary boundary metrics.

Rather than focussing solely on greenhouse gas emissions, Klabin's SLB included strict Key Performance Indicators (KPIs) targeting the Freshwater Change and Biosphere Integrity boundaries. The bond's targets mandated a 16.7% reduction in water consumption intensity, a 97.5% industrial waste reuse rate, and the successful reintroduction of at least two extinct or threatened native species into the local ecosystem.

This holistic approach to Earth system resilience attracted large investor demand (order book of $5.3bn), allowing Klabin to tighten pricing and achieve an estimated greenium of up to 40 basis points, lowering its overall cost of debt. If Klabin fails to meet the targets by the observation date, the bond triggers a penalty via a 25-basis-point coupon step-up. By financially committing to the restoration of natural capital, Klabin successfully lowered its cost of capital, diversified its investor base, and set a global precedent for linking corporate finance directly to biodiversity outcomes.

Iguazu Falls, Brazil

[65] "Klabin Sustainability-Linked Bond Framework", Sustainalytics (2021); "Green bonds come of age in Latin America", Euromoney (2021); Baringa analysis.

6 Tools and methodologies to unlock growth and resilience

6.1 Existing planetary-boundary-aligned market activity

Proactive investors and corporates are moving beyond basic compliance, utilising advanced analytical tools to unlock growth and Earth-system-aligned value creation.

As established in earlier chapters, the systemic risks posed by the transgression of planetary boundaries are profound. While the global regulatory landscape is rapidly expanding to mandate disclosures on nature, water, and climate, compliance frameworks alone remain insufficient to ensure efficient, forward-looking exposure assessment. Standardised reporting often fails to capture the granular location-specific, asset-based, and time-dependent data required to fully map Earth system vulnerabilities.

Furthermore, treating planetary boundary science purely as a compliance exercise obscures the existential financial imperatives at stake. The cost of inaction is substantial, and the financial penalties for breaching ecological limits are already materialising on corporate balance sheets. According to CDP data, corporate water-related risks alone carry a potential financial impact of almost $600 billion (driven mostly by stranded assets, supply chain failures, and regulatory fines), while the cost to actively mitigate these risks is estimated at a mere fraction of that figure.[66] Furthermore, broader macroeconomic assessments by the World Economic Forum have established that $44 trillion of economic value generation, representing over half of global GDP, is highly or moderately dependent on intact nature, exposing unprepared global supply chains to unprecedented physical shocks.[67]

As set out in chapter 4, waiting for legislation to lead the way is inherently too risky. Corporates and investors need to take a proactive stance, with many already making decisive moves. The financial sector is increasingly recognising that businesses operating within the safe operating space of planetary boundaries are structurally insulated from physical resource constraints and impending environmental taxes. European assets under management in biodiversity-focused funds have grown rapidly in recent years as investors proactively shift capital toward nature-positive solutions, while collaborative initiatives like Nature Action 100 are driving targeted corporate engagement well ahead of regulatory deadlines.[68]

Planetary-boundaries-aligned decision-making can also help companies navigate the complex dynamic between commercial growth and sustainability. As businesses scale, achieving decarbonisation goals (e.g. absolute scope 3 emissions reductions) becomes increasingly complex, laying out an inherent tension between commercial success and sustainable footprint. Several corporates have begun assessing how the Planetary Boundary Framework can help them overcome this challenge, thus achieving sound and sustainable operational growth within Earth's safe operating space.

To navigate this environment, make sense of Earth system science, and capitalise on the transition, a new generation of sophisticated analytical tools and frameworks has emerged. This chapter focuses on a small selection of some of the most prominent methodologies that translate macro-ecological limits into actionable business and investment metrics. By moving beyond backward-looking ESG scores, these frameworks provide a forward-looking blueprint for unlocking long-term portfolio growth, driving alpha, and ensuring value creation and improved operational resilience in an era of increasing Earth system instability.

[66] "From Insight to Implementation: Building Water Resilient Operations", Schneider Electric (2025).
[67] "Nature generates $44 trillion for the global economy", World Economic Forum (2023).
[68] "Can Carney's example prod corporates to talk about climate action again?", Reuters (2026).

Case study 14. L'Oréal anchoring 2030 targets to planetary boundaries[69]

Rather than setting arbitrary, incremental sustainability goals, L'Oréal launched its "L'Oréal for the Future" strategy by explicitly anchoring its 2030 targets to planetary boundaries science. Using an internal Sustainable Product Optimisation Tool (SPOT), the company transformed its approach from measuring purely direct operational impacts to addressing the extended footprint of its value chain.

For example, to actively respect the Freshwater Change and Land-System Change boundaries, the company established hard strategic limits: Committing that by 2030, 100% of the water used in its industrial processes will be recycled and reused in a loop, and 100% of its biobased ingredients will be traceable and completely free of deforestation links.

By aligning its corporate strategy directly with Earth system limits in this way, L'Oréal is decoupling its financial growth from ecological degradation. This scientific approach has yielded profound metrics: By the end of 2021, L'Oréal successfully reduced the absolute CO_2 emissions of its plants and distribution centres by 87% compared to a 2005 baseline, while simultaneously increasing its production volume by 37%.

Case study 15. Kering monetising nature via Environmental Profit & Loss[70]

The luxury fashion group Kering pioneered the Environmental Profit & Loss (EP&L) methodology to integrate planetary boundaries directly into financial decision-making.

Recognising that standard supply chain metrics obscured true ecological risks, the EP&L measures the company's environmental footprint across its entire value chain, from Tier 1 manufacturing down to Tier 4 raw material extraction. It uniquely translates impacts on GHGs, water consumption, land use, and pollution into a monetary value.

By assigning a financial cost to ecological degradation, the EP&L provided Kering's management with a clear, asset-based view of where planetary boundary risks threaten future profitability. This allowed the business to proactively redirect sourcing, successfully achieving its ambitious target of reducing its EP&L intensity by 40% (relative to revenue) against a 2015 baseline by 2021. Achieving this milestone four years early cemented Kering's status as a market leader, earning the company a Triple-A ESG rating from CDP. Emboldened by this progress, management augmented its ambitions, transitioning from relative intensity metrics to a much stricter 40% absolute emissions reduction target by 2035.

[69] "L'Oréal for the Future", L'Oréal website (2026); L'Oréal Climate Report (2021); Baringa analysis.

[70] "Environmental Profit & Loss – 2021 Group Results, Kering (2021); "Kering Sustainability", The Sustainable Innovation (2026); Baringa analysis.

Case study 16. SSEN Transmission's pioneering planetary boundary assessment[71]

Recognising the need to measure their operational footprint against leading science, and acknowledging their vital role in enabling the UK's transition to Net Zero, SSEN Transmission (part of FTSE-100 listed SSE plc) has committed to assessing its impacts on planetary boundaries by 2030. The company is planning to establish an academic partnership with planetary boundary experts in 2026 to quantify its specific allocation of a planetary boundaries budget. This work will underpin SSEN Transmission's efforts in quantifying their impact on planetary boundaries, and wider activities to stay within safe limits.

By pioneering this assessment, the company will be among the first businesses globally to measure their performance against an academic framework explicitly designed and tailored to a company's specific business activities. This approach will provide access to data that allows for more informed and targeted decisions regarding sustainability actions, based on both global and local impacts.

In alignment with timelines for its next regulatory cycle beginning in 2031, SSEN Transmission plans to publish its performance by 2029 and develop a comprehensive management plan by 2030, making a significant contribution to scientific knowledge in sustainable business.

High-voltage power lines in East Lothian, Scotland

[71] "Sustainability Action Plan 2024-2031", SSEN Transmission (2024); Baringa analysis.

6.2 Frameworks for Earth systems alignment

Prominent frameworks now translate macro-ecological limits into actionable investment metrics, enabling precise, science-based portfolio construction and risk management.

For corporates and investors seeking to operationalise planetary boundary science, the following example frameworks and methodologies provide highly useful guidance. Each is assessed against its core function, data requirements, coverage, and analytical outputs.

For clarity, the examples reviewed below include both public frameworks and proprietary approaches. These represent only a selection from a growing array of frameworks, datasets, tools, and methodologies developed by academics and practitioners.

As such, these frameworks are not presented as equivalent products, nor as an exhaustive universe of available tools. Rather, they demonstrate the expanding range of approaches being used to translate planetary-boundary science into corporate, investment, and portfolio decision-making. In particular, the EEIV / ESI tool (Figure 27) and the NGFS scenarios (Figure 29) contain publicly accessible datasets that investors and corporates can use freely.

Figure 27. Public Framework: Essential Environmental Impact Variables (EEIV) & Earth System Impact (ESI) Score[72]

EEIV / ESI score	Stockholm Resilience Centre · Stockholm University
High-level description	A dual framework that helps assess a firm's exposure to planetary boundaries and compare the calculated exposure to the wider market / other firms operating in the same sector • EEIVs provide standardised raw data metrics (e.g. GHG emissions, cubic meters of water used, etc.) • The ESI score provides the translation mechanism (weighting and combining the EEIVs against the Earth's carrying capacity into a single score)
Data requirements	Requires collection of detailed corporate and product-level Life Cycle Assessment (LCA) data, tracking resource inputs, land use footprints, and specific pollutant emissions across the value chain
Assessment coverage	☑ Location-specific ☑ Sector- and asset-based ☒ Time-dependent Excels at asset-based and sector-specific assessment: By utilising LCA data, they isolate the exact environmental intensity of specific production facilities or product lines
Coverage of planetary boundaries	Comprehensive coverage, by specifically quantifying impacts on **Climate Change**, **Freshwater Change**, **Land-System Change**, **Biogeochemical Flows**, and **Novel Entities**
Benefits to corporates and investors	The primary benefit is comparability: By converting disparate environmental metrics into a unified ESI score, corporates and asset managers can benchmark the actual ecological intensity of different companies and competitors against absolute scientific limits
Example of generated insights	An investor can use the ESI score to directly compare two agricultural firms. If Firm A scores 1.5 for Freshwater Change (score >1.0 indicates a breach of the safe operating space) and Firm B scores 0.8, the investor can infer that Firm A's supply chain is highly exposed to drought-induced margin compression and regulatory rationing.

***Open-source data available:** EEIV Dataset, accessible via Stockholm University Library Dataverse; ESI Application Dataset, accessible via Stockholm University Library Dataverse; ESI Prototype Tool via Royal Swedish Academy of Sciences

[72] "Essential environmental impact variables: A means for transparent corporate sustainability reporting aligned with planetary boundaries", Wassenius et al, ScienceDirect (2024); "Going beyond carbon: An "Earth system impact" score to better capture corporate and investment impacts on the earth system", Croana et al, ScienceDirect (2023); "A prototype Earth system impact metric that accounts for cross-scale interactions", Lade et al., IOPscience (2021); Baringa analysis.

Figure 28. Public Framework: Planetary Boundaries Investment Framework[73]

Planetary Boundaries Investment Framework	Stockholm Resilience Centre | Stockholm University
High-level description	An investment framework developed by a large Asset Manager in collaboration with the Stockholm Resilience Centre, which translates the macro-level planetary boundaries into an operational investment universe by mapping environmental limits across more than 100 distinct sub-industries
Data requirements	Requires granular revenue segmentation data, life-cycle analysis of corporate activities, and supply chain tracing to determine a company's "economic intensity" relative to environmental limits
Assessment coverage	☒ Location-specific ☑ Sector- and asset-based ☒ Time-dependent Highly sector-based: It explicitly acknowledges that different sub-industries have vastly different impact and financial materialities, tailoring the boundary limits to the specific economic activity being assessed
Coverage of planetary boundaries	A holistic framework that explicitly **covers all nine planetary boundaries** to ensure that investments do not solve one environmental issue at the expense of another
Benefits to corporates and investors	It provides a systematic, scientifically validated screening tool. Investors can distinguish companies driving critical boundary transgressions from those that are aligned with safe operating spaces – this distinction supports allocation strategies, investment decision-making, and portfolio operations.
Example of generated insights	The framework flags the "traditional meat processing" sub-industry as fundamentally breaching the Biogeochemical Flows boundary. An investor can use this insight to adjust its allocation to traditional meatpackers and allocate more capital to "alternative protein" sub-industries operating safely within the boundary.

Figure 29. Public Framework: NGFS (Network for Greening the Financial System) scenarios[74]

NGFS (Network for Greening the Financial System) scenarios	NGFS
High-level description	While the NGFS is a network of central banks and supervisors, its scenarios act as the de facto standard and operational tool for the entire financial sector to model climate and nature risks
Data requirements	Utilises complex macroeconomic variables, carbon pricing forecasts, and GDP impact models under various warming and nature-loss pathways
Assessment coverage	☑ Location-specific ☒ Sector- and asset-based ☑ Time-dependent Highly location-specific and time-dependent: The scenarios demand that financial institutions project physical and transition risks across different geographies and specific time horizons (e.g. 2030 vs. 2050)
Coverage of planetary boundaries	Originally focused exclusively on **Climate Change**, the NGFS framework is rapidly expanding to incorporate nature-related financial risks, including **Land-System Change** and **Biosphere Integrity**
Benefits to corporates and investors	Using NGFS scenarios allows investors to properly value assets with consideration of three critical impacts: Valuation Impact (standardised scenario modelling), Supervisory Trickle-Down (preparing for inevitable regulatory compliance), and Credit Repricing
Example of generated insights	Applying the NGFS "Delayed Transition" scenario reveals that 30% of e.g. a real estate portfolio's value is at risk of becoming a stranded asset by 2035 due to sudden carbon pricing. Investors can use this to consider their allocation to these highly exposed, un-retrofitted commercial buildings.

***Open-source data available:** NGFS scenarios datasets, available on NGFS Scenarios Portal; NGFS Phase 5 Scenario Explorer, available at International Institute for Applied Systems Analysis; Climate Impact Explorer, available at Climate Analytics

[73] "Planetary Boundaries: measuring the business world's environmental footprint", Stockholm Resilience Centre, University of Stockholm (2020); Baringa analysis.

[74] NGFS Scenarios Portal, NGFS website (2026); Baringa analysis.

Figure 30. Proprietary Approach: Planetary Boundaries VC Framework[75]

Planetary Boundaries VC Framework	
High-level description	A private equity / venture capital investment and portfolio management framework that explicitly uses planetary boundaries to identify pressing global challenges and structure value-creation strategies
Data requirements	Demands deep-dive impact metrics from portfolio companies, including forward-looking emissions trajectories, resource efficiency ratios, and localised ecosystem impact assessments
Assessment coverage	☑ Location-specific ☒ Sector- and asset-based ☑ Time-dependent Strong on both location and time : The framework leverages highly localised ecological data (e.g. site-specific biodiversity health) while incorporating the "time value of carbon", recognising that near-term emissions reductions are substantially more valuable than distant pledges due to looming tipping points
Coverage of planetary boundaries	While it maps against all nine boundaries, it heavily prioritises action on boundaries currently in critical or high-risk conditions, such as **Biosphere Integrity** and **Biogeochemical Flows**
Benefits to corporates and investors	It enables private market investors to future-proof their portfolios by targeting business models that directly support pushing boundaries back into safe zones, locking in structural growth
Example of generated insights	By calculating the "time value of carbon," a PE or VC firm can determine that investing $10 million in CapEx today to eliminate 50,000 tons of methane preserves more enterprise value than a cheaper pledge to eliminate 100,000 tons by 2040, justifying immediate action over deferred pledges

Figure 31. Proprietary Approach: Portfolio Composition Framework[76]

Portfolio Composition Framework	
High-level description	A large Investment Manager's approach to categorising equities for a sustainable economy, providing practical guidance for portfolio construction
Data requirements	Demands fundamental financial analysis combined with forward-looking assessments of product pipelines, R&D expenditure, and capital expenditure alignment with transition pathways
Assessment coverage	☒ Location-specific ☑ Sector- and asset-based ☑ Time-dependent Strong on both sector-based and time-dependent factors: Evaluates how rapidly a company can scale its technology or pivot its heavy industrial assets before systemic pain points are reached
Coverage of planetary boundaries	Focuses intensely on **Climate Change**, resource efficiency (**Novel Entities** and **Biogeochemical Flows**), and the broader bioeconomy (**Biosphere Integrity**)
Benefits to corporates and investors	It allows investors to capture green alpha by balancing the portfolio between two distinct profiles: Solution Providers (innovators supplying the direct technologies needed to fix boundaries) and Transition Leaders (incumbents rapidly decarbonising)
Example of generated insights	The framework identifies if e.g. a legacy steel manufacturer is a "Transition Leader" rather than a liability, because 80% of its current R&D is dedicated to green hydrogen furnaces. This allows investors to stay invested during the more carbon-heavy current phase to capture the upside of the transition down the line.

[75] Baringa analysis of a specialist VC firm's Planetary Boundaries framework.

[76] Baringa analysis of a large Investment Manager's planetary-boundaries-aligned portfolio composition framework.

The frameworks and tools reviewed above should not be viewed as belonging to a single category or serving the same purpose. They differ significantly in their objectives, methodological approaches, geographic and sector coverage, data requirements, and intended users. As a result, some frameworks are better suited to particular sectors, asset classes, or decision-making contexts than others.

For example, scenario-based tools such as the NGFS scenarios are designed primarily to explore macroeconomic transition pathways and climate-related risks across economies and sectors over time. They can be particularly useful for banks, insurers, and diversified investors seeking to understand portfolio-level transition exposures, but they are generally less suited to assessing site-specific environmental pressures or local ecological thresholds. By contrast, frameworks such as the Planetary Boundaries Investment Framework seek to translate global planetary-boundary limits into sector-relevant performance expectations, making them more useful for evaluating whether activities in sectors such as energy, agriculture, chemicals, or materials are aligned with Earth system constraints.

Similarly, public datasets and assessment tools such as the EEIV / ESI work can help investors and corporates identify environmental impacts and dependencies across value chains, benchmark exposures, and improve comparability and transparency. These approaches may be particularly valuable for sectors with complex supply chains and significant nature-related impacts, such as food production, forestry, mining, consumer goods, and manufacturing. However, they may provide less insight into future technology deployment pathways or strategic transition opportunities than scenario-based approaches.

Alongside these public resources, proprietary practitioner methodologies (examples shown in Figure 30 and Figure 31) demonstrate how planetary-boundary concepts are increasingly being adapted for specific investment contexts. Venture capital and growth-equity investors, for example, may use approaches that assess the time value of emissions reductions or resource-efficiency gains aligned to their investment cycle, helping identify technologies capable of delivering disproportionate environmental benefits before planetary-boundary pressures intensify. Infrastructure and private equity investors may instead focus on asset-level transition readiness, technology scalability, or the ability of firms to pivot business models before systemic environmental risks materialise. In sectors such as renewable energy, circular economy technologies, or industrial decarbonisation, these approaches may provide insights that are not captured by broader portfolio-level frameworks.

The diversity of available approaches reflects the fact that planetary-boundary assessment is inherently multi-dimensional. Some frameworks are designed to assess environmental impacts, others to evaluate dependencies, transition pathways, physical risks, or investment opportunities. Some operate at the level of individual assets or locations, while others focus on sectors, portfolios, or entire economies. Consequently, the appropriate choice of tool, or combination of tools, will depend on the objective, asset class, sector exposure, geographic footprint, data availability, and desired level of analytical precision.

7 The critical role of investors

7.1 The opportunity for investors

By deploying a multi-faceted approach to portfolio management and capital allocation, investors can actively mitigate risks, unlock growth opportunities, and drive the macro-level shifts required to operate safely within planetary boundaries.

The financial imperative for addressing Earth system change has never been clearer. As established in earlier chapters, the deterioration of planetary boundaries places at least $58 trillion of global economic value generation, equivalent to over 50% of the world's GDP, at severe risk from physical and operational shocks. Conversely, the transition to a sustainable, Earth-systems-aligned global economy represents an unparalleled value creation opportunity. The World Economic Forum estimates that Earth-systems-aligned models could generate over $10 trillion in annual business value and create 395 million new jobs by 2030. Within this macro landscape, specific sectors possess massive growth potential, including a $4.5 trillion opportunity in the circular economy by 2030 and a projected $1.3 trillion market for green building materials by the early 2030s. However, systemic market failures, such as missing markets for natural capital, chronic information asymmetry, and the failure to price in externalities, mean these risks and opportunities remain heavily obscured in traditional financial models. The challenge is further enhanced by recent macroeconomic and geopolitical volatility, which channel policy attention and financial flows more towards short-term stabilisation, diverting resources and effort away from the longer-term systemic issues that bear the risk of causing irreparable damage to people, planet, and businesses, thus undermining the functioning of markets and economic activity.

Despite the market imperfections and acute challenges posed by planetary boundary deteriorations, investors are in a unique position to navigate these complexities, and even catalyse collaborative action that supports the long-term stability and viability of global markets. Firstly, they provide the necessary funding required for innovation, transition and adaptation technologies, shifting capital away from extractive models and directly into planetary boundary solutions. Secondly, investors offer crucial capacity-building and strategic support for portfolio companies, enabling them to build operational resilience and execute complex, science-based transition plans. Thirdly, institutional investors possess the leverage and influence to inform policy decision-making through constructive engagement, e.g. by actively advocating for the regulatory clarity required to eliminate time horizon misalignments. Finally, large asset managers and asset owners can lead the way for the broader market via collaborative action, market signalling, and thought leadership: By adopting and adapting new frameworks, setting out and collecting improved sets of data, and supporting techno-economic research, investors are able to directly combat information asymmetry, providing the financial ecosystem with the tools needed to accurately value natural capital and price systemic environmental risk.

Capitalising on the Earth-system-driven macro transition requires investors to adopt a multi-faceted approach and circumvent misconceptions and pitfalls, as the previous chapters in this report have shown. We can translate this into four **principal planetary boundary considerations for investors**.

A. **Planetary boundary implications and risks (chapter 3):** Investors need to understand how planetary boundary risks differ across locations, asset/sector levels, and time horizons to properly assess idiosyncratic and systemic risks.

! **Pitfall:** Assuming boundaries manifest uniformly across markets and expecting that markets will self-correct without targeted coordination.

B. **Regulation and policy (chapter 4):** Investors need to work with portfolio companies to translate these exposures into effective disclosures that meet the highest necessary standards for regulatory obligations – in addition to supporting portfolio companies with their regulatory disclosures, investors need to also exercise diligence for their own reporting responsibilities (e.g. SFDR/SDR).

! **Pitfall:** Treating regulator obligations purely as a compliance box-ticking exercise and waiting for policymaking to lead the way, rather than using frameworks for strategic shaping and improved insights generation.

C. **Opportunities for value creation (chapter 5):** Investors need to understand how Earth system changes and planetary boundary deteriorations are reshaping market demand in order to unlock growth, build resilience, and secure favourable funding arrangements.

! **Pitfall:** Assuming BAU operations and decision-making will resolve challenges or deliver strong long-term commercial outcomes in an increasingly volatile ecological climate.

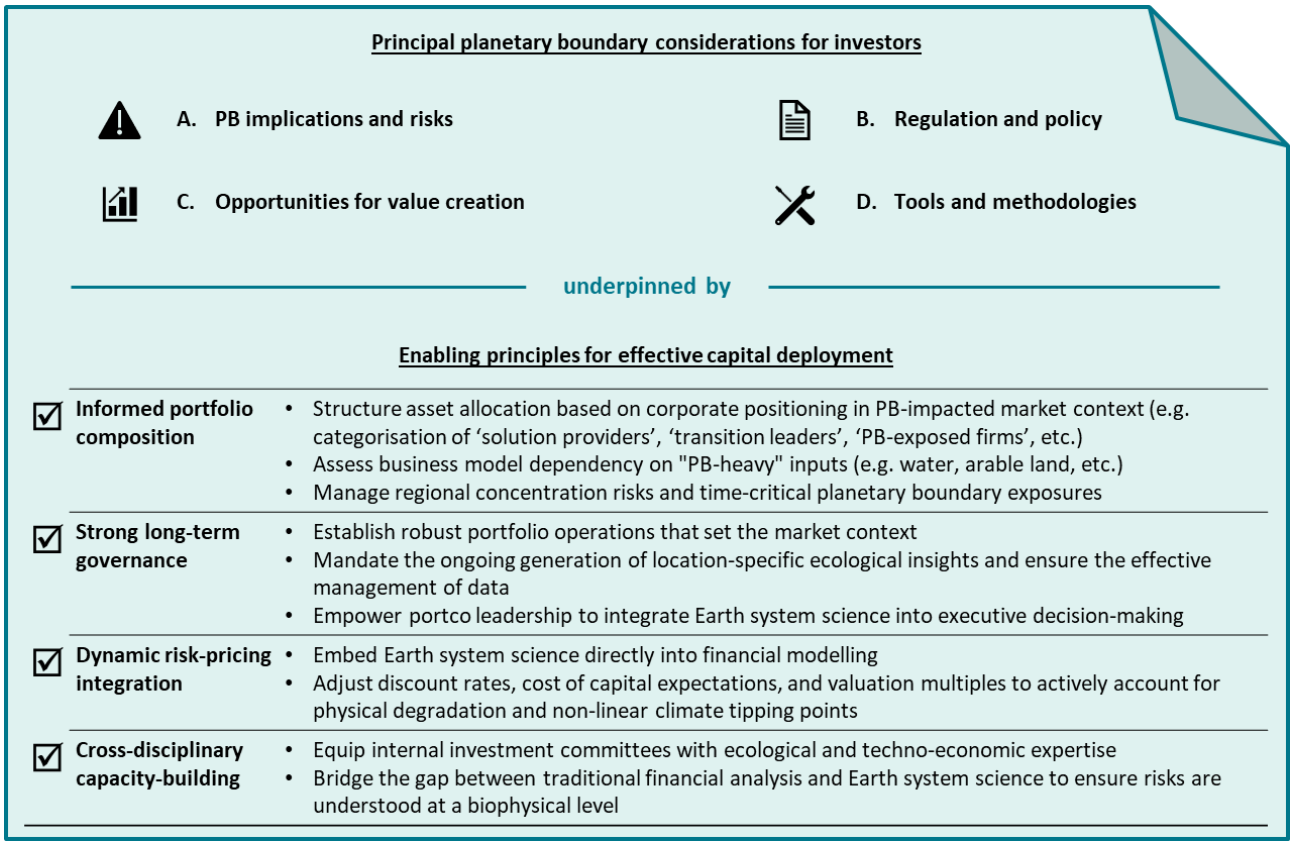
D. **Tools and methodologies (chapter 6):** Investors should leverage new tools to better understand planetary boundary exposures, enhance analytical capabilities, and improve informed decision-making.

! **Pitfall:** Relying on broad catch-all metrics that fail to assess location-specific, asset-based, or time-dependent tipping points, especially in light of oftentimes lagging regulation and market reactions to changing conditions.

Executing the above effectively is likely to be insufficient without the structural foundation provided by several **enabling principles for effective capital deployment**. By pairing a granular, science-based understanding of planetary boundaries with informed portfolio composition characteristics, strong long-term governance, dynamic risk-pricing integration, and cross-disciplinary capacity-building and expertise, investors can systematically decode complex Earth system risks and opportunities, and generate resilience value for their (co-)investors and portfolio companies.

Thus, combining the principal planetary boundary considerations with enabling principles can help ensure that capital deployment is protected against ecological shocks and positioned to capture the substantial transitional value at play.

Figure 32. Framework for effective planetary-boundaries-aligned capital deployment[77]



[77] Baringa analysis.

7.2 Investor engagement plan

Systemic ecological challenges cannot be solved in isolation. Realising the massive upside of the planetary transition requires investors to move beyond individual actions and drive systemic collaboration across the entire stakeholder ecosystem.

To maximise the impact investors can have on Earth-systems-aligned value creation, they need to tap into the wider ecosystem to drive meaningful systemic collaboration, identify emerging opportunities, and remove critical roadblocks. This extends beyond the portfolio-level considerations and principles outlined in chapter 7.1, as it requires broader coordination across systems and stakeholder groups. Ultimately, the effects of planetary boundary deterioration on the planet, people, and markets are too complex, deeply intertwined, and wide-ranging to be solved by single actors, no matter how determined, effective, or influential they may be.

Ensuring long-term economic growth and prosperity is fundamentally inconceivable without the resilience and health of the Earth ecosystems that underpin so much of the value the global economic system creates for market actors and communities. Addressing this requires systems change at a substantial, macroeconomic scale, which can only be achieved through highly effective, cross-disciplinary collaboration and strategic engagement with a number of different key stakeholders groups across the global value chain.

Figure 33. Stakeholder engagement challenges, desired outcomes, and investor actions[78]

Stakeholder groups	Key challenges	Desired outcomes	Investor actions
Portfolio companies	Achieving improved company- and industry-level understanding of key exposures and opportunities without excessive red/green tape	A transparent level playing field where accurate, sector-specific disclosures enable efficient risk pricing and improved systemic decision-making	1. Mandate that portcos integrate PB dependencies into core risk management and scenario planning 2. Support corporates in investing in predictive modelling and geospatial capabilities required for site-specific assessment 3. Engage with management to break disclosure disincentives and encourage proactive reporting on Earth system impacts
Other investors and co-investors	Fragmented market signals and limited demand feeding a substantial financing gap between nature-negative ($5tn) and nature-positive ($200bn) investments	A strengthened 'PB-aware' investor voice that mobilises and pools capital at scale and demands global best-practice for effective Earth system risk management	1. Pool capital and market influence with peers to drive large-scale funding mobilisation for green and transition tech 2. Join collaborative platforms like NZAM or the Deforestation Investor Group to establish unified market expectations 3. Drive joint standards to rebalance portfolio ratios away from nature-negative activities and towards restorative solutions
Policymakers and regulators	Misaligned economic incentives and persistent market failures, underpinned by $1.7 trillion in annual 'planetary-boundary-negative' public subsidies	Coherent industrial strategies and regulations that internalise externalities and align financial timelines with Earth system stability	1. Advocate for sector-specific and place-based PB policies that are aligned with national nature and climate commitments 2. Push for economic disincentives on harmful subsidies that undermine the transition to a nature-positive economy 3. Engage to eliminate time-horizon discrepancies in financial reporting that prevent accurate valuation of natural capital
NGOs, Academia, Local Communities	Significant gaps in science-based reporting and a lack of on-the-ground operational context for location-, site-, and time-specific risk assessments	Rigorous, science-based targets and regenerative value chains that respect human rights and local ecological dependencies	1. Leverage academic frameworks and Earth system science to establish precise, quantitative, science-based targets 2. Partner with NGOs and local stewards to obtain bottom-up data needs for accurate local exposure assessments 3. Ensure supply chain transition plans are socially inclusive, respecting human rights and local ecosystem stewardship

[78] Baringa analysis.

Concluding remarks: The return to a safe operating space

The transgression of planetary boundaries represents an existential threat to the stability of the Earth system and, by extension, the global economy. As this report has detailed, the compounding risks of climate change, biosphere loss, freshwater scarcity, and chemical pollution, to name a few, threaten to strand assets, shatter supply chains, and erase trillions of dollars in market value. Business as usual is no longer a viable financial strategy; the assumption that markets will organically self-correct without systemic, coordinated intervention is a critical fallacy.

However, while the scale of the challenge is unprecedented, it is not insurmountable. History has proven that when unequivocal scientific consensus meets decisive global policy, targeted industry innovation and realistic action plans, the trajectory of Earth's systems can be fundamentally corrected. The 1987 Montreal Protocol stands as the ultimate testament to this, successfully phasing out ozone-depleting substances and placing the Stratospheric Ozone boundary on a path to full recovery through united international and industrial action.

Equipped with a rigorous understanding of how Earth systems interact across specific geographies, sectors, and time horizons, forward-thinking corporates and investors possess the tools required to reap the rewards of substantial value creation opportunities the transition creates. By moving beyond reactive compliance, breaking the deadlock of disclosure disincentives, and actively directing capital towards planetary solutions, the investment sector can support more resilient long-term outcomes and better-informed capital allocation through successfully governing Earth's return to a safe operating space.

8 Appendix

8.1 Glossary

Term	Definition
Anthropocene	The proposed current geological epoch, frequently described as the end of the stable Holocene and the beginning of a new, likely less stable planetary state driven by human activity.
Atmospheric Aerosol Loading	One of the nine planetary boundaries. It refers to the concentration of microscopic particles, such as soot, dust, and sulphates, suspended in the air that affect both regional climate patterns and human health.
Biogeochemical Flows	One of the nine planetary boundaries. It refers to the disruption of global nutrient cycles, particularly Nitrogen (N) and Phosphorus (P), which often leads to severe aquatic dead zones.
Biosphere Integrity	One of the nine planetary boundaries, encompassing the biological diversity and ecosystem functions on Earth that regulate the cycles of nutrients, energy, and chemicals.
Blended Finance Vehicles	Public-private investment structures that use concessional or philanthropic capital to absorb initial risk and attract commercial funding in complex, often not (yet) fully developed markets.
Climate Change	One of the nine planetary boundaries. It measures the concentration of greenhouse gases in the Earth's atmosphere and the resulting radiative forcing, which drives global warming and systemic environmental shifts.
Corporate Sustainability Due Diligence Directive (CSDDD)	European Union legislation mandating active due diligence for human rights and environmental impacts across companies' value chains, translating supply chain tracing into a legal liability mechanism.
Corporate Sustainability Reporting Directive (CSRD)	European Union legislation aimed at standardising corporate sustainability reporting across the EU market. It introduces a dedicated sustainability statement detailing the double materiality of ESG impacts, risks, and opportunities.
Double Materiality	An assessment framework that evaluates two distinct dimensions of sustainability risk: *financial materiality* (how environmental degradation threatens enterprise value) and *impact materiality* (how a company's operations physically impact the planet).
Earth System Impact (ESI) Score	A quantitative framework, developed by the Stockholm Resilience Centre, which translates complex, disparate corporate environmental metrics (such as Life Cycle Assessment data) into a single score benchmarked against the absolute carrying capacity of the Earth.
European Sustainability Reporting Standards (ESRS)	The foundational blueprint and reporting standards that companies must use to comply with the EU's Corporate Sustainability Reporting Directive (CSRD).
Eutrophication	A process caused by nutrient runoff (such as excessive fertiliser use), leading to algal blooms and decreased oxygen levels in aquatic ecosystems that result in dead zones and biosphere degradation.
Financial Materiality	The 'inward-looking' baseline of sustainability reporting, focusing strictly on how sustainability and climate-related issues affect a company's enterprise value, cash flows, and access to capital.
Freshwater Change	One of the nine planetary boundaries. It measures human-induced alterations to the surface and groundwater systems that support life, tracking both 'blue water' (streamflow) and 'green water' (root zone soil moisture).
Global Reporting Initiative (GRI)	The de-facto global standard framework for impact reporting, focusing on a company's outward impact on the economy, environment, and people.
Green & Blue Bonds	Fixed-income instruments where capital is strictly ring-fenced for projects that directly mitigate boundary breaches, such as water infrastructure or marine conservation.

Holocene	The interglacial geological epoch of the last ~12,000 years. The Planetary boundaries framework uses this exceptionally stable environmental state as the baseline for humanity's 'safe operating space'.
Impact Materiality	The "outward-looking" assessment of how a specific sector or company drives planetary boundary transgressions and contributes to environmental problems.
Intergovernmental Panel on Climate Change (IPCC)	The authoritative scientific body responsible for assessing climate change. Its 'Shared Socioeconomic Pathways' (SSPs) are widely utilised for future climate scenario modelling.
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)	An intergovernmental body that provides scientific assessments on the state of global biodiversity, its ecosystems, and the 'drivers of nature change'.
International Sustainability Standards Board (ISSB)	A standard-setting body (responsible for IFRS S1 and S2) established to deliver a comprehensive global baseline for financial sustainability disclosures, focused on single financial materiality.
Land-System Change	One of the nine planetary boundaries. It tracks human transformation of natural ecosystems, such as forests and grasslands, into land designated for agriculture and urbanisation.
Network for Greening the Financial System (NGFS)	A network of central banks and supervisors whose macro-prudential scenarios act as the de facto standard for the financial sector to model physical and transition climate and nature risks.
Novel Entities	One of the nine planetary boundaries. It refers to the introduction of geologically new substances, such as synthetic chemicals, PFAS, plastics, and modified organisms, into the Earth's system.
Ocean Acidification	One of the nine planetary boundaries. It refers to the reduction in ocean pH levels caused by the absorption of excess atmospheric carbon dioxide into seawater, which threatens marine ecosystems and calcifying organisms.
Parametric Catastrophe Bonds	Debt instruments that pay out automatically to provide immediate liquidity when predefined biophysical or environmental thresholds (e.g. hurricane wind speed or regional drought levels) are crossed.
Planetary Boundaries Framework	A science-based framework introduced in 2009 by the Stockholm Resilience Centre that identifies nine critical Earth system processes and defines quantitative thresholds regulating the stability and resilience of the planet.
Safe Operating Space	The scientifically defined limits within the Planetary boundaries framework where humanity can continue to develop with a low risk of triggering systemic, non-linear environmental feedback.
Science Based Targets Network (SBTN)	A framework providing methodologies for companies to set measurable, actionable, and time-bound physical targets that align with Earth's safe operating spaces.
Stranded Assets	Investments, infrastructure, or property that suffer from sudden devaluation or become unusable liabilities due to physical ecological shocks, uninsurable zones, or rapid regulatory shifts.
Stratospheric Ozone Depletion	One of the nine planetary boundaries. It tracks the thinning of the protective ozone layer in the upper atmosphere that shields the Earth from harmful ultraviolet radiation.
Sustainability-Linked Bond (SLB)	A general corporate purpose debt instrument where the cost of debt (coupon rate) is tied directly to the achievement of overarching, predefined sustainability targets.
Taskforce on Nature-related Financial Disclosures (TNFD)	A global framework aimed at shifting financial flows toward nature-positive outcomes, guiding companies to disclose dependencies and impacts using the LEAP (Locate, Evaluate, Assess, Prepare) approach.
Tipping Point	A critical threshold within our planetary system where a relatively small change in external conditions triggers a large, non-linear, and often irreversible structural shift in the system (e.g., the collapse of warm-water coral reefs).

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8.3 Planetary boundary interdependencies

Boundary	High interconnectivity	Medium interconnectivity	Low interconnectivity
Climate Change	• **Biosphere Integrity:** Rising temperatures and shifting weather patterns lead to habitat loss and extinction events. • **Land-System Change:** Climate stress, such as increased wildfires and drought, accelerates deforestation and land degradation. • **Freshwater Change:** Altered precipitation patterns significantly disrupt the global water cycle. • **Ocean Acidification:** Increased atmospheric CO_2 levels directly drive higher CO_2 absorption by oceans.	• **Freshwater Change:** Melting glaciers and changing precipitation affect freshwater availability. • **Biosphere Integrity:** Extreme events lead to the salinization of freshwater ecosystems.	• **Biogeochemical Flows:** Extreme precipitation increases agricultural runoff. • **Atmospheric Aerosol Loading:** Droughts increase dust formation. • **Stratospheric Ozone Depletion:** Lower stratospheric temperatures slow ozone-depleting reactions. • **Novel Entities:** Higher temperatures increase the volatility of chemical pollutants.
Biosphere Integrity	• **Land-System Change:** Degraded ecosystems increase the vulnerability of forests to shocks and pests.	• **Climate Change:** Reduced biodiversity limits the ocean's capacity for CO_2 uptake and eutrophication can increase methane emissions. • **Freshwater Change:** Loss of ecosystem functions reduces the regulation of the hydrological cycle.	• **Biogeochemical Flows:** Biodiversity loss alters nutrient cycles. • **Ocean Acidification:** Decline in reefs exacerbates acidification. • **Novel Entities:** Reduced ecosystem capacity to degrade and assimilate pollutants.
Land-System Change	• **Climate Change:** Deforestation reduces carbon sinks and alters surface albedo (radiative forcing). • **Biosphere Integrity:** Habitat loss and fragmentation reduce genetic diversity.	• **Freshwater Change:** Deforestation reduces evapotranspiration, drying the atmosphere, and land change increases river discharge. • **Atmospheric Aerosol Loading:** Forest fires from land clearing emit large amounts of aerosols.	• **Biosphere Integrity:** Forest loss decreases water quality and species diversity
Freshwater Change	• **Land-System Change:** Reduction of soil moisture ("green water") leads to desertification and land degradation.		• **Biosphere Integrity:** Changes in streamflow cause habitat destruction and salinization. • **Climate Change:** Surface water and snow/ice changes alter earth surface albedo. • **Biogeochemical Flows:** Streamflow changes alter nutrient transport.

Boundary	High interconnectivity	Medium interconnectivity	Low interconnectivity
Biogeochemical Flows		• **Biosphere Integrity:** Runoff leads to algal blooms and dead zones in freshwater. • **Land-System Change:** Excessive fertilizer use leads to soil degradation. • **Freshwater Change:** Runoff degrades freshwater quality. • **Atmospheric Aerosol Loading:** Ammonia from agriculture forms fine particulate matter.	• **Biosphere Integrity:** Soil acidification and ocean hypoxic events degrade ecosystems. • **Stratospheric Ozone Depletion:** Nitrogen fertilizers release N_2O, depleting ozone.
Ocean Acidification		• **Biosphere Integrity:** Degradation of coral reefs collapses marine food webs.	• **Climate Change:** Decreasing pH increases dimethyl sulfide emissions (aerosols) and alters carbonate formation (CO_2 feedback). • **Biogeochemical Flows:** Changes in nitrification and nitrogen fixation. • **Novel Entities:** Acidification alters the behaviour of pollutants like heavy metals
Atmospheric Aerosol Loading		• **Climate Change:** Sulfates reflect sunlight (cooling) while black carbon absorbs it (warming); aerosols also influence cloud formation.	• **Biogeochemical Flows:** Bioaerosols alter nutrient deposition and acid rain acidifies soils. • **Ocean Acidification:** Sulphur compounds in rain increase ocean acidification. • **Stratospheric Ozone Depletion:** Aerosols provide surfaces for chemical reactions that deplete ozone.
Stratospheric Ozone Depletion			• **Climate Change:** Reduced UV absorption increases surface radiation. • **Biosphere Integrity:** Increased UV radiation damages DNA and impairs photosynthesis. • **Atmospheric Aerosol Loading:** UV changes influence aerosol production.
Novel Entities	• **Biosphere Integrity:** Pesticides and heavy metals cause diversity loss. • **Atmospheric Aerosol Loading:** VOCs and persistent pollutants form secondary aerosols.	• **Freshwater Change:** Pharmaceuticals and industrial chemicals contaminate freshwater systems.	• **Biosphere Integrity:** GMOs lead to genetic pollution. • **Ocean Acidification:** Abiotic plastic degradation reduces seawater pH.

8.4 Sectoral double materiality assessments

Impact materiality assessments – all sectors

Earth System	Agriculture & Food	Energy	Construction / Built Environmt.	Manufacturing & Chemicals	Transportation
Climate Change	Methane (livestock) & N_2O (soil); land use change	Combustion of fossil fuels; fugitive methane	Embodied carbon (cement/steel) & operational energy	Industrial heat; process emissions	CO_2 from global fuel combustion
Biosphere Integrity	Primary driver of habitat loss & extinction globally	Site fragmentation; oil spills; tailings impact	Urban sprawl fragments migration corridors	Pollution accumulating in food webs	Invasive species (shipping); noise pollution
Land-System Change	Deforestation for commodities (soy, beef, palm)	Degradation from surface mining & drilling pads	Soil sealing (impermeable surfaces) & sprawl	Industrial site footprint	Road and rail infrastructure bisecting ecosystems
Freshwater Change	70% of global withdrawals; aquifer depletion	Intensive use for cooling, fracking & processing	High local demand stressing municipal grids	Water-intensive processing (textiles/tech)	Minimal consumptive use (excluding canals)
Biogeochemical Flows	N & P runoff causing "Dead Zones" (fertilizers)	NOx emissions depositing nitrogen	Wastewater and sewage mismanagement	Industrial discharge of phosphates and nitrates	NOx emissions from shipping and trucking
Ocean Acidification	Agricultural runoff impacting coastal pH	The primary source of CO_2 driving global acidification	Indirect impact via energy use	Indirect via CO_2 & chemical fallout	Shipping emissions (SOx and CO_2) absorbed by oceans
Atmospheric Aerosol Loading	Ammonia (manure) & biomass burning smoke	SOx, particulate matter, and ash from coal / flaring	Construction dust (PM2.5/PM10) and demolition risk	Factory stack emissions & chemical vapours	Black carbon (soot) from diesel and bunker fuel
Stratospheric Ozone Depletion	Methyl bromide usage (soil fumigant)	Methane interaction (minor); historic ozone-depleting substances	Leaks of synthetic gases (HFCs/CFCs) from cooling & insulation	Production of solvents and refrigerants	High-altitude aviation emissions
Novel Entities	Pesticides, herbicides, microplastics in soil	Tailings toxins, fracking fluids, and oil dispersants	Microplastics in paint and PFAS in materials	Primary producer of plastics, PFAS, synthetics	Tire wear particles as major microplastic source

Key: Low impact: Negligible contribution | High impact: Significant contribution | Moderate impact: Indirect contribution | Critical impact: Primary global driver

Financial materiality assessments – all sectors

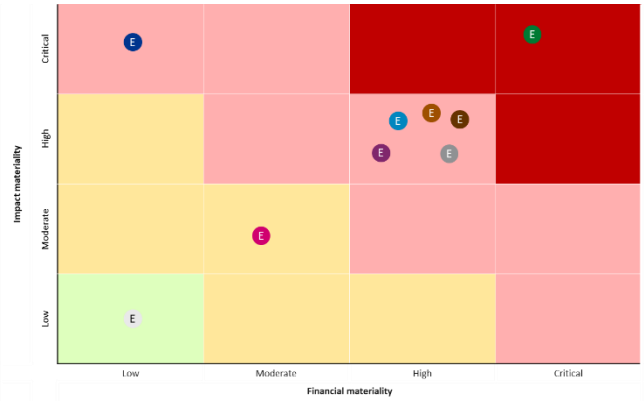
Earth System	Agriculture & Food	Energy	Construction / Built Environmt.	Manufacturing & Chemicals	Transportation
Climate Change	Crop failure; heat stress; shifting arability zones	Transition risk (stranded assets); storm damage	Physical risk to assets; uninsurable zones	Supply chain disruption due to floods and extreme weather; cooling costs	Infrastructure damage; carbon pricing / levies
Biosphere Integrity	Loss of pollinators (yield collapse); soil health	Loss of operating licences; remediation costs	Planning rejections; "Biodiversity Net Gain" laws	Loss of bio-based inputs, especially rubber and fibres	Strict bio-fouling rules affecting shipping costs
Land-System Change	Market access bans (EUDR); certification costs	Rehabilitation liabilities; restricted access to new sites	Land scarcity; strict zoning / planning delays	Raw material price and supply volatility	Cost of re-routing to avoid protected zones
Freshwater Change	Stranded asset risk; irrigation quotas; substantial yield loss	Plant shutdowns due to lack of cooling water; risk of socio-political conflicts	Connection moratoriums halting development	Operational shutdowns (textiles / chip manufacturing & cooling)	Inland shipping halted by low river levels
Biogeochemical Flows	Input costs (fertilizer regulation); pollution fines	Scrubber retrofits; air quality compliance costs	Cost of wastewater treatment upgrades	Strict effluent (wastewater) permits; litigation risks	Emission Control Area fuel costs
Ocean Acidification	Fisheries and Aquaculture collapse	Indirect reputational risks	Coastal erosion threatening property value and functioning of RE insurance market	Minimal direct financial impact	Minimal direct impact
Atmospheric Aerosol Loading	Dimming reducing yields; worker health liability	Shutdown mandates during smog alerts (Asia)	Construction stoppages; health & safety costs	Filtration CapEx; regulatory caps	Low Emission Zone charges and bans
Stratospheric Ozone Depletion	Phase-out of key fumigants	Fugitive emission penalties	Retrofit costs for cooling systems	Production bans on profitable chemicals	Minimal impact
Novel Entities	Litigation risk; bans on inputs	Liability for spills / dams; clean-up costs	"Sick building" liability; material bans	"Toxic tort" litigation risk (PFAS); product bans	Regulations on tires and paint; clean-up levies

Key: Low risk: Minimal financial risk and exposure | High risk: Material cost and compliance risk | Moderate risk: Manageable risk and financial exposure | Critical risk: Existential threat

Energy sector exposure – current state and potential 2050 outcome

In the **current state**, the Energy sector faces elevated double materiality exposure, with the highest number of Earth systems assessed as "high" across impact and financial materiality.

Energy sector DMA – current state

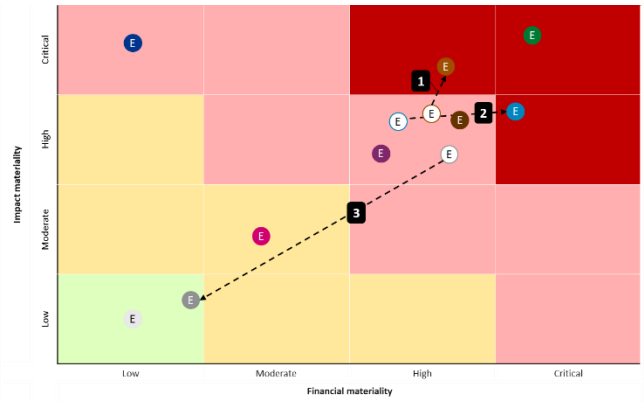


Energy acts as a primary driver (critical impact) for Climate Change and Ocean Acidification, with five other planetary boundaries (Biosphere Integrity, Land-System Change, Freshwater Change, Novel Entities, and Aerosol Loading) ranked as high impact.

The sector's financial exposures are high against 6 / 9 boundaries, emphasising the diverse nature of commercial risks for Energy firms.

In a **2050 base case scenario**, the phase-out of coal and combustion engines drives a major improvement in Aerosol Loading. However, Climate and Freshwater risks are critical due to insufficient decarbonisation and cooling water scarcity.

Energy sector DMA – 2050 base case

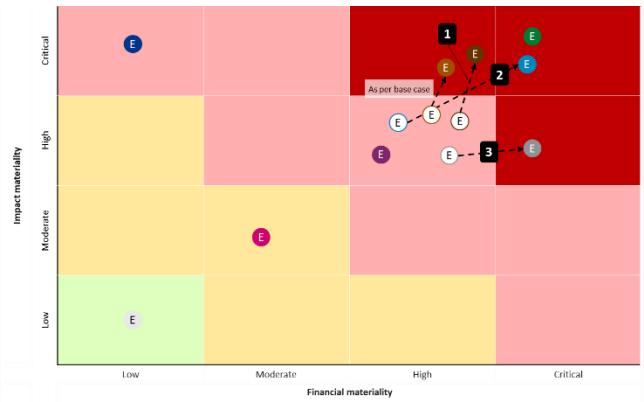


Major materiality movements:

1. Bioenergy demand worsens land status, increasing competition for sites.
2. Global deterioration threatens cooling water availability for thermal and nuclear plants.
3. Global improvements thanks to internal combustion engine and coal phase-outs remove the risk of smog-mandated plant shutdowns.

In the **adverse case scenario**, uncoordinated fragmentation and a resurgence of fossil fuel reliance severely exacerbate physical climate and water risks, while deregulated extraction drives localised ecological collapse and stranded assets.

Energy sector DMA – 2050 adverse case



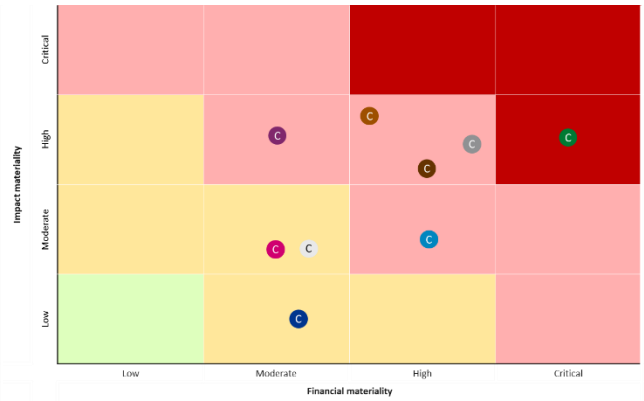
Major materiality movements:

1. Fragmented regulation accelerates resource extraction, driving habitat collapse and loss of op. licenses and severe remediation liabilities.
2. Severe regional water scarcity and extreme heatwaves force widespread, chronic shutdowns of thermal and nuclear cooling systems, crippling baseline generation capacity.
3. Unabated combustion and weak environmental cooperation cause extreme local smog, triggering plant closures and health-related liabilities.

Construction / Built Environment sector exposure – current state and potential 2050 outcomes

In the **current state**, the Construction sector faces dispersed double materiality exposure, with most Earth systems situated in the moderate – high impact and financial materiality buckets.

Construction / Built Environment DMA – current state

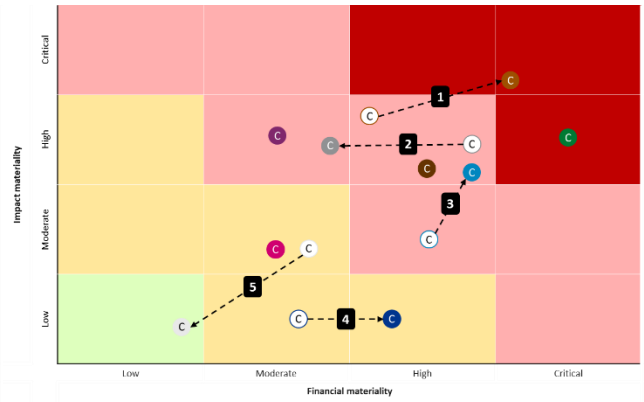


Construction has high impact on 5 / 9 planetary boundaries: Climate Change, Biosphere Integrity, Land-System Change, Atmospheric Aerosol Loading, and Novel Entities.

Physical risks to assets and increasing insurability concerns in highly exposed areas lead to a critical financial materiality for Climate Change, with Aerosol Loading, Biosphere Integrity, Land-System Change, and Freshwater Change posing high financial risks.

In the **2050 base case scenario**, Land-System Change worsens as bioenergy demand competes with urban sprawl, driving up land costs, while coastal real estate exposure increases due to more pronounced storm risks.

Construction / Built Environment DMA – 2050 base case

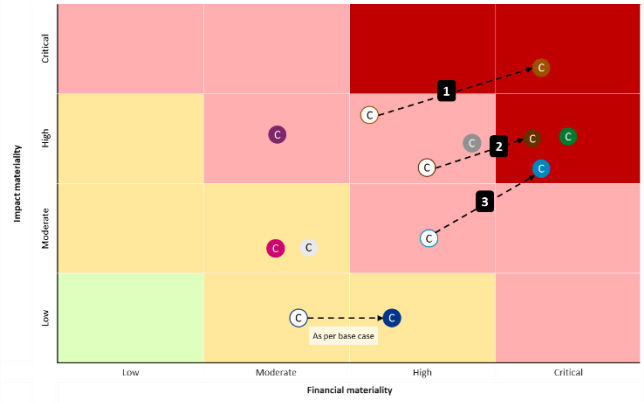


Major materiality movements:

1. Bioenergy and agricultural expansion make land scarcer and costlier.
2. Global improvements reduce the frequency of construction stoppages due to air quality alerts.
3. Pressure on water-intensive cement production.
4. Worsening acidification degrades reefs, increasing storm surge risk for coastal properties.
5. Phase-out of old refrigerants diminishes / removes retrofit costs.

In the **adverse case scenario**, severe physical climate impacts render major real estate uninsurable, while unchecked urban sprawl and water scarcity halt new developments and strand existing assets.

Construction / Built Environment DMA – 2050 adverse case



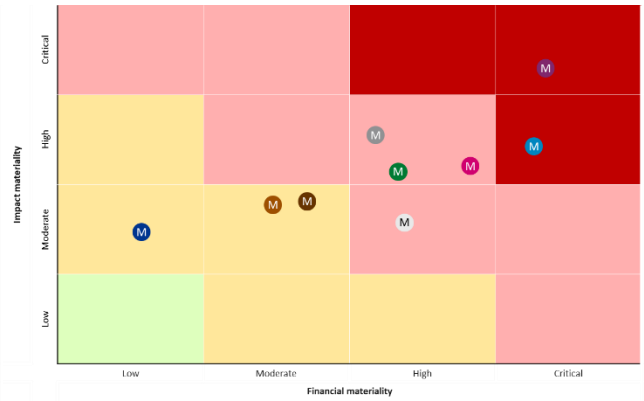
Major materiality movements:

1. Uncoordinated urban sprawl and aggressive land clearing drive severe land scarcity, halting new permits and inflating development costs.
2. Fragmented trade and severe terrestrial ecosystem collapse drastically disrupt supply chains and inflate prices of bio-based building materials.
3. Chronic, severe water scarcity triggers permanent municipal connection moratoriums, stranding new developments and paralysing water-dependent construction sites.

Manufacturing & Chemicals sector exposure – current state and potential 2050 outcomes

In the **current state**, the Manufacturing & Chemicals sector faces high or critical double materiality exposure across several Earth Systems, with Novel Entities and Freshwater Change the most acute areas of concern.

Manufacturing & Chemicals DMA – current state

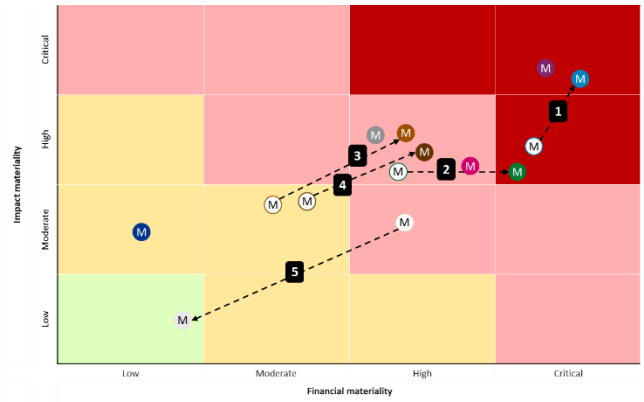


5 / 9 planetary boundaries are highly or critically impacted by Manufacturing & Chemicals: Novel Entities, Freshwater Change, Biogeochemical Flows, Aerosol Loading, and Land-System Change.

Financial materiality exposures are high or critical across six boundaries, with Novel Entities and Freshwater Change posing the largest threat due to the elevated production and release of plastic compounds, and water intensity of operations.

In the **2050 base case scenario**, freshwater deterioration poses a growing threat to operations, while aerosol improvements lower filtration and compliance costs.

Manufacturing & Chemicals DMA – 2050 base case

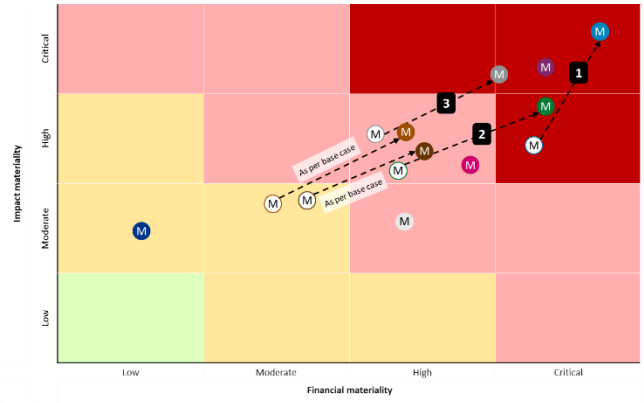


Major materiality movements:

1. Global deterioration makes water access a critical bottleneck for textiles and chips/processors.
2. Further emissions transgression increases physical supply chain shocks via floods and storms.
3. Agricultural expansion competes with industrial raw materials (e.g. timber, rubber).
4. Land use pressures intensify, threatening stability of bio-based supply chains.
5. Chemicals industry has ensured Montreal Protocol compliance on production processes and solvents.

In the **adverse case scenario**, severe physical climate impacts render major real estate uninsurable, while unchecked urban sprawl and water scarcity halt new developments and strand existing assets.

Manufacturing & Chemicals DMA – 2050 adverse case



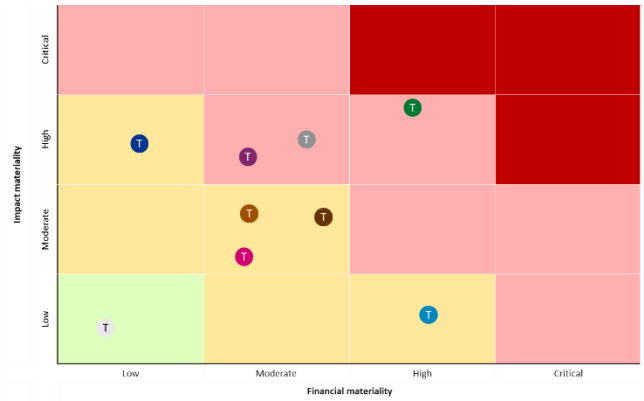
Major materiality movements:

1. Endemic physical water shortages force permanent rationing, halting water-intensive manufacturing outputs (e.g. semi-conductors, textiles).
2. Unpredictable extreme weather regularly disrupts uncoordinated global supply chains, destroying industrial facilities and making just-in-time manufacturing impossible.
3. Deregulated emissions cause severe local air pollution spikes, threatening worker health and prompting operational bans by local municipalities.

Transportation sector exposure – current state and potential 2050 outcomes

In the **current state**, the Transportation sector faces on paper the least material exposures of all five principal sectors assessed, with risks in the moderate bucket for most Earth systems.

Transportation DMA – current state

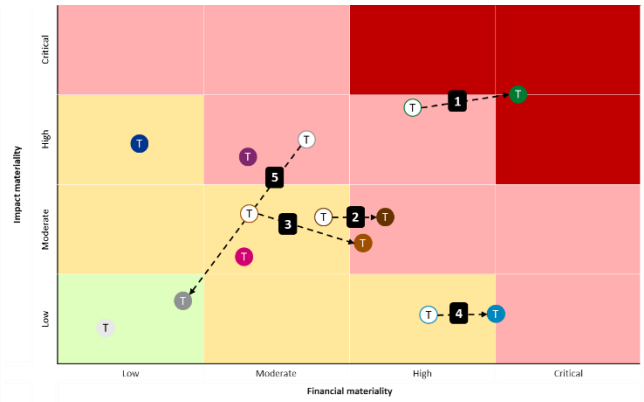


Four planetary boundaries are highly impacted by Transportation: Climate Change, Aerosol Loading, Novel Entities, and Ocean Acidification.

Financial materiality exposures are high for Climate Change and Freshwater Change, given infrastructure damage risks to assets and carbon pricing, as well as inland shipping disruption due to low river/canal levels, respectively.

In the **2050 base case scenario**, the transition to EVs and clean fuels drives a massive improvement in aerosols. However, climate risks (physical infrastructure damage) and Freshwater (river levels) boundaries worsen.

Transportation DMA – 2050 base case

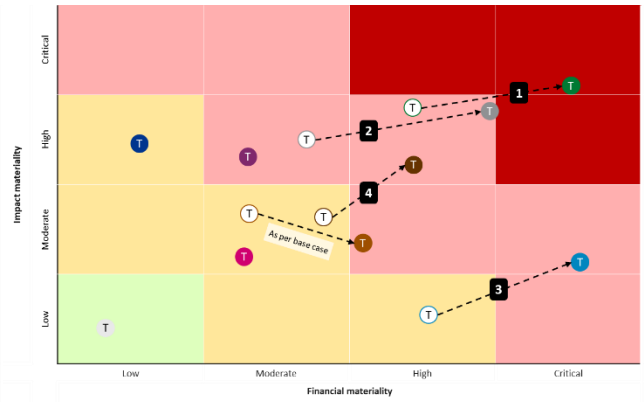


Major materiality movements:

1. Insufficient overall decarbonisation levels cause more frequent port and rail infrastructure damage.
2. Nature deterioration causes strict enforcement on invasive species & noise, raising compliance costs.
3. Worsened status of land systems forces expensive re-routing of infrastructure to avoid degraded or climate-vulnerable zones.
4. Freshwater deterioration increases frequency of low-river levels, disrupting inland freight.
5. EVs transition eliminates black carbon emissions, removing material impact and regulatory costs

In the **adverse case scenario**, accelerating extreme weather and drought structurally break global logistics infrastructure, while reliance on heavily polluting fuels forces draconian urban exclusions.

Transportation DMA – 2050 adverse case



Major materiality movements:

1. Accelerating global warming causes structural damage to exposed critical logistics infrastructure, severing global supply chains.
2. Persistent reliance on heavy diesel and bunker fuels exacerbates smog, triggering sudden LEZ bans and fleet exclusions across major megacities.
3. Prolonged droughts lead to permanent drying of inland waterways, paralysing key shipping routes.
4. Fragmented shipping networks exacerbate marine pollution and invasive species transfers, prompting aggressive regional penalties and access bans.

8.5 Regulatory factsheets

Global standards

TNFD (Taskforce on Nature-Related Financial Disclosures)	Overall status: Live Live since September 2023
High-level description	• Overall aim: Shift global financial flows toward nature-positive outcomes • Scope of disclosures: Covers direct operations + upstream and downstream value chain • Evolution: Modelled in alignment with the TCFD 4-pillar structure (Governance, Strategy, Risk, Metrics) to allow for easier adoption • Alignment with other standards: Acts as the methodology framework for reporting standards (notably IFRS and GRI); explicitly aligns with the Global Biodiversity Framework (GBF) Target 15 and uses IPBES 'drivers of nature change' as scientific basis
Coverage of planetary boundaries	**Comprehensive coverage for 8/9 PBs** Addresses all PBs except ozone depletion: **Climate Change** (GHG emissions), **Biosphere Integrity** (high-risk ecosystems, invasive species), **Land-System Change** (spatial footprint), **Freshwater Change** (water consumption & withdrawal), **Biogeochemical Flows** (nutrient discharge), **Ocean Acidification** (marine ecosystem dependency), **Atmospheric Aerosol Depletion** (SOx, NOx, PM2.5 emissions), **Novel Entities** (plastic pollution, hazardous waste)
In-scope entities	• Voluntary for corporates and financial institutions with material dependencies on nature
Reporting requirements	• Disclosure focus: Flexible – accommodates both financial and impact materiality • Using the LEAP approach (Locate, Evaluate, Assess, Prepare), companies must disclose dependencies on nature (e.g. water for cooling) and impacts on nature (e.g. pollution runoff) in priority locations
Compliance complexity and level of effort	**Very high** • "Locate" requires mapping supplier sites to identify "priority interaction" zones – work requires geospatial data to overlay with biodiversity maps • Limited data availability and quality, since nature metrics are less mature than carbon
Adoption status	**Low-Medium** • Voluntary, but growing strongly with over 300 early adopters committed to reporting against TNFD • Likely to follow TCFD's path to becoming mandatory in some markets (e.g. active reviews by UK and Australian governments)

IFRS S1 & S2 (ISSB)	**Overall status:** Live Live since January 2024
High-level description	• Overall aim: To establish a **global baseline for financial sustainability disclosures** • Scope of disclosures: Covers full value chain (scope 1/2/3) for climate (IFRS S1); broader sustainability risks if financially material (IFRS S2) • Evolution: Consolidates and replaces TCFD and SASB, with more stringent requirements, e.g. by mandating industry-specific metrics, detailed transition planning, and (previously voluntary) quantitative scenario analysis • Alignment with other standards: Designed to be the 'financial pillar' that pairs with GRI's 'impact pillar'
Coverage of planetary boundaries	**Partial catch-all coverage for all 9 PBs, with explicit guidance currently skewing to 4/9 PBs** • IFRS S1: All PBs cover in theory if they are expected to materially affect a company's cash flows, access to finance, or cost of capital; firms are advised to use SASB/CDBS frameworks for relevant metrics (guidance indexes heavily on **Freshwater Change**, **Biosphere Integrity**, and **Land-System Change**) • IFRS S2: **Climate Change** (scope 1-3 GHG emissions) covered comprehensively
In-scope entities	• Mandatory for listed companies in adopting jurisdictions • Voluntary for companies looking to meet investor demands for a global baseline
Reporting requirements	• Disclosure focus: Financial materiality • Disclosure of financial vulnerability to climate/nature risks, quantified financial impacts (current & anticipated), and resilience of strategy under different scenarios (e.g. 1.5°C warming vs >2°C)
Compliance complexity and level of effort	**High** • Substantial effort on quantifying "anticipated financial effects" and conducting climate scenario analysis, which requires actuarial and economic modelling expertise • Necessitates publication of investment-grade data, with limited assurance rapidly becoming mandatory in many jurisdictions
Adoption status	**High** • 20+ jurisdictions (e.g. UK, Brazil, Japan, Australia, Canada) have decided to adopt ISSB or ensure alignment of relevant national regulations • EU CSRD is broader (due to double materiality), but highly interoperable • Voluntary in the US under SEC climate rule (currently stalled)

GRI (Global Reporting Initiative)	**Overall status:** Live Universal Standards live since 2021, recent updates effective since 2026
High-level description	• Overall aim: To provide a 'common language' for impacts on the economy, environment, and people • Scope of disclosures: Focuses on a company's outward impact on the world across all stakeholders • Evolution: Recently updated to align with CSRD double materiality principle and TNFD impact disclosures • Alignment with other standards: Acts as the impact counterpart to ISSB's financial baseline
Coverage of planetary boundaries	**Comprehensive coverage for 8/9 PBs** Addresses multiple PBs through specific "topic standards": **Climate Change** (GRI 102: GHG removals and transition planning), **Biosphere Integrity** (GRI 101: Species extinction and ecosystem loss), **Land-System Change** (GRI 101: Land and sea use change), **Freshwater Change** (GRI 303: Water withdrawal, consumption, and discharge), **Atmospheric Aerosol Loading** (GRI 305: NOx, SOx emissions), **Stratospheric Ozone Depletion** (GRI 305: emissions of ozone-depleting substances), **Novel Entities** (GRI 306: Plastic pollution and hazardous waste; GRI 101: Pollution leading to biodiversity loss), **Biogeochemical Flows** (GRI 303 & 305: N and P run-off through water discharge, NOx emissions); **Ocean Acidification** indirectly tracked via CO_2 emissions
In-scope entities	• Mandatory for large listed companies in diverse markets (e.g. Singapore, India, Brazil) and foundational for EU companies under CSRD
Reporting requirements	• Disclosure focus: Impact materiality • Mandates detailed quantitative data on withdrawals, discharges, and habitat protection; however, unlike ISSB, there is no requirement to quantify financial risk to the company
Compliance complexity and level of effort	**Medium - High** • High volume of indicators, but methodologies are mature and well-understood by sustainability teams • Lower conceptual complexity than TNFD and ISSB (no scenario analysis required), but high operational data collection burden (e.g. on litres of water used, tons of waste generated, etc.)
Adoption status	**High** • The global de-facto standard for impact reporting (used by over 10,000 companies) • Mandatory "by proxy" in some regions (e.g. through strong alignment with EU CSRD); voluntary but increasingly expected by societal stakeholders globally

SBTN (Science Based Targets Network)	Overall status: In pilot phase First validation services launched in 2023
High-level description	• Overall aim: To provide a methodology for setting measurable, actionable, and time-bound targets that align with Earth's safe operating spaces • Scope of disclosures: Value chain focus, mostly on high-impact commodities (e.g. leather, soy, palm oil) • Alignment with other standards: The 'nature sibling' of the SBTi (Science Based Targets initiative)
Coverage of planetary boundaries	**Targeted coverage for 5/9 PBs** • Current coverage: **Climate Change** (SBTi scope 1/2/3 GHG emissions), **Biosphere Integrity** (% reduction in sourcing from overexploited stocks; mitigating risks to endangered, threatened, and protected marine species), **Freshwater Change** (basin-specific targets for reducing surface water withdrawals to maintain minimum environmental flows), **Land-System Change** (area of land footprint reduction, zero conversion of natural ecosystems), **Biogeochemical Flows** (basin-specific reduction targets for N and P loading to stay below eutrophication thresholds) • In development: Updated coverage for Freshwater Change (groundwater extraction limits and toxic chemicals – directly tying Freshwater Change with Novel Entities), Land-System Change (working land regeneration and ecoregional thresholds), and ocean use (maritime shipping, offshore wind, coastal tourism)
In-scope entities	• Voluntary for 'pioneering companies' seeking to prove their nature commitments are credible and aligned with planetary boundaries
Reporting requirements	• Disclosure focus: Impact materiality • Companies must set physical targets (e.g. "reduce water withdrawal by 20% in Basin X") based on the specified local ecological threshold of that basin, rather than based on an arbitrary % reduction target
Compliance complexity and level of effort	**Extremely high** • Setting a valid SBTN target is a multi-year scientific exercise requiring engagement with local expert hydrologists and ecologists • Requires granular, site-specific data on local ecological thresholds (e.g. detailed scientific assessments on maximum sustainable water withdrawal for a specific river)
Adoption status	**Nascent** • A core group of ~20 pilot companies have set targets • Expected to become gold standard for nature target-setting, mirroring the SBTi's dominance in climate

NGFS (Network for Greening the Financial System)	Overall status: Live Live: Framework released in 2023
High-level description	• Overall aim: To integrate nature-related risks into financial stability monitoring and supervision • Scope of disclosures: Portfolio-level exposure to physical and transition risks under a set of scenarios • Evolution: Moved from 'climate only' to 'nature-integrated' in 2022, acknowledging that nature loss is a systemic threat to financial stability • Alignment with other standards: Provides the macro-prudential overlay to the micro-prudential disclosures of ISSB and TNFD
Coverage of planetary boundaries	**Systemic coverage of all planetary boundaries** • Focussed on interdependencies and the key transmission channels where boundary breaches create economic shocks – the NGFS Conceptual Framework explicitly maps all nine boundaries as distinct sources of physical and transition risk that can cause financial system shocks • Potential transmission channels modelled include: Collapse of ecosystem services (e.g. pollination, flood defences), systemic drought risks, transition risks
In-scope entities	• Directly targets Central Banks and indirectly establishes the foundational risk scenarios, cost-of-capital environment, and regulatory expectations for commercial banks, insurers, asset managers, and private market investors
Reporting requirements	• Disclosure focus: Macro-prudential financial risk • Does not set reporting standards for companies, but drives stress testing scenarios (e.g. impact on a national banking system if pollinator collapse destroys 10% of agricultural output)
Compliance complexity and level of effort	**High** • Requires translating ecological shocks into macroeconomic variables (e.g. GDP, inflation) and credit risk model outcomes • Relies on aggregated data from TNFD and ISSB disclosures to feed macro models
Adoption status	**High** • Over 125 Central Banks and Supervisors (covering ~90% of global economy) are members • Trickles down to financial institutions via stress tests and supervisory expectations

Regulatory factsheets – EU regulations

CSRD (Corporate Sustainability Reporting Directive)	Overall status: Live / Delayed Omnibus amendments finalised in February 2026 to narrow scope
High-level description	• Overall aim: To standardise corporate sustainability reporting across the EU market • Scope of disclosures: Dedicated sustainability statement detailing the double materiality of ESG impacts, risks, and opportunities • Evolution: Omnibus I package drastically narrowed the scope thresholds and introduced value-chain reporting caps to protect smaller suppliers • Alignment with other standards: Designed as the mandatory equivalent to GRI (impact materiality) and explicitly aligns financial materiality baseline with IFRS S1 & S2; nature framework heavily mirrors TNFD LEAP approach
Coverage of planetary boundaries	**Comprehensive coverage of 8/9 planetary boundaries** • Full coverage: **Climate Change** (scope 1/2/3 GHG emissions and mandatory 1.5C transition plans), **Biosphere Integrity** (species population impacts and ecosystem dependencies), **Land-System Change** (land-use change and conversion footprint), **Freshwater Change** (water consumption and withdrawals in high-stress areas), **Biogeochemical Flows** (nutrient runoff to water and soil), **Atmospheric Aerosol Loading** (reporting of NOx, SOx, and PM2.5), **Stratospheric Ozone Depletion** (disclosure of ODS emissions), **Novel Entities** (microplastics, PFAS, hazardous waste) • Partial coverage: **Ocean Acidification** (indirectly via GHG metrics)
In-scope entities	• EU companies with >1,000 employees and >€450 million net turnover • Non-EU parents with >€450 million EU turnover and an EU branch >€200 million
Reporting requirements	• Disclosure focus: Double materiality • Companies assess against a streamlined 320 mandatory data points (reduced from over 1,000) across environmental, social, and governance categories
Compliance complexity and level of effort	**Very high** • Requires collection and assessment of large amounts of data across entire value chain • Backed by mandatory third-party limited assurance
Adoption status	**Low** • First wave of large companies are actively publishing their first CSRD-aligned reports • Member states must transpose the new Omnibus I amendments by March 2027

EU Taxonomy	Overall status: Live Core framework active and actively expanding
High-level description	• Overall aim: To provide a science-based classification system for sustainable economic activities • Scope of disclosures: Proportion of Turnover, CapEx, and OpEx aligned with Taxonomy criteria • Evolution: A revised Delegated Act officially came into effect in early 2026, introducing a 10% materiality threshold to simplify reporting for non-material activities • Alignment with other standards: Aligns conceptually with SBTN by establishing rigid local ecological thresholds to define sustainability; frequently maps to NGFS scenarios
Coverage of planetary boundaries	**Comprehensive coverage of 8/9 planetary boundaries** • Full coverage: **Climate Change** (mitigation and adaptation screening thresholds), **Biosphere Integrity** (restrictions on habitat degradation), **Land-System Change** (prevention of 'sustainable' classification for habitat conversion), **Freshwater Change** (screening for water efficiency and recycling), **Biogeochemical Flows** (DNSH criteria against nutrient loading causing eutrophication), **Atmospheric Aerosol Loading** (restricts industrial air emissions), **Stratospheric Ozone Depletion** (restricts production or emission of ODS), **Novel Entities** (phases out PFAS and targets plastic waste) • Partial coverage: **Ocean Acidification** (indirectly climate and marine objectives)
In-scope entities	• Financial Market Participants and large non-financial companies subject to the CSRD
Reporting requirements	• Disclosure focus: Double materiality • Requires assessing financial metrics (turnover / CapEx / OpEx percentages) against six specific environmental objectives, proving alignment and strictly demonstrating Do No Significant Harm
Compliance complexity and level of effort	**Very high** • Requires granular assessment of revenues and expenses against complex technical criteria • Must legally prove DNSH across all other environmental objectives
Adoption status	**High** 2026 marks the first year that companies are legally required to report their alignment across all six environmental objectives (including biodiversity and pollution) for their 2025 financial year, stepping up from previous eligibility-only reporting.

CSDDD (Corporate Sustainability Due Diligence Directive	Overall status: Delayed Go-live delayed to 2029 following Omnibus package
High-level description	• Overall aim: To mandate active due diligence for human rights and environmental impacts across companies' value chains • Scope of disclosures: Annual statement detailing identified adverse impacts and mitigation actions taken • Evolution: Omnibus package deleted the mandatory publication of climate transition plans, narrowed the scope, and delayed enforcement to July 2029 • Alignment with other standards: Forms analytical basis for parts of CSRD reporting obligations, operationalises the 'Locate' and 'Evaluate' steps of the TNFD framework into a legal liability mechanism, and adheres closely to IFRS S1 and GRI
Coverage of planetary boundaries	**Comprehensive coverage of 7/9 planetary boundaries** • Full coverage: **Biosphere Integrity** (liability for measurable ecological degradation), **Land-System Change** (prohibition against deforestation and harmful soil change), **Freshwater Change** (prohibits excessive water consumption impairing safe drinking water), **Biogeochemical Flows** (Prohibits water pollution that impairs food or water access), **Atmospheric Aerosol Loading** (bans on air pollution damaging human health), **Stratospheric Ozone Depletion** (mandates compliance with the Montreal Protocol), **Novel Entities** (enforces Basel, Stockholm and Minamata conventions on hazardous waste) • Partial coverage: **Climate Change** (mandatory transition plan publication removed, relies on CSRD alignment), **Ocean Acidification** (mandates compliance with UNCLOS, but lacks chemistry metrics)
In-scope entities	• EU companies with >5,000 employees and >€1.5 billion net global turnover • Non-EU companies with >€1.5 billion of net EU turnover
Reporting requirements	• Disclosure focus: Impact materiality and liability • Requires a formal Due Diligence Statement detailing actual/potential adverse human rights and environmental impacts identified and mitigated across the company's value chain
Compliance complexity and level of effort	**Medium - Very high** *(depending on supply chain complexity)* • Shifts burden from mere reporting to active supply chain intervention • Requires formal scoping exercises and enforceable supplier codes of conduct
Adoption status	**Delayed** While formally approved, the EU Omnibus pushed the Member State transposition deadline to July 2028, with active compliance and enforcement for the first wave of in-scope companies not before July 2029

EUDR (EU Deforestation Regulation)	Overall status: Delayed Enforcement starting in December 2026 for large & medium operators
High-level description	• Overall aim: To ban the sale of products contributing to global deforestation • Scope of disclosures: Due diligence statement containing exact geolocation coordinates of origin • Evolution: Enforcement delayed by one year in December 2025, and due diligence requirements heavily simplified for downstream and micro-operators • Alignment with other standards: Directly executes the SBTN 'Land Target' mandate and serves as the ultimate regulatory expression of TNFD's supply chain traceability
Coverage of planetary boundaries	**Limited, targeted coverage of 1/9 planetary boundaries; partial coverage of 1/9 planetary boundaries** • Full coverage: **Land-System Change** (requires geolocation polygons proving zero deforestation after end of 2020) • Partial coverage: **Biosphere Integrity** (indirectly protects terrestrial species through strict habitat preservation)
In-scope entities	• Any operator or trader placing relevant commodities (soy, beef, palm oil, wood, coffee, cocoa, rubber) on the EU market
Reporting requirements	• Disclosure focus: Impact materiality • Requires submitting a formal Due Diligence Statement containing exact geolocation polygons and risk assessments to prove commodities are 100% deforestation-free
Compliance complexity and level of effort	**Very high** • Requires advanced GIS (geographic information system) mapping and exact geolocation polygons • Necessitates complex supplier auditing down to the specific plot of land
Adoption status	**Delayed** Enforcement officially pushed back to 30 December 2026 for large & medium operators; companies are using this grace period to actively test the EU's Information System and run geolocation pilot programs

SFDR (Sustainable Finance Disclosure Regulation)	Overall status: Live Integrated into EU financial markets
High-level description	• Overall aim: To mandate transparency on how investors integrate sustainability risks • Scope of disclosures: Entity-level Principal Adverse Impacts (PAIs) and product-level fund disclosures • Evolution: EC published a proposal for SFDR 2.0 in late 2025, aimed at shifting from a disclosure regime to a product categorisation regime (in alignment with UK SDR) • Alignment with other standards: Feeds entirely on downstream corporate data sourced via CSRD/GRI; uses NGFS frameworks to map portfolio-level risks
Coverage of planetary boundaries	**Comprehensive coverage of 3/9 planetary boundaries; partial coverage of 5/9 planetary boundaries** • Full coverage: **Climate Change** (carbon emissions and fossil fuel exposure), **Biosphere Integrity** (investments affecting biodiversity-sensitive areas), **Novel Entities** (hazardous waste ratio disclosure) • Partial coverage: **Land-System Change** (optional deforestation policy), **Freshwater Change** (optional policy on exposure to areas of high water stress), **Biogeochemical Flows** (no specific focus on N and P), **Ocean Acidification** (captured indirectly via carbon), **Atmospheric Aerosol Loading** (optional policy)
In-scope entities	• Financial Market Participants, including asset managers, institutional investors, and financial advisers in the EU
Reporting requirements	• Disclosure focus: Double materiality • Requires reporting against 18 mandatory PAI metrics, detailing portfolio-level ESG risks and product categorisations
Compliance complexity and level of effort	**Medium - High** • Relies heavily on the downstream availability and quality of corporate data • Requires complex aggregation methodologies across global portfolios
Adoption status	**High** Widespread adoption; while product-level disclosures are increasing, entity-level PAI reporting remains largely confined to the biggest asset managers due to data gaps

Regulatory factsheets – UK regulations

UK SRS (Sustainability Reporting Standards)	Overall status: Live Published for voluntary use as of February 2026
High-level description	• Overall aim: To provide a unified, globally-aligned corporate sustainability reporting baseline • Scope of disclosures: Financial risks and opportunities arising from climate and broader sustainability • Evolution: UK government formally endorsed the standards in late February 2026; the FCA is actively consulting on mandating UK SRS by 2027 • Alignment with other standards: Directly adopts the ISSB (IFRS S1 / S2) global baseline, acting as the definitive foundation for future UK corporate reporting
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial for remaining 8/9 planetary boundaries** • Full coverage: **Climate Change** (scope 1/2/3 emissions reporting and climate transition plan disclosures) • Partial coverage: **Biosphere Integrity**, **Land-System Change**, **Freshwater Change**, **Biogeochemical Flows**, **Ocean Acidification**, **Atmospheric Aerosol Loading** and **Stratospheric Ozone Depletion**, **Novel Entities** (all covered if material exposure or risks identified – general financial materiality provision of SRS S1)
In-scope entities	• Currently voluntary – the FCA is considering mandating UK SRS for premium listed commercial companies for accounting periods beginning on or after 1 January 2027
Reporting requirements	• Disclosure focus: Financial materiality • Focuses strictly on how sustainability and climate-related issues affect a company's enterprise value, cash flows, and access to capital
Compliance complexity and level of effort	**High** • Requires rigorous financial risk modelling for long-term physical and transition climate scenarios • Demands robust scope 3 value-chain emissions data collection
Adoption status	**Nascent** FCA is actively consulting on rules to formally mandate SRS S2 (climate) for listed issuers by 2027, with S1 (general sustainability) on a 'comply or explain' basis

TPT (Transition Plan Taskforce)	**Overall status:** Pending To be integrated into upcoming mandatory UK SRS reporting
High-level description	• Overall aim: To define the gold standard for credible corporate climate transition plans • Scope of disclosures: Strategic plans detailing how reporting entities will transition their business models • Evolution: The FCA intends to embed TPT rules into UK SRS requirements • Alignment with other standards: Directly builds on TCFD and ISSB requirements, providing granular implementation guidance for the climate plans mandated by UK SRS S2
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial for 2/9 planetary boundaries** • Full coverage: **Climate Change** (detailed strategic pathways for achieving 1.5°C Paris-aligned decarbonisation targets) • Partial coverage: **Biosphere Integrity** (nature-positive strategies and carbon sink protection), **Land-System Change** (land-use changes impacting carbon sinks)
In-scope entities	• Expected to apply to UK-regulated financial institutions (banks, asset managers, insurers) and FTSE 100 companies
Reporting requirements	• Disclosure focus: Financial materiality • Requires disclosing specific actions, governance structures, and financial resourcing to deliver on stated climate targets
Compliance complexity and level of effort	**High** • Shifts the focus from mere historical disclosure to active, strategic business transformation • Requires extensive cross-functional coordination and long-term financial modelling
Adoption status	**Pending mandate** Currently viewed as voluntary best practice; following late-2025 consultations, the FCA is actively working to embed TPT requirements directly into the mandatory UK SRS rollout

BNG (Biodiversity Net Gain)	**Overall status:** Live Mandatory for infrastructure and housing developments
High-level description	• Overall aim: To ensure infrastructure and housing developments leave nature measurably better • Scope of disclosures: Statutory biodiversity metric calculations proving a minimum 10% ecological uplift • Evolution: In late 2025, HMG proposed a new exemption for small developments under 0.2 hectares to reduce burdens • Alignment with other standards: A direct domestic regulatory application of SBTN and TNFD principles regarding localised terrestrial habitat preservation and regeneration
Coverage of planetary boundaries	**Targeted coverage of 2/9 planetary boundaries; partial for 1/9 planetary boundaries** • Full coverage: **Biosphere Integrity** (measurable improvements in habitat quality and ecosystem health), **Land-System Change** (regulated land-use changes to prevent net loss of terrestrial ecosystems) • Partial coverage: **Freshwater Change** (covers aquatic habitats strictly within planning development boundaries)
In-scope entities	• Developers and landowners in England seeking planning permission under the Town and Country Planning Act, including major and small sites
Reporting requirements	• Disclosure focus: Impact materiality • Developers submit a formal Biodiversity Gain Plan proving physical ecological enhancement, secured legally for a minimum of 30 years
Compliance complexity and level of effort	**High** • Requires specialised ecological assessments using the statutory Defra biodiversity metric • Mandates legally binding 30-year habitat maintenance and monitoring agreements
Adoption status	**High** Mandatory for standard developments since early 2024; Nationally Significant Infrastructure Projects (NSIPs) will officially fall under the regime starting May 2026

Forest Risk Commodities	**Overall status:** Delayed HMG reviewing implementation approach
High-level description	• Overall aim: To prohibit the commercial use of illegally deforested supply chain commodities • Scope of disclosures: Annual due diligence reports proving commodities meet local producer laws • Evolution: Amid EUDR delays, HMG is actively considering its regulatory approach and timelines • Alignment with other standards: Interacts directly with the EUDR but differs by focusing on *illegal* deforestation rather than strict zero-deforestation, aligning with TNFD supply chain tracing
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial coverage of 1/9 planetary boundaries** • Full coverage: **Land-System Change** (explicitly targets the prevention of illegal land-system conversion for agriculture) • Partial coverage: **Biosphere Integrity** (indirectly protects species by mitigating illegal habitat destruction)
In-scope entities	• Expected to target large UK businesses exceeding specific turnover thresholds that use commodities like beef, soy, palm oil, and cocoa
Reporting requirements	• Disclosure focus: Impact materiality • Focuses strictly on supply chain traceability and assessing the risk of non-compliance with producer country environmental laws
Compliance complexity and level of effort	**High** • Likely to require complex supply chain mapping back to the point of harvest • Necessitates ongoing risk assessments of foreign environmental legal frameworks
Adoption status	**Delayed** Though established in the Environment Act 2021, the secondary legislation to enforce it remains unpublished; as of March 2026, the government confirmed it is still considering its approach

SDR (Sustainability Disclosure Requirements)	**Overall status:** Live Phased implementation progressing through December 2026
High-level description	• Overall aim: To eradicate greenwashing and standardise sustainability labelling for investment products • Scope of disclosures: Mandatory product labels, consumer-facing disclosures, and entity-level sustainability risk reports • Evolution: Anti-greenwashing rules applied May 2024; naming and marketing rules were delayed to April 2025 to ease industry compliance • Alignment with other standards: highly interoperable with TCFD and ISSB for entity reporting; UK equivalent to EU SFDR, albeit with a focus on product labelling rather than disclosure
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial for remaining 8/9 planetary boundaries** • Full coverage: **Climate Change** (entity and product-level GHG/climate risk reporting via TCFD/ISSB alignment) • Partial coverage: **Biosphere Integrity** (if material to entity risk, or if a fund label targets nature), **Land-System Change** (via general entity-level sustainability risk management), **Freshwater Change** (via general entity-level sustainability risk management), **Biogeochemical Flows** (if nutrient pollution poses a material financial risk), **Ocean Acidification** (indirectly via GHG tracking and broad marine sustainability objectives), **Atmospheric Aerosol Loading** and **Stratospheric Ozone Depletion** (implicitly under broad environmental/pollution risk disclosures), **Novel Entities** (waste and pollution disclosures if material to the fund's objective or entity risk)
In-scope entities	• UK asset managers, FCA-authorised firms, and distributors • Entity-level reporting thresholds target firms with AUM >£50bn (2025) and >£5bn (2026)
Reporting requirements	• Disclosure focus: Double materiality • Funds must prove sustainability label criteria (impact) and report entity-level sustainability risks (financial)
Compliance complexity and level of effort	**Medium - High** • Requires detailed substantiation for sustainability labels to avoid strict anti-greenwashing penalties • Demands extensive portfolio-level data aggregation and TCFD-aligned corporate reporting
Adoption status	**Nascent** The anti-greenwashing rule is actively enforced, and large asset managers (>£50bn AUM) have begun disclosing their first entity-level disclosures as of end of 2025

Regulatory factsheets – Australian regulations

ASRS (Australian Sustainability Reporting Standards)	Overall status: Live Mandatory phased implementation since January 2025
High-level description	• Overall aim: To mandate internationally aligned, climate-first financial disclosures across Australian markets • Scope of disclosures: Financial risks and opportunities arising exclusively from climate change initially • Evolution: The legislation passed in September 2024, enforcing strict phased timelines while actively delaying broader nature reporting • Alignment with other standards: Closely adopts the ISSB (IFRS S2) baseline but explicitly restricts the initial mandatory scope to climate only, delaying the broader general sustainability requirements of IFRS S1 to a later, undetermined date
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial coverage of 1/9 planetary boundaries** • Full coverage: **Climate Change** (strict GHG scope 1/2/3 emissions reporting, scenario analysis, and transition plan disclosures) • Partial coverage: **Ocean Acidification** (indirectly via overarching scope 1/2/3 GHG emissions tracking)
In-scope entities	• Group 1 (>$500m revenue or >$1bn assets) since January 2025 • Group 2 (>$200m revenue) from July 2026 • Group 3 (>$50m revenue) from July 2027
Reporting requirements	• Disclosure focus: Financial materiality • Focuses strictly on how climate-related physical and transition risks impact corporate enterprise value, requiring the publication of a formal sustainability report within the annual report
Compliance complexity and level of effort	**High** • Demands rigorous financial risk modelling for long-term climate scenarios • Requires robust Scope 3 value-chain emissions data collection and mandatory auditing
Adoption status	**Nascent** Australia's largest listed and unlisted entities (group 1) actively preparing disclosures for their first mandatory reporting cycles for the 2025 financial year, expected by mid-2026

Nature Positive Plan (EPBC Act Reform)	Overall status: Delayed EPA established, but full legislative overhaul remains split
High-level description	• Overall aim: To halt environmental decline and repair Australia's unique natural ecosystems • Scope of disclosures: Environmental approvals, biodiversity assessments, and corporate nature impact tracking • Evolution: The Australian government split the reform in 2024, establishing a national Environmental Protection Agency (EPA) but delaying the stricter National Environmental Standards • Alignment with other standards: Designed to serve as the domestic regulation for Australia's international commitments under the Global Biodiversity Framework, heavily influencing the local data points needed for voluntary TNFD disclosures
Coverage of planetary boundaries	**Targeted coverage of 2/9 planetary boundaries; partial coverage of 2/9 planetary boundaries** • Full coverage: **Biosphere Integrity** (strict federal protections for threatened species and ecosystems), **Land-System Change** (regulates land-clearing, mining, and agricultural expansion) • Partial coverage: **Freshwater Change** (regulates projects significantly impacting federal water resources), **Biogeochemical Flows** (regulates runoff specifically impacting the Great Barrier Reef)
In-scope entities	• Any corporate entity (e.g. in mining, agriculture, construction) proposing an action that will have, or is likely to have, a significant impact on a 'Matter of National Environmental Significance'
Reporting requirements	• Disclosure focus: Impact materiality • Requires detailed environmental impact assessments to prove project developments do not cause unacceptable localised ecological degradation
Compliance complexity and level of effort	**High** • Necessitates highly specialized, localized ecological surveys prior to project development • Faces immense regulatory uncertainty as specific standards continue to be debated in parliament
Adoption status	**Delayed** Underlying environmental standards still subject to substantial political negotiation and debate

Regulatory factsheets – Japanese regulations

SSBJ (Sustainability Standards Board of Japan)	Overall status: Pre-go-live Final standards published for implementation
High-level description	• Overall aim: To integrate global sustainability baselines into Japanese corporate financial reporting • Scope of disclosures: Financial risks and opportunities tied to climate and general sustainability • Evolution: Finalised in early 2025, with the Financial Services Agency (FSA) currently establishing rules to formally mandate the standards • Alignment with other standards: Acts as the direct Japanese equivalent to the ISSB (IFRS S1 and S2), translating the global baseline into specific, localised application guidance for Japanese securities law
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial for remaining 8/9 planetary boundaries** • Full coverage: **Climate Change** (scope 1/2/3 emissions reporting and climate transition plan disclosures) • Partial coverage: **Biosphere Integrity**, **Land-System Change**, **Freshwater Change**, **Biogeochemical Flows**, **Ocean Acidification**, **Atmospheric Aerosol Loading** and **Stratospheric Ozone Depletion**, **Novel Entities** (all covered if material exposure or risks identified under general financial materiality provision)
In-scope entities	• Will apply to companies listed on the Prime Market of the Tokyo Stock Exchange, capturing Japan's most systemically important global multinationals
Reporting requirements	• Disclosure focus: Financial materiality • Requires disclosure of how sustainability issues materially impact enterprise value, utilising both the general sustainability (theme 1) and climate-specific (theme 2) standards
Compliance complexity and level of effort	**High** • Requires complex actuarial and economic modelling for transition scenarios • Demands significant supply chain data aggregation from smaller, unlisted domestic suppliers
Adoption status	**Nascent** While the standards are finalised, mandatory application under Japanese law is expected to be phased in sequentially starting around the fiscal year ending March 2028

Act on Promoting Activities to Enhance Regional Biodiversity	Overall status: Live Legislation officially in force since April 2025
High-level description	• Overall aim: Incentivise corporate conservation to meet Japan's 30by30 biodiversity targets • Scope of disclosures: Certification of corporate land management and biodiversity activity plans • Evolution: Upgrades the 2023 "Sustainably Managed Natural Sites" pilot into formal law, expanding certification from specific land areas to broader corporate activity plans • Alignment with other standards: Directly implements the Kunming-Montreal Global Biodiversity Framework at domestic level, generating verified ecological data that companies can use for TNFD
Coverage of planetary boundaries	**Targeted coverage of 2/9 planetary boundaries; partial coverage of 2/9 planetary boundaries** • Full coverage: **Biosphere Integrity** (certifies private corporate land contributing to habitat and species conservation), **Land-System Change** (actively prevents land degradation by registering corporate land as OECMs (Other Effective area-based Conservation Measures) • Partial coverage: **Climate Change** (indirectly addresses climate via the protection of natural carbon sinks), **Freshwater Change** (aquatic and coastal conservation projects in scope)
In-scope entities	• Voluntary for corporations, local governments, and NGOs owning or managing land (such as factory buffer zones, corporate forests) and seeking official national certification
Reporting requirements	• Disclosure focus: Impact materiality • Companies must submit detailed ecological monitoring data and management plans to the Ministry of the Environment to achieve and maintain site certification
Compliance complexity and level of effort	**Medium** • Requires baseline ecological surveying and long-term land management commitments • Voluntary status allows companies to opt-in based on capability, limiting systemic burden
Adoption status	**Accelerating** Over 180 sites (covering >80,000 hectares) were certified under the precursor scheme; adoption is accelerating rapidly with the Act's formal launch in April 2025

Regulatory factsheets – Singaporean regulations

SGX / ACRA (Mandatory Climate Reporting)	Overall status: Live Phased mandatory reporting since 2025
High-level description	• Overall aim: To establish Singapore as a leading hub for high-quality, ISSB-aligned disclosures • Scope of disclosures: Financial risks and opportunities tied to climate and general sustainability • Evolution: Announced in 2024, the mandate captures both listed issuers and large, unlisted private companies • Alignment with other standards: Directly mandates the local equivalent of the ISSB (IFRS S1 and S2) standards, providing a highly comparable baseline for global investors
Coverage of planetary boundaries	**Targeted coverage of 1/9 planetary boundaries; partial for remaining 8/9 planetary boundaries** • Full coverage: **Climate Change** (scope 1/2/3 emissions reporting and climate transition plan disclosures) • Partial coverage: **Biosphere Integrity**, **Land-System Change**, **Freshwater Change**, **Biogeochemical Flows**, **Ocean Acidification**, **Atmospheric Aerosol Loading** and **Stratospheric Ozone Depletion**, **Novel Entities** (all covered if material exposure or risks identified under general financial materiality provision)
In-scope entities	• All listed issuers since FY2025 • Large non-listed companies (revenue >$1bn and assets >$500m) from FY2027
Reporting requirements	• Disclosure focus: Financial materiality • Focuses strictly on how climate and sustainability risks impact corporate enterprise value, requiring scope 1 and 2 tracking immediately, with scope 3 to follow
Compliance complexity and level of effort	**High** • Aggressive timeline forces immediate capability building, particularly for unlisted entities • Will require robust scope 3 data from complex Asian supply chains
Adoption status	**Nascent** All SGX-listed issuers are in the process of compiling mandatory ISSB-aligned climate reports for the 2025 financial year

SAT (Singapore-Asia Taxonomy for Sustainable Finance)	Overall status: Live Published by MAS in 2023
High-level description	• Overall aim: To define sustainable and transition activities to prevent greenwashing in Asia • Scope of disclosures: Classification of economic activities using a traffic light assessment system • Evolution: Continues to evolve as it integrates interoperability mapping with both the EU Taxonomy and Chinese taxonomies • Alignment with other standards: Acts as the Asian counterpart to the EU Taxonomy, but diverges by pioneering an 'Amber' transition category to accommodate heavy industries, aligning with NGFS transition goals
Coverage of planetary boundaries	**Comprehensive coverage of 7/9 planetary boundaries; partial for remaining 2/9 planetary boundaries** • Full coverage: **Climate Change** (strict thresholds for mitigation and adaptation), **Biosphere Integrity** (protection of healthy ecosystems and biodiversity), **Land-System Change** (promotes resource resilience and circular economy to prevent ecosystem conversion), **Freshwater Change** (promotes the sustainable use and protection of water and marine resources), **Biogeochemical Flows** (targets pollution prevention and control to stop nutrient loading), **Atmospheric Aerosol Loading** (air pollution prevention), **Novel Entities** (prevention and control of waste and hazardous chemical pollution) • Partial coverage: **Ocean Acidification** (indirectly via climate mitigation and marine protection), and **Stratospheric Ozone Depletion** (broadly covered under pollution prevention objective)
In-scope entities	• Financial institutions operating in Singapore, serving as a voluntary (but heavily encouraged and incentivised) standard for fund classification and corporate loan screening
Reporting requirements	• Disclosure focus: Double materiality • Requires assessing whether an activity positively contributes to environmental objectives while meeting strict 'Do No Significant Harm' criteria
Compliance complexity and level of effort	**Medium-High** • Requires assessing activities against specific, scientifically derived emissions thresholds • 'Amber' category requires proving a strict, time-bound pathway to becoming 'Green'
Adoption status	**High** Widely adopted by Singapore-based banks and asset managers to structure green loans, transition finance, and sustainable fund products across the ASEAN region

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