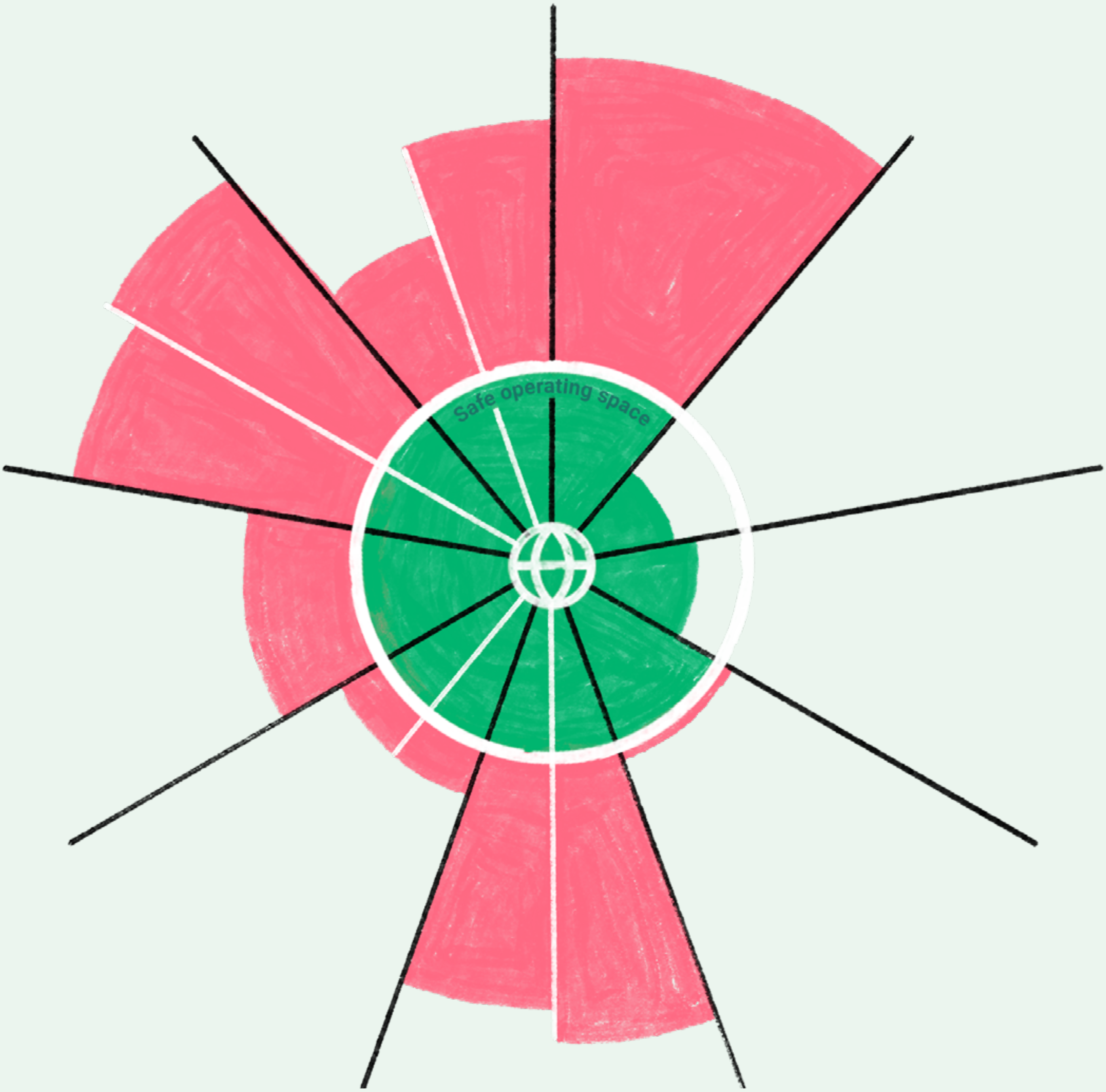
Planetary Boundaries Report

2025



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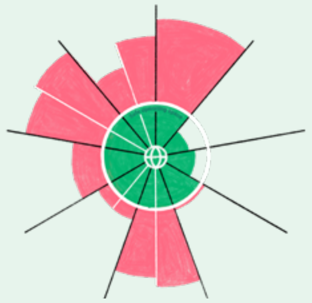

About this report

Thank you for reading Summa's second Planetary Boundaries Report. This report provides a comprehensive assessment of the state of Earth's planetary boundaries and their implications for investors, economies, and societies. It connects the science of Earth system stability to the investment decisions and ownership practices that can help restore it. Summa's thematic investment approach targets the systems where planetary boundary transgression is most acute, demonstrating that pushing them back toward safe operating spaces offers structurally attractive investment opportunities. For the first time, this report includes a portfolio-level assessment of how Summa's investments influence the planetary boundaries, capturing both the positive contributions delivered through products and services and the negative pressures generated across operations and value chains. We hope this report serves not only as an informative resource but as a catalyst for directing capital toward the transitions the science calls for.

Planetary boundaries	A scientific framework developed by the Stockholm Resilience Centre that identifies nine critical Earth system processes and defines measurable thresholds for each. Together, these thresholds mark the safe operating space for humanity. When a boundary is transgressed, it signals that human activity has moved beyond these precautionary limits, increasing the risk of abrupt and potentially irreversible environmental change.
Planetary boundary pressure	The negative impact a company's operations and value chain exert on one or more planetary boundaries, for example through emissions, pollution, resource extraction, or land use change.
Planetary boundary contribution	The positive impact a company's products and services deliver by reducing pressure on one or more planetary boundaries, for example by displacing fossil energy, enabling material recycling, or removing pollutants from water systems.
PDF·m²·yr	Potentially Disappeared Fraction of species per square metre per year. A life cycle assessment endpoint metric, calculated using the ReCiPe framework, that translates multiple environmental pressures, including climate change, land use, freshwater consumption, pollution, and nutrient loading, into a single aggregated measure of impact on ecosystems.

Thanks to

Valuing Impact for their valuable contribution to the analysis and methodology underpinning this report. The Stockholm Resilience Centre and the Potsdam Institute for Climate Impact Research (PIK) for advancing the science of planetary boundaries on which this report builds.

Disclaimer
Analysis in this report relies on the best available data, models, and methodologies at the time of publication. Data quality varies across portfolio companies and value chains, and modelled estimates or proxy data are used where traceability is limited, introducing uncertainty. Methodologies and assumptions are expected to improve over time and will be updated accordingly.

Planetary Boundaries Report 2025

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From scientific warning to investment framework

The Earth's limits are being exceeded across seven of nine planetary boundaries. Summa connects science, investments, and value creation to drive system-level change and bring the boundaries back toward safe operating spaces.

The planetary boundaries framework was developed as a scientific description of the limits within which humanity can safely operate, not as an investment framework. It identifies nine critical Earth system processes that together regulate the stability and resilience of the planet. Its relevance to investors has grown because the economic systems that depend on Earth system stability are now being reshaped by its erosion. Seven of the nine planetary boundaries are transgressed, and all seven are showing worsening trends.

The way we produce energy, use materials, treat water, and grow food sits at the centre of this transgression. These systems underpin much of the global economy, and as they come under stress, the consequences reach asset values, operating costs, and the viability of business models built for a world of stable inputs and predictable conditions. The same pressures also clarify where structural demand will compound over the coming decades, in clean energy and grid enablement, circular material systems, water resilience, sustainable food and land use, and solutions that address pollution and novel-entity impacts. For private-markets investors like Summa, the framework sharpens both downside and opportunity of the investment case.

Summa adopted the planetary boundaries framework in 2024 as a practical lens for understanding systemic risk and for identifying where capital can support the transition toward a more resilient economy. It provides a scientific foundation for directing capital and ownership effort toward returning the boundaries to safe operating spaces, grounding our thematic strategy in a rigorous assessment of where pressures on the Earth system originate, how they interact, and where the transitions needed to restore stability will require capital. In Summa's second planetary boundaries report, we build on that foundation in two new ways. For the first time, we have assessed how our portfolio companies influence the planetary boundaries, capturing both the positive contributions delivered through their products and services and the negative pressures generated by their operations and value chains. This allows us to focus where it matters most, scaling the solutions that measurably reduce planetary pressure while working with portfolio companies to address the operational and value chain pressures that, over time, translate into material business risk. Alongside this, we have deepened our analysis of what operating within planetary limits requires of investors, and of how a thematic portfolio can deliver financial returns while supporting the systems-level transitions the science calls for.

What follows is Summa's continued effort to translate the planetary boundaries framework into a private-markets context, connecting the science of Earth system stability to the investment decisions and ownership practices that can help restore it.

Reynir Indahl
Founder &
Managing Partner

Emelie Norling
Impact Director
Summa Equity

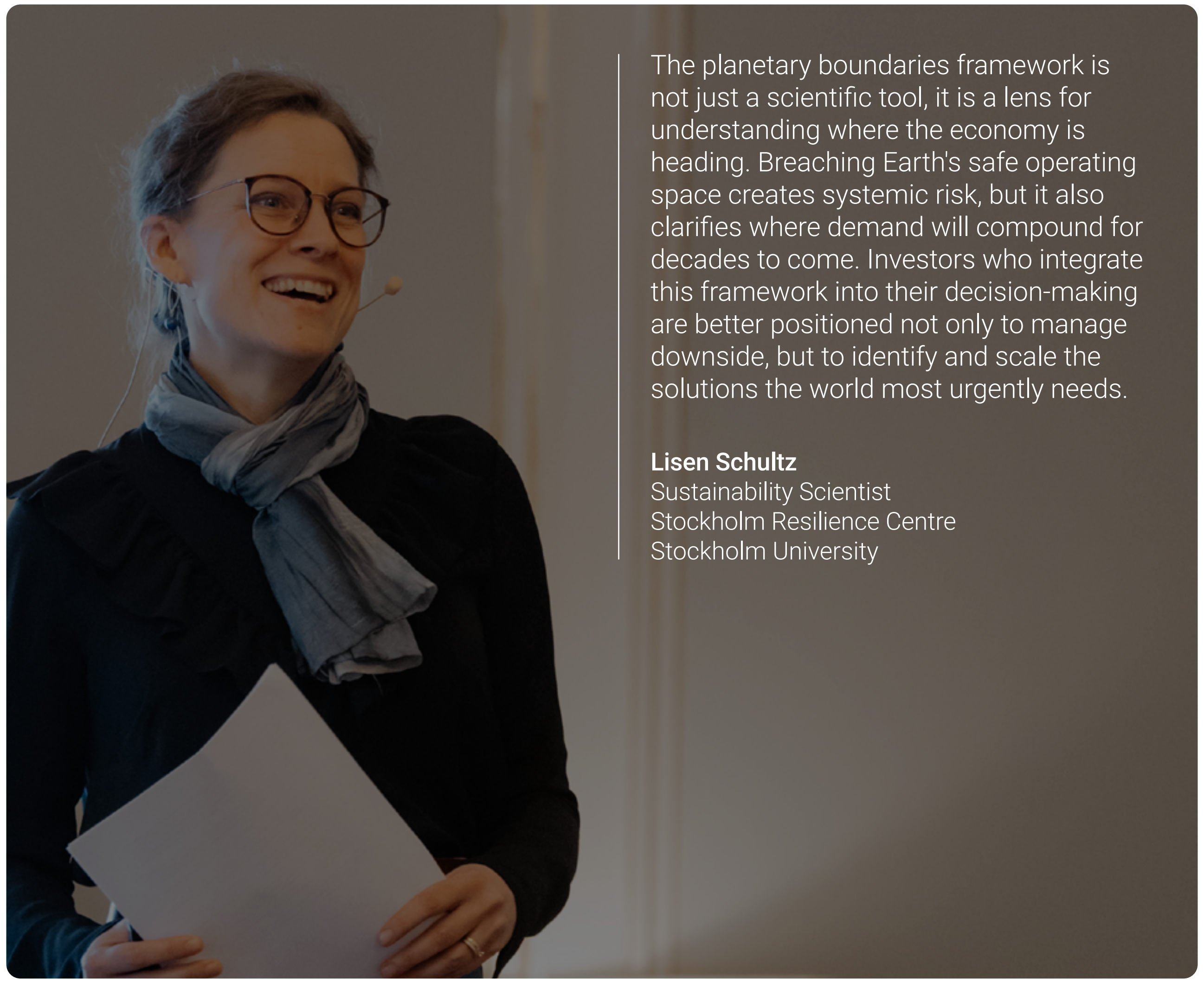
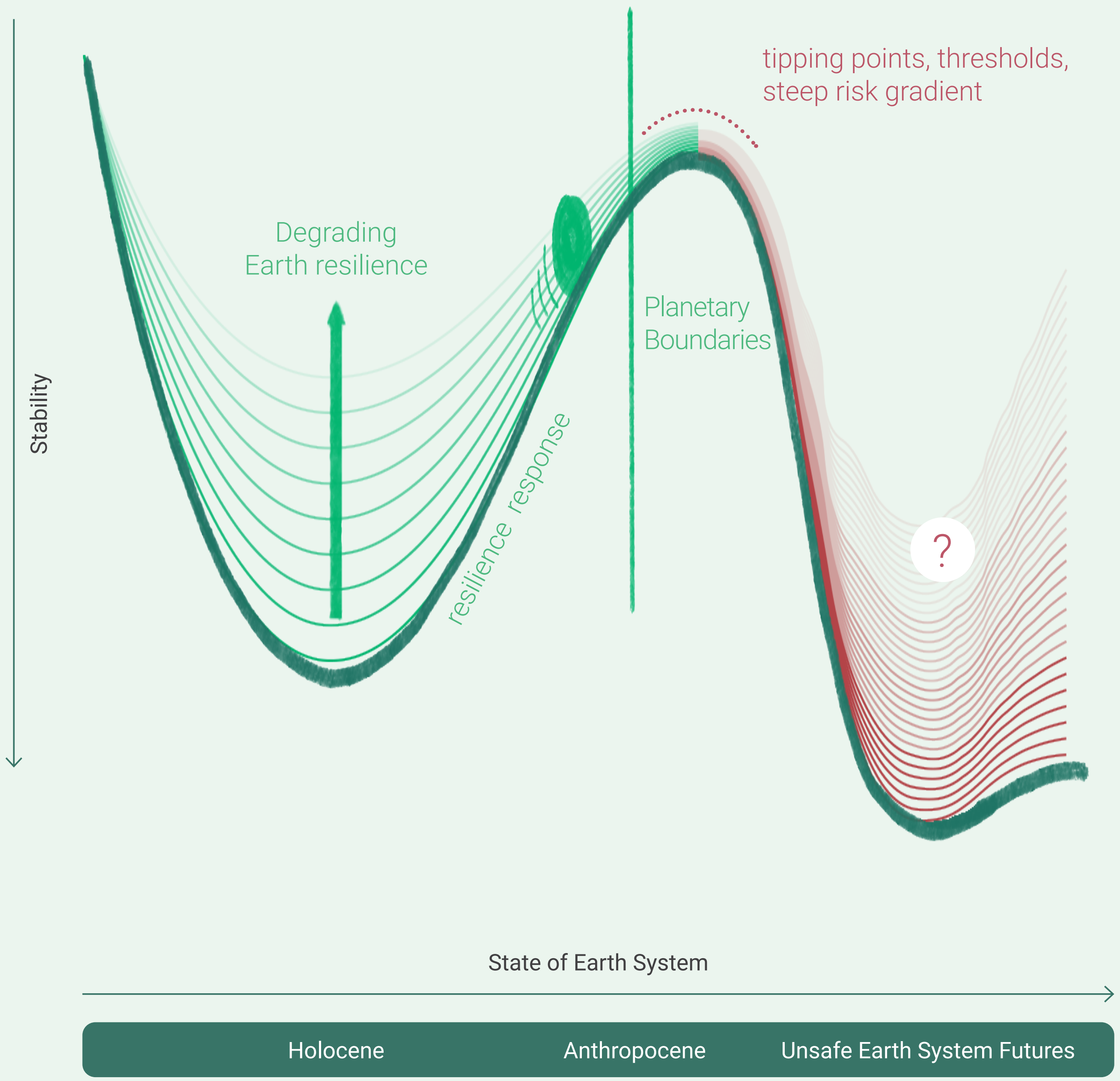


Figure 01
Visual representation of Earth system stability across Holocene, Anthropocene, and unsafe conditions.[1]

Planetary boundaries serve as a stop sign to avoid pushing systems beyond critical tipping points that risk unpredictable changes.



 1. Planetary Boundaries Science, 2025

An introduction to planetary boundaries science

Understanding planetary boundaries begins with the stable conditions of the Holocene and the accelerating human pressures that are now reshaping Earth system processes in the Anthropocene.

The guardrails of a livable planet

For more than ten thousand years, human societies developed within a narrow range of environmental conditions that made complex civilization possible, called the Holocene. During this period, Earth system processes such as climate regulation, freshwater availability, nutrient cycling, and ecosystem functioning remained relatively stable and predictable. These conditions supported food production, settlement, trade, and cultural development at a planetary scale. This relatively stable range is often described as the safe operating space for humanity, the biophysical conditions under which the Earth system can continue to provide the life support functions on which societies and economies depend.[2]

From the 18th and 19th centuries onward, rapid population growth and industrialization accelerated humanity's use of energy and materials. The expansion of fossil fuel-based systems, industrial agriculture, and resource intensive production pushed the Earth system away from Holocene-like conditions, weakening resilience and increasing instability. This shift is often framed as the transition from the Holocene into the Anthropocene, a period defined by human pressure on the Earth system at a scale large enough to shape planetary processes.[3] It is this shift, and the urgent need to reverse it, that defines the context in which Summa was founded and continues to invest.

The planetary boundaries framework

The planetary boundaries framework was developed by the Stockholm Resilience Centre to make the safe operating space scientifically explicit and measurable. It identifies nine critical Earth system processes that together regulate Earth system stability and resilience. For each process, scientists define one or more control variables that can be monitored to assess whether human pressures remain within safe limits. The resulting boundaries act as precautionary risk guardrails, leveraging multiple lines of evidence, including how conditions have varied since the Holocene, how resilience changes as ecosystems are stressed, and what is known about tipping point risks, with the aim of keeping human pressure at levels consistent with Holocene-like conditions.[4]

When a boundary is transgressed, it signals that human pressure has moved beyond these precautionary guardrails, and the Earth system's capacity for self-regulation is being weakened. In a transgressed state, ecosystems lose their capacity to absorb pressures and recover, resilience declines, and the risk of tipping points increases. Tipping points are critical thresholds in large-scale parts of the Earth system, such as the Amazon Rainforest, the Greenland and West Antarctic ice sheets, tropical coral reefs, and the Atlantic Meridional Overturning Circulation (AMOC), where continued pressure can trigger a fundamental shift in how the system behaves. Beyond such a threshold, stabilizing feedback can be replaced by self-reinforcing feedback, with small additional changes leading to disproportionate responses causing the system to change in a self-perpetuating way. The result can be abrupt, widespread, and long-lasting shifts that are potentially irreversible on human timescales, for example accelerating sea level rise, altering rainfall patterns, or weakening carbon sinks, with cascading consequences for food systems, infrastructure, health, and economic stability.

2. Planetary Boundaries Science, 2025 3. Planetary Boundaries Science, 2025 4. Planetary Boundaries Science, 2025

Tipping of the Atlantic Meridional Overturning Circulation (AMOC)

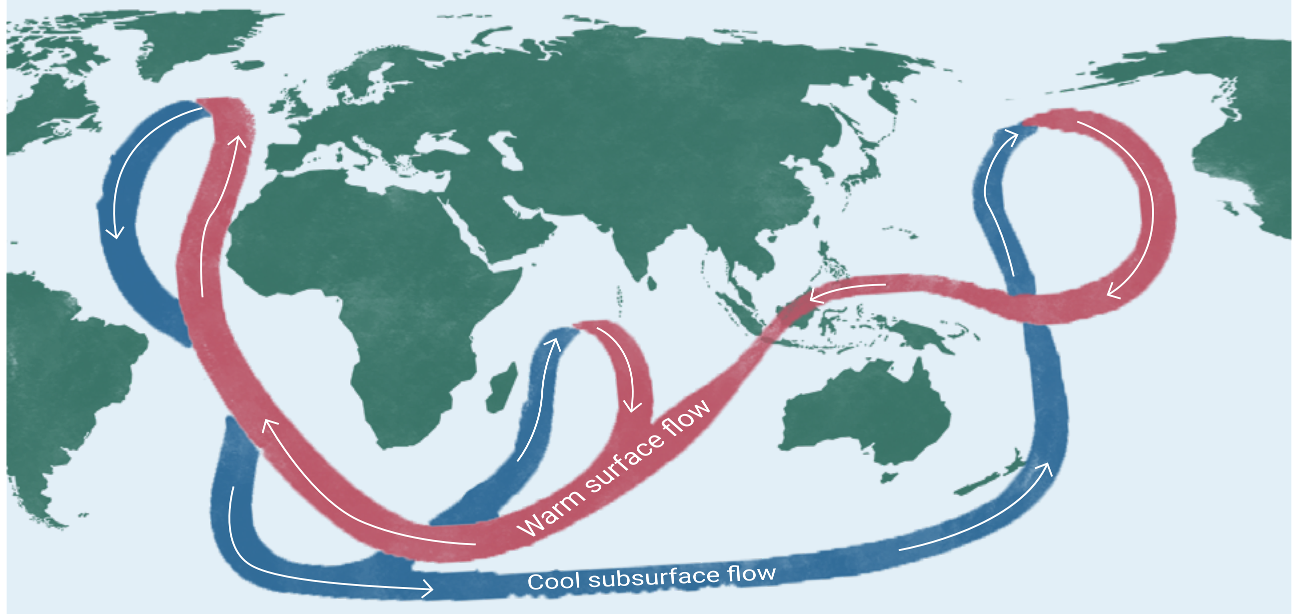
CASE STUDY

The AMOC is a critical Earth system process now showing signs of weakening, with potential to trigger abrupt, far-reaching climate impacts.

As a Northern European-focused investor, few systems carry more direct implications for Summa's portfolio than the Atlantic Meridional Overturning Circulation (AMOC), whose stability underpins the regional climate conditions on which much of Northern Europe's economic activity depends. This large-scale ocean circulation system redistributes heat, salt, and dissolved gases across the Atlantic, playing a critical role in shaping weather patterns, sea levels, and broader environmental conditions across Northern Europe. It carries warm surface waters northward and returns colder, denser waters southward at depth, influencing everything from regional temperatures to agricultural productivity and infrastructure resilience.

As climate change accelerates the melting of Arctic sea ice and the Greenland ice sheet, increasing volumes of freshwater enter the North Atlantic. This freshening reduces water density, weakening the sinking and mixing processes that sustain the AMOC, with potentially significant implications for the stability of Northern European climate systems.[5]

Figure 02
The Atlantic Meridional Overturning Circulation (AMOC)



5. Sybren Drijfhout, 2025

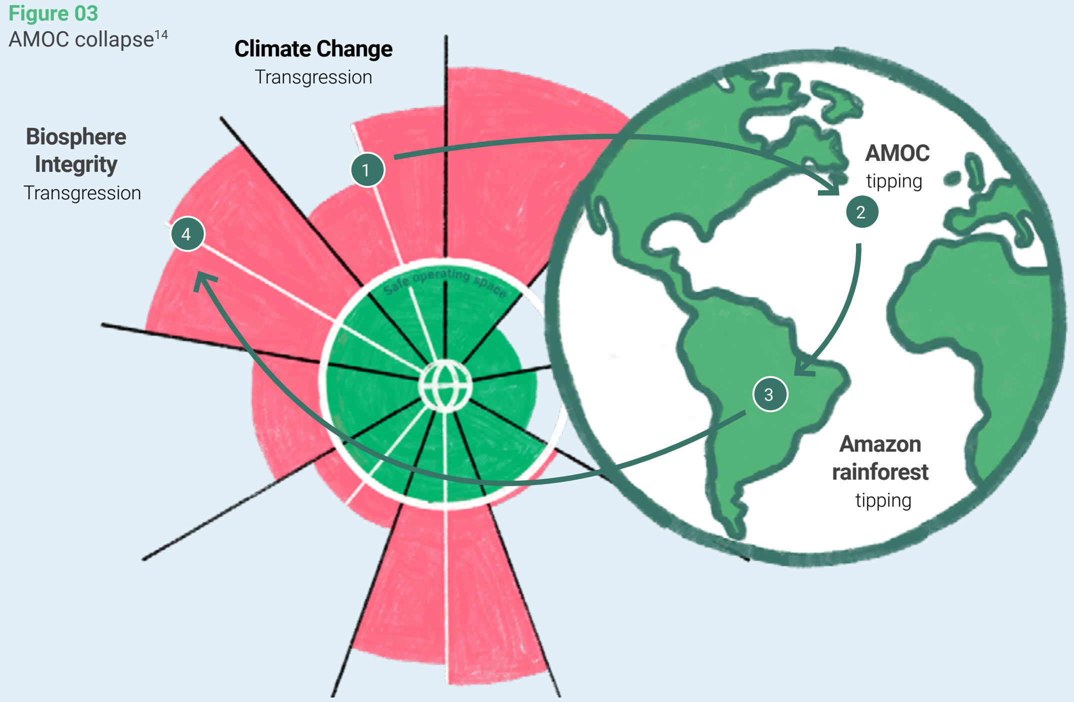
The AMOC illustrates how sustained human pressure on a single planetary boundary can undermine Earth system resilience, triggering cascading impacts that extend far beyond the region where the change begins. In October 2024, a group of 44 climate scientists urged the Nordic Council of Ministers to treat tipping driven shifts in Atlantic circulation as a major near-term threat, arguing that both likelihood and consequences have been underestimated.[6] Evidence suggests the AMOC has already weakened substantially relative to its long-term baseline, reaching its weakest state in at least the last 1,600 years.[7] Research also indicates that a critical deterioration of deep winter mixing in key North Atlantic seas could occur within the next one to two decades, pushing the system closer to conditions associated with abrupt change.[8]

So far, the Intergovernmental Panel on Climate Change (IPCC)'s assessment has been that the likelihood of an AMOC collapse before 2100 was <10%.[9] However, new research extending standard projections beyond 2100 suggests the longer run risk remains material. Under high emissions, it finds a 70% likelihood that the AMOC evolves toward an extremely weak, shallow state, with deep overturning linked to North Atlantic Deep Water formation effectively shutting down. Even under intermediate and low emissions scenarios, the probability of a northern AMOC shut down by 2300 remains meaningful, around 37% and 25% respectively.[10]

For Northern Europe, the implications are significant. Model simulations of an AMOC collapse show rapid cooling across parts of northwestern Europe, with annual average temperature trends exceeding 1°C per decade and some cities experiencing drops of roughly 5°C to 15°C over a few decades, with especially pronounced changes in winter. Circulation driven shifts can also raise sea level along parts of the North Atlantic coast by more than half a meter, adding stress to coastal infrastructure and increasing the compounding risks from storms and flooding.[11] As part of a wider pattern of cascading change following an AMOC collapse, these shifts would strain food systems, infrastructure, and economic stability, as climate and ocean dynamics reinforce each other across connected systems.

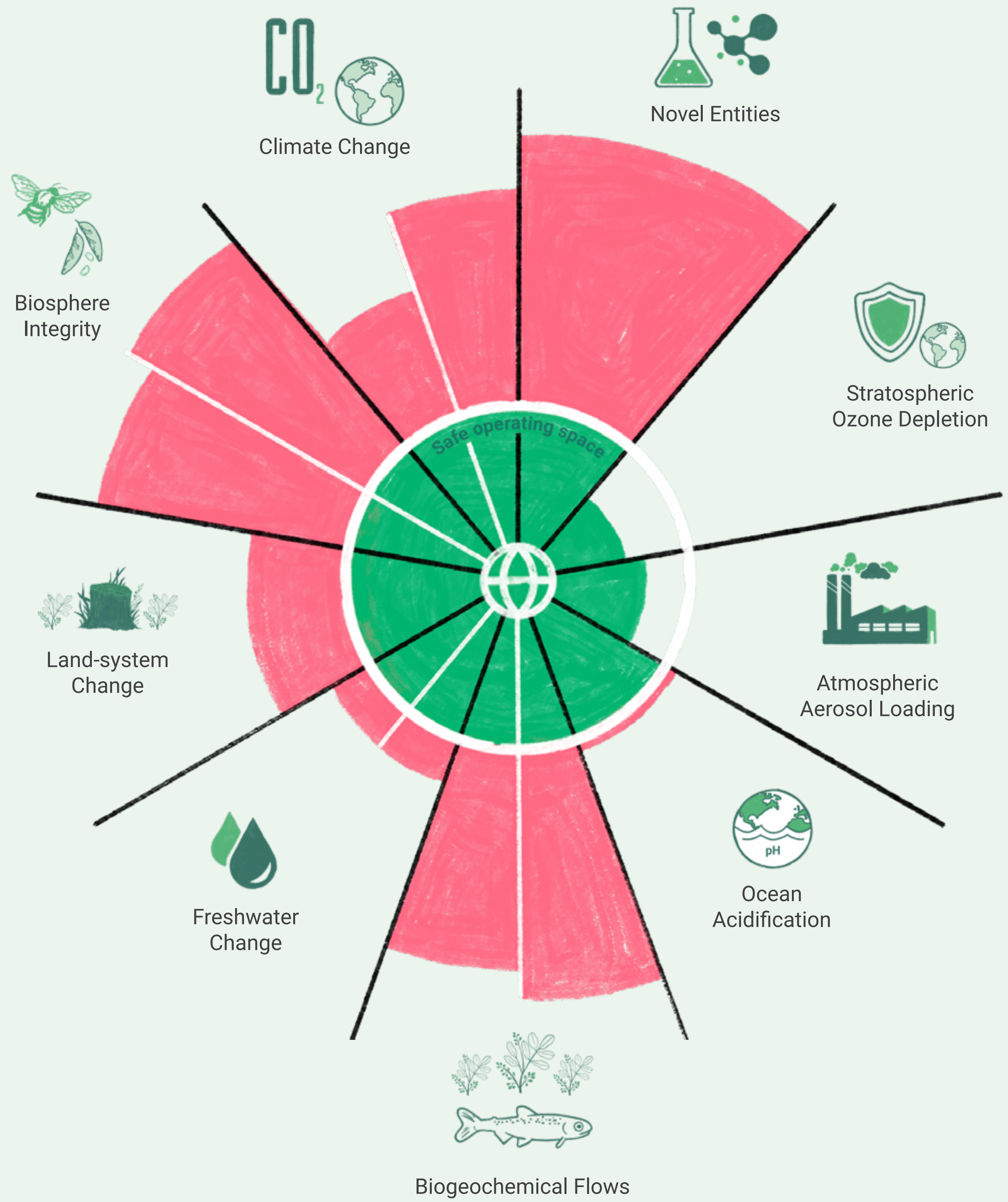
The consequences would also extend beyond Northern Europe, because the AMOC links the North Atlantic and the tropics through heat and freshwater transport, making it a potential amplifier of wider tipping cascades. A weaker AMOC can reduce Atlantic moisture transport into South America and shift the Intertropical Convergence Zone southward, lowering rainfall that helps sustain the Amazon biome. Because large parts of the Amazon depend on an internal moisture recycling network, repeated drought stress can destabilize the system and raise the risk of a self-reinforcing shift toward large scale dieback.[12] Such a transition would release carbon stored in vegetation and weaken key ecological functions, including carbon sequestration, moisture recycling, and habitat provision, with knock on effects for biodiversity given the Amazon's outsized role in global terrestrial biodiversity.[13]

Figure 03
AMOC collapse[14]



6.Rahmstorf, 2024 7.Caesar, 2021; René M. van Westen et al, 2024 8.Sybren Drijfhout, 2025 9.IPCC, 2023 10.Sybren Drijfhout, 2025 11. van Westen RM, 2024 12. Akabane, 2024 13. Planetary Boundaries Science, 2025 14. Planetary Boundaries Science, 2025

Figure 04
State of the planetary boundaries in 2025[15]



15. Planetary Boundaries Science, 2025

The state of the planetary boundaries in 2025

Earth's systems are moving further beyond safe limits, with growing pressure on the foundations that underpin economic activity and human wellbeing.

Recent scientific updates confirm that seven of the nine planetary boundaries are now transgressed, with ocean acidification newly crossing its threshold, signaling increasing strain across interconnected Earth systems. The relevance of these developments is not only scientific, it is strategic. The transgression of planetary boundaries reflects shifts in the underlying systems that shape markets, value chains, long-term growth, and ultimately, human health and wellbeing. For Summa, understanding the state and trajectory of each boundary is essential to identifying where systemic risk is building, where demand for solutions is accelerating, and where capital can be deployed to generate both measurable environmental progress and long-term financial returns.

Rather than viewing boundaries in isolation, we interpret their development through a systems and investment lens, focusing on how they interact, how pressures accumulate across systems, and where change is both necessary and investable. Building on our portfolio analysis, we highlight the boundary processes most relevant to Summa's investment themes and examine the broader consequences for markets, value chains, and societies, with the goal of moving beyond diagnosis and toward identifying where capital can support the transition back toward a safe operating space for humanity.

Climate Change

Emissions hit a new record high, leaving little remaining chance of limiting warming to 1.5°C.

Climate change, in the Planetary Boundaries framework, describes how human activities are pushing the planet's temperature system away from the relatively stable conditions in which human societies developed. It depends on keeping a steady balance between energy coming in from the sun and heat escaping back to space, a balance that is strongly influenced by the buildup of carbon dioxide, methane and other heat trapping gases, and by how much heat the ocean absorbs. When we burn fossil fuels and clear forests and other ecosystems, these gases accumulate and trap extra heat, shifting rainfall patterns, raising sea levels, and increasing the risk of damaging extremes such as heatwaves and droughts.

Where we stand today

The planet's global warming trend continued at an exceptional pace in 2025. Copernicus Institute records 2025 as the world's third warmest year, at about 1.47°C above the 1850 to 1900 reference period. For the first time, the three-year average for 2023 to 2025 has now exceeded 1.5°C.[16] A decade after the Paris Agreement, the rate of global emissions growth has slowed sharply compared to the decade before 2015, but absolute emissions are still increasing, and remain far out of line with pathways consistent with 1.5°C and well below 2°C.[17]

The Global Carbon Budget projects 38.1 billion tons of fossil CO_2 in 2025, a new record and 1.1% higher than 2024, with increases across coal, oil, and gas, and total anthropogenic CO_2, including land use change, of about 42.2 billion tons.[18] When accounting for non-CO_2 greenhouse gases, such as methane and emissions from land use change, net anthropogenic GHG emissions amount to ~57.7 $GtCO_2e$.[19] All major CO_2 emitters are projected to increase emissions in 2025, with the United States showing the largest rise at 1.9%, followed by India at 1.4%, and China and the European Union at 0.4% each.[20 21]

At today's emissions levels, the global carbon cycle is being pushed further out of balance and the remaining room for maneuver is shrinking rapidly. The remaining global carbon budget consistent with a 1.5°C pathway is now extremely limited, estimated at roughly 170 billion tons of CO_2, equivalent to around four years of emissions at the current rate.[22] This means the margin for delay has largely disappeared, if emissions do not fall rapidly, the remaining budget is used up within a few years, and every additional ton of CO_2 further increases the scale and duration of overshoot beyond 1.5°C.[23]

Even with full implementation of current Nationally Determined Contributions, the world is still heading for around 2.3 to 2.5°C of warming over this century, while current policies point to about 2.8°C, implying a serious escalation of climate risks and damages. UNEP also notes that a multi decadal exceedance of 1.5°C is now very likely within the next decade, shifting the objective from avoiding overshoot to making it as small and temporary as possible through faster, deeper emissions reductions.[24]

16. Copernicus, 2025 17. Energy and Climate Intelligence Unit, 2025 18. Global Carbon Budget, 2025 19. UNEP, 2025 20. Global Carbon Budget, 2025 21. Hausfather & Friedlingstein, 2025 22. Global Carbon Budget, 2025 23. Global Carbon Budget, 2025 24. UNEP, 2025

Figure 05
Global C02 emissions estimates (fossil and land use) for 1959-2025[25]

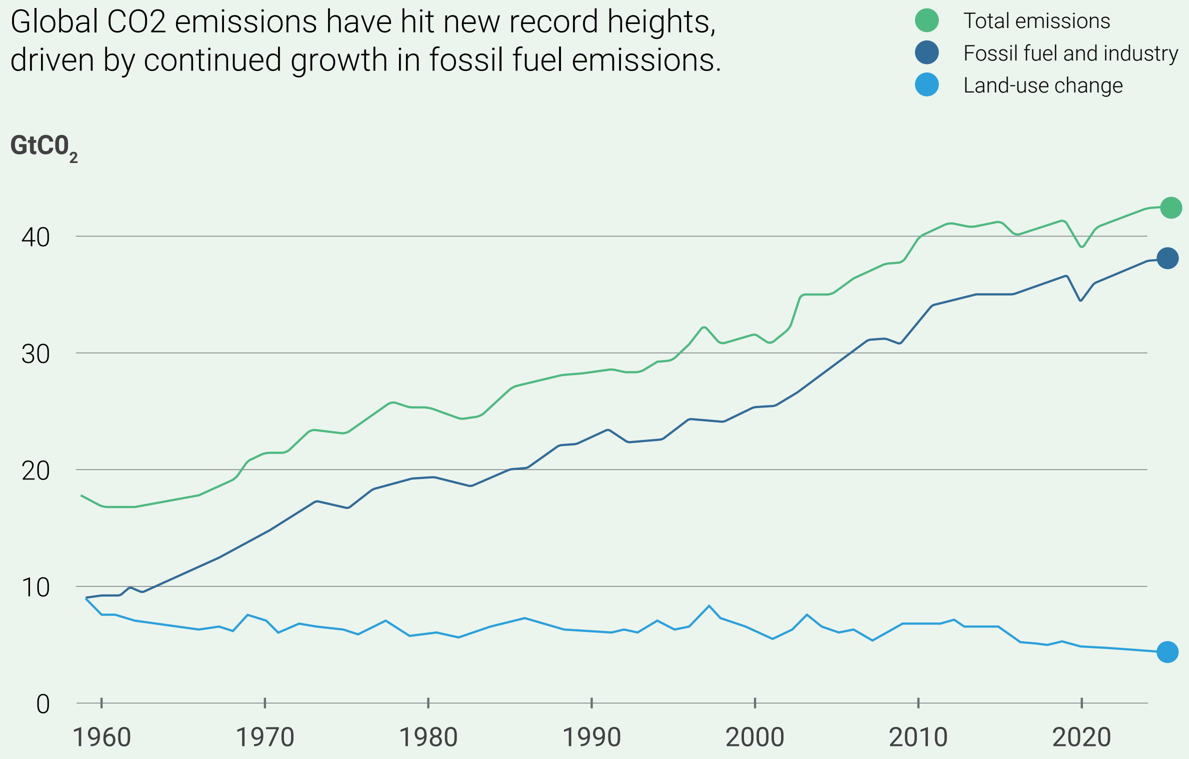
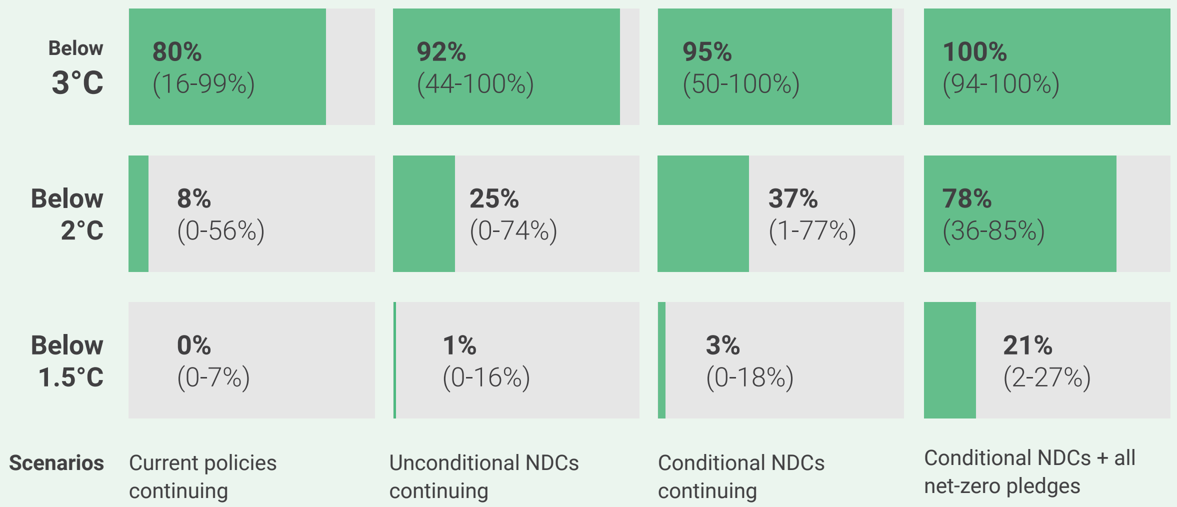


Figure 06
Likelihood of limiting warming below a specific temperature limit (%) over the twenty-first century[26]

Breaching 1.5°C this decade is now very likely, and current policies remain on a trajectory well beyond 2°C.



25. Global Carbon Budget, 2025 26. UNEP, 2025

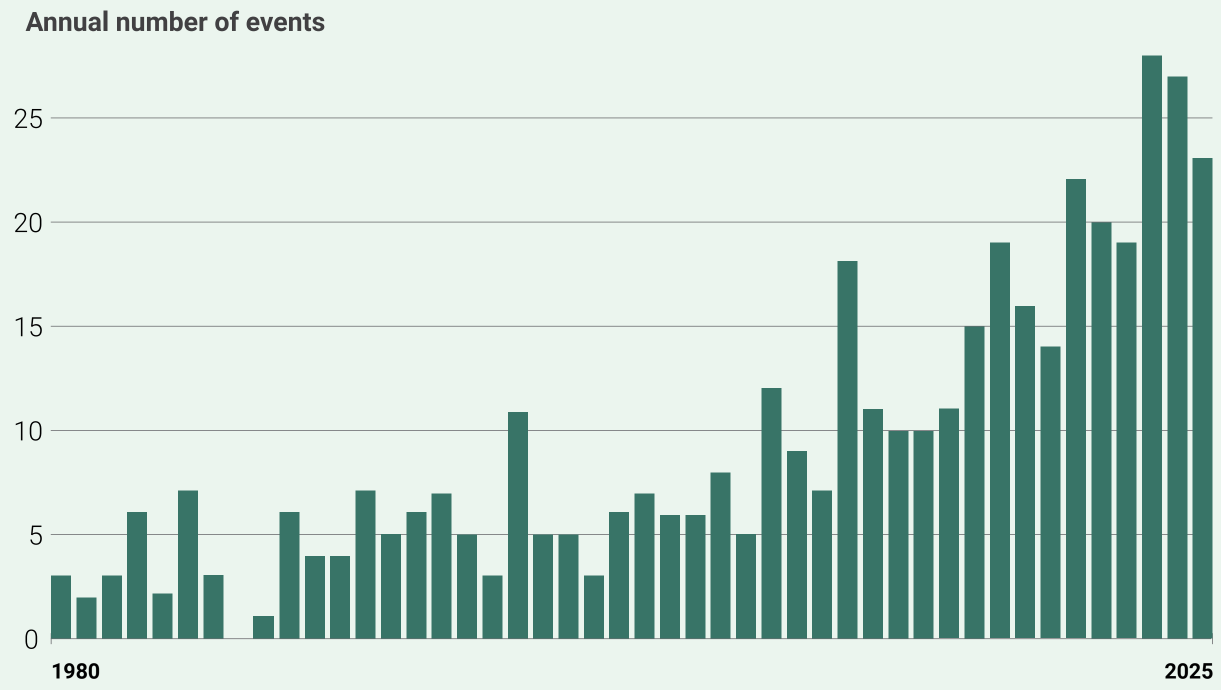
What this means for markets and companies

The physical impacts of climate change are already visible, with direct consequences for people, assets, and economic activity. One of the clearest near-term expressions is the rising cost of extreme weather. In 2025, natural disasters generated roughly USD 260 billion in global economic losses, with about 49 events exceeding USD 1 billion each, highlighting how frequent, high impact events are accumulating into material, recurring damage.[27] More than half of these losses occurred in the United States, reflecting concentrated exposure and high asset values, with the costliest single events including the California wildfires, estimated at around USD 58 billion in economic losses. At the same time, headline global totals can understate the severity of climate impacts for less developed economies, where losses may be smaller in absolute terms but far more disruptive relative to economic capacity and recovery resources. Hurricane Melissa illustrates this asymmetry, preliminary estimates put physical damage in Jamaica at USD 8.8 billion, equal to 41% of the country's 2024 GDP, with broader economic losses expected to be even larger.[28]

The short- and long-term consequences for businesses are increasingly material. Climate driven hazards are translating into operational disruption, and rising litigation. In the US, business interruption lawsuits linked to events such as wildfires, floods, and deep freezes have more than doubled over the past decade, from about 290 to nearly 640 cases per year.[29] Recent corporate disruptions show how quickly local hazards can cascade through value chains. Porsche cut its 2024 revenue outlook by over USD 1bn after flooding at a key European aluminum supplier triggered shortages of specialized alloys and threatened weeks of production disruption.[30] Looking-ahead, World Economic Forum estimates that climate hazards, primarily extreme heat, could drive roughly USD 560 billion to USD 610 billion in annual fixed asset losses across listed companies by 2035, or an average of 6.6% to 7.3% losses relative to EBITA, with knock on effects that extend well beyond physical damage into supply chain continuity, productivity, and earnings stability.[31]

Figure 07
Annual number of billion-dollar weather and climate disasters (CPI-adjusted) that impacted the U.S.[32]

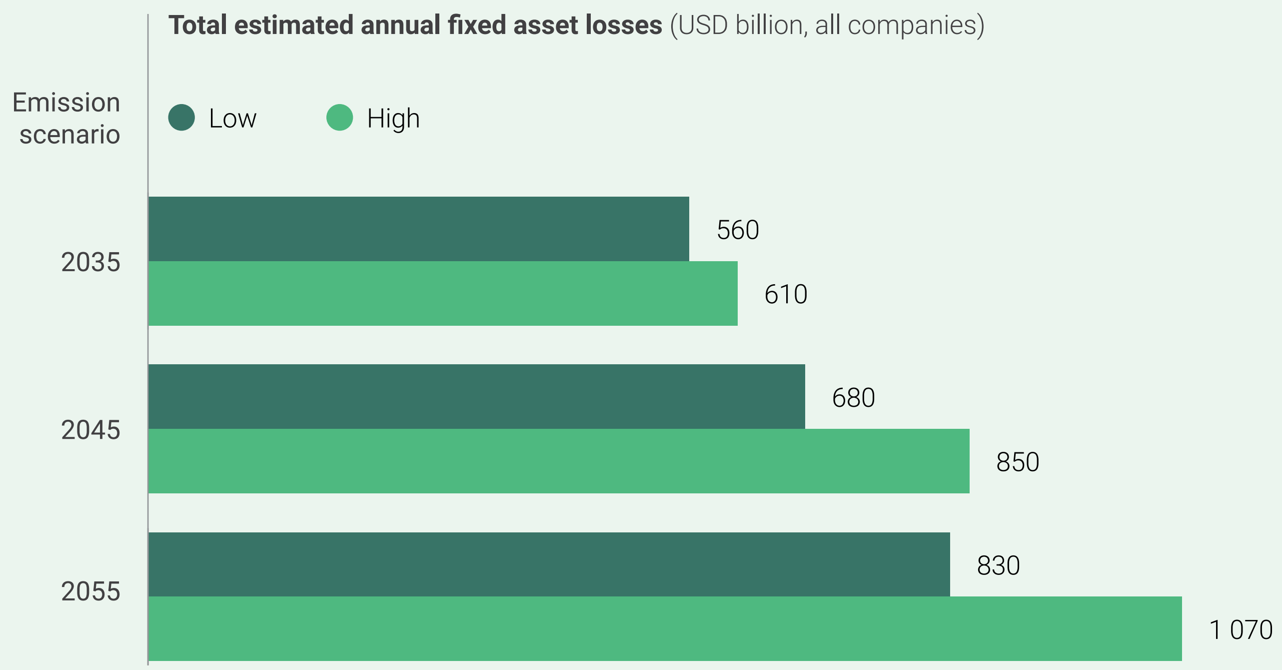
The US has now seen three consecutive years of >25 weather and climate disasters with more than USD 1 billion in damages.

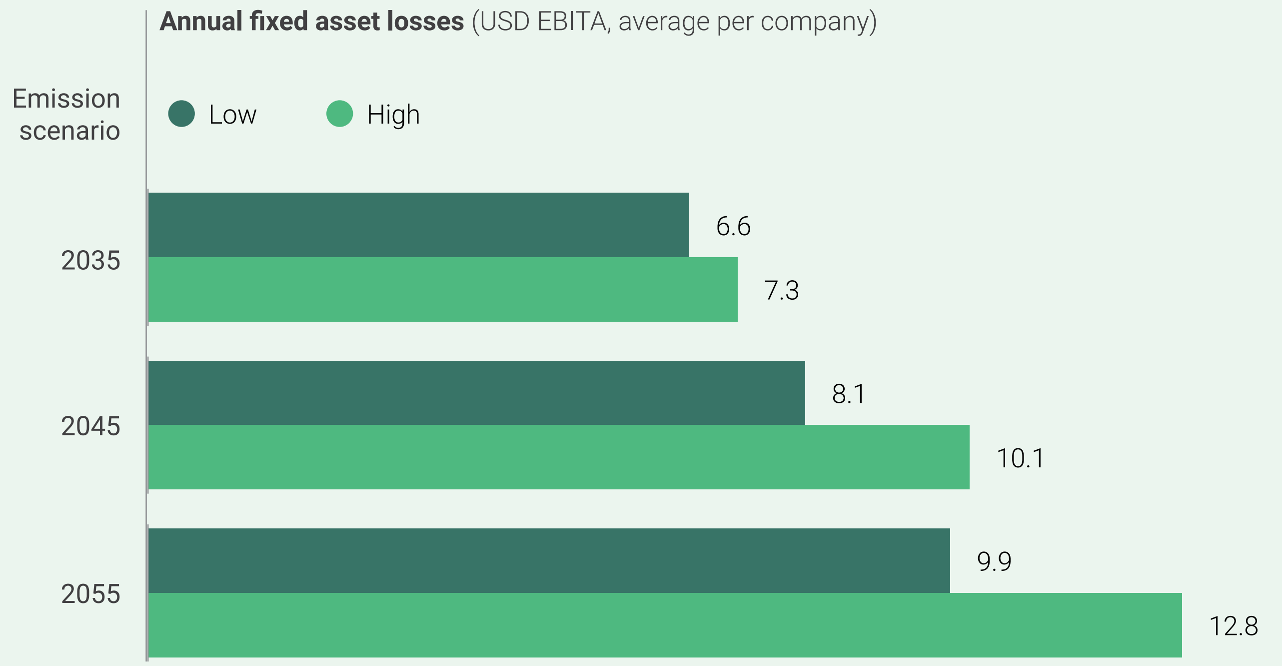


27. World Bank, 2025 28. Climate Central, 2025 29. Financial Times, 2026 30. Dr. Ing. h.c. F. Porsche Aktiengesellschaft, 2024 31. World Economic Forum, 2024
32. Climate Central, 2025

Figure 08
Summary of estimated annual fixed asset losses.[33]

Annual climate-driven fixed asset losses could reach USD 1tn by 2055, with higher emissions amplifying both aggregate and company-level exposure.





33. World Economic Forum, 2024

Stratospheric Ozone Depletion

The ozone layer is the only planetary boundary to have been reversed through sustained reductions in human pressure.

Stratospheric ozone depletion tracks the concentration of ozone in the upper atmosphere, where it forms a protective layer that shields life on Earth from the Sun's harmful ultraviolet radiation. Human-made chemicals, particularly chlorofluorocarbons (CFCs) used in refrigerants and aerosols, break down ozone molecules when they reach the stratosphere, thinning this layer and exposing ecosystems, crops, and human health to elevated UV levels. As the ozone layer weakens, its ability to regulate the amount of UV radiation reaching Earth's surface diminishes, with cascading consequences for biodiversity, food systems, and the stability of the broader Earth system.

Where we stand today

The stratospheric ozone boundary is currently within the safe operating space, with the global mean extra-polar ozone concentration sitting at approximately 286 Dobson Units (DU) against a planetary boundary of 277 DU and a pre-industrial reference level of 292 DU. This places it as the planetary boundary with the most room between current conditions and the boundary threshold, and the only one where deterioration has been measurably reversed.[34]

From the late 1970s through the mid-1990s, the stratospheric ozone layer declined rapidly across all latitudes outside the tropics, driven by the accumulation of chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODS) released through decades of industrial use in refrigerants, aerosols, and fire suppressants. At their peak, these chemicals thinned the ozone layer sufficiently to allow a measurable increase in ultraviolet radiation reaching the Earth's surface. Over Antarctica, a seasonal ozone hole opened each spring that by the early 1990s covered an area roughly comparable to North America, with ozone concentrations falling to levels that doubled surface UVB exposure in affected regions.[35]

The scale of industrial CFC use that drove this deterioration was immense. From the 1950s onward, global production of ozone-depleting substances increased substantially decade by decade, reaching a peak in the late 1980s. CFC-11 alone, one of the most widely used compounds, was produced at around 400,000 tons per year at its late-1980s peak, and an estimated 10 million tons of CFC-11 had been produced in total by 2010.[36] Because CFCs are chemically inert in the lower atmosphere and persist for decades, their chlorine content continued accumulating in the stratosphere long after ground-level emissions began to slow, with total stratospheric chlorine from ozone-depleting substances not peaking until 1993.[37]

16 34. Planetary Boundaries Science, 2025 35. NASA Ozone Watch, 2020; Ritchie et al., 2023 36. UNEP Ozone Secretariat, 2019 37. WMO/UNEP, 2022

Elevated UVB radiation reaching the surface increased the incidence of skin cancers, cataracts, and immune suppression across human populations. Skin cancer is today the world's most common cancer, and incidence rates rose substantially through the latter part of the 20th century, with melanoma rates increasing 4% to 5% annually among fair-skinned populations during the peak depletion period.[38] In the United States alone, skin cancer treatment now costs more than USD 8 billion annually, and a 10% reduction in stratospheric ozone is estimated to cause approximately 300,000 additional skin cancer cases globally.[39] Modeling of a world without any controls on ozone-depleting substances estimates that, in the United States alone, uncontrolled depletion would ultimately have caused approximately 443 million additional cases of skin cancer and 2.3 million additional deaths from skin cancer among people born between 1890 and 2100.[40] Beyond human health, elevated UVB suppressed photosynthesis in phytoplankton, the microscopic organisms at the base of marine food webs, with estimates suggesting that a 16% ozone depletion could result in a 5% loss in phytoplankton productivity, equivalent to a loss of around 7 million tons of fish per year.[41]

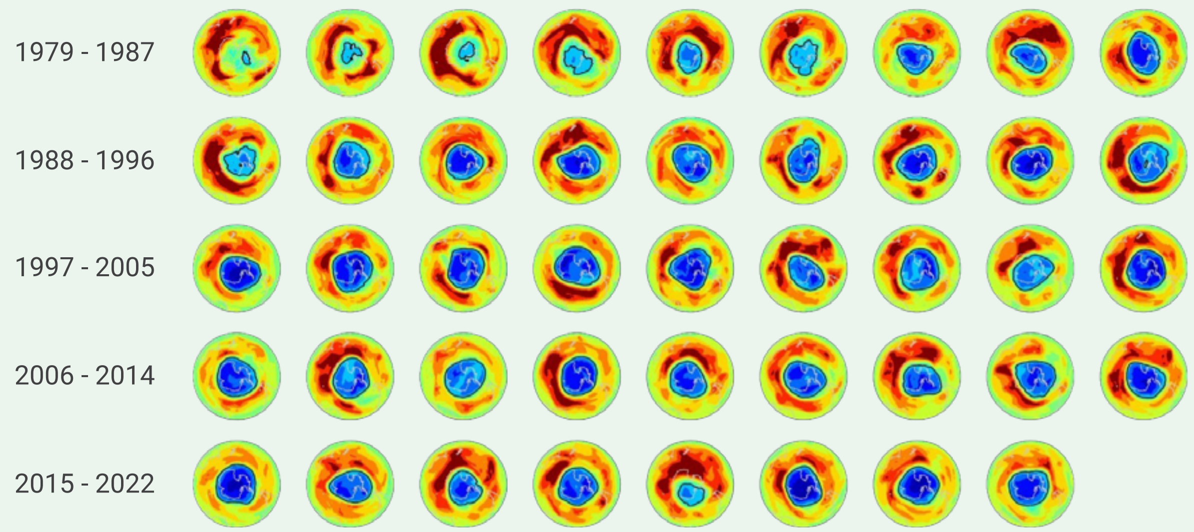
Without global regulation of CFCs and ozone-depleting substances, the resulting rise in UVB radiation would cause an estimated

443 million

additional cases of skin cancer in the United States alone [42]

Figure 09
Annual ozone hole over Antarctica, 1979–2022: blue and purple areas indicate severe ozone depletion.[43]

Rapid expansion of the Antartic ozone hole through the 1990s and early 2000s, followed by gradual stabilization as CFC phase-outs take effect.



38. Matthews et al., 2017 39. Parker, 2021 40. Madronich et al., 2021; UNEP, 2021 41. UNEP, 1994 42. Madronich et al., 2021 43. Copernicus Atmosphere Monitoring Service, 2023

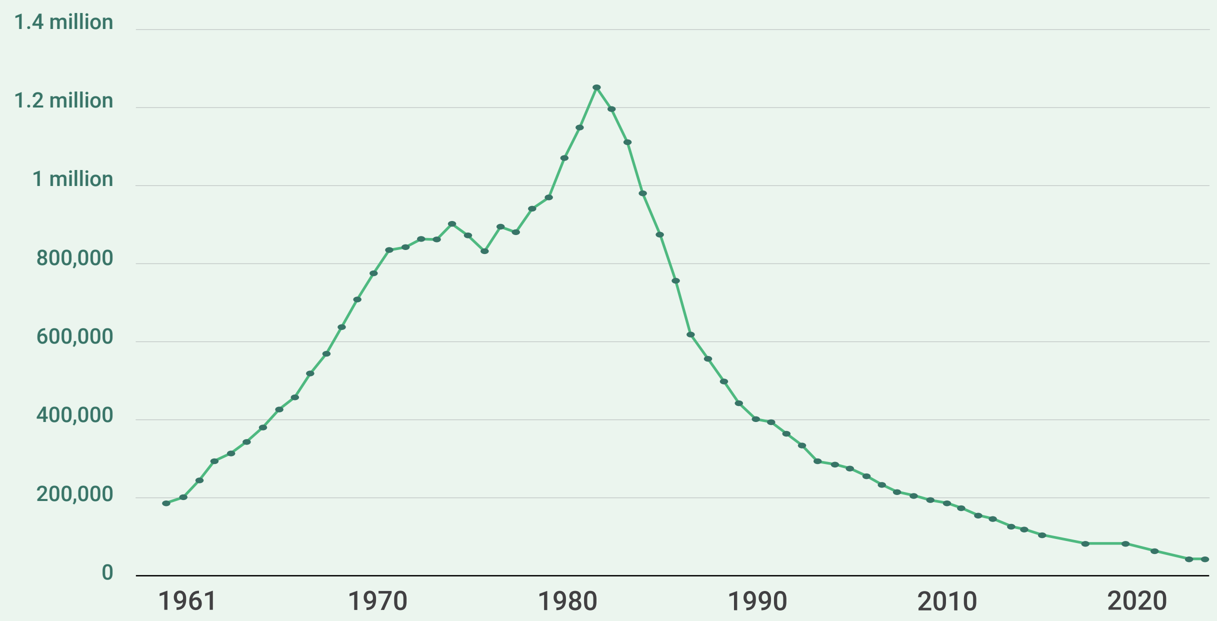
How we solved it

The response to ozone depletion stands as one of the most effective examples of coordinated international environmental action in history. Signed in 1987 and entering into force in 1989, the Montreal Protocol on Substances that Deplete the Ozone Layer became the first treaty in United Nations history to achieve universal ratification, with 197 countries committing to phase out the production and consumption of controlled ozone-depleting substances. Crucially, the Protocol was strengthened through successive amendments, with the Copenhagen Amendment of 1992 accelerating phase-out timelines and broadening the scope of controlled substances. As a result, global emissions of ozone-depleting substances have fallen by more than 99% since the Protocol entered into force, with the production of CFC-11 declining from a peak of around 400,000 tons per year in the late 1980s to near zero today.[44] Total stratospheric chlorine, the key driver of ozone destruction, has decreased by approximately 15% since its peak in the early 1990s, and the Antarctic ozone hole has been slowly improving in both area and depth since 2000.[45] If current policies remain in place, the ozone layer is expected to recover to 1980 levels globally by around 2040, over the Arctic by 2045, and over the Antarctic by 2066.[46]

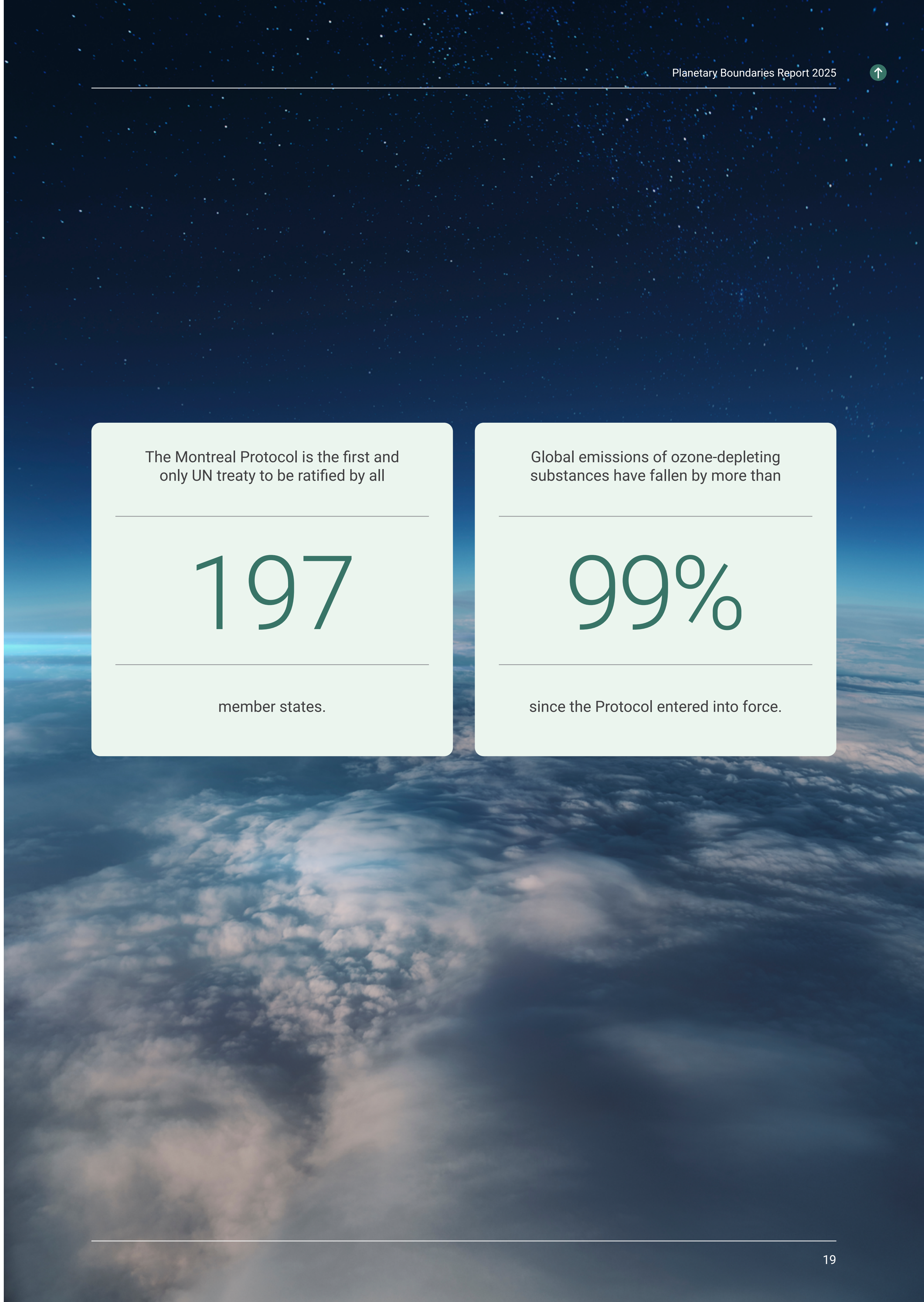
Protection of the ozone layer has also delivered an estimated USD 460 billion in avoided damages to agriculture, fisheries, and materials between 1987 and 2060, by limiting the UV-driven losses to plant productivity and marine ecosystems that unchecked depletion would have caused.[47] Because most ozone-depleting substances are also potent greenhouse gases, with common CFCs carrying global warming potentials more than 10,000 times that of carbon dioxide, the phase-out delivered a significant and largely unplanned climate benefit: between 1990 and 2010 alone, the Protocol prevented greenhouse gas emissions equivalent to approximately 135 billion tons of CO_2, representing one of the largest single contributions to climate protection ever achieved.[48] Research further suggests that by protecting terrestrial vegetation from UV damage, the Protocol may have preserved between 325 and 690 billion tons of carbon stored in plants and soils that would otherwise have been lost, potentially avoiding an additional 0.5 to 1.0 degrees of warming by the end of the century.[49]

Figure 10
Global emissions of ozone-depleting substances, 1961–2022 (tons)[50]

Global CFC emissions climbed steadily for two decades before the Montreal Protocol triggered a sharp and sustained decline.



44. Ritchie et al., 2023; UNEP Ozone Secretariat, 2019 45. WMO/UNEP, 2022 46. WMO/UNEP, 2022 47. UNEP, 2022 48. UNEP, 2021; Velders et al., 2007 49. Young et al., 2021 50. Ritchie, Roser, & Rosado, 2023



The Montreal Protocol is the first and only UN treaty to be ratified by all

197

member states.

Global emissions of ozone-depleting substances have fallen by more than

99%

since the Protocol entered into force.

Atmospheric Aerosol Loading

Harmful aerosol pollution is declining globally, a rare positive signal in a worsening planetary picture.

Atmospheric aerosol loading describes the concentration of fine particles suspended in the atmosphere and their capacity to influence the energy balance, water cycle, and climate stability of the Earth system. Aerosols originate from natural processes, such as volcanic eruptions, desert dust, and wildfires, as well as from human activities, including fossil fuel combustion and biomass burning. They interact with solar radiation and clouds, altering temperature patterns and precipitation across the globe. When aerosol distribution becomes strongly asymmetric between hemispheres, it shifts major rainfall bands and weakens the tropical monsoon systems that billions of people and ecosystems depend upon, increasing the risk of disrupting the climatic and hydrological processes that underpin Earth system stability.

Where we stand today

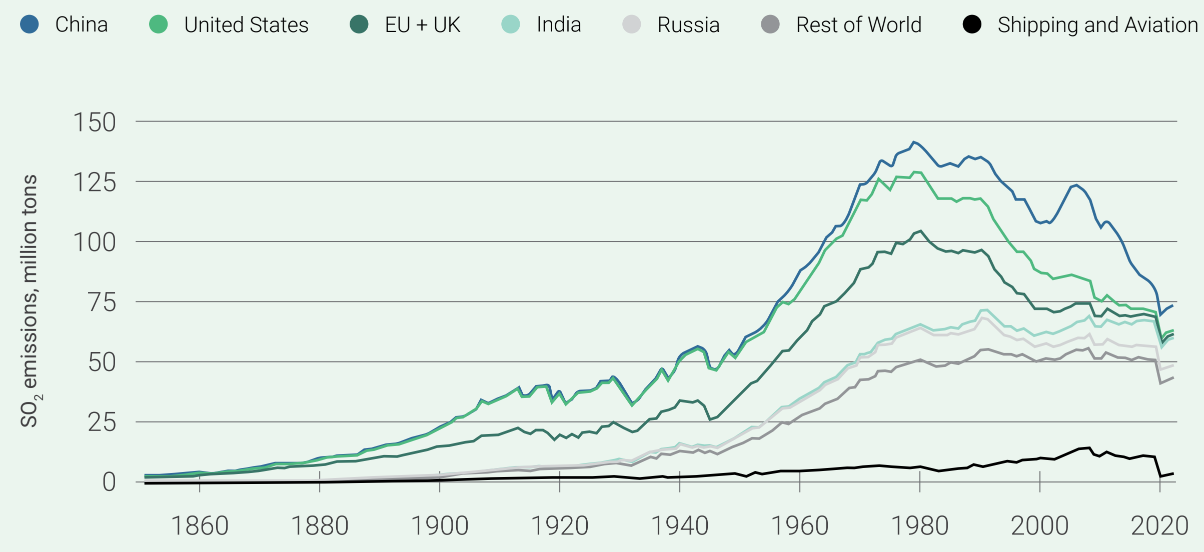
Atmospheric aerosol loading currently remains within the safe operating space. The control variable, the annual mean interhemispheric difference in aerosol optical depth (AOD), stands at approximately 0.063, well below the planetary boundary of 0.1 and roughly double the pre-industrial Holocene baseline of around 0.03.[51] The interhemispheric AOD difference has been declining steadily since around 2010, and global SO_2 emissions, the primary precursor of cooling sulfate aerosols, have fallen by around 40% since the mid-2000s.[52] Humanity appears to be moving further into the safe operating space for this boundary, making it one of only two planetary boundaries showing an improving global trend.

Unlike greenhouse gases, which persist in the atmosphere for decades to centuries, aerosols have an atmospheric lifetime of only days to weeks before being removed through wet and dry deposition. This short residence time means that changes in emissions are reflected relatively rapidly in atmospheric loading, and that aerosol concentrations remain highly heterogeneous in space and time. Because the majority of anthropogenic emissions originate in the Northern Hemisphere, where industrial activity, energy generation, and dense populations are concentrated, the Northern Hemisphere consistently carries a substantially higher aerosol burden than the Southern. This asymmetry generates an uneven distribution of radiative forcing across the planet, producing a relative cooling of the Northern Hemisphere and a corresponding southward shift of the Intertropical Convergence Zone, the equatorial belt of rising air that governs the timing and intensity of monsoon systems across South Asia, West Africa, and the Americas. The observed decline in global land monsoon precipitation between the 1950s and the 1980s has been partly attributed to this human-driven hemispheric aerosol imbalance.[53]

Despite the improving global trend, the regional picture remains deeply concerning. In southern Asia, mean AOD values of 0.3 to 0.35, and in East China values approaching 0.4, already exceed the provisional regional planetary boundary of 0.25, above which monsoon rainfall is likely to be significantly suppressed.[54] Where monsoon systems are weakened or their timing disrupted, the consequences extend well beyond rainfall deficits. Across South Asia and West Africa, hundreds of millions of people depend on seasonal rains to replenish rivers, recharge groundwater, and sustain rain-fed agriculture. When rains arrive late, fall in shorter and more intense bursts, or fail to reach key agricultural windows, crop yields decline, food prices rise, and rural livelihoods are placed under severe stress. Because agriculture is deeply embedded in the economic structure of these regions, employing large shares of the workforce and underpinning national food security, disruptions to monsoon patterns propagate rapidly through local economies, increasing vulnerability to poverty, displacement, and food insecurity.[55]

Figure 11
Global SO_2 emissions by region, 1850–2020 (Mt SO_2)[56]

S02 emissions have declined rapidly in key regions



51. Richardson et al., 2023; Sakschewski et al., 2025 52. Hausfather, 2025 53. IPCC, 2021 54. Richardson et al., 2023 55. Gadgil & Gadgil, 2006; Clean Air Fund, 2025 56. Hausfather, 2025

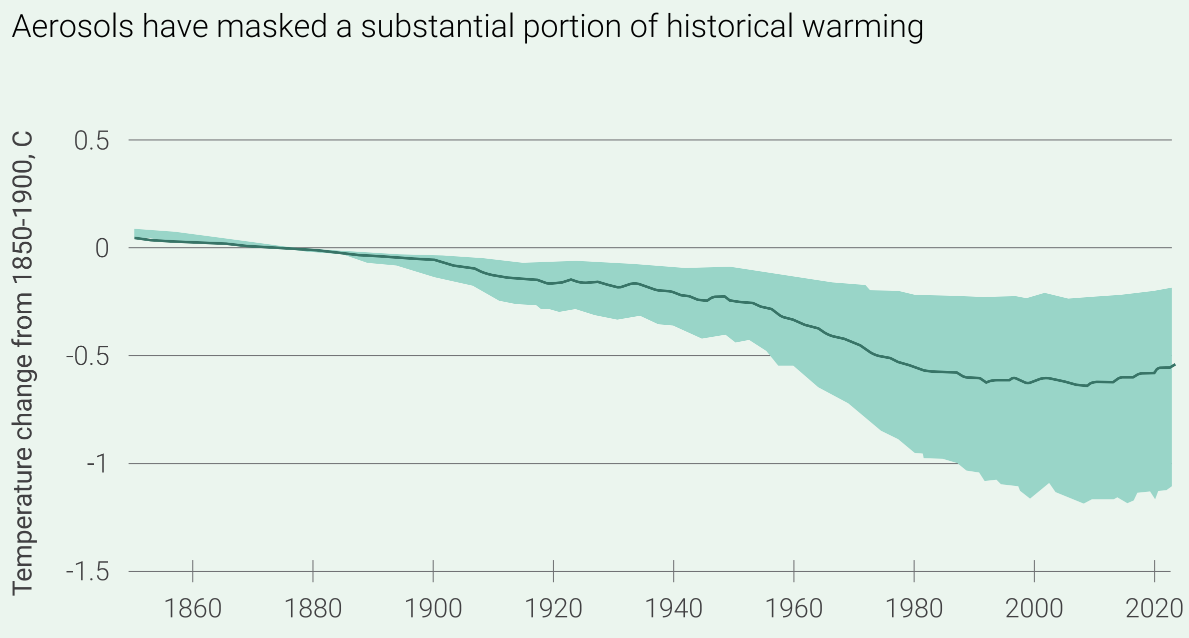
How we solved it

Atmospheric aerosol loading is one of the few planetary boundaries where deliberate human action has produced a measurable and sustained improvement in the global indicator. The declining interhemispheric AOD difference reflects decades of emissions regulation targeting the most concentrated sources of anthropogenic aerosols, primarily sulfur dioxide from power generation, heavy industry, and maritime shipping.

In the United States, the Acid Rain Program established under the Clean Air Act Amendments of 1990 created the world's first large-scale cap-and-trade system for SO_2, setting a binding ceiling on aggregate emissions from coal-fired power plants and allowing facilities to buy and sell allowances to emit. The program delivered results that exceeded its own targets: by 2007, annual emissions had already fallen below the 2010 goal, representing a 43% reduction from 1990 levels despite continued growth in coal-fired electricity generation.[57] Over the three decades that followed, US power sector SO_2 emissions fell by approximately 94%.[58] The European Union pursued parallel trajectories through successive industrial emissions directives, and after 2010 China introduced sweeping clean air policies that led to significant reductions in regional aerosol concentrations, particularly in East Asia.[59] Taken together, these regulatory efforts have contributed to a roughly 40% decline in global SO_2 emissions since the mid-2000s.[60] Maritime shipping has been a more recent and particularly instructive focus of intervention. In January 2020, the International Maritime Organization's IMO 2020 regulation reduced the maximum sulfur content in marine fuel from 3.5% to 0.5%, delivering an estimated 77% reduction in overall sulfur oxide emissions from ships, equivalent to an annual reduction of approximately 8.5 million metric tons of SO_2.[61]

This progress, however, carries an inherent paradox. Sulfate aerosols, while damaging to ecosystems and human health, have simultaneously been masking a substantial portion of greenhouse gas-driven warming. Without their cooling effect, current global temperatures would be approximately 0.5°C higher, placing the world close to 2°C above pre-industrial levels rather than the roughly 1.4°C experienced today.[62] Aerosol emission reductions have also been estimated to have strengthened Earth's energy imbalance by around 0.2 W/m² per decade between 2001 and 2019.[63] The IMO 2020 shipping regulations illustrate the immediacy of this dynamic with particular clarity: the abrupt 80% reduction in sulfur emissions from ships generated a radiative forcing of approximately +0.2 W/m² over the global ocean, concentrated in the North Atlantic and North Pacific shipping corridors, and some researchers have linked this step-change warming impulse to the anomalous ocean temperature spike observed in 2023.[64] One study estimated that IMO 2020 may have accelerated the pace of global warming by approximately two to three years.[65]

Figure 13
Global average surface temperature changes over 1850-2024 caused by aerosols.[66]



57. Stavins, 1998 58. Abel et al., 2021 59. Yang et al., 2024 60. Hausfather, 2025 61. IMO, 2020 62. Hausfather, 2025 63. Hodnebrog et al., 2024 64. Yu et al., 2024 65. Jordan & Henry, 2024 66. Hausfather, 2025

Coordinated regulation of industrial air pollution, from the US Clean Air Act to China's clean air policies and the IMO's 2020 shipping fuel standards, has driven a roughly

40% ↓
decline

in global SO_2 emissions since the mid-2000s.[67]

This progress carries a paradox: sulfate aerosols, while harmful, have also been masking greenhouse gas-driven warming. Without their cooling effect, global temperatures would be roughly

↑ 0.5°C
higher

placing the world close to 2°C above pre-industrial levels rather than the roughly 1.4°C experienced today[68]

67. Hausfather, 2025 68. Hausfather, 2025

Biosphere Integrity

Species loss is accelerating, eroding the genetic diversity and ecosystem services that sustain life on Earth.

Biosphere integrity describes the capacity of ecosystems across the planet to sustain life and to regulate the stability of the Earth system. It depends on the diversity of organisms, the habitats they rely on, and the stability of key nutrients, energy, and water flows within and across ecosystems. When species are lost and habitats are degraded, both genetic diversity and ecosystem functioning decline. As biosphere integrity erodes, the biosphere's capacity to co-regulate and stabilize the state of the planet is reduced, increasing the risk of broader Earth system destabilization.

Where we stand today

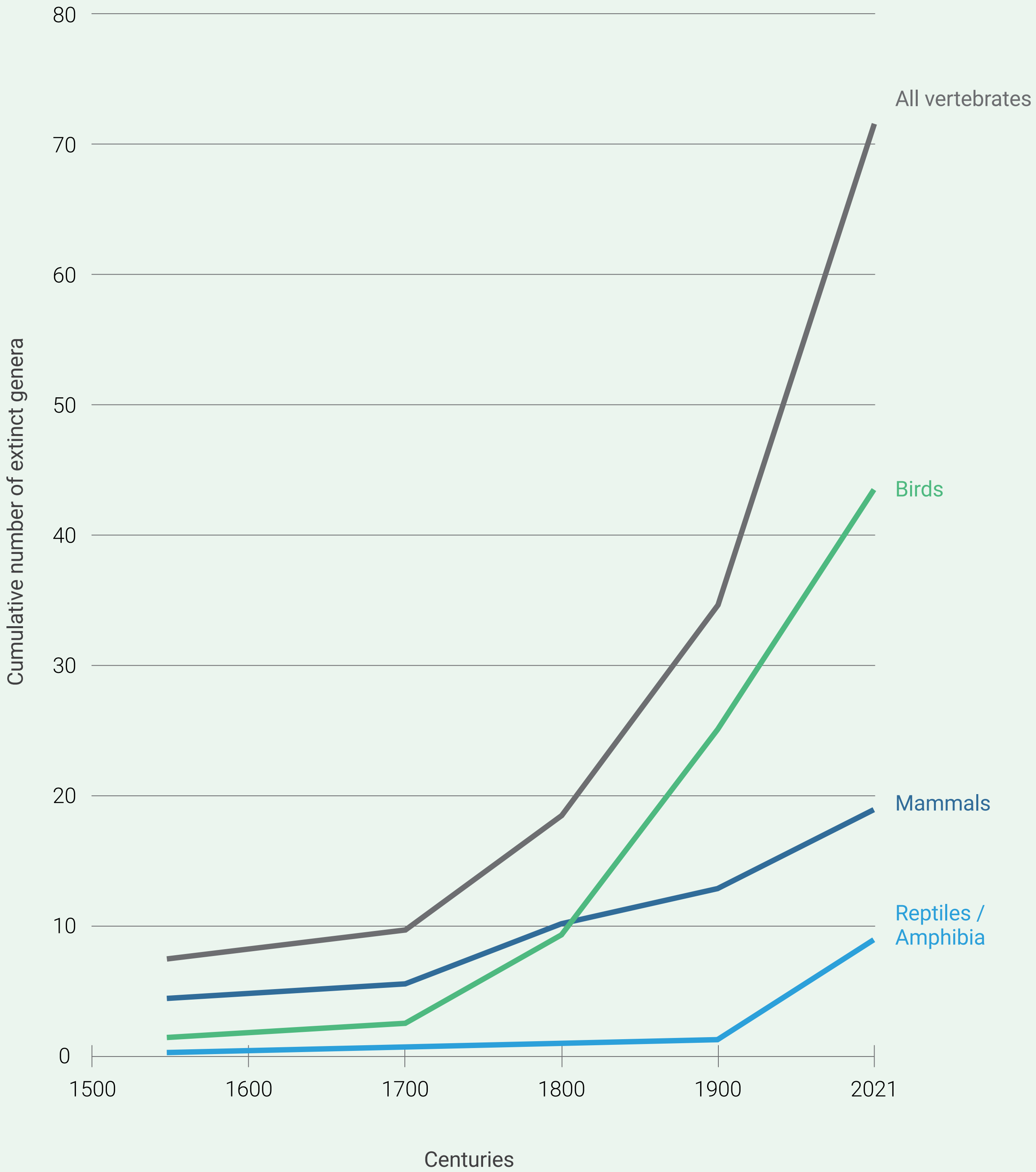
The biosphere integrity boundary is strongly transgressed and shows no clear signs of recovery. Over the past 500 years, at least 73 land vertebrate genera have disappeared. A genus is a taxonomic rank above species that groups closely related species, so the loss of a genus represents the disappearance of an entire evolutionary branch, not just a single species.[69] Based on the historic mammal genus extinction rate, the current vertebrate genus extinction rate is about 35 times higher than the typical rate over the last one million years. Put differently, at the background pace of loss, Earth would likely have lost only around two genera over the past 500 years. Instead, human pressures have driven a wave of genus extinctions in just five centuries that would otherwise have taken roughly 18,000 years to accumulate.[70]

The ongoing decline of monitored wildlife populations suggests maintained pressure and a growing risk of further extinctions. The Living Planet Index reports an average 73% decline in monitored vertebrate population sizes between 1970 and 2020, across almost 35,000 populations of 5,495 species, indicating widespread erosion of population abundance that often precedes extinction.[71] At a broader scale, IPBES concludes that the average abundance of native species has fallen by at least 20% in most major terrestrial biomes since 1900, reflecting sustained pressure on the ecological conditions needed to prevent further losses.[72] Consistent with these trends, the IUCN Red List currently includes 169,420 assessed species, of which 47,187, around 28% , are classified as threatened with extinction, showing that a substantial share of the species evaluated so far are already at elevated risk.[73]

69. Planetary Boundaries Science, 2025 70. Ceballos, 2023 71. WWF, 2024 72. IPBES, 2021 73. IUCN, 2025

Figure 14
Cumulative number of extinctions of genera (closely related species with likely common ancestors) per century in different classes of vertebrates.[74]

Species extinctions are accelerating at an alarming pace globally.



74. Planetary Boundaries Science, 2025

What this means for markets and companies

Despite increasing attention to nature loss, there is still limited understanding of how it affects business performance, partly because nature is often hidden or incorrectly priced in supply chains. Much of nature's value is effectively provided at no direct monetary charge, so it is rarely reflected in market prices, which weakens risk signals and encourages underinvestment in natural assets. As a result, risks can build quietly until ecosystem services become constrained and disruptions become economically visible. For companies, this typically materializes through dependence on ecosystem services for operations and supply chains, impacts that trigger regulation, litigation, reputation, and higher financing costs, and higher disaster losses that feed back into demand and credit risk.

The economic consequences of a collapse of the biosphere integrity boundary are significant because these systems generate ecosystem services that keep production possible and stable, including pollination, soil formation, nutrient cycling, water regulation and purification, pest and disease regulation, fisheries productivity, and the buffering of floods, storms, and heat. An estimated USD 58 trillion of economic value generation, roughly 55% of global GDP, is moderately or highly dependent on nature and its services.[75] In a case of collapse of key ecosystem services, including pollination, marine fisheries, and the provision from tropical forests, global GDP would contract by USD 2.7 trillion, or -2.3%, by 2030.[76]

Reflecting this systemic exposure, biodiversity loss and ecosystem collapse is consistently ranked among the most severe global risks on a 10-year horizon in the World Economic Forum Global Risks Reports and is highlighted as a leading long run threat alongside extreme weather and other Earth system risks.[77]

The risk and potential damage of market failure and economic damage vary across industries and regions. In five industries, essentially all economic value from direct operations is highly dependent on ecosystem inputs and services. Together, these industries account for about 12% of global GDP, more than USD 13 trillion, and at least 50% of their supply chain value is also highly nature dependent, meaning ecosystem disruption can quickly translate into operational losses and cascading supply shocks. The most exposed industries include agriculture, forestry, fishery and aquaculture, food, beverages and tobacco, and construction, with construction the largest contributor, at about USD 6.5 trillion of economic value in direct operations.[78]

Beyond these sectors, 11 additional industries have at least 35% of their economic value tied to moderate or high dependence on nature once both direct operations and supply chains are considered. This reflects "hidden dependencies", where a company may not rely heavily on ecosystems at the point of sale, but depends on nature through upstream inputs such as water, biomass-based feedstocks, and land intensive raw materials. [79]

An estimated USD58 trillion of economic value generation, roughly

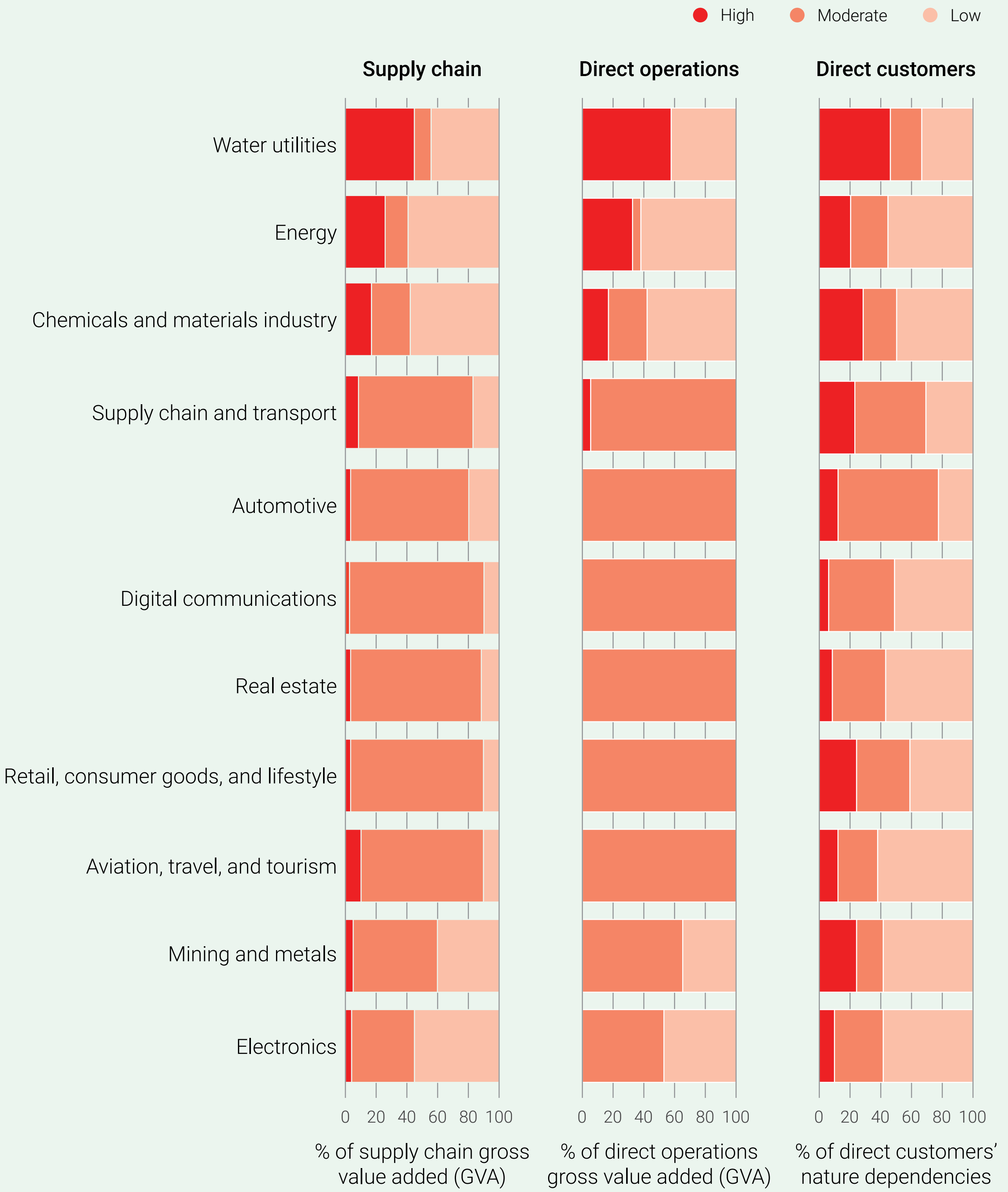
55%

of global GDP, is moderately or highly dependent on nature and its services[80]

 75. World Economic Forum, 2020 76. Johnson, o.a, 2021 77. World Economic Forum, 2026 78. Evison, 2023 79. Evison, 2023 80. World Economic Forum, 2020

Figure 15
Nature dependency across industries by value chain stage (% of gross value added)[81]

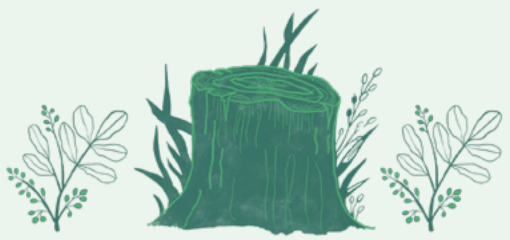
At least 35% of economic value in 11 major industries is dependent on nature, even when direct operations are less exposed.



81. World Economic Forum, 2020

Land System Change

Net forest loss is slowing, but pressure on critical biomes continues, eroding carbon storage, water cycles, and biodiversity.



Land-system change describes the extent to which Earth's natural landscapes are converted or intensively managed through deforestation, agricultural expansion, and urbanization. It shapes the structure of ecosystems and the capacity of land to store carbon, cycle water, and sustain habitats. When forests, wetlands, and other intact areas are cleared or fragmented, biodiversity declines and ecosystem functions weaken, reducing resilience to drought, fire, and other disturbances. As land system change intensifies, it undermines climate regulation and freshwater dynamics, increasing the risk of cascading feedback that destabilizes the Earth system.[82]

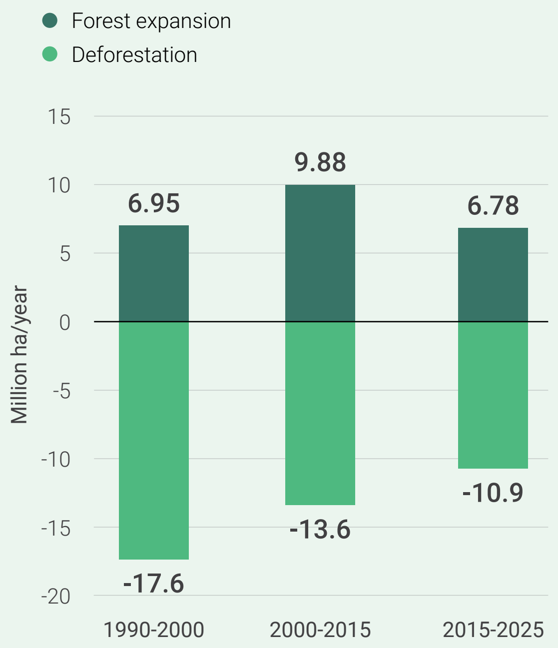
Where we stand today

Today, only about 59% of potential forest cover remains worldwide, far below the levels needed to maintain Earth system stability. Safe levels are estimated at around 85% of original cover for tropical and boreal forests, and 50% for temperate forests, reflecting evidence that tropical and boreal forests have particularly strong effects on regional and remote climate. Driven primarily by agriculture, and increasingly by climate change, forest cover has declined steadily over recent decades across all major biomes. As a result, most regions are now below their boundaries, with areas such as the temperate and tropical Americas having recently crossed them.[83]

Global net forest loss is still negative, but it is now roughly 60% lower than in the 1990s. Net loss has fallen from about 10.7 million hectares per year in the 1990s to around 4.1 million hectares per year in the last decade. This improvement reflects two important developments. Gross deforestation has slowed by 38% compared to the 1990s. At the same time, forest expansion and regrowth has increased, estimated at 6.8 million hectares per year, offsetting a large share of ongoing forest loss. However, the pace of forest expansion eased from earlier peaks, dropping from about 9.9 million hectares to about 6.8 million hectares per year, resulting in persistent net loss.[84]

Figure 16
Annual rates of forest expansion and deforestation, 1990–2025 (million ha/year)[85]

Deforestation is slowing, but forest expansion has not kept pace, leaving persistent net loss.

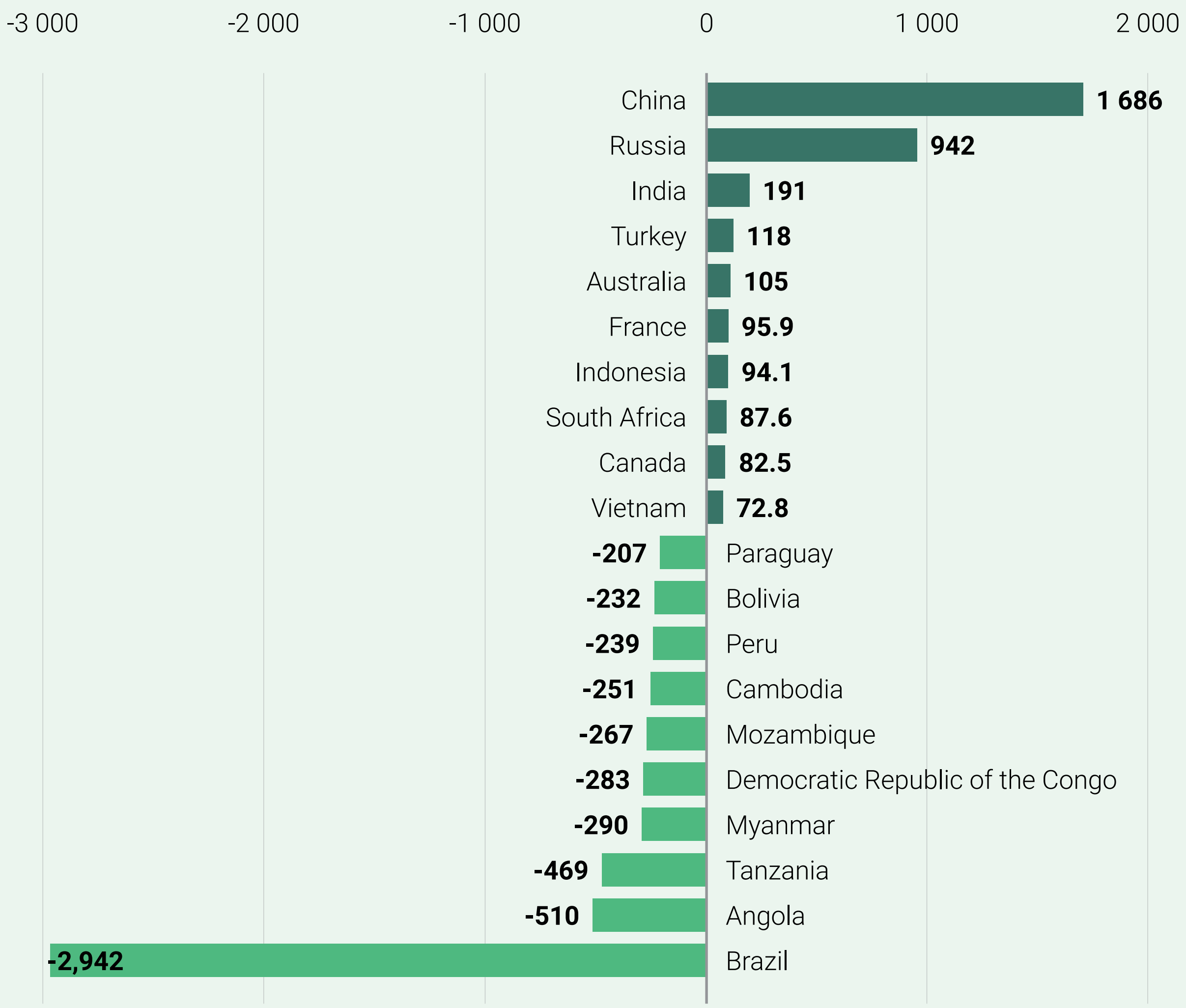


 82. Planetary Boundaries Science, 2025 83. Planetary Boundaries Science, 2025 84. FAO, 2025 85. FAO, 2025

Figure 17
Ten countries with highest net gain and net loss of forest area over 2015-25, in 1,000 hectares per year[86]

State-led afforestation in China is driving significant global forest gains, while agricultural expansion and climate-driven fires continue to erode primary tropical forest in the Amazon.

Ten countries with highest net gain and net loss of forest area over 2015-25, in 1,000 hectares per year



The global picture masks sharp regional differences. China recorded the largest net forest gain worldwide over the past decade, driven by state-led afforestation programs that have planted more than 66 billion trees since the late 1970s,[87] but planted forests in arid regions are not ecologically equivalent to the primary tropical forest being lost elsewhere. One of the key regions for land use change has been the Amazon ecosystem, where primary rainforests deliver outsized benefits for carbon storage, rainfall generation, and biodiversity. Brazil has the largest net forest loss worldwide, averaging about 2.9 million hectares per year in the last decade.[88] Recent policy intervention has caused annual deforestation rates to drop for three consecutive years, with early 2026 data hitting the lowest rate on record.[89] Still, the Amazon remains under significant pressure from ongoing land conversion for agriculture and pasture, illegal clearing, and increasingly from climate related extremes. In 2024, fires accounted for nearly 50% of Brazil's tropical primary forest loss, up from 20% in previous years, illustrating how drought and heat can rapidly erode gains achieved through reduced clearing.[90]

86. Pearson, 2025 87. FAO, 2025; NASA Earth Observatory, 2019 88. FAO, 2025 89. Instituto Nacional de Pesquisas Espaciais, 2026 90. World Resources Institute, 2025

What this means for markets and companies

Deforestation and land-system change is translating into direct and growing financial exposure for businesses. Global forests are valued at USD 50 to 150 trillion, nearly double the value of global stock markets, with 65–90% of that value derived from their role in regulating the climate through carbon capture and storage. If current threats are not addressed, forest value is projected to decline by 30% by 2050, with land-use change and rising temperatures accounting for roughly 70% of projected losses.[91]

Continued forest loss undermines the ecosystem services on which large parts of the global economy depend. Forests regulate water flows, stabilize soils, buffer against floods and droughts, purify air and water, and support the pollination systems that underpin agricultural productivity. As these services erode, businesses face rising operational costs, less predictable input supply, and greater exposure to extreme weather. The consequences are already visible. In 2024, 6.7 million hectares of primary rainforest were lost, nearly double the previous year and the highest level in two decades, releasing an estimated 3.1 gigatons of CO_2, more than three times the annual emissions of the entire EU transport sector, and accelerating the self-reinforcing feedback between forest loss and climate instability.[92] Food and agriculture, construction, and consumer goods are among the most nature-dependent industries globally, with material exposure across operations, procurement, and asset values[93]. An estimated 24% of global corporate revenue is linked to forest-risk commodities, yet only 7% of companies assessed in 2024 by CDP could demonstrate that at least one commodity supply chain was fully deforestation-free[94] , leaving a significant gap between exposure and preparedness. Deforestation-driven disruptions to water availability, soil quality, and local climate conditions are increasingly affecting agricultural yields and supply chain reliability in the regions where many of these commodities are produced, meaning that even companies with no direct forest footprint face indirect exposure through upstream dependencies.

These risks are amplified by the role forests play in the global carbon cycle. Forests remove CO_2 from the atmosphere through photosynthesis and store it as carbon stock in living biomass, deadwood and litter, and especially in soils. In 2025, global forest carbon stock across all carbon pools was estimated at about 714 gigatons of carbon, with nearly half stored in soils.[95] In a typical year, forests and other vegetation absorb roughly 30% of human CO_2 emissions from fossil fuels, with roughly 40% of global terrestrial carbon stored in tropical rainforests.[96] However, annual emissions from deforestation and decay now exceed the amount of carbon forests absorb, meaning forests have already become net carbon emitters at the global level.[97] Without action, forest emissions could rise to 15 $GtCO_2$ per year by 2050, more than China's current annual emissions. As forests shift from carbon sink to carbon source, they accelerate the very climate instability that is already driving physical asset losses, supply chain disruptions, and rising insurance and recovery costs across the global economy.

Roughly

40%

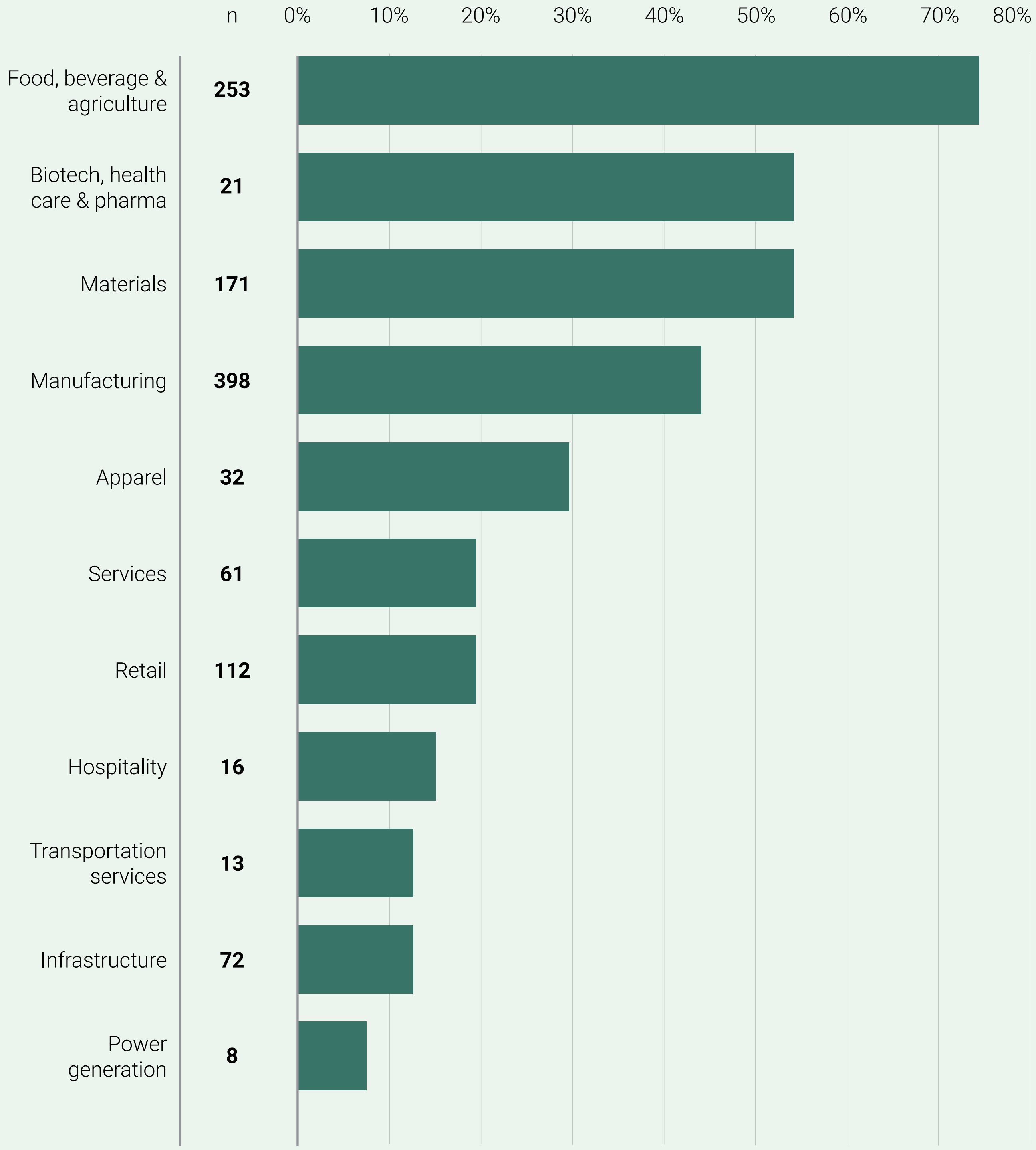
of global terrestrial carbon stored in tropical rainforests.[98]

 91. BCG, 2020 92. WRI, 2025 93. PwC, 2023 94. CDP, 2018; CDP, 2024 95. FAO, 2025 96. Harris, 2025; Yale, 2025 97. BCG, 2020 98. Yale, 2025

Figure 18
Median reported revenue dependence on deforestation-risk commodities reported per CDP industry[99]

Deforestation exposure reaches far beyond primary commodities, running through the raw materials and ingredients sourced across global supply chains.

Median revenue dependence across commodities



99. CDP, 2025

Freshwater Change

Freshwater systems are under mounting pressure, with only one-third of global river basins in normal condition and the UN declaring a new era of global water bankruptcy.

Freshwater change is the planetary boundary that tracks how much human activity is disrupting the way freshwater moves and is stored across land, and between land and the atmosphere. When we take too much water, reshape rivers, change landscapes, or shift rainfall patterns, water becomes less reliable, and nature's ability to support life, store carbon, and maintain biodiversity can weaken. This boundary looks at two parts of freshwater, blue water and green water. Blue water is the water in rivers, lakes, wetlands, reservoirs, and underground stores that people can withdraw and use directly. Green water is the moisture held in soils that plants depend on, and it also supports rainfall through evaporation from land.

Only about one

1/3

of global river basins had "normal" conditions in 2024[103]

Where we stand today

Today, the freshwater change boundary is assessed to be beyond the safe operating space in both of its dimensions, blue water and green water. Anomalously wet or dry conditions now occur across roughly double the land area seen under a pre-industrial like state, with both blue and green water crossing their boundaries around 1940 and continuing to rise since then, reflecting a water cycle that is becoming less stable and more extreme.[100] Only about one third of global river basins had "normal" conditions in 2024, with the rest either above or below average, marking another year of imbalance between drought and flood risks.[101] At the same time, natural wetlands have declined by roughly 410 million hectares, an area nearly equal to the size of the European Union, eroding nature's capacity to buffer droughts and floods.[102]

Natural wetlands have declined by roughly

410 million

million hectares, an area nearly equal to the size of the European Union[104]

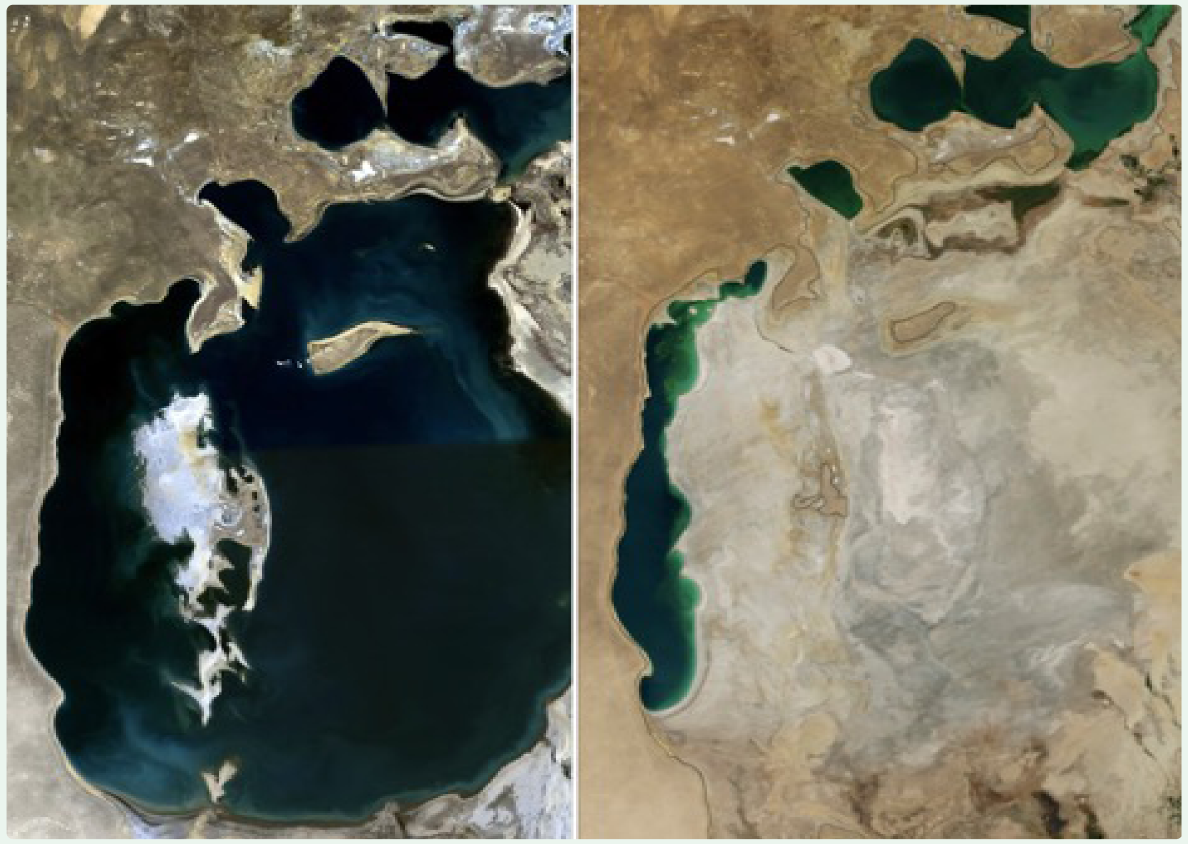
100. Planetary Boundaries Science, 2025 101. WMO, 2024 102. UNU-INWEH, 2026 103. Planetary Boundaries Science, 2025 104. UNU-INWEH, 2026

The drivers of this transgression operate across multiple fronts. Agriculture accounts for approximately 72% of global freshwater withdrawals[105], and continued irrigation expansion is increasing pressure on rivers and aquifers across water-stressed regions. Dam construction has altered natural flow regimes across the world's major river systems, changing the timing and quantity of water reaching downstream ecosystems.[106] Deforestation disrupts the freshwater cycle by reducing soil moisture and weakening atmospheric moisture recycling, connecting the freshwater change boundary directly to land-system change.[107] Climate change amplifies these pressures by intensifying the hydrological cycle, driving more extreme precipitation events alongside longer and more severe droughts.[108] The scale of the resulting disruption is significant. Local streamflow deviations now occur on 18.2% of global land area, equivalent to approximately 24 million square kilometers, representing a 94% increase from pre-industrial conditions. Soil moisture deviations affect 15.8% of global land area.[109]

In January 2026, the UN argued that this disruption has moved beyond a temporary crisis and into an era of global water bankruptcy, a persistent condition where withdrawals and pressures on water dependent ecosystems outstrip nature's ability to recover within relevant timeframes and available budgets.[110] Groundwater loss is a particularly stark signal: aquifers now supply about 50% of domestic water use and over 40% of irrigation water, yet around 70% of major aquifers show long-term declining trends, and excessive pumping has contributed to land subsidence across more than 6 million square kilometers, permanently reducing storage capacity and increasing flood risk.[111] More than half of the world's large lakes have lost water since the early 1990s, affecting nearly a quarter of the global population that depends on them directly.[112]

Figure 19
NASA satellite image of Aral sea.[113]

The shrinking of the world's third largest lake: The Aral Sea in 1989 and 2014.



105. FAO, 2025 106. Porkka et al., 2024 107. Wang-Erlandsson et al., 2022 108. WMO, 2024 109. Porkka et al., 2024 110. UNU-INWEH, 2026 111. UNU-INWEH, 2026 112. UNU-INWEH, 2026 113. NASA; collage by Producercunningham, Wikimedia Commons

What this means for markets and companies

Freshwater change is now a direct economic and societal risk, because the same forces that push water systems beyond a safe range also undermine the foundations that economies rely on, including stable food production, industrial output, and infrastructure resilience. The total quantifiable economic use value of water and freshwater ecosystems is estimated at about USD 58 trillion in 2021, roughly 60% of global GDP, with ecosystem functions such as purification, flood and drought buffering, and soil health underpinning around USD 50 trillion per year.[114] Around 10% of global GDP is currently generated in regions facing high water risk, and climate and socioeconomic pressures could amplify this exposure to 46% by 2050.[115]

The critical vulnerability is that water risk is not evenly distributed but concentrated in a small number of basins and production regions on which the global economy disproportionately depends. Just 10 countries produce 72% of the world's irrigated crops, and two-thirds of that production faces high to extremely high water stress, meaning disruption in a small set of basins can propagate rapidly into global markets.[116] Fresh water demand is expected to outpace supply by 40% by 2030,[117] tightening conditions further in exactly the regions where production is already concentrated. Across the broader economy, cumulative water-related losses from droughts, floods, and storms could reach USD 5.6 trillion between 2022 and 2050, with manufacturing and distribution the most heavily affected sector at over USD 4.2 trillion, because water scarcity restricts industrial processes while flooding damages assets and disrupts logistics networks.[118] 69% of listed companies sharing data with CDP report exposure to substantive water risks, yet integrating water stewardship into risk management remains the exception rather than the norm.[119]

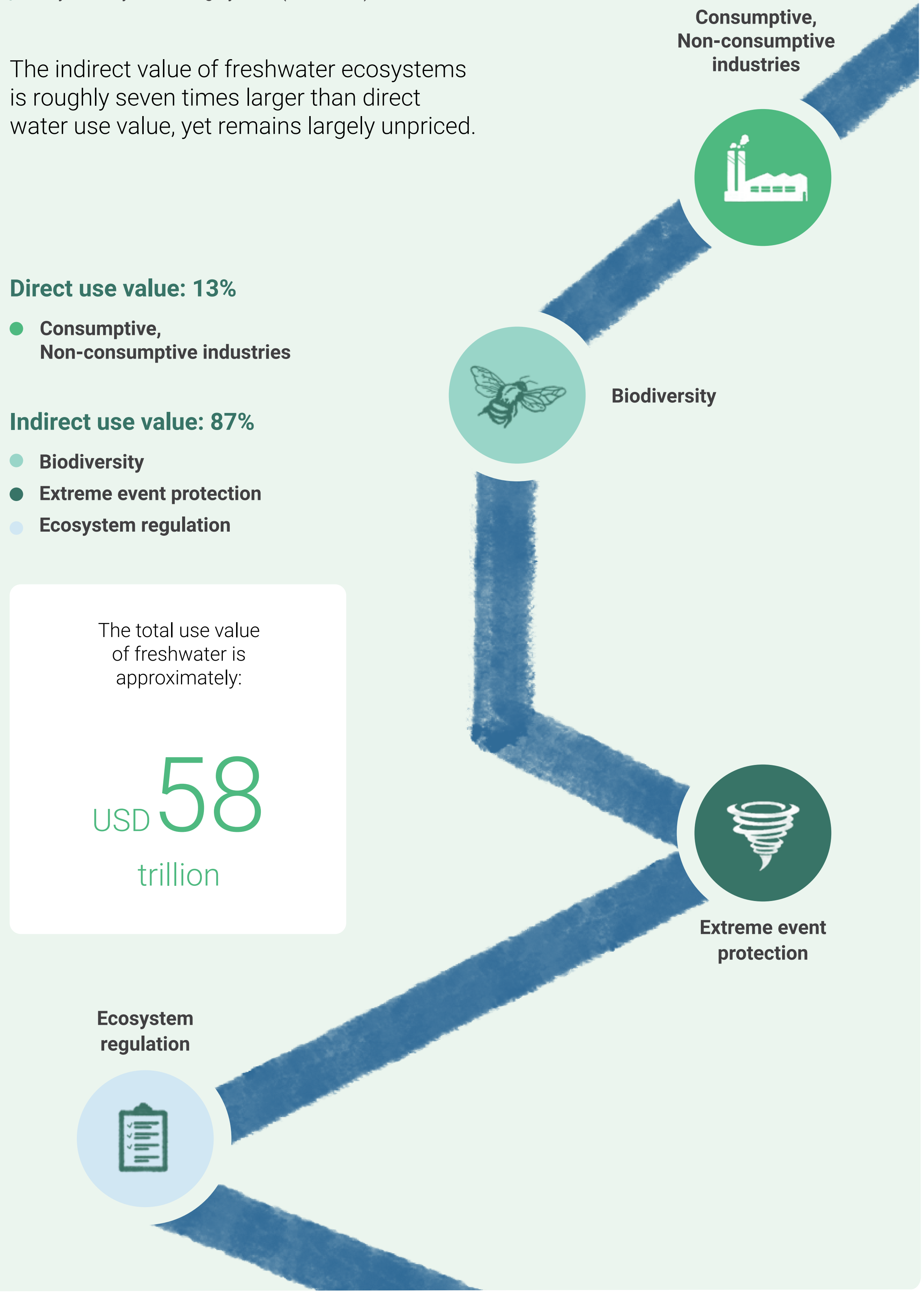
Agriculture and food systems sit at the center of this exposure. More than half of global food production is concentrated in areas where total water storage is already declining or unstable, with more than 170 million hectares of irrigated cropland under high or very high water stress, and a current annual global cost of drought of around USD 307 billion.[120] Globally, water-related impacts on the food system could reduce GDP by 8%, with an average of 15% GDP loss in lower-income countries.[121] Failing to improve water management could reduce GDP by 7–12% in India, China, and Central Asia, and by 6% across much of Africa by 2050.[122]

Ultimately, the water crisis also translates into an issue of safety and livelihood stability. Collapsing rural water reliability, crop failure, and rising living costs will force households to migrate, with around 700 million people potentially being displaced by intense water scarcity by 2030.[123] In parallel, competition over scarce water is increasingly spilling into violence. 420 water-related conflicts were recorded in 2024, nearly 20% higher than 2023 and 78% higher than 2022, with most incidents involving attacks on water infrastructure.[124]

8%

reduction of global GDP due to water-related impacts on the food system, with lower-income countries facing GDP losses of up to 15%.[125]

Figure 20
Estimated annual economic use value of water and freshwater ecosystems by value category, 2021 (USD trillion)[126]



114. WWF, 2023 115. WWF, 2023 116. Saccoccia, 2024 117. WRI, 2023 118. GHD, 2023 119. CDP, 2023 120. UNU-INWEH, 2026 121. Mazzucato, 2024 122. Global Commission on Adaptation, via WRI 123. UNICEF, 2026 124. Pacific Institute, 2025 125. Mazzucato, 2024

126. WWF, 2023

Biogeochemical Flows

Nitrogen and phosphorus cycles are out of balance, weakening soil and water systems.

Modification of biogeochemical flows is the planetary boundary that tracks how much human activity is changing the natural nutrient cycles of nitrogen and phosphorus, two essential building blocks that plants, crops and ecosystems need to grow. It focuses on the large, human driven flows of these nutrients, especially nitrogen made "reactive" through industrial and agricultural processes, and phosphorus mined and moved from rocks into soils and waterways. These shifts are driven mainly by fertilizers and manure, and by nutrient pollution from wastewater and some emissions from burning fossil fuels. When more nitrogen and phosphorus escape into rivers, lakes, and the sea, they can overfeed algae, trigger harmful blooms, and strip oxygen from the water, which can create dead zones where fish and other aquatic life struggle.

Where we stand today

Nitrogen and phosphorus are essential nutrients for plant growth; they underpin crop yields and the wider food chain. Yet most plants cannot use the largest nitrogen store directly, atmospheric nitrogen gas, and phosphorus is often locked in soils or must be supplied from mined rock. This constraint is a big reason why synthetic fertilizers in modern agriculture scaled so quickly, and to enormous levels. Global agricultural use of inorganic fertilizers increased from 142 million tons in 2002 to 190 million tons in 2023, including 112 million tons of nitrogen and 41 million tons of phosphorus, in 2023.[127] Use is concentrated in Asia, which applied about 107 million tons in 2023, around 56% of the global total, and saw the largest absolute increase since 2002, while Europe reduced its total use slightly over the same period.[128] As these inputs expanded, global average cereal yields have roughly tripled since 1961, helping increase output mainly through higher yields rather than an equivalent expansion of cropland.[129]

This development has disrupted the natural nutrient cycle and the balance of soil health. Summa's report on Investing in food and agriculture for health and planetary resilience highlights that only 30 to 40% of soils in the European Union remain healthy.[130] A big part of the damage comes from how high, repeated doses of synthetic nitrogen change soil chemistry and soil biology, acidifying soils and disrupting the microbial communities that naturally make nutrients available to plants. Over time, this can reduce soil biodiversity, suppress beneficial fungi, and harm earthworms that keep soils aerated and fertile, leaving soils less resilient and more dependent on further inputs.[131] A global meta-analysis found nitrogen fertilization reduced soil bacterial diversity by 11% and fungal diversity by 17%, and described soil acidification as an important mechanism shaping these changes.[132]

Nitrogen is

300x

more potent at warming the atmosphere than carbon dioxide emissions[133]

127. FAO, 2025 128. FAO, 2025 129. Ritchie, 2025 130. Summa Equity, 2025 131. Goswami, 2025 132. Chen, 2023 133. U.S. EPA, 2025

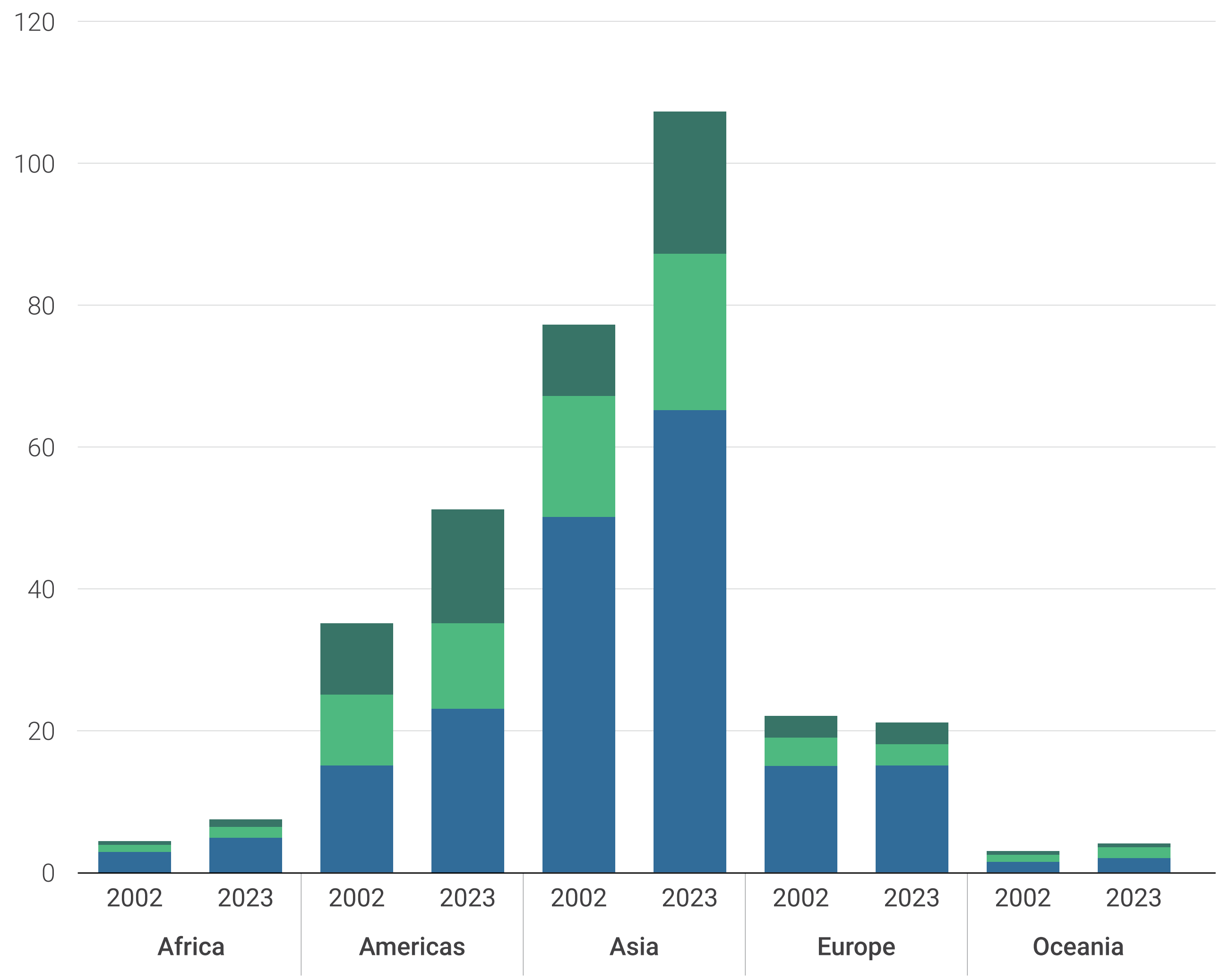
Beyond direct disruptions to soil health, the inefficient use of fertilizers also impacts water and marine biodiversity. Only around 20% of nitrogen compounds reach useful crop production globally, with about 80% leaking into the wider environment, and that up to 80% of phosphorus inputs can be lost or wasted, despite phosphorus being a finite resource.[134] These losses often leave fields through leaching and runoff, feeding algal blooms in rivers, lakes, and coastal waters, and setting off oxygen depletion as algae decay. In severe cases this creates dead zones, areas of very low oxygen, typically near the seafloor, where many fish and bottom dwelling organisms cannot survive, and mobile species are forced to move away, reducing habitat and simplifying ecosystems. UNESCO estimates there are now close to 500 coastal dead zones worldwide covering over 245,000 square kilometers, roughly the size of the United Kingdom.[135]

Synthetic fertilizer production accounts for

~11%

of agricultural emissions, and 2.1% of global emissions[136]

Figure 21
Inorganic fertilizer agricultural use by nutrient and region.[137]



134. UNEP, 2025 135. UNESCO, 2023 136. Menegat et al., 2022 137. FAO FAOSTAT, 2025

What this means for markets and companies

Synthetic fertilizers have become a cornerstone of modern farming, helping produce the crop yields that support global nutrition and health, and in turn increasing GDP. At the same time, they place direct pressure on multiple planetary boundaries and human health, causing widespread damage and long-term economic risks that largely remain unaccounted for.

Nevertheless, estimates point towards economic damage that has the potential to outweigh the benefit of increased crop production. In the early 2000s the United States faced about 210 billion dollars per year in combined health and environmental damages from reactive nitrogen released by human activities, with a range of 81 to 441 billion, much of it tied to nitrogen that escapes into freshwater and the air rather than ending up in crops.[138] In Europe, the European Nitrogen Assessment estimates total annual damages from reactive nitrogen losses at roughly EUR 70 to 320 billion, about EUR 150 to 750 per person.[139] A significant share of the damages stems from direct health impacts linked to airborne reactive nitrogen. Ammonia emissions from agriculture react in the atmosphere with other pollutants to form fine particulate matter. Recent high-resolution work focused on European agricultural ammonia emissions highlights research indicating that ammonia driven $PM_{2.5}$ exposure contributes about 2.6 million years of life lost per year in Europe.[140]

Another share of the economic burden comes through eutrophication, when rivers, lakes, and coastal waters receive more nutrients than ecosystems can absorb, triggering rapid algae growth. When these blooms die and break down, microbes consume oxygen, which can push waters into hypoxia, and in severe cases create dead zones, areas with too little oxygen to support most fish and bottom living species, leading to habitat loss and simplified food webs. The EEA tracks eutrophication pressure from atmospheric nitrogen deposition using "critical loads", thresholds above which ecosystems are expected to be harmed, and estimates that in 2023 around 1,068,000 km² of ecosystem area in the EU 27 still exceeded these limits, an area roughly comparable to France and Spain combined.[141] The economic impact of dead zones is significant as demonstrated by the impacts in the Baltic Sea, where eutrophication has created one of the world's largest human induced oxygen depleted marine areas. In 2024, 34% of bottom areas were affected by low oxygen conditions, including 18% where oxygen was completely absent.[142] Alleviating eutrophication in the Baltic Sea, which hosts seven of the world's ten largest marine dead zones and where oxygen-depleted seafloor covers an area 1.5 times the size of Denmark, is estimated to generate annual benefits of EUR 3 to 4 billion, outweighing the costs of nutrient abatement.[143]

Alleviating eutrophication in the Baltic Sea, which hosts seven of the world's ten largest marine dead zones, is estimated to generate annual benefits of

EUR

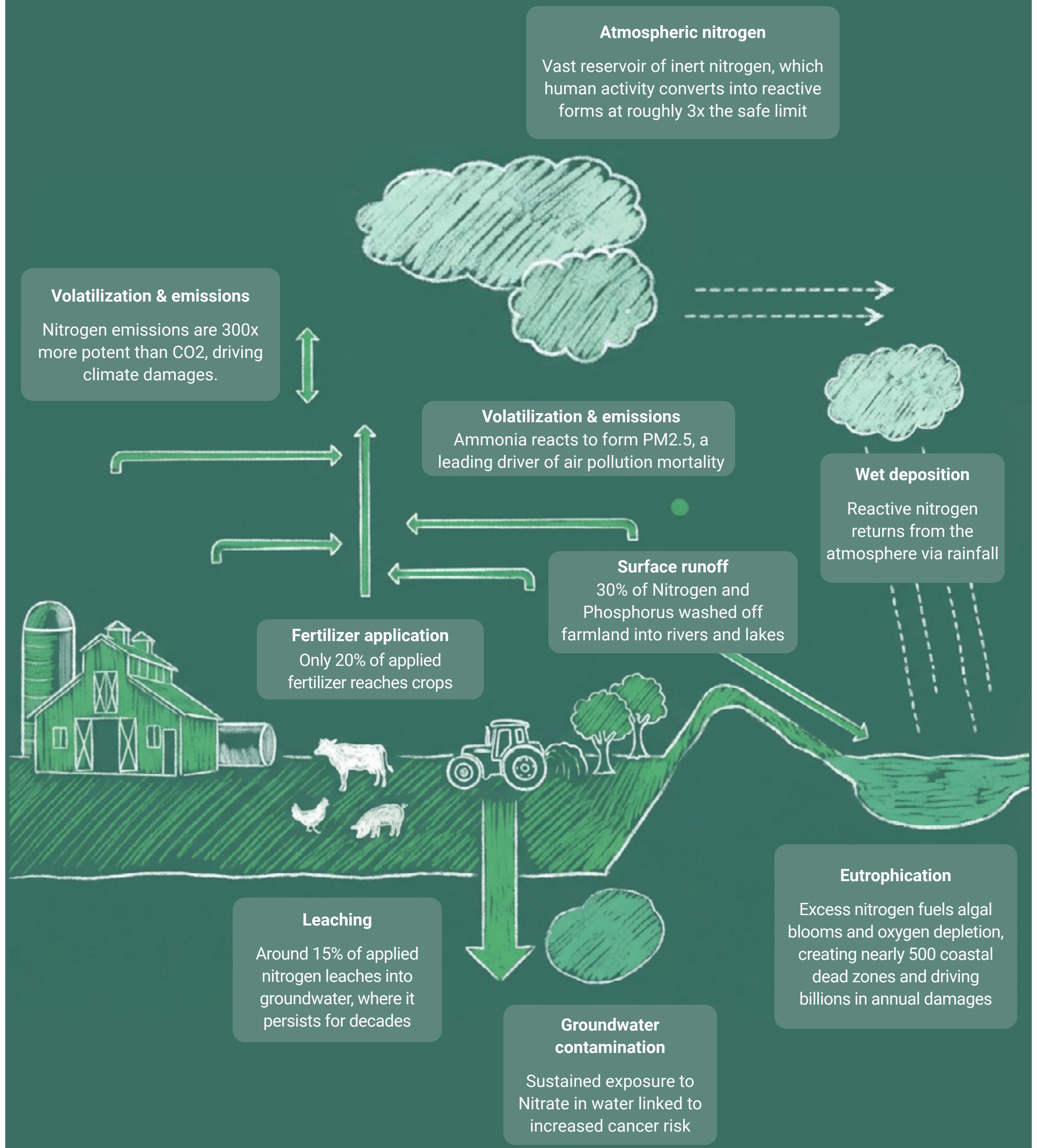
3-4bn

outweighing the costs of reaching nutrient abatement targets, estimated at EUR 1 to 4 billion per year.[144]

138. Sobota, 2015 139. Brink, 2011 140. Jin, 2025 141. European Environment Agency, 2024 142. Hansson, M., & Viktorsson, L. (2025) 143. Reusch et al., 2018 144. Reusch et al., 2018

Figure 22
The nitrogen cycle in agricultural systems, from application to environmental impact

Excess nitrogen cascades through air, soil, and water systems, driving EUR 70 to 320 billion in annual damages across Europe while only 20% of applied fertilizer reaches crops.



Ocean Acidification

Ocean acidification has crossed its boundary for the first time, weakening marine ecosystems and the food webs that depend on them.

Ocean acidification refers to the ongoing change in the chemistry of the world's oceans as they absorb carbon dioxide from the atmosphere. When CO_2 dissolves in seawater it forms a weak acid that lowers the ocean's pH and reduces the availability of key minerals like carbonate that many marine animals need to build shells and skeletons. This process is making the oceans more acidic than at any time in recent Earth history, harming organisms such as corals, shellfish and tiny plankton at the base of the food web, and in turn threatening entire marine ecosystems and the people who depend on them for food and livelihoods.

Where we stand today

The boundary for ocean acidification was crossed for the first time in 2025, confirming that the oceans have become more acidic than what is considered safe for marine life and for the long-term stability of the Earth system. The oceans absorb roughly 30% of human CO_2 emissions, thereby playing an integral role in slowing atmospheric warming, but it also forms carbonic acid in seawater and lowers pH.[145] Since the start of the industrial era, average surface ocean pH has fallen by about 0.1 units, which corresponds to roughly a 30% rise in acidity. Long-term measurements show a drop from about 8.11 in 1985 to about 8.04 in 2024.[146] Because the pH scale is logarithmic, this seemingly small shift represents a major change in ocean chemistry, happening more than ten times faster than comparable natural changes over the last 55 million years.[147] Looking forward, by 2100 ocean acidity is projected to rise by about 50% even under a mid-range emissions scenario.[148]

What makes the current situation especially concerning is that acidification is widespread and uneven, with some of the most valuable ecosystems seeing faster change than the global average.[149] Researchers find that no part of the ocean is untouched by the combined pressures of climate change, biodiversity loss, and pollution, and that over 10% of marine biodiversity hotspots are acidifying faster than the global average. This unevenness matters because marine species are adapted to the local chemistry they evolved in, and that local chemistry differs a lot across the planet. In tropical waters, conditions are naturally more favorable for shell and reef building, while polar waters start much closer to corrosive conditions, so the same extra CO_2 pushes high latitudes over harmful thresholds sooner. New research underpinning the 2025 assessment shows that, by 2020, more than 40% of the global ocean surface had already crossed into the uncertainty range of the planetary boundary, and the signal is strongest across high latitude basins, including the Southern Ocean, the North Pacific, and the Arctic.[150] In other words, the global average hides the fact that large parts of the ocean have moved into riskier conditions much earlier than others.

Acidification is creating also a vertical squeeze, where the layer of water that remains chemically "safe enough" for many species is getting thinner, especially below the surface. By 2020, about 40% of the surface ocean had crossed the safe boundary, and the share gets larger with depth, about 44% at 50 m, and 61% at 200 m. In some places, the depth where seawater becomes corrosive enough to start dissolving shell material has moved upward by more than 200 m, bringing harmful conditions much closer to where many organisms feed and grow, and compressing the amount of suitable habitat available.[151]

145. Hoegh-Guldberg, 2018 146. NOAA, 2025 147. Laffoley, 2017 148. NOAA, 2025 149. Von Schuckmann et al. 2025 150. Findlay, 2025 151.Findlay, 2025

Figure 23
Increase in ocean acidity since pre-industrial times (% change)[152]

Ocean acidity is rising more than ten times faster than at any point in the last 55 million years, and is projected to reach 50% above pre-industrial levels by 2100.

30%
more acidic
than before the industrial era

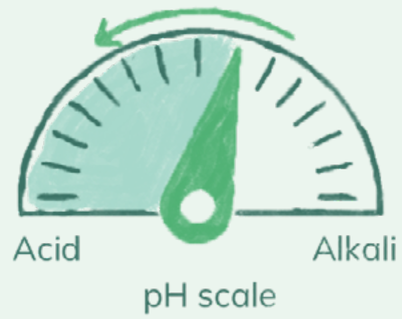
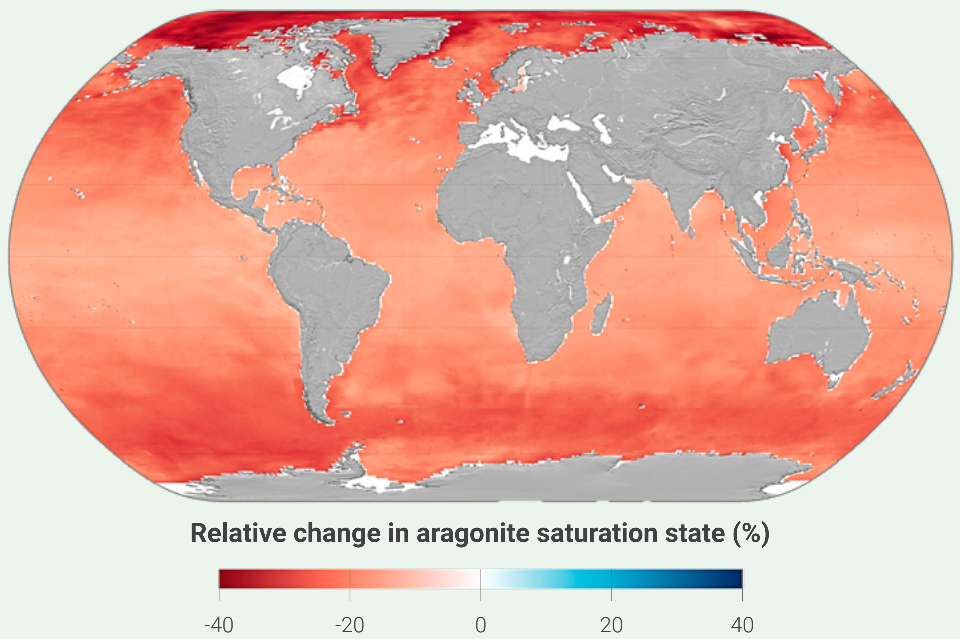


Figure 24
Global map of Ocean Acidification, as indicated by aragonite saturation state[153]

Ocean acidification is impacting the entire global ocean, with most severe conditions in polar waters.



152. NOAA, 2025 153. Planetary Boundaries Science, 2025

What this means for markets and companies

Ocean acidification creates economic exposure across seafood value chains, from wild-capture fisheries to commercial aquaculture, with risks materializing through species vulnerability, operational disruption, and feed chain instability. Summa's aquaculture report identifies ocean acidification and rising temperatures as among the key environmental stressors affecting the salmon farming sector's capacity to scale sustainably, noting that successful industry growth depends on adaptation strategies including closed-containment systems and feed innovations that reduce vulnerability to changing ocean chemistry.[154] While finfish like Atlantic salmon show greater physiological tolerance to pH changes, the transmission mechanism runs through feed chain disruption, disease vulnerability, and operational stress. Recent analysis of Norwegian salmon farms shows that warming and acidifying waters create favorable conditions for parasites like sea lice while affecting farmed salmon welfare, impacting productivity and operational stability.[155]

Rather than direct production loss from shell formation failure, salmon operations face rising costs from increased mortality, reduced feed conversion efficiency, and more intensive parasite management as water chemistry shifts. The scale of these pressures is substantial: the industry currently experiences EUR 100 million in annual revenue losses from fish mortality alone, and faces a projected 4 million tonne global feed shortage by 2040 if alternative ingredients are not developed.[156] Acidification-driven stress on both fish health and marine feed sources will intensify these existing challenges. With Norwegian salmon farming representing the country's second-largest export industry,[157] these climate-induced operational pressures represent material economic exposure for Nordic coastal economies.

Beyond the sea food supply chain, the loss of reef based economies poses additional risk. Globally, coral reefs are estimated to provide USD 2.7 trillion per year in goods and services, including tourism, fisheries, and coastal protection, meaning that reef decline can translate into lost income and higher disaster costs, especially for coastal and island economies.[158] A key reason is protection. Analysis of reefs as natural breakwaters shows without reefs, annual expected flood damages would more than double, and damages from frequent storms would triple. In 100-year storm events, the top 1 meter of reefs alone is estimated to avoid around USD 130 billion in damages.[159]

The risks of ocean acidification extend beyond direct industry impacts to systemic climate effects, as acidifying waters weaken the ocean's capacity to absorb atmospheric carbon. Chemically, falling pH comes with a loss of "buffering capacity", meaning each extra unit of carbon added to seawater causes a larger rise in ocean CO_2 levels, so the ocean's ability to keep drawing CO_2 out of the air weakens. Under a high emissions pathway, average surface ocean pH is projected to fall by a further ~0.33 from 2000 to 2100, and the ocean's buffering capacity is projected to decline by ~34% over the same period.[160] At the Earth system level, land and ocean carbon sinks are projected to become less effective as emissions rise, meaning a smaller share of emitted CO_2 is absorbed and more remains in the atmosphere. Under SSP2-4.5, the IPCC projects that land and ocean carbon sinks will weaken in the second half of the century, with CO_2 uptake falling by around one quarter to one third by 2100. This matters because it increases the risk of faster warming and stronger knock-on impacts, including more intense wet and dry extremes, and accelerating ocean driven changes such as continued acidification and sea level rise.[161]

Coral reefs are estimated to provide

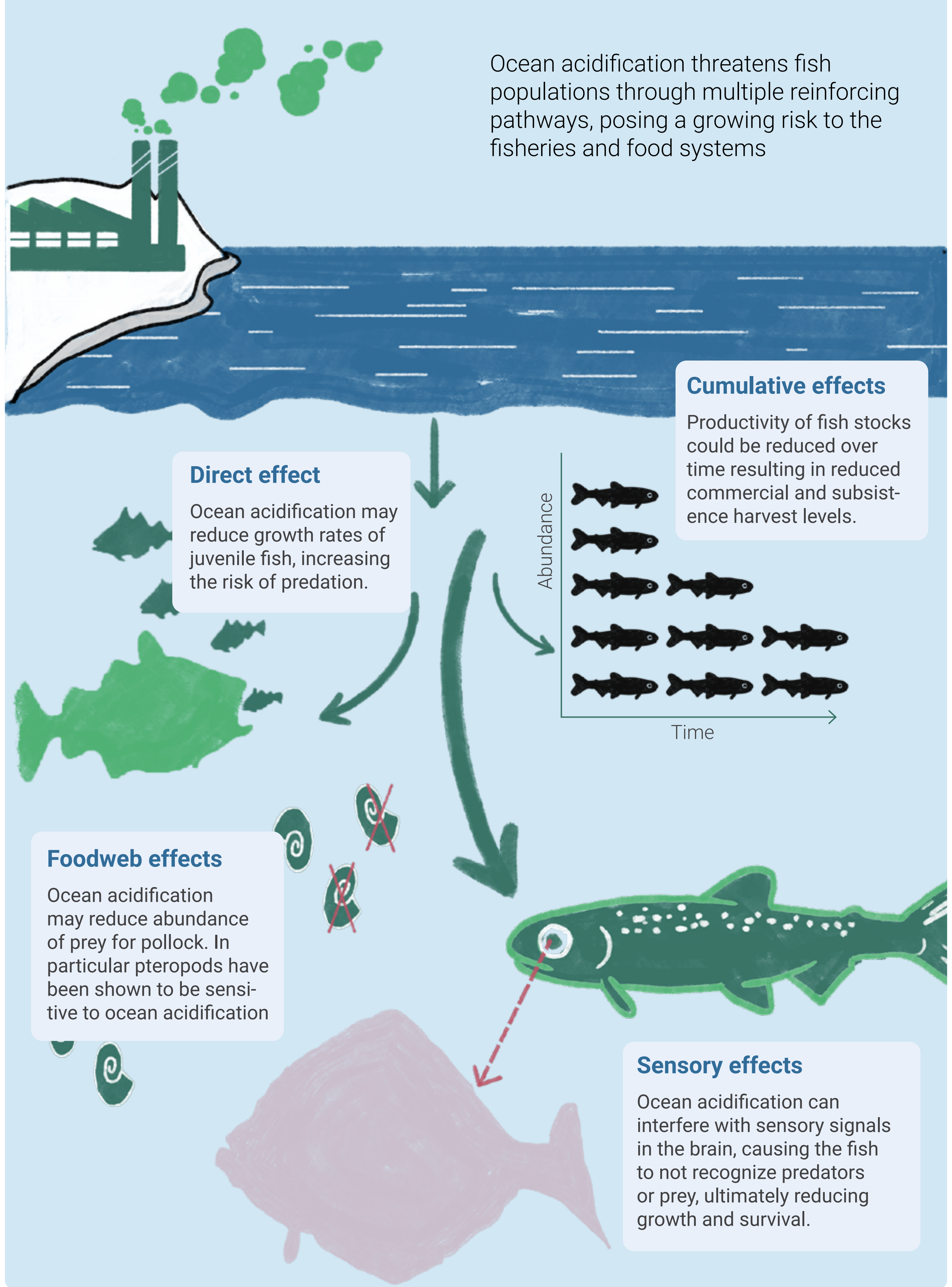
USD

2.7 trillion

per year in goods and services, including tourism, fisheries, and coastal protection[162]

154. Summa Equity, 2025 155. EY, 2025 156. Summa Equity, 2025 157. Summa Equity. (2025). 158. UNEP, 2025 159. Beck, 2018 160. Jiang, 2019 161. IPCC, 2021 162. UNEP, 2025

Figure 25
Increase in ocean acidity since pre-industrial times (% change)[163]



163. Alaska Ocean Acidification Network, n.d.

Novel Entities

Persistent chemicals and plastics are contaminating ecosystems worldwide, creating cocktail effects with unknown consequences.

Novel entities refers to the growing release of human-made substances and materials into the environment, including synthetic chemicals, plastics, pesticides, PFAS, heavy metals and other pollutants. Many of these substances persist for a long time, spread through air, water and soils, and can build up in living organisms and food webs. Novel entities can harm wildlife, contaminate water and food, disrupt ecosystems, and create long-lasting risks for human health and the stability of Earth's life-support systems. Because the effects of many new compounds and materials are not fully understood, their introduction into the environment must be treated as potentially harmful, which is why the planetary boundary for novel entities is considered transgressed.

Where we stand today

Human-made chemicals, plastics, and other novel entities are being produced and released into the environment at a scale that outpaces society's ability to assess, monitor, and control them. More than 350,000 chemicals and mixtures are registered for production and use globally.[164] In the U.S. alone, roughly seven new chemical compounds are being introduced to commerce daily.[165] Historic trends and future projections illustrate the pace of this growth: global chemical production has increased around 50-fold since 1950 and is projected to triple again by 2050, relative to 2010 levels.[166] The total mass of plastics on the planet is now over twice the mass of all living mammals, and roughly 80% of all plastics ever produced remain in the environment.[167]

Despite tighter scrutiny under regulatory frameworks such as the EU REACH regulation and the U.S. Toxic Substances Control Act, major information gaps remain. Of the 16,325 chemicals identified in plastics, more than 4,200 are persistent, bioaccumulative, mobile, and/or toxic, and two thirds lack official hazard classifications altogether.[168] More than 1,300 of these chemicals of concern are still being intentionally added to plastics during manufacturing, and only 6% of all plastic chemicals are currently subject to any global regulation.[169] A subsequent Nature inventory confirmed that among these inadequately classified substances are phthalates, endocrine-disrupting chemicals associated with reproductive, developmental, and metabolic disorders, as well as some cancers.[170] This reflects a continued failure to apply the precautionary principle, despite earlier lessons from compounds such as CFCs, which depleted the stratospheric ozone layer, and PCBs, which proved highly persistent, bioaccumulative, and toxic.[171]

Compounding the challenge is the fact that many novel entities persist in the environment for prolonged periods, in some cases effectively indefinitely, and the share of such long-lived compounds in global production has grown with each successive chemical generation.[172] Per- and polyfluoroalkyl substances (PFAS) represent the most acute contemporary illustration of this problem. As a class of nearly 15,000 synthetic chemicals, their carbon-fluorine bonds are among the strongest in organic chemistry, rendering them resistant to virtually all biological and environmental degradation.[173]

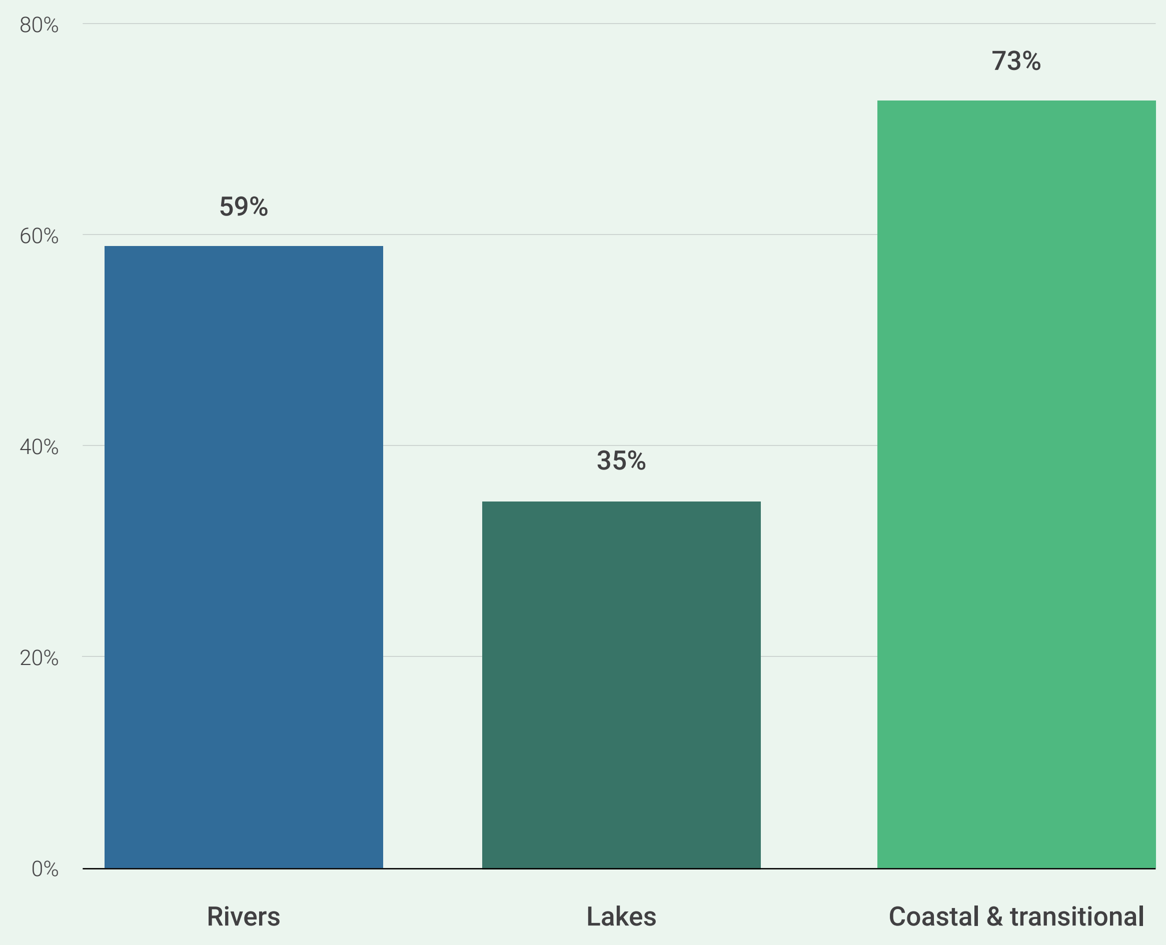
164. Wang et al., 2020 165. California DTSC, n.d. 166. Persson et al., 2022 167. Stockholm Resilience Centre, 2022 168. Monclús et al., 2025 169. Monclús et al., 2025 170. Monclús et al., 2025 171. WMO/UNEP, 2022; Hens & Hens, 2017 172. Persson et al., 2022 173. Cousins et al., 2020

Water is the primary transport and exposure pathway for PFAS, making it the most meaningful indicator of contamination severity. Within the PFAS class, perfluorooctane sulfonate (PFOS) serves as the key indicator compound, as it has established regulatory thresholds against which exceedances can be measured, while comprehensive standards for the full class of nearly 15,000 substances do not yet exist.

The scale of resulting contamination is now global and largely irreversible with current technology: PFAS levels in rainwater exceed safety guidelines virtually everywhere on Earth, including in Antarctica and the Tibetan Plateau. Summa Equity's Europe's Water Health Report documents the breadth of this crisis in Europe: around 23,000 PFAS-contaminated sites have been identified, and approximately 200 million people are currently exposed to PFAS through their drinking water, with PFAS detected in the blood of virtually all Europeans, including newborns.[174] These figures, however, capture compounds in isolation. In practice, humans and ecosystems are simultaneously exposed to mixtures of PFAS, microplastics, pesticides, and pharmaceuticals, and evidence is growing that the cocktail effect of these co-exposures produces harm significantly greater than any single substance alone.[175]

Figure 26
Share of water body sites exceeding PFOS safety standards, 2022, % of 1300 monitored sites across Europe.[176]

The majority of EU water bodies already exceed PFOS safety standards, with coastal and transitional waters the most severely affected.



174. Summa Equity, 2026; EEA, 2024 175. Kortenkamp et al., 2022; Summa Equity, 2026 176. EEA, 2024

What this means for markets and companies

The risks posed by novel entities operate across three interconnected dimensions: human health, ecosystem integrity, and economic stability. Unlike other environmental stressors, these risks are compounded by the irreversibility of contamination and the latency between exposure and harm, meaning that the full consequences of current production and release patterns will continue to materialize for decades regardless of regulatory action taken today.

Exposure to PFAS and other persistent compounds is associated with increased risk of kidney, testicular, and liver cancers, immune system suppression including reduced vaccine efficacy, endocrine disruption, impaired fertility, developmental harm in children, and cardiovascular disease.[177] Critically, these effects have been documented for only a small fraction of the chemicals in commercial use, meaning that current health assessments almost certainly understate true exposure risks. The populations most vulnerable are also those least equipped to avoid exposure: newborns, whose mothers transfer accumulated compounds in utero and through breast milk; children, who ingest proportionally higher quantities of contaminated water and dust; and communities located near industrial sites, military bases, and airports, which bear a disproportionate share of the contamination burden.[178]

In Europe, the cost of PFAS pollution if current levels continue without regulatory action is estimated at approximately EUR 440 billion by 2050, a figure the European Commission itself acknowledges is conservative, as it reflects only a handful of currently regulated substances. Treating contaminated water alone, without addressing emissions at source, would cost more than EUR 1 trillion.[179] Looking across the full spectrum of chemical contamination in European water systems, including PFAS, pesticides, nitrates, microplastics, and pharmaceuticals, Summa Equity's Europe's Water Health Report estimates that water pollution already costs Europeans at least EUR 180 billion annually in health impacts and ecosystem service losses, equivalent to approximately 1% of EU GDP lost annually, and that EUR 226 billion in targeted investment would be required to restore European water systems to health by 2040.[180] On a broader scale, the economic impact is even larger because pollution and ecosystem degradation remove services that nature currently provides at no cost. Europe's wetlands, riparian corridors, and soils currently deliver water purification worth around EUR 60 billion per year in avoided treatment costs, and this natural dividend is shrinking as contamination loads exceed sustainable thresholds.[181] As these ecosystems degrade, costs shift from nature to taxpayers, utilities, and ultimately customers, while the investment gap persists. The European Commission's own estimates suggest that environmental protection spending would need to rise from around 1.6% to 2.4% of EU GDP, an increase of roughly 50%, or about EUR 122 billion per year, to meet existing objectives.[182]

Beyond direct health and financial costs, novel entity contamination increasingly threatens the integrity of the broader Earth system. Persistent chemicals accumulate in soils, disrupting the microbial communities and nutrient cycles that underpin agricultural productivity. They concentrate in aquatic ecosystems, reducing the biodiversity and ecosystem services on which fisheries, water supply, and coastal resilience depend. The cocktail effect of simultaneous exposure to mixtures of PFAS, microplastics, pesticides, and pharmaceuticals adds a further layer of systemic risk that is poorly understood but likely to exceed the sum of its parts.[183] These interactions create feedback loops that connect the novel entities boundary directly to the boundaries for biosphere integrity, freshwater change, and biogeochemical flows, meaning that transgression in this domain accelerates pressure across multiple planetary systems simultaneously.

Read more about the systemic contamination of Europe's water systems and the investment opportunity behind it in Summa's thematic report:

Investing in Europe's water health: from toxic to thriving.

Read the report here

177. U.S. EPA, 2024; IARC, 2023 178. European Commission, 2026 179. European Commission, 2026 180. Summa Equity, 2026 181. Summa Equity, 2026 182. European Commission, via Summa Equity, 2026 183. Kortenkamp et al., 2022

Looking across the full spectrum of chemical contamination in European water systems, including PFAS, pesticides, nitrates, microplastics, and pharmaceuticals, Summa Equity's Europe's Water Health Report estimates that water pollution already costs Europeans at least

EUR **180** billion

annually in health impacts and ecosystem service losses, equivalent to approximately 1% of EU GDP lost annually

Figure 27
Summa's thematic investment approach targets the systems at the center of planetary boundary transgression and restoration

Materials system

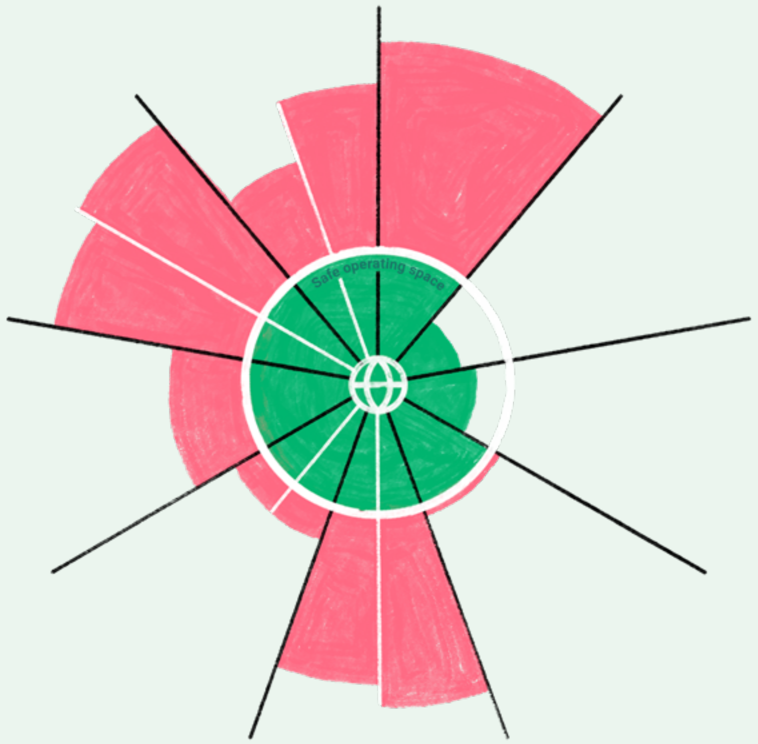
CIRCULARITY

By investing in waste and recycling, sustainable materials, and depollution, we reduce the extraction of virgin resources, recover materials otherwise lost in the linear economy, and cut the release of harmful chemicals and persistent pollutants into soils, water, and air, easing pressure on biogeochemical flows, biosphere integrity, and land-systems.

Energy system

ENERGY TRANSITION

By investing in renewable generation, industrial electrification, grid modernization, and green mobility, we reduce fossil fuel combustion, cutting greenhouse gas emissions, particulate pollution, and the ocean CO_2 absorption that drives acidification, while slowing the warming that intensifies drought, fire, and habitat loss.



Food system

SUSTAINABLE FOOD

By investing in aquaculture, alternative proteins, next generation agriculture, and food waste reduction, we support a food system that delivers nutrition with a lighter footprint, reducing land conversion, easing nutrient runoff into waterways, and relieving pressure on freshwater systems and ecosystems.

Water system

CIRCULARITY

By investing in water treatment technologies, digital monitoring solutions, and decentralized and modular infrastructure, we support reliable access to clean freshwater, remove legacy and emerging contaminants, and reduce excess nutrient loading into rivers, lakes, and coastal waters.

Systemic vulnerabilities

TECH-ENABLED RESILIENCE

Our Tech-Enabled Resilience theme addresses the systemic vulnerabilities that intensify as planetary boundaries are transgressed, from escalating cyber and operational risk to growing pressure on care and safety systems.

Planetary boundaries as a guiding lens for investing

The planetary health crisis is driving structural change across economic systems, revealing where investment can accelerate the transition to more resilient and sustainable outcomes.

The simultaneous crossing of multiple planetary boundaries signals systemic stress across Earth's core processes, and that stress is generating material economic risk. Supply chain disruption, asset value erosion, regulatory responses, and shifting societal expectations are already translating planetary pressure into financial exposure for businesses and investors. That exposure is likely to increase over time, as all seven of the transgressed boundaries are showing worsening trends.

At the same time, these pressures clarify where capital is needed most. The science points to three systems whose transformation would fundamentally change the state of the boundaries: energy, materials, and food. These three systems underpin a vast share of the global economy, but they are also responsible for the majority of planetary pressure, from greenhouse gas emissions and resource depletion to nutrient overloading and land-system degradation. Water connects all three, both as a resource on which each system depends and as the medium through which their pressures accumulate and interact. Transforming these systems is both a prerequisite for returning to a safe operating space and one of the defining structural shifts of the coming decades.

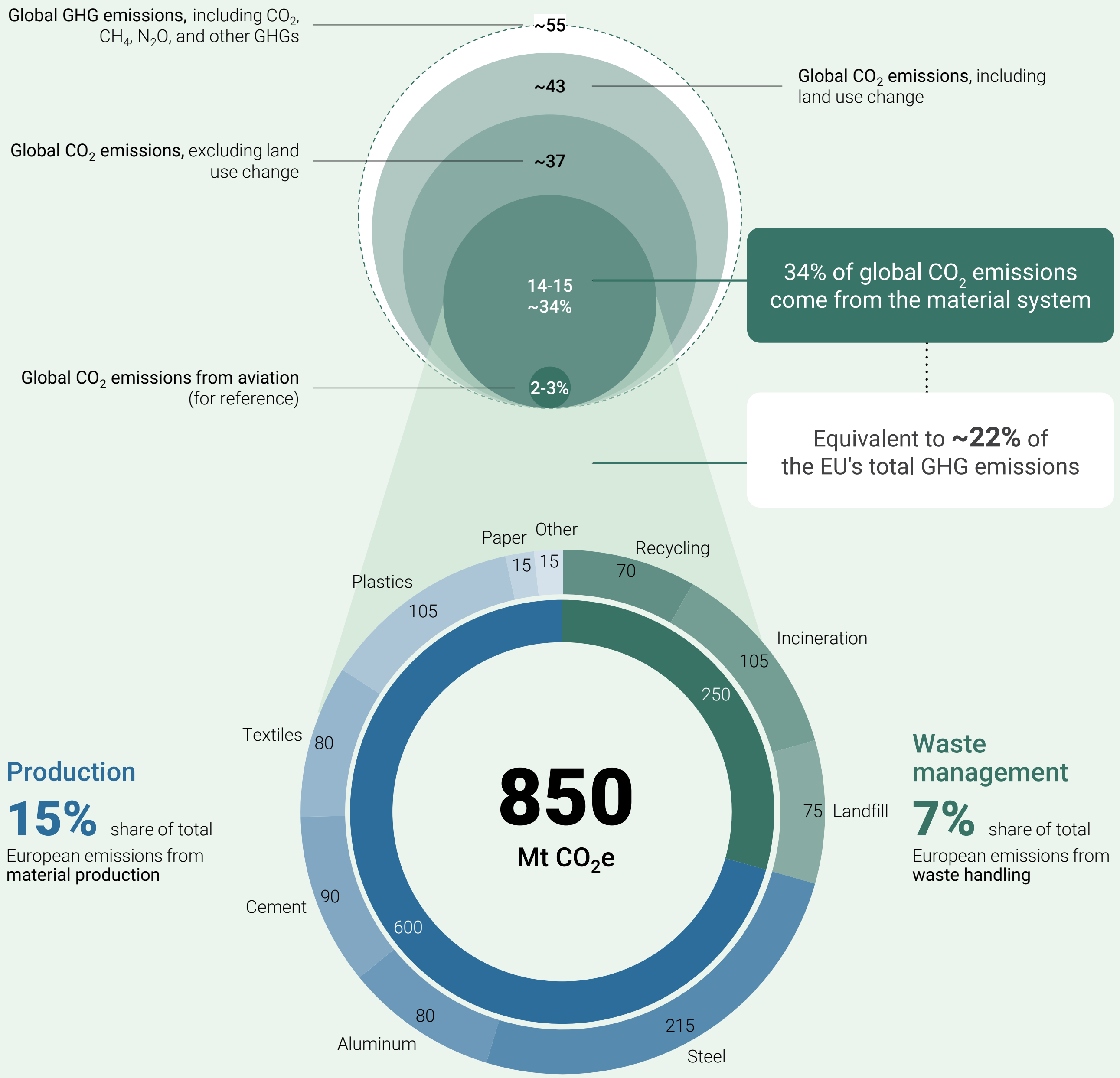
This is the foundation of Summa's investment approach. Our thematic strategy targets the systems where structural global challenges are most acute, because the scale and urgency of their transformation is generating large and growing addressable markets with resilient, long-duration demand. Circularity addresses how materials and resources, including water, are extracted, used, and recovered, supporting the transition from linear consumption patterns toward closed-loop systems that reduce waste, pollution, and resource depletion. Energy Transition encompasses the companies and technologies enabling the shift from fossil-based to renewable energy systems, spanning generation, distribution, storage, and efficiency across sectors. Sustainable Food targets the transformation of how food is produced, processed, and distributed, and the land, water, and nutrient systems on which the entire food value chain depends. Summa's fourth theme, Tech-Enabled Resilience, underpins the broader investment universe, strengthening the digital and operational systems that protect businesses and critical infrastructure across all three themes while also addressing systemic vulnerabilities in its own right, spanning cyber and data security, governance, risk and compliance, and care tech. As planetary pressures intensify, demand for systems-critical solutions continues to compound, strengthening the economic case for the companies delivering them. We examine how each theme addresses the key drivers of boundary transgression, and where scalable solutions can deliver both measurable environmental progress and compelling investment cases.

Figure 28
Global GHG emissions, 2019(Gt)

Material accounts for around one-third of global CO_2 emissions.

Investing in a circular and waste free Europe

Read the report here



Challenges in the materials system

CIRCULARITY

The linear material system is a key driver of planetary boundary transgression, and responsible for ~22% of the EU's GHG emissions.

The modern economy is built on a foundation of material flows, and remains highly linear. Materials are extracted, manufactured, used once, and discarded. Of the 530 megatons of end-of-life material flows generated annually in the EU27 and UK, approximately 135 megatons end up in landfills and 170 megatons are incinerated, while only a fraction is genuinely recycled back into equivalent-quality secondary production. Plastics are recycled at a rate of just 13%, less than 1% of textiles undergo fiber-to-fiber recycling, and structural overuse across construction and manufacturing adds a further layer of waste baked into the design of value chains themselves.[184] Beyond waste, the linear system creates deep dependencies on primary material extraction. The EU relies on China for 98 to 100% of its supply of several critical raw materials, including heavy rare earth elements and magnesium, a level of concentration that exposes European industrial systems to geopolitical and supply chain risk that the circular transition could materially reduce.[185]

The planetary impacts of this linear system are distributed across multiple boundaries simultaneously. Material production and waste management account for approximately 850 megatons of CO_2 equivalent annually in Europe, equivalent to 22% of the EU's total greenhouse gas emissions, making the material system one of the continent's largest and most structurally embedded source of climate pressure.[186] Beyond climate change, the extraction and processing of natural resources drives more than 90% of global biodiversity loss and water stress impacts, a direct pressure on the Biosphere Integrity boundary.[187] Textile production alone consumes an estimated 93 billion cubic meters of water annually, placing material strain on freshwater systems, while the land claims of agricultural inputs to industrial material value chains compound land-system change pressures already operating well beyond safe limits.[188] Critically, the proliferation of synthetic chemicals, plastic polymers, and persistent organic compounds embedded in linear material flows is a primary driver of transgression of the novel entities boundary, as these substances accumulate in soils, waterways, and organisms at rates that outpace any meaningful assimilative capacity.[189] No other major economic system presses simultaneously on so many planetary limits.

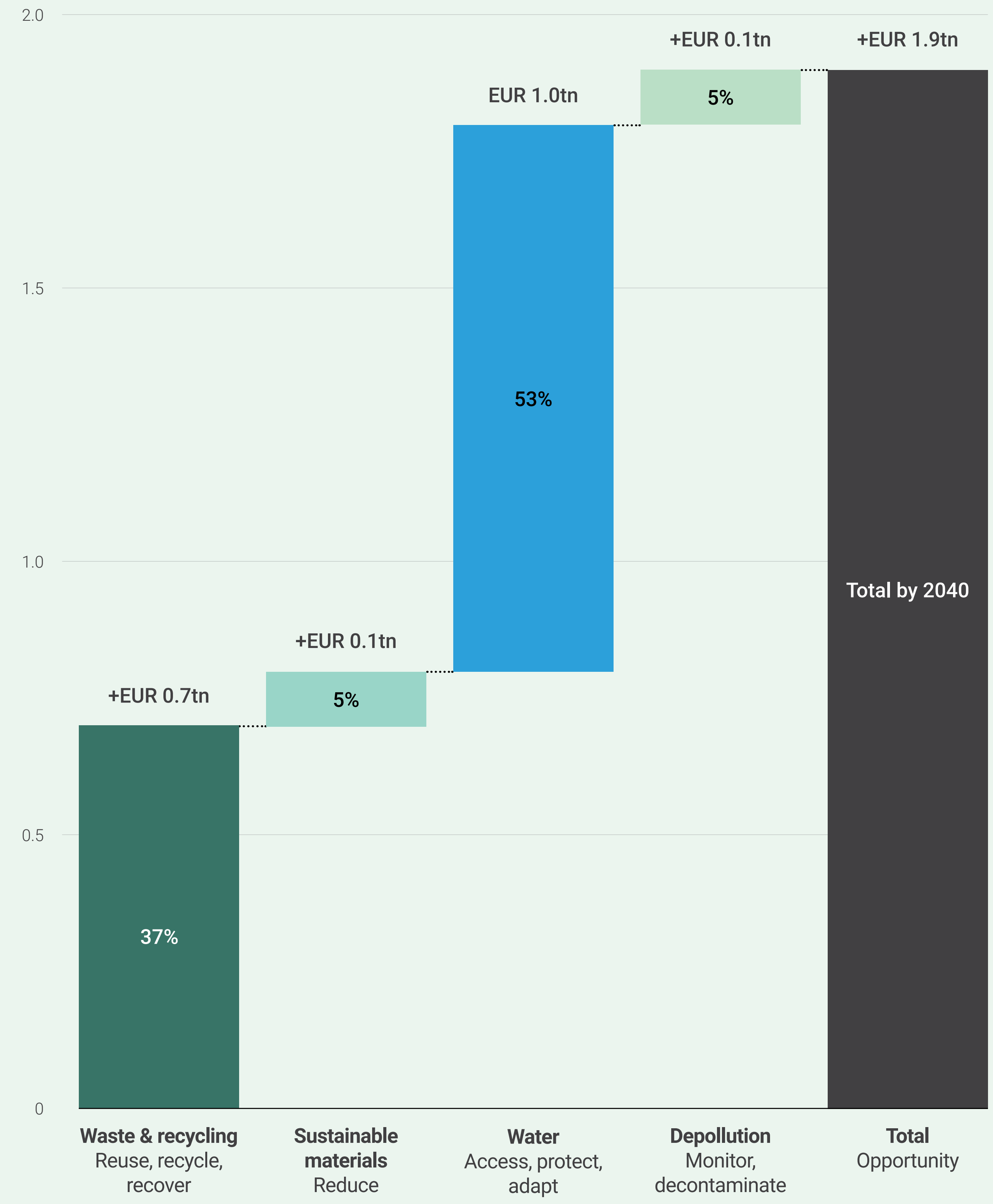
The economic cost of the linear economy is significant. In the EU, estimated losses from value destruction in the steel, plastics, and aluminum cycles alone range to over EUR 78 billion annually, as materials that could be recycled are instead incinerated or landfilled after a single use.[190] A further EUR 20 billion in electronics and fashion is destroyed each year as unsold goods or customer returns, reflecting the depth of inefficiency in how products are designed, used, and recovered rather than recirculated.[191] These figures do not account for the wider costs of ecosystem degradation and long-term planetary boundary transgression, meaning the true economic cost of the linear economy is substantially higher direct value losses alone.

The material system is one of the few transitions where regulatory mandates and carbon pricing are now moving in the same direction, beginning to restructure the industrial base around secondary rather than primary feedstock. EU legislation has introduced binding recycled content mandates across packaging, batteries, and textiles, mandated separate collection infrastructure, and committed to diverting recyclable and recoverable waste from landfill, with municipal waste landfilling capped at 10% by 2035. Carbon pricing is beginning to reach material production and waste management in ways that are starting to alter the economics of linearity. With CO_2 prices now exceeding EUR 80 per ton and CBAM transmitting these costs into commodity prices for steel, aluminum, cement, and plastics, the cost advantage of virgin primary production is being structurally eroded.[192] These shifts are not yet sufficient on their own, but they represent system-level signals that begin to redirect capital across entire value chains. Summa intends to lean into this transition and invest heavily across it.

184.Summa Equity, 2023 185,European Parliament, 2021 186.Summa Equity, 2023 187. IRP, 2019 188. Ellen MacArthur Foundation, 2017 189. Richardson et al., 2023 190. Material Economics, 2020 191. Summa Equity, 2023 192. Summa Equity, 2023

Figure 29
EUR trillions, estimated adressable market

Investing across four sub-themes can unlock a EUR 1.9tn investment opportunity.



The investment opportunity

CIRCULARITY

Summa's Circularity theme targets four key areas aligned with the principles of circularity, spanning across waste & recycling, sustainable materials, water, and depollution.

The circular transition requires investment in infrastructure, technology, and people to scale the business models and companies needed to deliver it, creating significant opportunity for investors. Healthy returns are achievable across the full spectrum of capital supporting the transition, from nascent technologies through to the physical infrastructure underpinning it. Summa's Circularity strategy is centered across four interconnected sub-themes, each targeting a distinct set of challenges, each at a different stage of maturity, and each offering a different risk-return profile. Together, they represent a combined market opportunity of approximately EUR 1.9 trillion by 2040.[193]

- **Waste** and recycling spans the full value chain from reuse, recommerce, and rental platforms through to feedstock aggregation, advanced sorting, and materials recycling, as well as waste bioeconomy products and carbon recovery from residual streams. The annual market size is estimated at EUR 700 billion by 2040, driven by recycled content mandates, binding collection requirements, and the progressive erosion of primary production's cost advantage as carbon prices rise.[194]
- **Sustainable materials** addresses structural material overuse and the design of value chains that depend on primary extraction, through circular product design, closed-loop manufacturing, durable and recyclable materials, and bio-based innovation. The market opportunity is estimated at EUR 100 billion by 2040, largely retained as cost savings across construction, manufacturing, and packaging rather than as revenues.[195]
- **Water** represents one of the largest investment opportunities within Circularity, with an estimated market of EUR 1 trillion by 2040.[196] Mounting pressure on freshwater systems, deteriorating surface water quality, and inadequate existing infrastructure create structural demand for solutions spanning treatment technologies, digital monitoring, decentralized infrastructure, and resource recovery from wastewater.
- **Depollution** removes hazardous substances that cannot be recycled or reused, encompassing hazardous waste treatment, air emission monitoring and control, soil remediation, and decommissioning services. It addresses some of the most acutely transgressed planetary boundaries, including novel entities and atmospheric aerosol loading. The market could reach EUR 100 billion by 2040, supported by intensifying regulatory pressure on legacy contamination and persistent synthetic substances across the EU.[197]

Summa's conviction in the circular transition is long-standing and reflected in a track record that predates the current wave of policy and market momentum. Circularity is Summa's largest theme by capital deployed, with investments spanning material recycling, waste infrastructure, recommerce platforms, sorting technology, and depollution services.

- **NG Nordic,** a leading Nordic provider of circular solutions and environmental services, operates across the full waste value chain at 90 sites, managing over 4 million tons of waste annually and achieving 78% taxonomy-aligned revenue.[198] Its depollution business focuses on the safe extraction and treatment of hazardous substances from end-of-life products and industrial waste streams.
- **TBAuctions,** a European digital auction platform operating in over 15 countries, brought together around 790,000 active bidders and 54,000 sellers in 2025. Over the same period, more than 1.2 million items were given a second life through the platform, extending product lifecycles and reducing demand for primary production through recommerce at scale.
- **Bollegraaf** delivers turnkey sorting and recycling solutions across waste streams globally, with 87% taxonomy-aligned revenues, enabling waste managers and public authorities to recover materials that would otherwise be lost to landfill or incineration.

Together, these investments span the circular value chain from waste recovery and material recirculation to pollution control, positioning Summa across the sub-themes where the circular transition will require the most capital, and where the intersection of planetary boundary pressure and structural market demand is sharpest.

193. Summa Equity, 2023; Summa Equity, 2025 194. Summa Equity, 2023 195. Summa Equity, 2023 196. Summa Equity, 2025 197. Modor Intelligence; Roland Berger estimates 198. Summa Equity, 2025

Challenges in the energy system

ENERGY TRANSITION

The energy transition is not constrained by the ability to generate sustainable power, but by the system that delivers it.

Fossil fuel combustion remains the largest single source of anthropogenic CO_2, accounting for roughly 75% of GHG emissions, and therefore, alongside industrial agriculture and land use change, the dominant driver of the climate change boundary pressure. The energy supply sector is the highest emitter of fossil CO_2, accounting for 27% of all CO_2 emissions, making the energy system one of the primary levers for reducing cumulative emissions, and a key focus area for investors wanting to address global climate change.[200] The pressure extends beyond climate. CO_2 absorbed by the oceans is driving ocean acidification past its safe threshold, combustion of coal, oil, and gas releases sulfur dioxide and fine particulate matter that drive atmospheric aerosol loading and contribute to 8.7 million premature deaths annually,[201] and thermal power generation places significant strain on freshwater systems through cooling water demand.[202]

The transition is underway, and parts of it are moving quickly. In 2025, global renewable capacity additions surged to 793 GW, an 11% increase from 2024, and for the first time on record, renewable energy production in the EU surpassed fossil energy.[203] Total renewable electricity capacity is set to double between 2025 and 2030.[204] This strong growth has not yet translated into a net decline in global carbon emissions. Gains in sustainable power capacity have been offset by rising electricity demand and continued regional increases in fossil fuel use. In 2024, global electricity demand grew by 2.4%, driven by electrification, higher cooling needs, industrial expansion in emerging markets, and rapid growth in digital demand from data centers and AI.[205] Forward-looking scenarios suggest electricity consumption could more than double by mid-century.

The binding constraint on decarbonization is not the ability to generate clean power, but the legacy system that must deliver it. 206 Renewable generation is now the cheapest source of new power in most markets, and the complimentary battery energy storage systems are seeing growth of 30% per annum 207. Despite this, grid infrastructure, and markets and regulations, continue to operate largely in the legacy paradigm of centralized, fossil generation with one-way power flows and limited visibility. Today's new generation, advanced manufacturing, data centers and electric vehicles require a flexible and dynamic grid that is optimized for utilization.

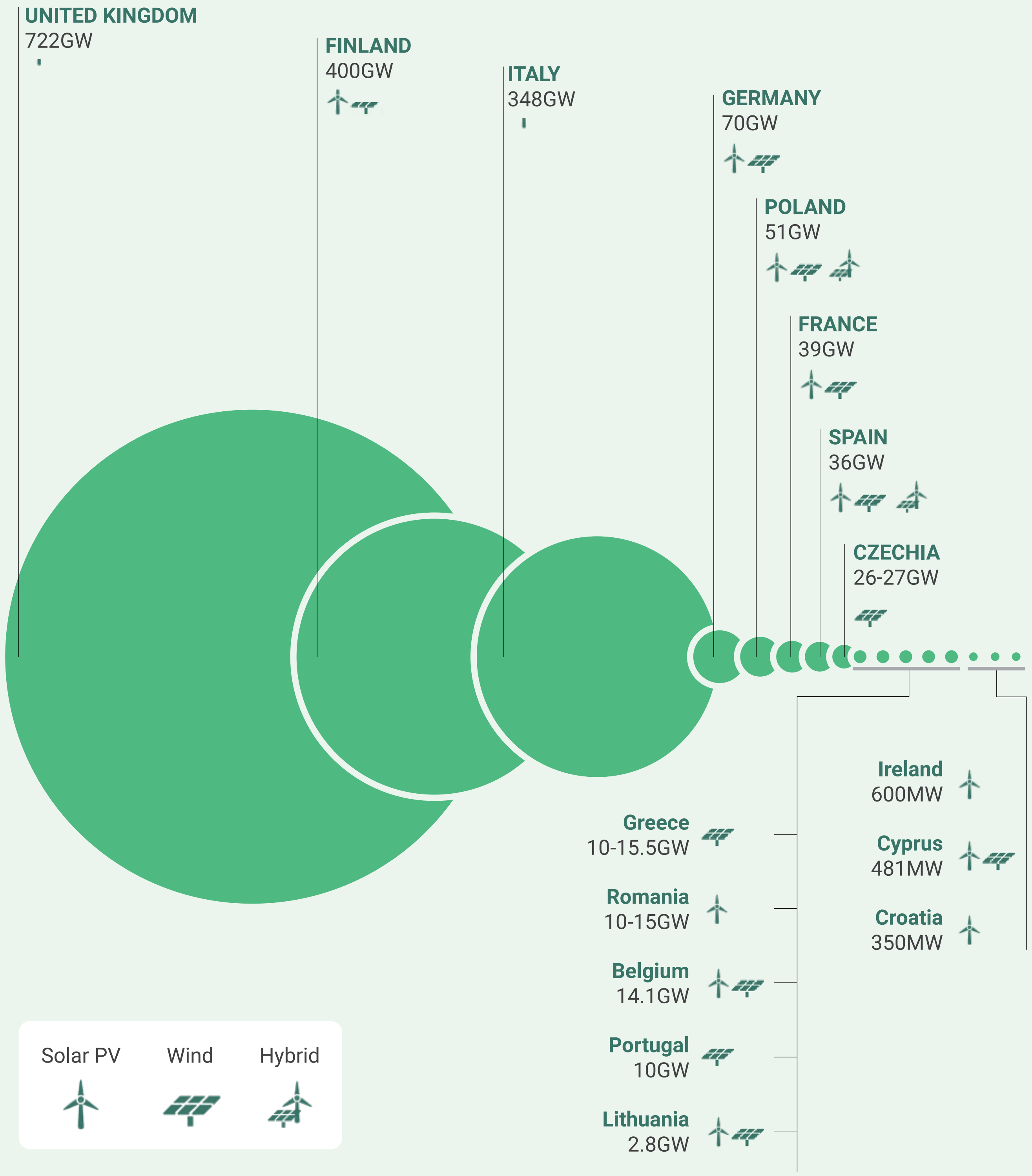
In 2024, grid bottlenecks forced renewable generators across just seven European countries to curtail output worth EUR 7.2 billion, power that was produced but could not reach consumers.[208] Globally, over 50 TWh of renewable energy was curtailed in 2024, roughly equivalent to Portugal's entire annual electricity consumption, wasted before reaching a single consumer.[209] Across Europe and the UK, approximately 1,700 GW of renewable energy projects were sitting stranded in grid connection queues, unable to come online, with the EU-only pipeline already exceeding twice the additional renewable capacity needed to meet the bloc's 2030 climate targets.[210] Beyond economics, insufficient grid investment carries direct climate consequences. The IEA's Grid Delay Case finds that inadequate grid investment and reform could add almost 60 billion tons of cumulative CO_2 emissions between 2030 and 2050, as renewable deployment slows and fossil generation fills the gap, equivalent to four years of total global power sector emissions and enough to put warming well above 1.5°C.[210]

Reducing the pressure the energy system exerts on planetary boundaries will therefore require more than scaling generation and electrifying demand. It demands a deep focus on the connective tissue of the system, the grid infrastructure, system services, and flexibility solutions that determine whether sustainable power can actually reach consumers and displace fossil fuels at the pace the climate requires. This is where the most compelling near-term investment opportunity lies.

199. UNEP, 2025 200. Vohra et al., 2021 201. IEA, 2023 202. Ember, 2025 203. IEA, 2025 204. IEA, 2025 205. Ember, 2025 206. IEA, 2023 207. Beyond Fossil Fuels, E3G, Ember, & IEEFA, 2025 208. IEA, 2025; Eurelectric, 2025 209. Beyond Fossil Fuels, E3G, Ember, & IEEFA, 2025 210. IEA, 2023

Figure 30
Share of EU electricity generation by source, 2015–2025 (%)[211]

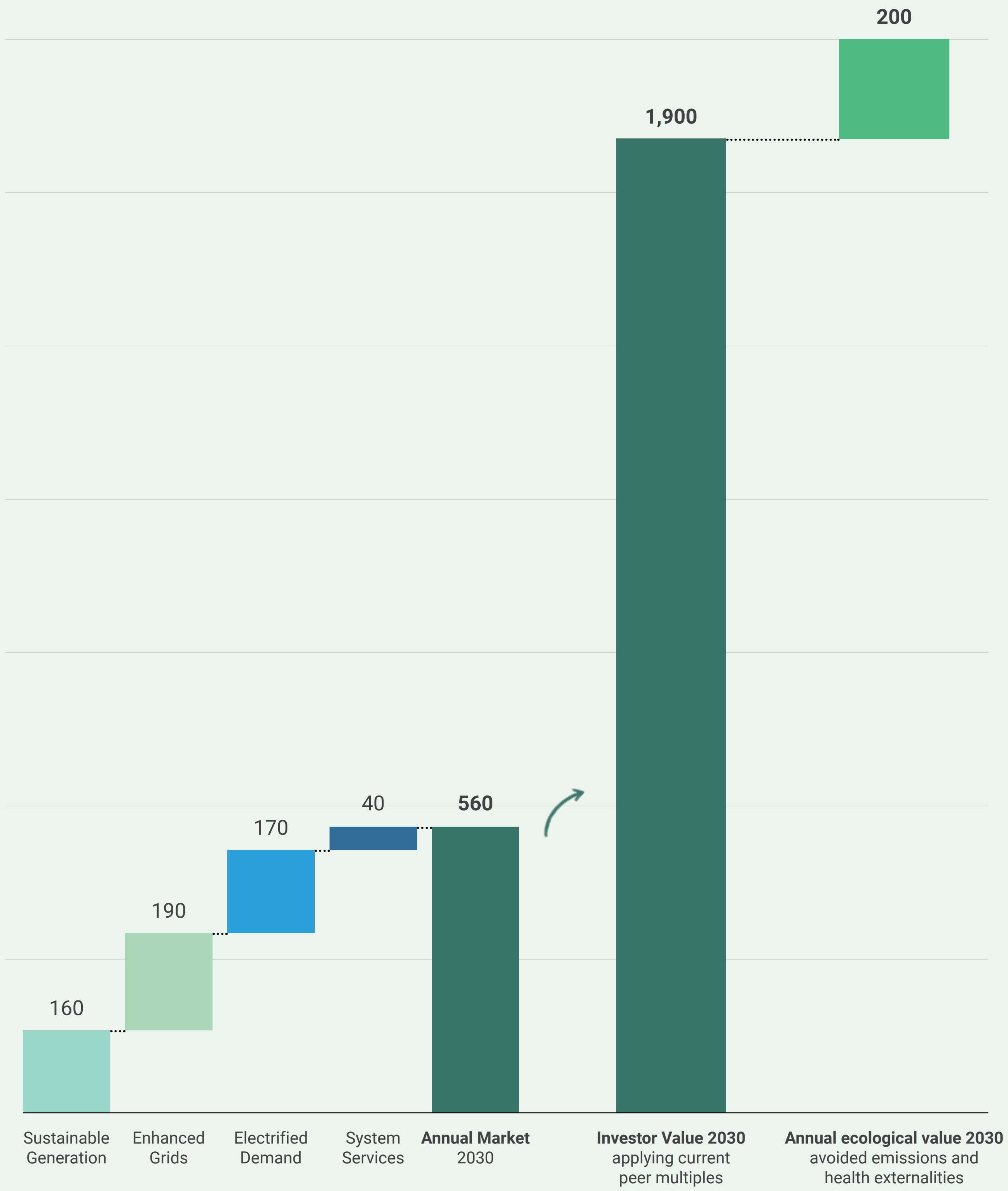
1,700 GW of renewable energy projects are stranded in EU and UK grid queues, with EU projects alone exceeding the renewable capacity needed to meet 2030 targets by 2x.



211. Beyond Fossil Fuels, E3G, Ember, & IEEFA, 2025

Figure 31
EUR billion, estimated addressable market

Summa targets a EUR 560 bn annual market by 2030, generating EUR 1,900 bn in investor value and EUR 200 bn in annual ecological value.



The investment opportunity

ENERGY TRANSITION

Four sub themes that address the structural constraints holding back the energy transition.

Modernizing the energy system to resolve the grid, operational, and market constraints described above represents one of the most significant investment opportunities in the transition towards a low-carbon future. Without decisive action, the result will be continued congestion, curtailment, and a system that remains more expensive and more polluting than necessary. Grid investment in Europe is accelerating but remains well short of what is required. Annual EU grid spending is set to exceed EUR 63 billion in 2025, doubling the level of a decade ago, yet investment has not kept pace with clean energy deployment, resulting in long connection queues and the inability to move cheap renewable electricity to where it is needed.[212] For distribution alone, Europe is currently investing approximately EUR 33 billion per year against an estimated need of EUR 67 billion annually through to 2050, leaving a persistent gap of roughly EUR 34 billion per year in distribution networks alone.[213]

Summa has identified four areas where impact capital can profitably resolve the energy transition's most material structural constraints. To qualify, solutions must be cost-competitive without sustained subsidy support, address genuine bottlenecks rather than speculative future demand, and generate value through efficiency and avoided capital expenditure. Together, these four themes represent a combined annual addressable market of EUR 560 billion in Europe and North America by 2030:

- **Sustainable Generation,** supplying reliable and affordable electricity where and when it is needed by coupling renewable generation with storage and optimizing existing assets, represents an addressable market of EUR 160 billion by 2030.
- **Enhanced Grids,** unlocking latent grid capacity and improving system performance through digitization, smart grid technologies, and power compensation solutions, represents an addressable market of EUR 190 billion by 2030.
- **Electrified Demand**, converting industry, transport, and buildings to secure and affordable electricity through clean manufacturing, thermal efficiency, and smart metering, represents an addressable market of EUR 170 billion by 2030. Summa's sub-theme Industrial Transition shares the opportunities of clean and efficient manufacturing, but addresses process efficiency, safety, and competitiveness more broadly
- **System Services and Flexibility**, designing, installing, operating, and maintaining a dynamic and flexible modern energy system through demand response, virtual power plants, predictive maintenance, and workforce development, represents an addressable market of EUR 40 billion by 2030.

The financial opportunity is larger than the annual market size alone suggests. Summa estimates the total investor value across these four themes at approximately EUR 1.9 trillion by 2030, reflecting the scalability, recurring revenue characteristics, and structural demand of the companies operating in each segment. Many of these solutions can leverage existing infrastructure to accelerate grid connections and enable renewable capacity already built to displace fossil generation at pace. Beyond direct financial returns, Summa estimates an additional EUR 200 billion in direct ecological value from the transition away from fossil fuels, reinforcing that in the energy transition, bringing planetary boundaries back to safe operating spaces and delivering superior financial returns are the same objective.

Two existing portfolio investments illustrate how Summa targets these structural constraints in practice:

- **EA Technology**, a UK-based grid asset monitoring and analytics company acquired in 2024, whose VisNet Hub product enables grid operators to increase low-voltage network capacity while deferring costly new infrastructure, directly addressing the grid constraint Summa identifies as the binding bottleneck.
- **Tibber**, a Norwegian digital energy retailer, uses dynamic pricing and consumption data to optimize renewable uptake and reduce grid load, enabling households to participate actively in balancing an increasingly variable system.

Together, these investments are built around the connective tissue of the energy transition, the infrastructure, intelligence, and services that allow sustainable power to be delivered reliably, affordably, and at the pace the science requires.

212. IEA, 2025 213. Eurelectric, 2025

Figure 32
The economic and social footprint of global food systems: its contribution, hidden costs, and access disparities

The true cost of the food system outweighs the value it delivers, with USD 15 trillion in annual societal cost against USD 8 trillion in GDP contribution.

Investing in food and agriculture for health and planetary resilience

Read the report here

Investing in sustainable aquaculture for a resilient food system

Read the report here

Challenges in the food system

SUSTAINABLE FOOD

The food and agriculture system has delivered unprecedented productivity, but at the expense of natural capital and human health, making structural transformation inevitable.

The food and agriculture system has delivered one of the great achievements of the 20th century, feeding a rapidly growing global population through dramatic gains in productivity. Yet the path that brought us here is not the one that will take us forward. The true cost of the current system far exceeds the value it generates. Environmental and social damages, including biodiversity loss, climate change, and health-related impacts, carry a societal cost of USD 15 trillion per year, approximately 12% of global GDP, surpassing the food system's entire USD 8 trillion contribution to global GDP[214]. This breaks down into three categories: health-related impacts account for the largest share at USD 11 trillion, driven by diets high in processed foods, sugars, and unhealthy fats that have contributed to higher rates of obesity, cardiovascular disease, and diabetes. These conditions now account for more than one in five adult deaths globally.[215] Environmental degradation accounts for a further USD 3 trillion, encompassing the costs of biodiversity loss, land, water, and air pollution, with the remainder stemming from structural poverty linked to food accessibility and affordability.[216] In effect, the food system is generating more harm than economic value, and approximately one third of all food produced globally is lost or wasted, meaning a substantial share of those costs generates no nutritional value whatsoever.[217]

The most structurally embedded challenge is the degradation of the natural capital on which food production depends. Conventional agriculture has become reliant on synthetic nitrogen fertilizers to sustain yields, but this has come at significant cost. Since 1961, fertilizer use has increased by approximately 800%, yet only around 20% of applied nitrogen ever reaches the crop it was intended for.[218] The remainder leaks into soils, waterways, and the atmosphere, acidifying land, creating oxygen-depleted dead zones in coastal waters, and disrupting the microbial communities that underpin long-term soil fertility. In the European Union, only 38% of soils remain in healthy condition.[219] This deterioration carries consequences that extend beyond yields. As soil health declines, so does the nutritional density of the food it produces, compounding negative human health impacts. Fruits and vegetables have lost an estimated 25 to 50% of key minerals over the past 70 years, contributing to a situation where over two billion people globally suffer from micronutrient deficiencies.[220]

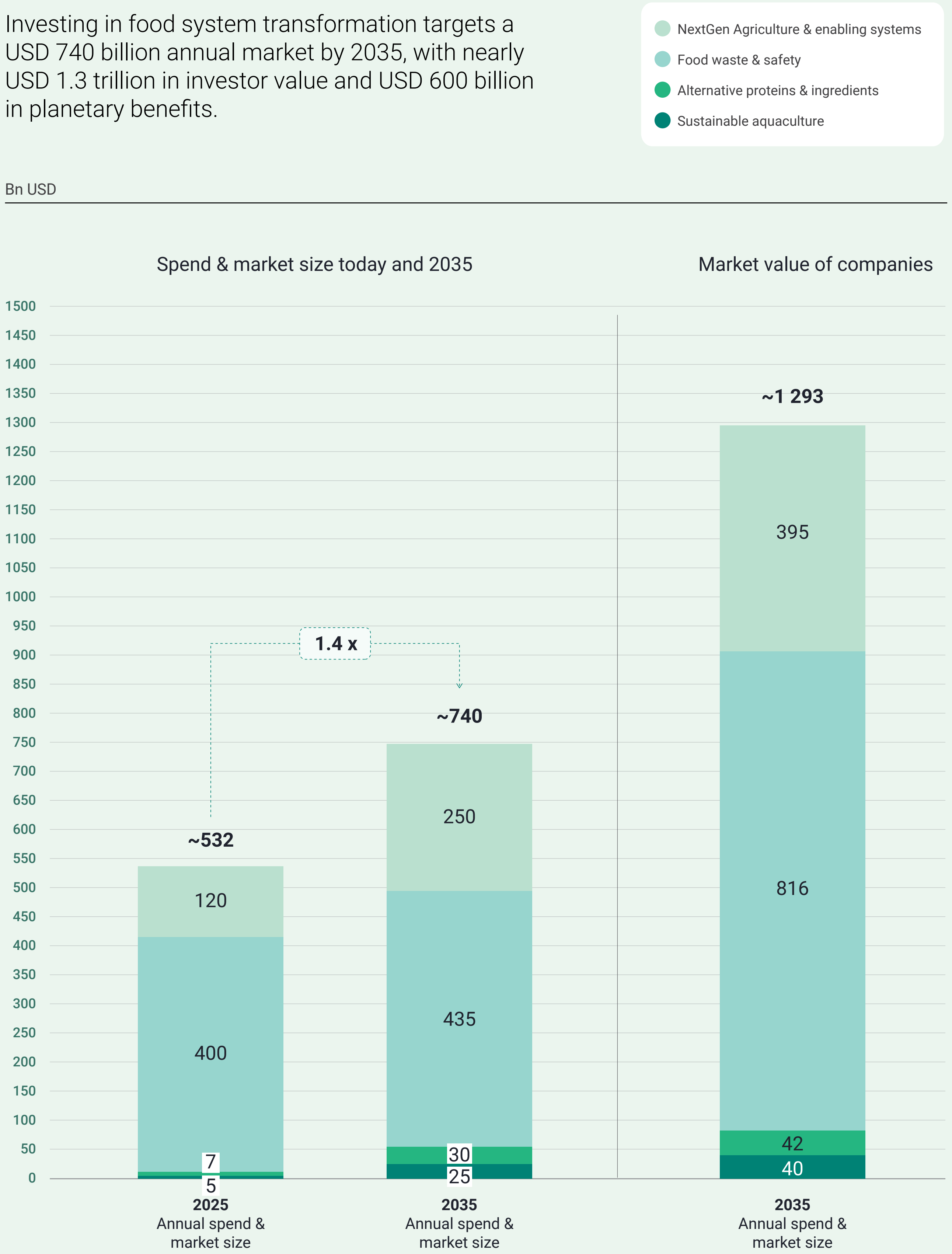
The pressure on land and climate is equally structural. Agricultural expansion is the primary driver of deforestation globally, with nearly 90% of tropical forest loss between 2000 and 2018 linked to land conversion for crops and grazing, the majority driven by demand for animal feed and livestock pasture.[221] The food system as a whole accounts for approximately 34% of total global greenhouse gas emissions, with livestock alone responsible for around 15% of global GHG output through methane from enteric fermentation and land use change.[222] Agriculture also accounts for over 70% of global freshwater withdrawals, with irrigated cropland facing rising water stress across many of the world's most productive regions.[223] Without transformation, the environmental effects of global food systems are projected to increase by 50 to 90% by 2050 as population growth, rising incomes, and dietary shifts compound existing pressures.[224]

Bringing the food system back within planetary boundaries will require more than marginal improvements to existing practices. Industrial agriculture and food production puts the system on a trajectory that becomes increasingly untenable, both economically and ecologically, as soils degrade further, water stress intensifies, and the hidden costs of production continue to outpace the value the system generates. Structural transformation across production methods, protein sources, and supply chain waste is inevitable, and it will require substantial capital. For investors prepared to back the companies driving that transformation, the structural tailwinds are significant and growing.

214. Food System Economics Commission, 2024; Summa Equity, 2025 215. Summa Equity, 2025; The Lancet, 2019 216. Summa Equity, 2025
217. FAO, 2011; Summa Equity, 2025 218. UN Food Systems Coordination Hub, 2025 219. Panagos et al., 2024 220. Summa Equity, 2025 221. World Resources Institute, 2025
222. Crippa et al., 2021; Summa Equity, 2025 223. UN Food Systems Coordination Hub, 2025 224. UN Food Systems Coordination Hub, 2025

Figure 33
Investable market – Summa

Investing in food system transformation targets a USD 740 billion annual market by 2035, with nearly USD 1.3 trillion in investor value and USD 600 billion in planetary benefits.



Note: McKinsey & Company and Summa estimates. Alternative proteins includes processing, manufacturing and distribution stages. NextGen agriculture includes product from greenhouses, vertical farms and technology. Food waste includes parts of food spoilage and optimization through supply chain, packaging, harvesting, etc., but excludes consumer behavior.

Planetary Boundaries Report 2025

The investment opportunity

SUSTAINABLE FOOD

Summa targets four structural leverage points across the food value chain, from production and protein supply through to waste reduction and food safety.

The issues of the current food system are well understood and documented. At the same time, solutions for transformative change are readily available. So far, most capital flowing into the sector continues to be directed toward conventional agricultural expansion and incremental efficiency improvements, sustaining a model that generates substantial hidden costs rather than resolving them. The scale of the funding gap underscores both the urgency and the opportunity: transitioning agrifood systems to a 1.5°C-aligned pathway requires an estimated USD 1.1 trillion annually, yet current climate finance for the sector amounts to less than 3% of that figure, making food and agriculture one of the most underfunded areas in the global economy relative to its impact.[225] For investors prepared to close that gap, the opportunity is substantial. Summa estimates the annual spend and market size of companies driving food system transformation at approximately USD 740 billion by 2035, with the potential to deliver approximately 2.5 billion saved lives, a 75% reduction in food system GHG emissions, and USD 600 billion in savings from reduced waste and improved nutrition.[226]

Summa has identified four specific areas where impact capital can profitably accelerate that transformation. To qualify, solutions must demonstrate commercial viability, address genuine structural bottlenecks, and generate value through efficiency gains, resource productivity, or waste reduction. Together, these four sub-themes represent a structurally de-risked opportunity with an attractive return profile:

- **Sustainable aquaculture** supports a more efficient and environmentally responsible aquaculture sector that helps meet growing global demand for healthy protein while safeguarding ocean health, representing a market opportunity of approximately USD 25 billion by 2040.
- **Alternative proteins & ingredients** invests in scalable plant-based, fermentation-derived, and cultivated protein solutions alongside specialty ingredients and feed additives that improve livestock health and reduce methane emissions, representing a market opportunity of approximately USD 30 billion by 2035.
- **Food waste and safety** targets solutions and business models that prevent, reduce, or redistribute food waste across the value chain, from production to consumption, representing a market opportunity of approximately USD 435 billion by 2035.
- **Next-gen agriculture & enabling systems** promotes technologies that increase productivity and enable more resilient farming systems, including the shift from chemical inputs to biological alternatives that lower both costs and risk for farmers, representing a market opportunity of approximately USD 250 billion by 2035.

Summa's commitment to sustainable food is grounded in an investment track record spanning the breadth of the theme:

STIM provides health and biological solutions for the aquaculture industry, addressing a key leverage point in reducing the environmental footprint of fish farming.

Nofitech develops land-based aquaculture technology, enabling production to be closer to end markets with lower transport emissions.

Nutris develops science-based nutritional solutions that improve the resource efficiency of food production, targeting the input side where marginal improvements carry significant downstream benefits.

Holdbart operates a digital platform helping redistribute close-to-expiry food products, directly targeting one of the food system's most avoidable sources of waste.

Oda operates an automated online grocery platform, reducing food waste through demand-driven inventory management and replacing inefficient retail distribution with centralized fulfillment.

Together, these investments span the food system from aquaculture inputs through processing and distribution to waste reduction.

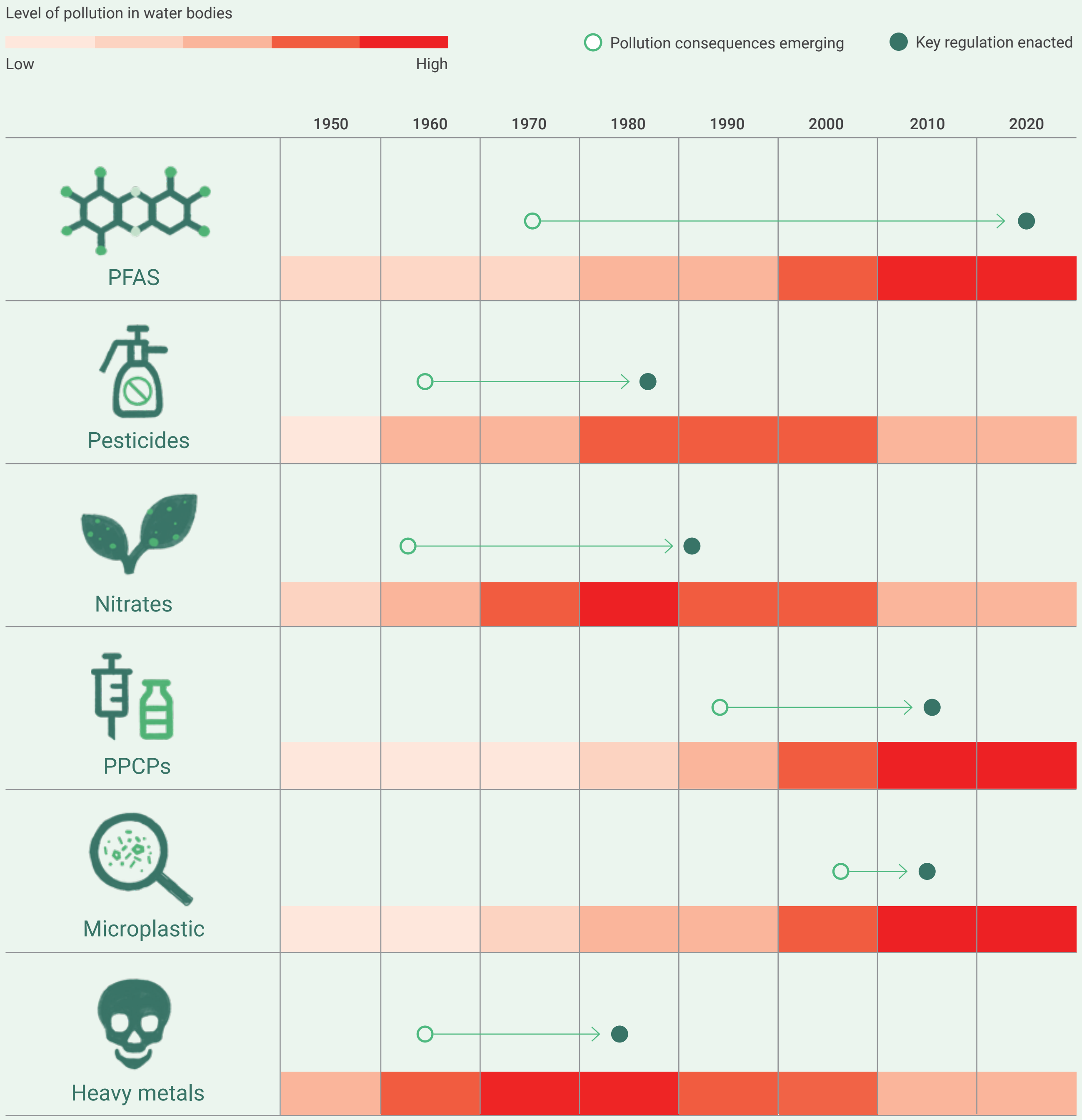
225. FAO & CLIC, 2024; Global Alliance for the Future of Food, 2024 226. Summa Equity, 2025

Figure 34
Timeline of pollution emergence and regulatory response across six major contaminant categories in European water bodies.

Regulation consistently lags pollution by at least two decades, deepening contamination before action begins.

Investing in Europe's water health

Read the report here



Challenges in the water system

CIRCULARITY – WATER

Only 40% of EU surface waters meet ecological standards, driving an annual healthcare cost of EUR 180bn.

Water, part of Summa's Circularity theme, cuts across all three of the systems targeted by Summa's investments, energy, materials, and food, both as a resource on which each depends and as the medium through which their pressures accumulate and interact. Only 40% of surface waters currently meet ecological quality standards, and fewer than 27% pass good chemical status.[227] There is a structural mismatch between the scale and complexity of modern pollution and the systems built to manage it. Six families of contaminants, PFAS, pesticides, nutrients, microplastics, pharmaceuticals, and heavy metals, now move continuously through the water cycle, transferring between soils, groundwater, surface water, and the ocean, accumulating in organisms and sediments faster than any meaningful assimilative capacity can absorb them. Many are chemically stable for decades. Several are carcinogenic or endocrine disrupting at nanogram concentrations. The planetary pressures this generates span the freshwater change boundary, the biogeochemical flows boundary, the novel entities boundary, and biosphere integrity simultaneously.

These pressures compound through climate extremes, ecosystem degradation, and persistent legacy contamination. Droughts shrink rivers into slow-moving channels where pollutants spike 20 to 60% above baseline, while floods overwhelm wastewater infrastructure, with overflow volumes potentially rising by as much as 256% under plausible future scenarios.[228] Rivers and lakes across Europe have warmed by 1 to 3°C since 1900, reducing dissolved oxygen and amplifying the toxic effects of contaminants already in the water column. Behind every functioning water system is a network of natural infrastructure, wetlands, riparian buffers, and healthy soils, that once filtered and absorbed these loads before they reached open water. Europe has lost approximately 50% of its wetlands since 1970, removing ecosystems capable of eliminating 40 to 55% of nitrates, 40 to 60% of phosphates, and over 90% of certain pesticides from passing water flows.[229] Their loss transfers purification costs from diffuse ecological processes to concentrated engineered infrastructure, at far greater expense. The total ecosystem service value of Europe's freshwater systems is estimated at more than EUR 230 billion annually, with water purification alone contributing EUR 60 billion in avoided treatment costs, a natural dividend that is quietly shrinking as nutrient and chemical loads exceed what remaining systems can absorb.[230]

The biological and human consequences are already severe. Migratory freshwater fish populations have declined by 93% since 1970, and only 15% of EU habitats are in good ecological condition.[231] Nutrient and chemical runoff from degraded catchments enters warming seas, contributing to ocean acidification, feeding coastal dead zones, and delivering persistent organic pollutants into marine food chains. For most of the six major pollutant families, food has become the primary route of human exposure: over 90% of pesticide exposure in Europe is dietary, and around 85% of PFAS intake is linked to crops, fish, and livestock.[232] The cumulative, lifelong burden of these mixed exposures, what scientists now describe as the exposome, represents a systemic public health challenge that single-substance regulatory frameworks were never designed to address. The full costs of this degradation, spanning health impacts, ecosystem losses, and remediation, are estimated at a minimum of EUR 180 billion annually across the EU.[233]

What makes the water system particularly resistant to transformation is what Summa's analysis terms the pollution time lag: regulation consistently chases contamination by at least two decades, arriving after substances have already accumulated in sediments, aquifers, and organisms across a continent.[234] PFAS contamination has been confirmed at over 23,000 sites across Europe, and legacy pesticides banned in the 1980s continue to leach from groundwater today. Addressing this will require a system-level response across the full pollution value chain, from eliminating the most persistent substances at source, to intercepting contaminants along their pathways, to remediating the legacy stocks already embedded in soils and sediments.

227. European Environment Agency, 2024 228. Blunke et al., 2019; Rodriguez et al., 2024 229. Summa Equity, 2025 230. European Commission, 2021
231. Summa Equity, 2025 232. Summa Equity, 2025 233. Summa Equity, 2025 234. Summa Equity, 2025

The investment opportunity

CIRCULARITY – WATER

The water opportunity spans four intervention stages, from reduction at source to capturing, shielding, and remediating existing contamination.

The scale of Europe's water crisis is matched by the investment opportunity it creates. Current spending on environmental protection, spanning water, air, waste, and biodiversity, remains structurally insufficient. The European Commission estimates that closing the implementation gap on existing environmental objectives would require spending to rise by roughly 50%, an additional EUR 122 billion per year, while the cost of inaction already runs to at least EUR 180 billion annually.[235] Private capital has largely stayed away, deterred by fragmented governance, long payback periods, and regulatory uncertainty, but conditions are shifting. The polluter-pays principle is gaining traction through extended producer responsibility schemes and PFAS levies, and a new generation of treatment, destruction, and monitoring technologies is reaching commercial maturity. For investors prepared to move ahead of that wave, the opportunity is compelling.

Summa's Water Health Scenario estimates the total incremental investment requirement at EUR 226 billion between 2025 and 2040, on top of the EUR 420 billion in water treatment spending already projected under current regulatory baselines.[236] Water health markets are projected to generate around EUR 370 billion in annual revenues by 2040, driven by expanding demand for advanced treatment, resource recovery, and ecosystem restoration, supporting a total market valuation exceeding EUR 1 trillion by 2040.

- **Reduce**, eliminating harmful substances through precision farming, chemical phase-outs, and substitution of the most persistent compounds, requires an estimated EUR 28 billion by 2040 and addresses contamination at the most cost-effective point of intervention, before it enters water systems.[237]
- **Capture**, intercepting pollutants at source or along their pathways through wastewater treatment upgrades, decentralized runoff systems, agricultural buffer zones, and sludge destruction, represents the largest single investment area at EUR 155 billion by 2040.[238] As extended producer responsibility shifts financing toward pharmaceutical and cosmetics producers from 2028, revenue models for these upgrades are becoming more predictable, and safe destruction of pollutant concentrates, including PFAS-laden sludge, is reaching commercial scale.
- **Shield,** upgrading drinking water treatment to remove PFAS, microplastics, and pharmaceutical residues at the tap, requires an estimated EUR 31 billion by 2040. Equipment suppliers and solution integrators delivering membrane, ion-exchange, and advanced adsorption technologies sit at the centre of this upgrade cycle. Meeting the more protective 2 ng/L PFAS threshold, far beyond the current EU Drinking Water Directive limit of 100 ng/L, would require nanofiltration across a significant share of European drinking water capacity.[239]
- **Remediate and Regenerate**, cleaning up the 23,000-plus PFAS-contaminated sites identified across Europe and treating soils and sediments that continue to leach pollutants into groundwater and coastal systems, requires an estimated EUR 12 billion by 2040, with polluter-pays enforcement progressively shifting costs toward identifiable industrial actors.[240]

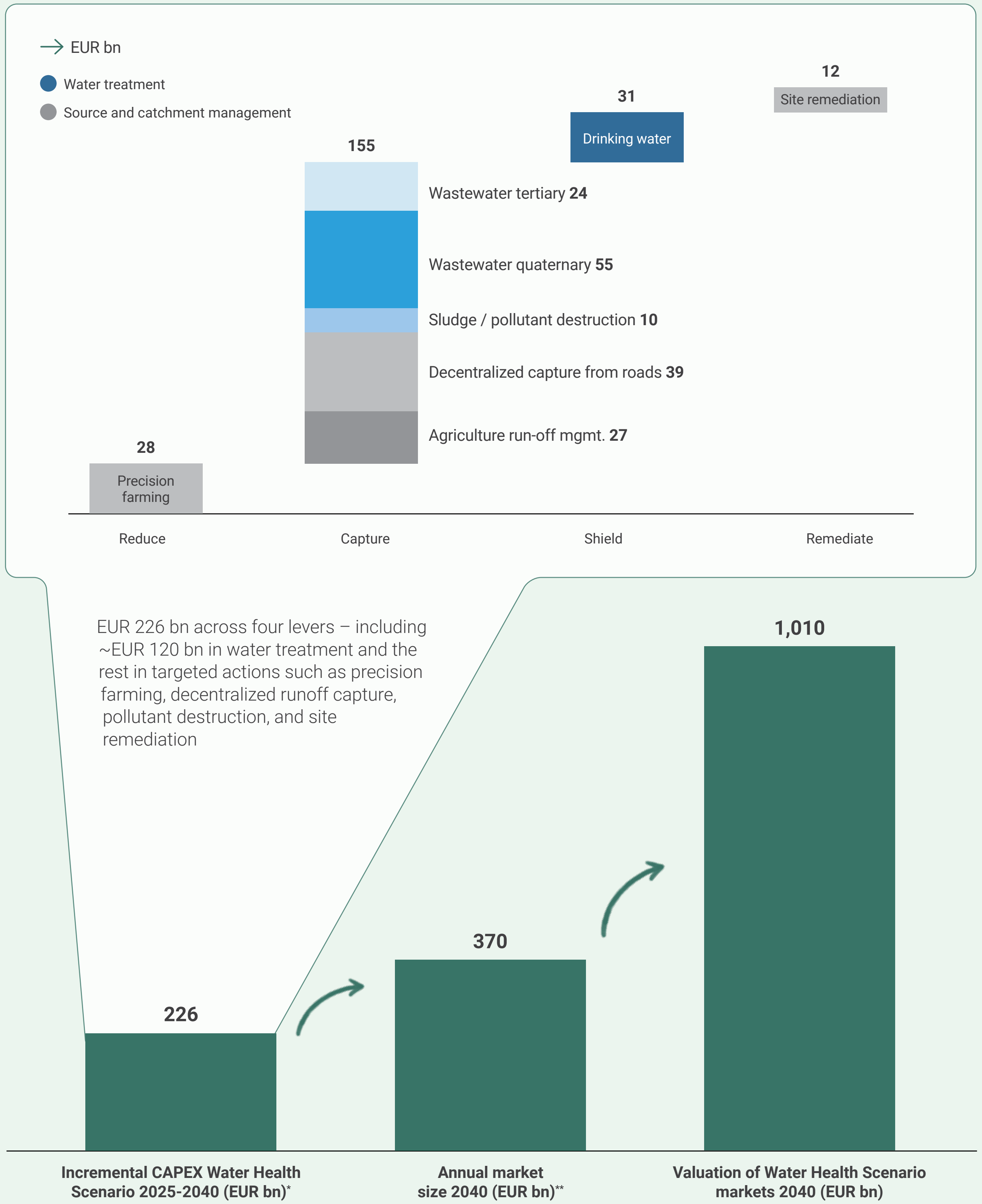
Summa's conviction in the water health transition is grounded in a portfolio that has been built around the same structural logic that underpins this analysis.

- **NG Nordic** has developed and patented the LoopCarb system for PFAS treatment in wastewater, demonstrating over 80% removal efficiency including ultrashort-chain compounds, and operates high-temperature incineration facilities for the complete destruction of PFAS concentrate, closing the loop between capture and elimination.
- **Waterise** is pioneering deep-sea desalination at depths of 400 to 600 meters, where natural hydrostatic pressure drives the reverse osmosis process at a fraction of conventional energy cost, producing microplastic-free and PFAS-free permeate water for water-scarce regions.
- **Nutris** demonstrates how regenerative agriculture can be scaled profitably, reducing reliance on synthetic inputs and cutting the nutrient runoff that drives eutrophication and coastal dead zones across Europe.

235. European Commission, 2025 236. Summa Equity, 2025 237. Summa Equity, 2025 238. Summa Equity, 2025 239. Summa Equity, 2025 240. Summa Equity, 2025 241. Summa Equity, 2025

Figure 35
Financing the Water Health Scenario

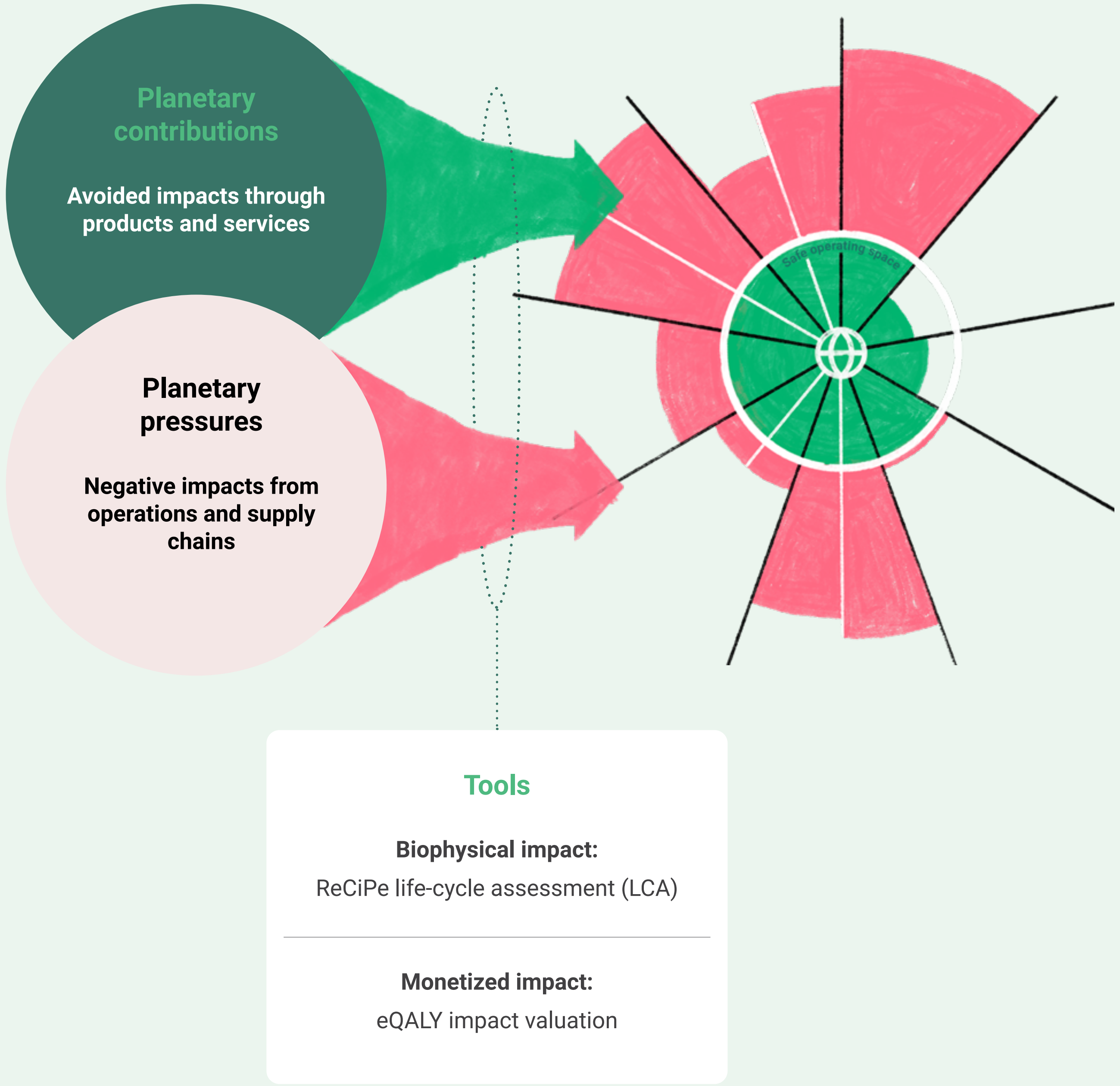
Investing EUR 226 bn in incremental CAPEX to unlock a EUR 1 tn water market opportunity by 2040.



* Represents incremental CAPEX identified in the Water Health Scenario, on top of a baseline investment of EUR 570 bn projected under current regulatory and market trends over the next 15 years ** Calculated as annual turnover in 2040

Figure 36
Conceptual presentation of planetary boundaries accounting framework

Assessing Earth systems impact requires accounting for both the pressures companies exert and the positive contributions their solutions deliver.



Planetary Boundaries Report 2025

Measuring impact across the boundaries

To direct capital toward companies that genuinely move the needle on planetary health, we must measure both pressures and contributions systematically, across all nine boundaries.

As a private markets investor focused on solving global challenges, Summa views the planetary crisis as central to both our investment strategy and the long-term resilience of our portfolio. With multiple boundaries now transgressed, restoring Earth system stability requires holistic approaches that reflect the interconnected nature of the pressures involved.

Traditional ESG frameworks are largely designed around managing adverse company impacts, capturing what companies report rather than what their activities actually do to Earth systems. Summa's planetary boundaries approach poses a different question: whether portfolio company activities push critical Earth systems closer to, or further from, the thresholds beyond which conditions for human and economic life become fundamentally less stable. This shifts the basis of our investment and ownership work from company-level metrics to systems-level impact, giving us a more honest account of where our portfolio contributes to solutions and where it generates pressure.

In 2025, together with Valuing Impact, we conducted our first portfolio-wide assessment of planetary boundary impact, spanning all four investment themes. Of our eighteen portfolio companies, thirteen were selected through a materiality screening using ENCORE, which identifies the significance of each company's interface with Earth systems at the sector and activity level. At its core, the assessment traces what each portfolio company actually does to Earth systems, from operational pressures through to the positive contributions its solutions deliver. Making this visible requires a consistent methodology for translating company activities into boundary-level impacts, a clear account of where pressures and contributions sit across the portfolio, and a combined view that identifies where ownership can reduce the most material pressures and where capital can scale solutions with the greatest systemic benefit.

Translating the planetary boundaries into a structured account of portfolio-wide impact and exposure remains an evolving discipline, and this assessment represents what we believe is a meaningful step toward making the framework practical and actionable in private markets. We will look to refine the approach as science, methods, and our own understanding continue to develop.

Why both sides of the equation matter: accounting for pressures and contributions

Understanding how a portfolio of companies interacts with the planetary boundaries requires a system-level assessment that captures the full range of environmental pressures generated across value chains, from greenhouse gas emissions and land-system change to freshwater consumption, nutrient loading, and ecotoxicity, and connects those pressures to the boundary processes they affect.

For a portfolio built around solving structural global challenges, accounting for only the pressures companies generate gives an incomplete picture. The extent to which company products and services contribute to reducing pressure on transgressed boundaries is as material as the operational footprint those companies leave behind. A framework that measures only one side of this balance cannot distinguish between a company that adds pressure to Earth systems and one that contributes to reducing it. Understanding where a company's solutions deliver the greatest positive contribution also helps identify which products and services to scale, which markets to prioritize, and where commercial effort will compound as the demand for systemic solutions intensifies.

In previous years, Summa's environmental accounting focused primarily on comprehensive carbon accounting across all three emission scopes, including value chain emissions, supplemented by high-level biodiversity assessments. This year, together with Valuing Impact, we have conducted a more granular assessment across thirteen portfolio companies spanning all four investment themes. For each company, we mapped both positive and negative impact pathways across the value chain, applying life-cycle assessment data to quantify the footprint from energy use, procurement, and downstream product impacts. Using the same methodology, we estimated the potentially avoided impacts attributable to the products and services these companies provide, capturing the systemic change they enable through innovation and disruption in their value chains.

How pressures and contributions connect to planetary boundaries

The pathway from a company's operations to its effect on the planetary boundaries runs through a broad set of environmental pressures and positive contributions. The assessment maps each to the planetary boundary most closely connected, making it possible to trace operational activities through to their consequences for Earth systems, both where they add pressure on the boundaries and where they provide a positive contribution by reducing this pressure. The pathway-based approach reflects the systemic nature of planetary boundary pressures, where a single industrial process can affect multiple boundaries simultaneously and where cross-boundary feedback can amplify or attenuate the overall effect. For example, a solution that delivers significant climate benefits, may simultaneously exert pressure on, or deliver benefits for, other environmental systems, including freshwater, land use, biodiversity, and nutrient cycles.

Biophysical impact: pressures and contributions expressed in PDF·m^2·yr

The main metric we use to assess planetary boundary impact is PDF·m^2·yr (Potentially Disappeared Fraction of species, per square meter, per year). Every activity in the value chain contributes to habitat degradation through clearing land, emitting pollutants, consuming water, or releasing greenhouse gases. As habitats are altered, a portion of the species that would otherwise inhabit these ecosystems is lost. The PDF·m^2·yr metric translates these diverse pressures, estimated from life-cycle assessment (LCA) data, into a single comparable unit of biophysical harm, making it possible to compare pressures that would otherwise be measured in entirely different units and to identify which parts of a value chain are causing the most damage.

The assessment covers the pressure categories that connect most directly to the transgressed planetary boundaries: climate change and ocean acidification, land-system change, biosphere integrity, freshwater change, biogeochemical flows, aerosol loading, and novel entities.

While PDF·m^2·yr captures the ultimate consequence for biosphere integrity, the underlying pressures work through each of the other boundaries via complex linkages. To present these results clearly, we have mapped each relevant LCA midpoint category to the most directly affected boundary. It is important to note that these mappings reflect our assessment of the most relevant connection for each pressure category. In practice, several pressures affect multiple planetary boundaries simultaneously. The mapping is intended to provide a structured and transparent view of where avoided pressures are concentrated, rather than a claim that each midpoint affects only the boundary to which it is assigned.

Human impact: pressures and contributions expressed in societal cost (EUR)

To measure the human consequences of planetary boundary transgression, we also express each impact as a monetary cost or benefit to society, using country-specific valuation factors that reflect local ecosystem sensitivity and economic context. Environmental pressures are first converted into impacts on human wellbeing, then valued in EUR. The monetized metric captures a broader set of impacts

than the biophysical metric. Several pressure categories, including human toxicity, particulate matter formation, and ozone depletion, affect human health but lack a direct species-loss endpoint in the LCA framework used and therefore cannot be expressed in PDF·m^2·yr. These are included in the monetary valuation, making it a more complete measure of the portfolio's effect on the boundaries, while the biophysical metric offers a more direct gauge of pressure on biosphere integrity.

Climate pressure: The role of GHG emissions

GHG emissions, measured as global warming potential (GWP100), are a key driver of planetary boundary transgression and remain the most widely tracked and regulated environmental pressure. We therefore report GHG emissions as a standalone metric alongside the two broader measures introduced above. This ensures that GHG emissions remain visible and actionable alongside the broader biophysical and societal cost metrics.

In the life-cycle assessment framework used to calculate biophysical impact, GHG emissions feed into the climate change midpoint, which is then characterized as species loss and expressed in PDF·m^2·yr. Because ocean acidification shares the same underlying driver, its biophysical impact is captured within the same pathway rather than modeled as a separate boundary category. PDF·m^2·yr aggregates the consequences of all environmental pressures, not only climate change, into a single measure of biodiversity impact. The monetized societal cost builds on this by translating these consequences into costs and benefits for society in EUR, using regionalized damage cost factors.

Life-cycle assessment footprinting using ReCiPe

PDF·m^2·yr is a metric calculated using the ReCiPe LCA method, where the environmental footprint is expressed as species loss. Every environmental pressure generated across the value chain, from clearing land and emitting pollutants to consuming water and releasing greenhouse gases, contributes to habitat degradation. As habitats are altered, a portion of the species that would otherwise inhabit these ecosystems disappears. ReCiPe quantifies this effect for each type of environmental pressure, grounded in observed scientific data linking habitat degradation to factors such as soil toxicity, acidification, and land conversion.

For land use, species loss is estimated per square meter relative to a natural reference state. Other midpoint impact categories, including ecotoxicity, eutrophication, and water use, are translated into land-use equivalents, making it possible to compare distinct types of environmental pressure on the same scale and to identify which parts of a value chain are causing the most damage.

These impacts are aggregated across the value chain into a single metric: PDF·m^2·yr (Potentially Disappeared Fraction of species, per square meter, per year). This unit captures the fraction of species lost over a specified area and time period, providing a comparable measure of environmental impact across companies and pressure categories.

PDF·m^2·yr can be thought of as replacing 1m^2 of untouched habitat with 1m^2 of asphalt for one year, with no support for natural life

Mapping LCA categories to the planetary boundaries

Closest boundary affected	Midpoint category (ReCiPe)	Mechanisms driving planetary pressure and contribution
Climate change	Global warming potential (CO2e)	Rising temperatures shift species ranges, disrupt seasonal timing, and can push ecosystems beyond their thermal tolerances
Ocean Acidification	Global warming potential (CO2e)	CO_2 dissolves into seawater due to increasing atmospheric levels, lowering pH and impairing the ability of corals, shellfish, and other calcifying organisms to build shells and skeletons. This destabilizes the reef and other ecosystems that support marine biodiversity.
Stratospheric Ozone Depletion	Ozone depletion	Thinning of the stratospheric ozone layer increases UV-B radiation, damaging DNA in plants and marine organisms
Atmospheric Aerosol Loading	Particulate Matter Formation	Fine particles deposit e.g. toxic compounds onto soils and waterbodies, negatively impacting ecosystems.
	Photochemical oxidant formation potential	Ground-level ozone damages plant tissue, reduces photosynthesis, weakens vegetation and degrades habitat.
Biogeochemical flows	Terrestrial acidification	Acid deposition lowers soil pH, leaches essential nutrients, degrading conditions for acid-sensitive organisms and dependent species.
	Marine eutrophication	Excess nitrogen enrichment of coastal waters fuels algal blooms that deplete oxygen, creating dead zones where most marine life cannot survive.
	Freshwater eutrophication	Phosphorus runoff triggers algal blooms in lakes and rivers, depleting oxygen and light, driving out sensitive aquatic species.
Freshwater change	Total water extraction	Removing water from rivers, lakes, and aquifers reduces habitat availability, concentrates pollutants, and eliminates the flows that aquatic and riparian species depend on.
Land-system change	Agricultural land occupation	Converting natural habitats to farmland directly destroys ecosystems, fragments landscapes, and is the single largest driver of terrestrial biodiversity loss globally.
Novel entities	Marine ecotoxicity potential	Toxic substances accumulate in marine sediments and food chains, impairing reproduction, development, and survival across a wide range of ocean species.
	Terrestrial ecotoxicity potential	Pollutants in soils harm invertebrates, microorganisms, and plants that form the foundation of terrestrial food webs and ecosystem functioning.
	Freshwater ecotoxicity potential	Chemical contaminants in rivers and lakes poison aquatic organisms, disrupt food webs, and reduce the diversity of freshwater communities.
Biosphere integrity	All	Total impact is the sum of all impacts mapped to the other boundaries

Measuring pressure to drive reduction

A small number of companies with material and agriculture-intensive supply chains account for the majority of pressures, with the largest effects on land-system change and climate change.

Every company in Summa's portfolio generates environmental pressures through its operations and value chain. Sourcing materials, consuming energy, manufacturing, logistics, and end-of-life disposal all leave a planetary boundary footprint. What matters is whether we understand them well enough to manage and reduce them over time.

We have examined those pressures in detail. Greenhouse gas emissions warrant particular attention as climate change is the boundary with the broadest systemic reach, connecting through physical and economic pathways to virtually every other planetary boundary. GHG accounting also benefits from the most mature methodologies and standardized reporting frameworks, making it the most reliable basis for tracking progress over time. Beyond climate, the biophysical assessment traces pressures across the remaining boundaries, from land use and freshwater consumption to novel entities and biogeochemical flows.

Understanding pressures is the foundation for reducing them, and the analysis that follows identifies where they are concentrated, how they are distributed across the portfolio, and where the most material opportunities for improvement lie.

Broader boundary pressures

Land-system change

Land use is the largest driver of ecosystem degradation globally. Across the portfolio, it is the boundary where the portfolio exerts the greatest pressure, at approximately 274 million PDF·m²·yr, driven primarily by agricultural land occupation, which reduces habitat quality and fragments ecosystems. The principal driver is food-related supply chains, particularly upstream agricultural procurement, where Oda accounts for the majority of the footprint at approximately 316 million PDF·m²·yr. Secondary contributions arise from upstream material supply chains linked to industrial and construction activities. Land-system change also interacts closely with other boundaries, as the habitat loss and fragmentation described above weaken ecosystem resilience to climate change, disrupt freshwater regulation, and accelerate biodiversity decline.

Climate change / Ocean acidification

Climate change is the planetary boundary with the broadest systemic reach, connecting through physical and economic pathways to virtually every other boundary. Across the portfolio, the total pressure attributable to climate change and ocean acidification amounts to approximately 257 million PDF·m²·yr, or roughly 32% of the total, making it the second-largest boundary category after land-system change. The principal driver is operational and supply chain greenhouse gas emissions, where NG Nordic accounts for the majority of the footprint at approximately 1.6 million tCO_2e, reflecting the emissions intensity of waste collection and processing. Beyond NG Nordic, emissions are concentrated in Tibber, where fossil fuels within grid electricity drive the footprint, and Oda, where carbon emissions from agricultural and food production are intensive.

Novel entities

Chemical pollution across terrestrial, freshwater, and marine ecosystems produces a combined pressure of approximately 74 million PDF·m²·yr, measured through terrestrial (TETP), freshwater (FETP), and marine ecotoxicity potential (METP). These indicators reflect the release of heavy metals, persistent organic pollutants, pesticides, and industrial chemicals. Terrestrial ecotoxicity accounts for the largest share, driven primarily by upstream material and food supply chains, with freshwater and marine ecotoxicity adding pressure through chemical discharge and runoff from industrial and agricultural activities. These pollutants also pose direct risks to human health, making this boundary relevant not only from a planetary perspective but also from a public health standpoint. As regulatory scrutiny around chemical exposure intensifies globally, the health dimension reinforces the importance of tracking and reducing pollution across portfolio value chains

Biogeochemical flows

Disruption of nitrogen and phosphorus cycles generates a portfolio pressure of approximately 69 million PDF·m²·yr, driven by freshwater eutrophication from nitrogen and phosphorus runoff and terrestrial acidification from SO_2 and NO_x emissions. Nutrient loading from agricultural supply chains represents the dominant pathway, particularly in food-related activities, with industrial material processing and energy use adding further pressure through acidifying emissions and pollutant discharge.

Aerosol loading

The Aerosol Loading boundary tracks fine particle concentrations in the atmosphere and their effects on the energy balance, water cycle, and climate stability. Across the portfolio, pressure on this boundary amounts to approximately 21 million PDF·m²·yr, driven by ozone precursor emissions from upstream food production, industrial material processing, and combustion in logistics and waste handling.

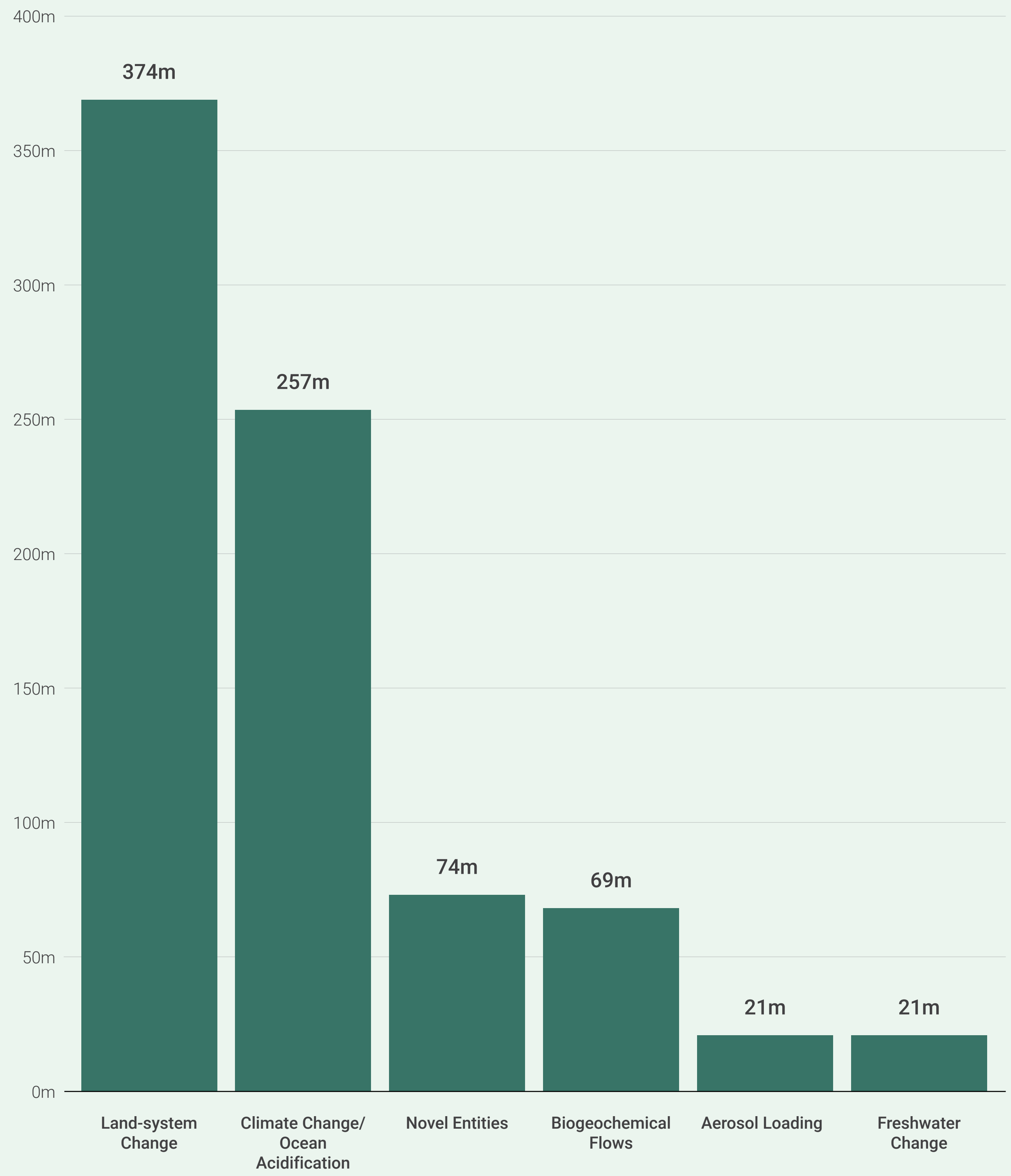
For this assessment, photochemical ozone formation for ecosystems (EOFP), which covers ground-level ozone precursors (notably NO_x and VOCs) and their damage pathway to ecosystem quality, is mapped to this boundary. Although ozone is a gas rather than an aerosol, the same precursors drive atmospheric aerosol loading, making this the closest applicable boundary for EOFP. Particulate matter formation (PMFP) has no defined endpoint pathway to ecosystem quality damage in ReCiPe 2016 and is therefore excluded from the biophysical footprint analysis, meaning pressure on the Aerosol Loading boundary is likely underestimated by the biophysical metric.

Freshwater change

Pressure on the freshwater boundary reaches approximately 21 million PDF·m²·yr, reflecting water extraction and its translation into species loss through reduced freshwater availability and altered hydrological regimes. The primary drivers are upstream material processing and food-related procurement, where irrigation and agricultural water demand dominate. A secondary pathway runs through energy consumption, where upstream power generation adds to freshwater withdrawal. Compared with other boundaries, the pressure is smaller in magnitude but broadly distributed across portfolio activities.

Figure 37
Portfolio pressure by planetary boundary (million PDF·m²·yr)

Portfolio pressure is concentrated in land-system change and climate change.



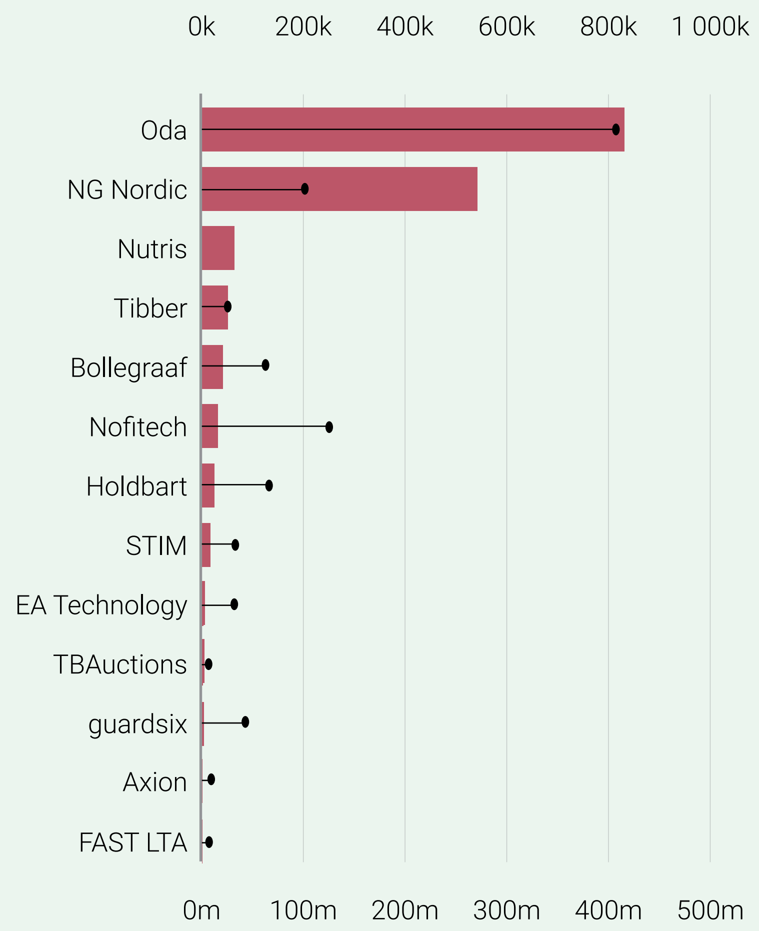
Total pressure and intensity by company

Across the portfolio, the negative footprint is concentrated in upstream food production, material procurement, and energy consumption. Oda alone accounts for approximately 420 million PDF·m²·yr in total footprint, followed by NG Nordic at approximately 274 million PDF·m²·yr. At the opposite end, asset-light technology companies such as FAST LTA (0.3 million PDF·m²·yr), Axion Biosystems (0.4 million PDF·m²·yr), and guardsix (2.2 million PDF·m²·yr) generate comparatively small footprints.

Impact intensity varies significantly across the portfolio. Oda has the highest intensity relative to revenue at 817k PDF·m²·yr per EUR million, reflecting the environmental pressure embedded in food production value chains. Nofitech shows relatively high intensity at approximately 251k PDF·m²·yr per EUR million, driven by the energy and infrastructure requirements of recirculating aquaculture systems. FAST LTA and TBAuctions operate at approximately 11k PDF·m²·yr per EUR million, consistent with their asset-light business models. The spread in intensity highlights where targeted efficiency improvement and supply chain engagement can deliver the greatest reduction in boundary pressure.

Figure 38
Planetary boundary pressure and intensity (PDF·m²·yr)

Absolute pressure and intensity vary significantly across the portfolio, with companies in agriculture and material-intensive supply chains exerting the largest pressure.



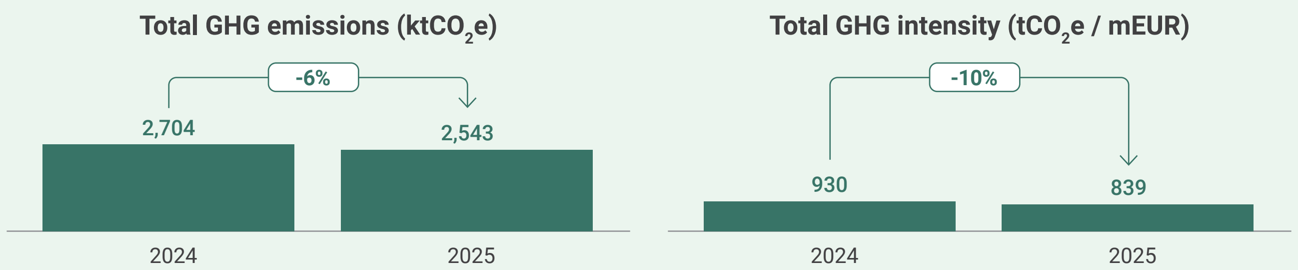
Company	Pressure	Intensity
Oda	419.6m	817k
NG Nordic	273.5m	203k
Nutris	32.2m	N/A
Tibber	25.7m	44k
Bollegraaf	21.0m	125k
Nofitech	15.8m	251k
Holdbart	12.5m	126k
STIM	8.4m	61k
EA Technology	3.1m	61k
TBAuctions	2.5m	11k
guardsix	2.2m	83k
Axion	0.4m	17k
FAST LTA	0.3m	11k

Climate change boundary pressure: GHG emissions across the portfolio

Summa's total portfolio emissions amounted to 2,543 ktCO2e in 2025. The larger magnitude compared to total emissions reported in 2024 of 2,183 ktCO2e is primarily driven by the NG Groups acquisition of Fortum Recycling & Waste to form a new Nordic circularity champion, NG Nordic. When adjusted for M&A, exits, as well as data quality improvements, 2024 GHG emissions amount to 2,704 ktCO2e, constituting a like-for-like reduction of 5.9% in total portfolio emissions in 2025. Across the portfolio, 16 of 18 companies reduced their absolute emissions. Carbon intensity also decreased by 9.8%. The stronger reduction in intensity relative to absolute emissions indicates that portfolio companies are successfully decoupling revenue growth from their carbon footprint, growing their businesses while reducing emissions per unit of output.

Figure 39
Portfolio GHG emissions across Scope 1, 2, and 3

The portfolio's climate pressure decreased in 2025, driven by reductions in both absolute emissions and emission intensity.



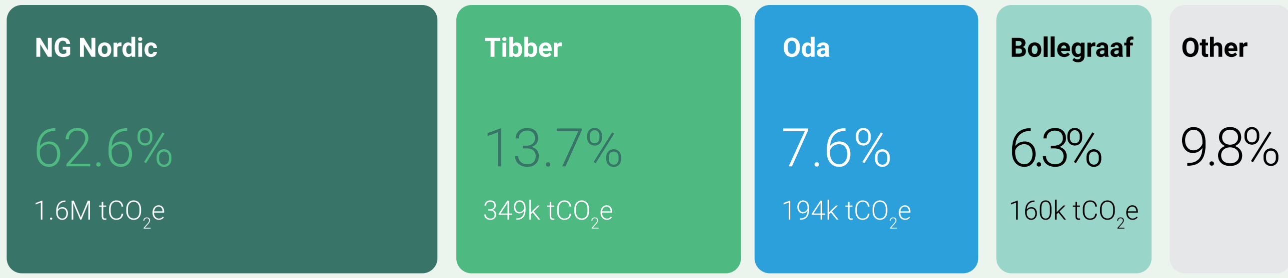
Total portfolio GHG emissions are highly concentrated, with four companies accounting for 90% of the aggregate footprint. All four operate in sectors where value chains are inherently emission-intensive, spanning waste processing, food production, and energy retail. Interpreting these figures requires acknowledging a structural limitation of the GHG Protocol. Reported emissions capture what a company generates through its operations and value chain, but not what its products and services prevent elsewhere in the economy.

NG Nordic accounts for 63% of the total portfolio footprint at 1.6 million tCO_2e. Waste processing methods designed to retain material properties and reintegrate them into the circular economy inherently generate higher direct emissions than linear disposal, but reduce the need for virgin material production and the substantial emissions associated with it.

Tibber's emissions relate almost entirely to the electricity it brokers rather than its own operations, while its technology platform drives energy efficiency and renewable adoption across its customer base.

Oda's footprint reflects the emissions intensity of the food value chain, with the majority embedded in upstream agriculture, processing, and transportation, while its centralized fulfillment model generates lower last-mile emissions and less food spoilage than conventional grocery retail.

Bollegraaf manufactures the sorting and recycling machinery that enables circular waste processing, with each system deployed displacing virgin material production over decades of operation.



Measuring contributions to scale solutions

Companies displacing virgin material production deliver the largest positive contributions, concentrated in climate change and land-system change.

The avoided impact dimension of the assessment captures the planetary boundary benefits that portfolio companies deliver through the displacement of more harmful alternatives. These impacts fall outside the conventional Scope 1–3 boundary of the GHG Protocol, but they are essential for understanding the planetary impact of companies whose products and services are designed to reduce environmental pressure. With multiple planetary boundaries transgressed and deteriorating, avoided impacts provide a necessary complement to the negative footprint, making it possible to evaluate whether capital is being directed toward reducing systemic pressure on Earth systems.

Avoided impact estimates are inherently more uncertain than the accounting of exerted pressures because they depend on assumptions about counterfactual scenarios, additionality, and attribution. Summa's methodology applies conservative baselines and attribution assumptions throughout, and the resulting Scope 4 values should be interpreted as credible lower bounds rather than precise point estimates. The results are most meaningful when viewed as a portfolio-level signal that the direction of capital allocation is aligned with the reduction of planetary boundary pressures, rather than as company-level offset claims.

We assess the positive contribution of portfolio company activities across all nine planetary boundaries. Evaluating contributions to a single boundary would capture only a fraction of the environmental value that portfolio companies deliver and risks overlooking the pressures and contributions that matter most for the stability of Earth systems as a whole. Within this holistic assessment, we present avoided emissions separately, as climate is one of the key drivers of planetary boundary transgression and the most established and widely communicated dimension of positive environmental contribution, enabling more direct comparison with industry peers and alignment with existing disclosure practices. Both perspectives draw on the same underlying activity data, meaning they represent two views of the same assessment rather than separate or additive calculations. A detailed overview of each portfolio company's contribution pathways is provided in the Appendix.

Summa will continue to strengthen and expand its planetary boundary assessment as the methodology and underlying data improve. Over time, a broader shift across private markets toward similarly holistic frameworks would enable greater comparability across portfolios and a more complete picture of how private capital contributes to reducing systemic environmental risk.

Climate change

In the ReCiPe method, emissions are converted into biophysical consequences using a global warming potential (GWP) factor for each kilogram of CO_2-equivalents. Because ocean acidification is also driven by atmospheric CO_2, its impact is included in the same conversion pathway. Applying this method to avoided emissions reveals approximately 465 million PDF·m²·yr in avoided pressure, making climate change and ocean acidification the boundary category where the portfolio delivers the largest positive impact. This exceeds the corresponding negative pressure of approximately 257 million PDF·m²·yr by a significant margin, reflecting the displacement of carbon-intensive activities, most notably through circularity (avoided virgin material production), energy transition (enabling energy efficiency, grid optimization, and adoption of renewable energy), and sustainable food (displacing emissions from food waste and agricultural production).

Land-system change

The portfolio's avoided impact on this boundary totals 282 million PDF·m²·yr, driven primarily by reduced reliance on land-intensive primary production in both materials and food systems. Circular material flows reduce demand for forestry and extraction, while food-related solutions displace upstream agricultural land use.

As deforestation risk, land scarcity, and sustainable sourcing requirements intensify, the ability to decouple output from land use is becoming a competitive differentiator, strengthening market positioning and supply chain resilience for companies that can demonstrate reduced land dependence.

Biogeochemical flows

Total avoided impact reaches 247 million PDF·m²·yr, reflecting reduced nutrient pollution and acidifying emissions across industrial and food-related value chains. Avoided terrestrial acidification accounts for the larger share, driven primarily by displaced virgin material production, where combustion and chemical processing generate both acidifying emissions and nutrient-laden discharge. A distinct pathway comes from aquaculture, where Nofitech's recirculating systems reduce nitrogen and phosphorus discharge relative to conventional baselines, with the benefit concentrated in freshwater eutrophication. Holdbart adds further avoided pressure by displacing the fertilizer use and nutrient runoff associated with upstream food production.

As environmental standards on wastewater discharge, nutrient runoff, and acidifying emissions tighten across jurisdictions, the operational cost of managing these pressures is rising for industrial and agricultural producers, strengthening the commercial case for solutions that reduce nutrient and acidification loads at source.

Novel entities

Avoided impact on this boundary amounts to 136 million PDF·m²·yr, reflecting the avoided release of heavy metals, persistent organic compounds, and industrial chemicals. Terrestrial ecotoxicity accounts for the largest share. The dominant pathway is displaced primary extraction, smelting, and refining, which release ecotoxic substances across all three environmental compartments. Smaller shares come from grid optimization, which reduces ecotoxic emissions from fossil fuel-based generation, and from displaced animal protein production, which avoids the pesticide and pharmaceutical loading associated with intensive livestock systems.

Liability exposure around chemical pollution is growing, particularly as regulation expands to cover PFAS, persistent organic pollutants, and industrial discharge. Companies whose products displace the use or release of ecotoxic substances are better positioned in value chains where downstream customers increasingly face obligations to demonstrate reduced chemical risk.

Freshwater change

The portfolio avoids an estimated 118 million PDF·m²·yr of freshwater pressure, with more diverse mechanisms than for other boundaries. Material recovery accounts for the largest share, as virgin paper, metals, and plastics production is highly water-intensive. Nofitech's recirculating aquaculture systems, which recirculate approximately 99.7% of water, deliver meaningful avoided pressure through dramatically reduced freshwater extraction relative to conventional systems. Energy transition companies reduce the cooling water demand associated with thermal power generation, and Holdbart displaces water use embedded in water-intensive food commodities such as dairy and beverages.

Water scarcity is emerging as a binding constraint in many regions and industries, with direct implications for production continuity and cost. Solutions that reduce water dependency provide operational resilience and cost advantages to customers, reinforcing demand in water-stressed markets and supporting long-term scalability.

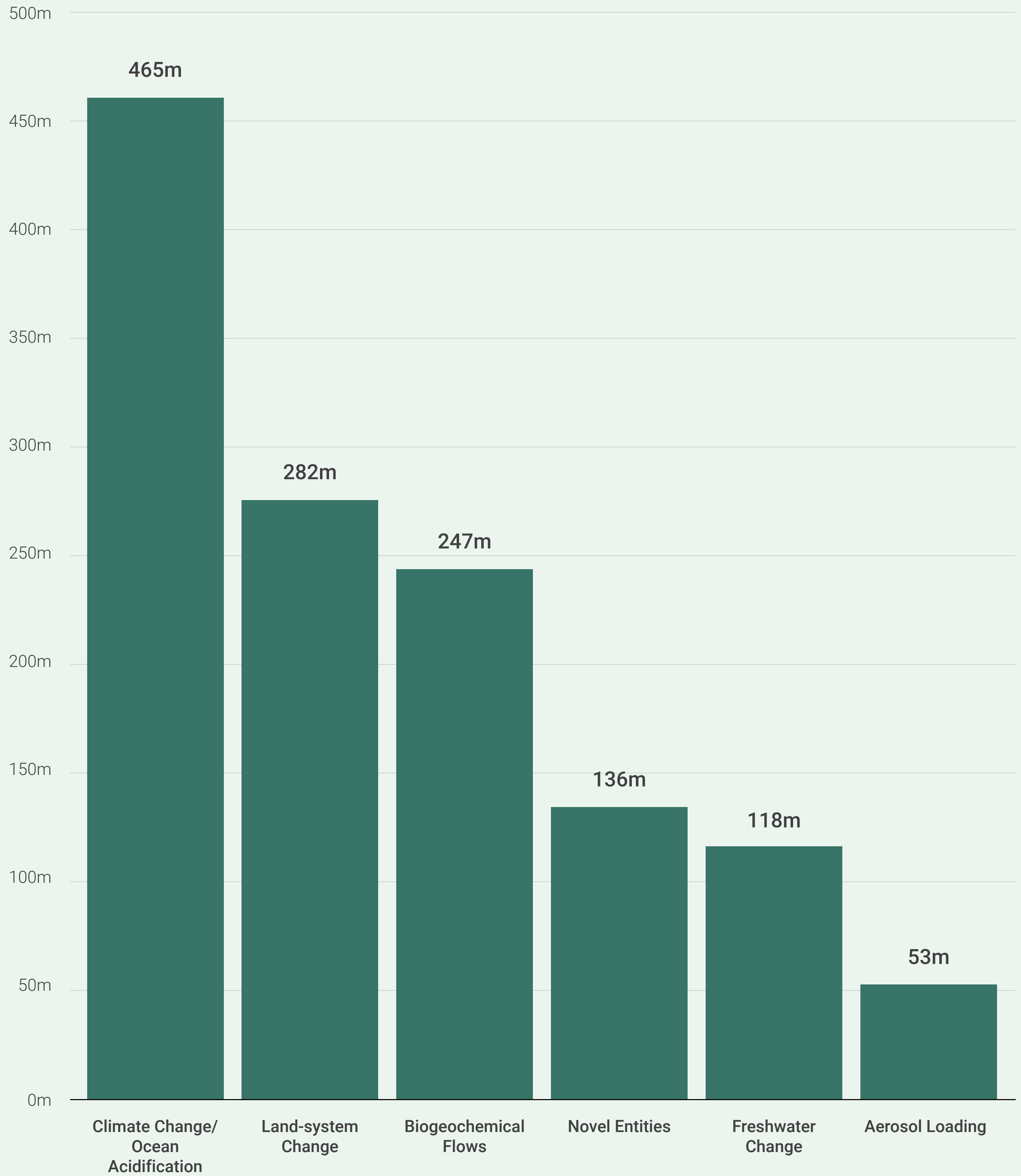
Aerosol loading

Avoided pressure on this boundary reaches 53 million PDF·m²·yr, although this figure is likely understated due to the exclusion of particulate matter formation (PMFP) from the biophysical metric.

Air pollution is closely linked to public health regulation, urban policy, and industrial emissions standards. By enabling reductions in pollutant precursors, the portfolio supports customers in meeting stricter air quality requirements. This creates a competitive advantage in regulated markets, particularly where compliance costs are rising and low-emission alternatives are favored.

Figure 40
Portfolio contribution by planetary boundary (million PDF·m²·yr)

Contributions are most material across climate change and land-system change, the same boundaries where portfolio pressures are highest.



Avoided impact by activity

Avoided production of virgin materials represents the largest share of avoided impact by a wide margin, accounting for 988 million PDF·m²·yr out of a total of 1,300 million PDF·m²·yr. This reflects the broad, cross-cutting effects of circular models that displace primary extraction and processing, generating avoided pressure across multiple boundaries simultaneously. The distribution of avoided impacts across the remaining activities highlights a set of complementary pathways through which the portfolio reduces pressure on underlying systems.

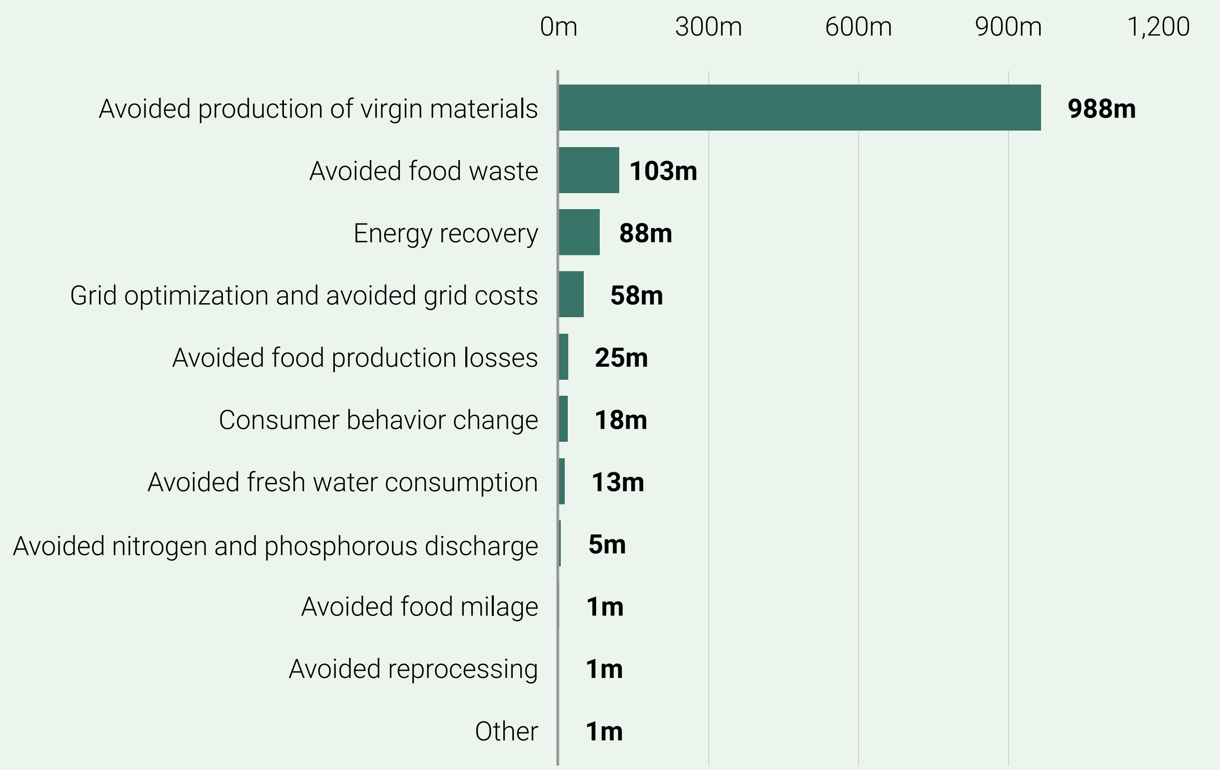
Energy-related activities account for a significant share, with energy recovery (88 million PDF·m²·yr) and grid optimization (58 million PDF·m²·yr) reducing the environmental intensity of how energy is generated and delivered. In parallel, food system interventions, including avoided food waste (103 million PDF·m²·yr) and reduced production losses (25 million PDF·m²·yr), address inefficiencies at source, preventing land use, water consumption, and nutrient pressures before they materialize.

Additional pathways, including consumer behavior change (18 million PDF·m²·yr), reduced freshwater use (13 million PDF·m²·yr), and lower nitrogen and phosphorus discharge (5 million PDF·m²·yr), deliver more targeted effects within specific boundary processes, while smaller categories reflect incremental improvements across value chains.

The portfolio's positive impact is therefore shaped by multiple reinforcing mechanisms. Some reduce the need for resource-intensive production, while others improve the efficiency and environmental profile of existing systems. It is the combination of these pathways that enables meaningful reductions across several planetary boundaries simultaneously, consistent with the interconnected nature of the pressures involved.

Figure 41
Avoided planetary boundary impact by activity (PDF·m²·yr)

Avoided production of virgin materials accounts for the vast majority of positive contribution, reflecting the importance of transitioning from a linear to a circular material system.



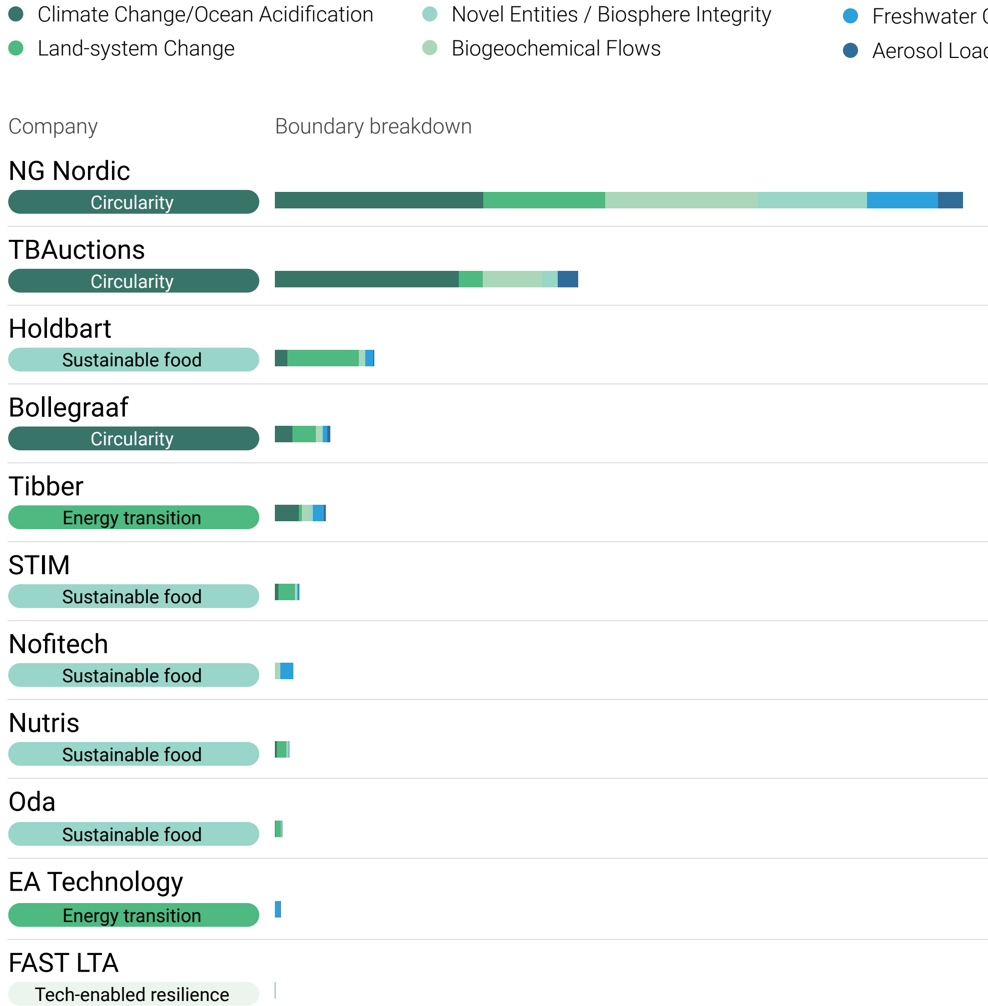
Positive contributions across the portfolio companies

The distribution of avoided planetary boundary pressure follows a similar pattern to avoided emissions, partly because GHG-intensive processes are closely linked to other environmental pressures such as land use, acidification, and ecotoxicity, and partly because of operational scale.

NG Nordic accounts for 56% of the total, reflecting its position across the full waste value chain, where the processing of large volumes of paper, cardboard, metals, plastics, and glass generates avoided pressure across every boundary assessed. TBAuctions, at 25%, delivers a disproportionately large share relative to its operational footprint. As a digital platform connecting buyers and sellers of second-hand equipment, its own operational pressures are small, but each transaction displaces significant upstream burden associated with manufacturing new heavy machinery, among the most resource and pollution-intensive industrial processes. This holds even when attributing only a modest lifetime extension to each transaction. Among the Sustainable Food companies, Holdbart stands out because each kilogram of surplus food rescued displaces a meaningful share of the upstream agricultural footprint that replacement production would generate. The remaining companies account for smaller absolute shares, but several demonstrate high avoided impact relative to size, notably Nofitech, whose recirculating aquaculture technology delivers measurable freshwater and nutrient benefits despite operating at a fraction of the revenue of the circularity companies.

Figure 42
Avoided planetary boundary impact by company (million PDF·m²·yr)

NG Nordic drives more than half of the portfolio's planetary contribution.



Company	Boundary breakdown	Total	%
NG Nordic (Circularity)		706.5	54.3%
TBAuctions (Circularity)		311.6	24.0%
Holdbart (Sustainable food)		101.7	7.8%
Bollegraaf (Circularity)		56.9	4.4%
Tibber (Energy transition)		52.2	4.0%
STIM (Sustainable food)		24.8	1.9%
Nofitech (Sustainable food)		18.6	1.4%
Nutris (Sustainable food)		14.8	1.1%
Oda (Sustainable food)		7.4	0.6%
EA Technology (Energy transition)		5.4	0.4%
FAST LTA (Tech-enabled resilience)		0.1	<0.1%
Total		**1,300.0**	**100%**

Climate Change boundary contribution: Avoided emissions

The largest avoided emissions across the portfolio come from companies that displace the production and use of virgin materials, one of the most carbon-intensive activities in the global economy. NG Nordic is the single largest source, accounting for 1.4 million tCO_2e, or 42% of the portfolio total, by transforming waste into circular raw materials across the full waste value chain, from collection and sorting to material recovery and recycling. TBAuctions accounts for approximately 1.4 million tCO_2e (40%) by extending the useful life of industrial machinery and equipment through secondhand markets, displacing the emissions embedded in new manufacturing. Bollegraaf accounts for a further 425 ktCO2e (13%) by designing and manufacturing the sorting and recycling technology that enables material recovery at scale.

Together, these three companies represent 95% of the portfolio's total avoided emissions of approximately 3.4 million tCO_2e.

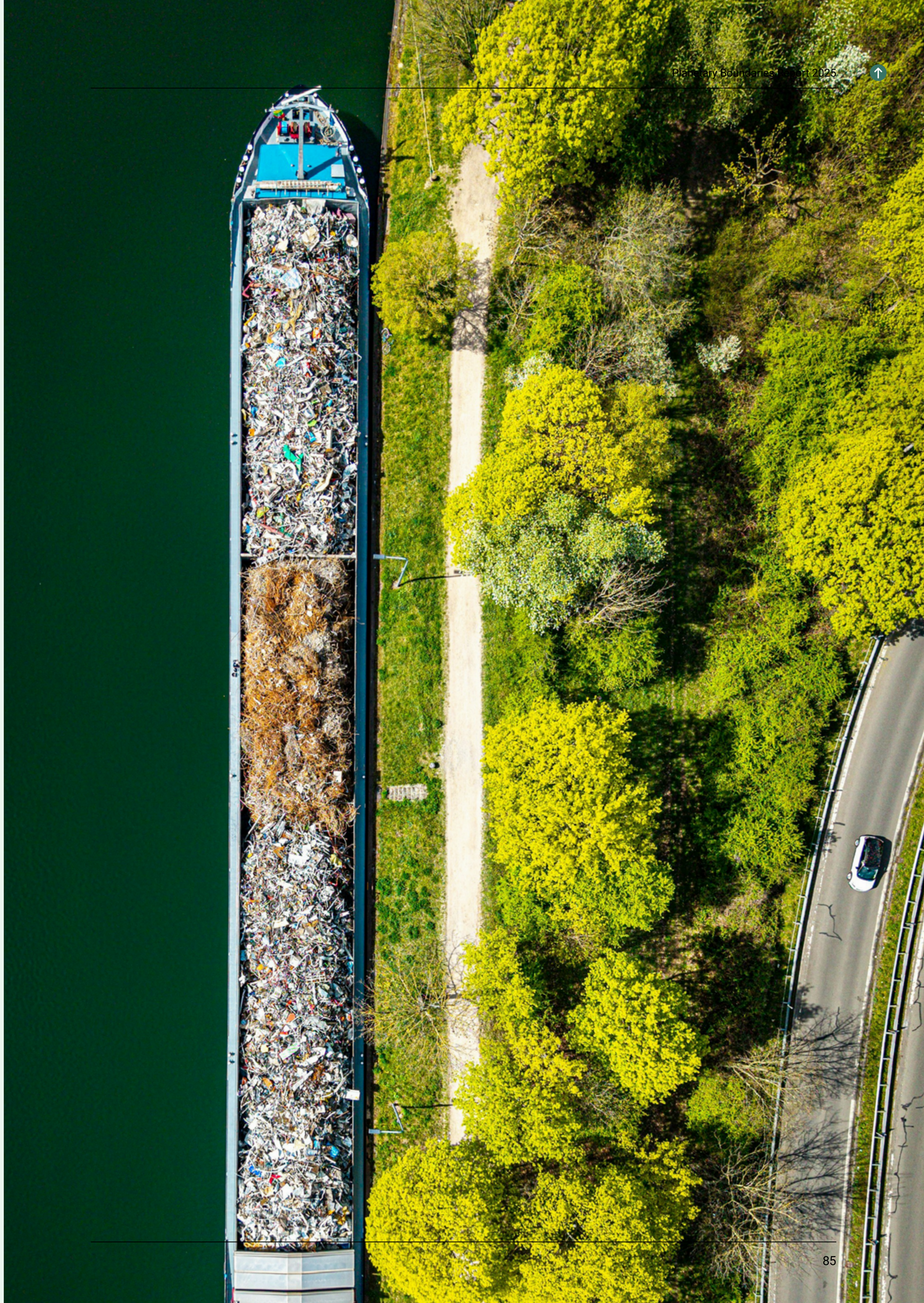
Avoided emissions are quantified using a methodology that draws on the WBCSD's product-level avoided emissions guidance but adapts it to a corporate, multi-capital lens. For each company, the full value chain is mapped, each activity is classified using a counterfactual test and control grid, and credible reference scenarios are defined representing the most plausible without-the-solution case. The figures reported for NG Nordic, Bollegraaf, and TBAuctions reflect total system-level displacement before attribution adjustments, consistent with how the WBCSD framework presents avoided emissions at the company level. In the portfolio-wide planetary boundaries assessment presented later in this report, attribution is applied consistently across all companies to enable like-for-like comparison and prevent overclaiming at the portfolio level.

Figure 43
Avoided emissions by company (tCO2e), 2025

Circularity companies drive the majority of avoided emission.

Company		**Total**	%
NG Nordic Circularity	Avoided production of virgin materials & energy recovery	**1,401,868**	41.7%
TBAuctions Circularity	Avoided virgin material production & reprocessing impact	**1,357,615**	40.4%
Bollegraaf Circularity	Avoided production of virgin materials	**424,828**	12.7%
Tibber[242] Energy transition	Grid optimization	**81,818**	2.4%
Holdbart Sustainable food	Avoided food waste	**47,690**	1.4%
EA Technology Energy transition	Grid optimization and avoided development costs	**27,935**	0.8%
Nutris Sustainable food	Displaced animal protein & improved soil health	**11,357**	0.3%
Oda Sustainable food	Avoided food waste & food mileage	**4,761**	0.1%
FAST LTA Tech-enabled resilience	Avoided production of virgin materials	**330**	<0.1%
Total		**3,358,203**	**100%**

242. Avoided emissions and planetary boundary impacts were estimated by Summa Equity and Valuing Impact using best available data as of March 2025. Results rely on key assumptions, are subject to uncertainty, have not been independently verified, and do not constitute representation by Tibber regardign its environmental performance



The full picture: where to reduce and where to scale

The portfolio exerts approximately 817 million PDF·m²·yr of planetary boundary pressure, while its companies' products and services contribute 1,300 million PDF·m²·yr of avoided pressure.

Adopting a dual view

The preceding sections examined the portfolio's pressures and its avoided impacts separately. Bringing them together makes it possible to see the full picture of how the portfolio interacts with the planetary boundaries: where the largest pressures sit, where positive contributions are concentrated, and how these relate to one another at the boundary and theme levels. This dual view clarifies where scaling products and services delivers the greatest reduction in boundary pressure, and where operational and supply chain improvements are needed to reduce residual impact.

Comparing pressures and positive contributions should be approached with care. Avoided impact estimates carry greater uncertainty than the accounting of exerted pressures, as they depend on assumptions about counterfactual scenarios, additionality, and attribution. The conservative baselines and attribution assumptions applied throughout this assessment are designed to guard against overclaiming, meaning the positive contribution figures presented here are more likely to understate than overstate the portfolio's effect. With that in mind, presenting both sides together offers a meaningful signal of where the portfolio's capital allocation is reducing planetary boundary pressure, and where the greatest opportunities for further improvement lie.

Pressures and contributions by boundary

The portfolio's pressures and positive contributions vary significantly across the six planetary boundaries assessed. The largest positive contributions are concentrated in climate change and ocean acidification (465 million PDF·m²·yr of avoided impact against 257 million of pressure) and biogeochemical flows (247 million against 69 million), where reductions in emissions, nutrient loading, and industrial pollution are most pronounced. Positive contributions also exceed pressures in freshwater change (118 million against 21 million), novel entities (136 million against 74 million), and aerosol loading (53 million against 21 million), reflecting the cross-boundary reach of solutions that reduce dependence on resource- and pollution-intensive processes.

Land-system change is the boundary where the portfolio's pressures are most pronounced: 374 million PDF·m²·yr of pressure against 282 million of positive contribution. This pressure is concentrated in food system supply chains and reflects the deep structural challenge of conventional agricultural production, where upstream land conversion and soil degradation remain embedded in how food is sourced and processed at scale. The gap signals an area where system-level transformation is still in its early stages, and where continued innovation in sustainable sourcing, land-efficient production models, and supply chain engagement will be essential to closing it.

Figure 44
Pressures and contributions by ReCiPe midpoint category and planetary boundary

The same two boundaries, climate change and land-system change, drive the largest pressures and the largest contributions.

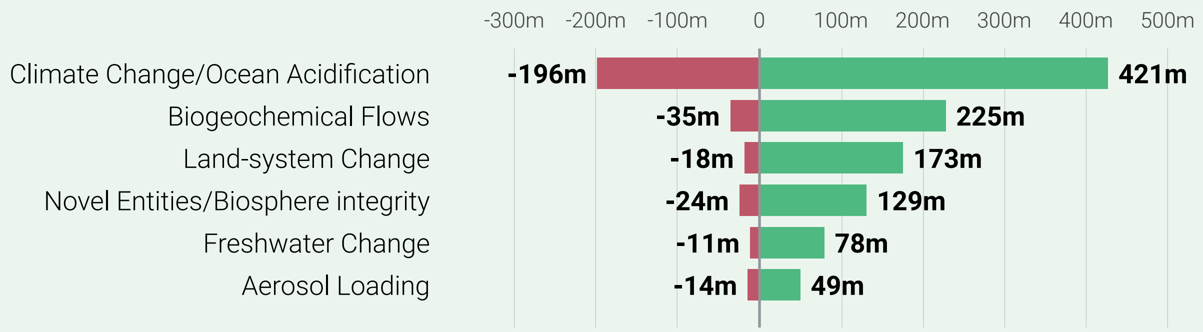
Pressures and contributions by investment theme

Circularity: the compounding effect of keeping materials in use
The Circularity theme, comprising NG Nordic, TBAuctions, and Bollegraaf, accounts for the largest share of positive contribution across the portfolio, delivering approximately 1,075 million PDF·m²·yr of avoided impact against a combined pressure of 297 million PDF·m²·yr. The underlying mechanism is the displacement of primary production through recycling, reuse, and lifecycle extension, an effect that runs across multiple boundaries, with particularly strong contributions in climate change and ocean acidification, biogeochemical flows, and land-system change, alongside reduced ecotoxic pressure. The outcome is a broad-based reduction in environmental pressure linked to industrial production systems.

Figure 45
Circularity - Pressure and contributions by planetary boundary

Outsized contributions across all planetary boundaries.

(million PDF·m²·yr)

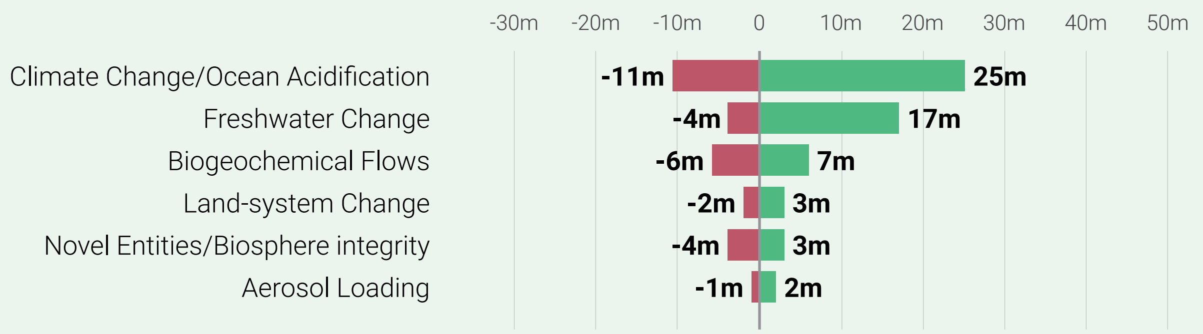


Energy Transition: small footprint, outsized system efficiency gains
The Energy Transition theme, comprising Tibber and EA Technology, delivers a more focused but consistently positive contribution of approximately 58 million PDF·m²·yr of avoided impact against a pressure of 29 million PDF·m²·yr. The primary pathway runs through improvements in the efficiency and performance of electricity systems, reflected mainly in the climate change boundary, with additional effects in freshwater systems. The relatively small footprint is consistent with asset-light, technology-driven models that improve system performance without significant direct resource use.

Figure 46
Energy Transition - Pressure and contributions by planetary boundary

System improvements concentrate in climate and freshwater.

(million PDF·m²·yr)

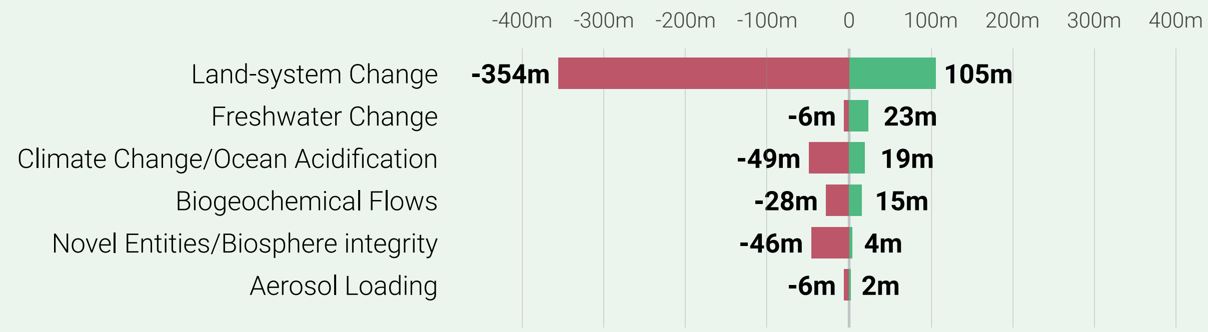


Sustainable Food: inside a high-pressure system, pushing for change
The Sustainable Food theme, represented by Holdbart, Oda, STIM, Nofitech, and Nutris, presents the most complex impact profile in the portfolio. The theme exerts the largest pressure among the themes at approximately 488 million PDF·m²·yr, driven primarily by land-system change (approximately 354 million PDF·m²·yr), alongside climate, nutrient flows, and chemical pollution. These pressures reflect the underlying reality of food production, which remains one of the most resource-intensive sectors globally. At the same time, the companies in this theme deliver significant positive contribution of approximately 167 million PDF·m²·yr by reducing waste, improving production efficiency, and shifting resource use patterns. This reflects a portfolio segment operating within a high-pressure system and that is contributing to its gradual transformation.

Figure 47
Sustainable Food - Pressure and contributions by planetary boundary

Pressures and contributions reflect the food system transformation.

(million PDF·m²·yr)

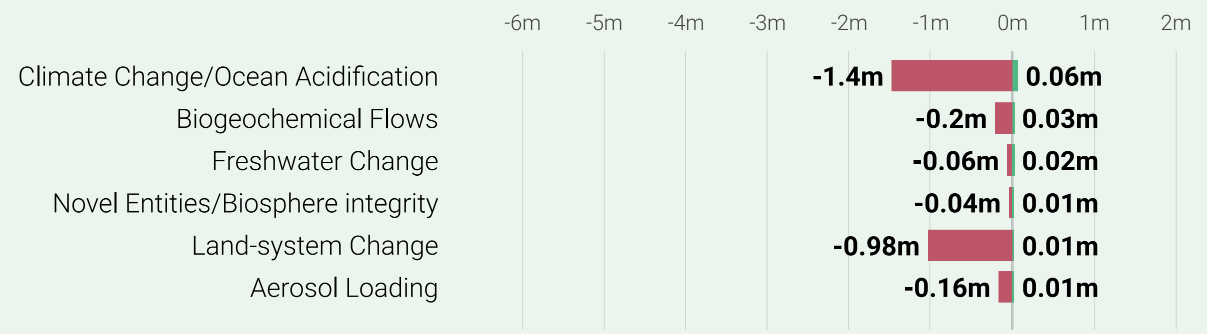


Tech-Enabled Resilience: the lightest footprint, protecting what planetary metrics cannot measure
The Tech-Enabled Resilience theme, comprising FAST LTA, guardsix, and Axion Biosystems, has the smallest footprint in the portfolio at 3 million PDF·m²·yr of pressure, with a positive contribution of approximately 0.1 million PDF·m²·yr. The pressure is modest and primarily linked to energy use in digital infrastructure. Solutions such as data storage optimization reduce hardware demand and improve resource efficiency, illustrating how technology-driven models can lower system-wide environmental intensity with a small direct footprint.

Figure 48
Tech-Enabled Resilience - Pressure and contributions by planetary boundary

Modest interactions across six boundaries.

(million PDF·m²·yr)



From biophysical to societal impact: monetized results

Monetizing impact reveals the full human cost of planetary boundary transgression, with novel entities emerging as a key boundary once health impacts are included.

The monetized results extend the analysis from ecological to human consequence, translating each pressure on the Earth system into its effect on health, livelihoods, and economic stability. Where the biophysical metric captures how ecosystems are degraded, the monetary lens captures what that degradation means for people, making visible the pathways through which planetary boundary transgression is already affecting societies.

This shift in perspective changes what is counted. The biophysical metric aggregates pressures into species loss equivalents, focusing on how ecosystems respond to land use, emissions, and pollution. The monetized framework follows the same causal chain one step further, tracing how those same pressures translate into human outcomes such as disease burden, reduced productivity, increased healthcare costs, and the loss of ecosystem services that underpin economic activity.

A complementary view of impact
As the focus shifts from direct ecosystem effects to the societal implications, the relative importance of different pressures changes. Climate remains the largest driver in both frameworks, reflecting its systemic reach across physical and economic systems. But in the monetary view, pressures that act directly on human health move to the foreground.

Exposure to air pollutants, for example, translates into respiratory and cardiovascular disease, lost working days, and increased mortality risk. Similarly, toxic chemical exposure manifests through cancer, endocrine disruption, and long-term chronic illness. These impacts are immediate, local, and unevenly distributed across populations, and they carry a high societal cost per unit of emission.

The burden of human toxicity
This is why human toxicity emerges as one of the largest categories in the monetized results, despite being absent from the biophysical metric. In the underlying life cycle framework, human toxicity does not have a defined pathway to ecosystem quality and therefore does not contribute to species loss.

Yet it represents one of the most direct interfaces between environmental pressure and human wellbeing. The inclusion of carcinogenic and non-carcinogenic toxicity in the monetary model captures the health burden associated with persistent pollutants, heavy metals, and synthetic chemicals that accumulate in water, soils, and food systems. These exposures are often diffuse and long-lived, affecting populations far removed from the original source of emissions, and creating costs that are only partially reflected in markets today.

A similar dynamic applies to particulate matter formation and ozone depletion. These pressures have no representation in the biophysical endpoint, but they play a central role in shaping human health outcomes. Fine particulate matter penetrates deep into the lungs and bloodstream, contributing to chronic disease and premature mortality, while ozone depletion increases exposure to harmful ultraviolet radiation with direct health consequences.

A more complete picture
At the same time, the monetary approach allows us to incorporate ecological pathways that are only partially represented in the biophysical metric. Marine ecosystem degradation, for instance, is not fully captured in a land-based species loss framework, but its consequences are reflected through impacts on fisheries productivity, coastal ecosystem health, and food security. By valuing these effects through their contribution to human welfare, the analysis broadens the scope of material impacts that can be measured.

The combined analysis is a more complete representation of impact. The biophysical metric highlights where pressures are most damaging to ecosystem integrity, often emphasizing land-system change, ecotoxicity, and nutrient flows. The monetized metric highlights where those same pressures translate most directly into human cost, elevating climate, air pollution, and toxic exposure. Neither view is sufficient on its own. Together, they reveal that the most material risks are those that propagate across both domains, where ecological degradation and human harm reinforce each other.

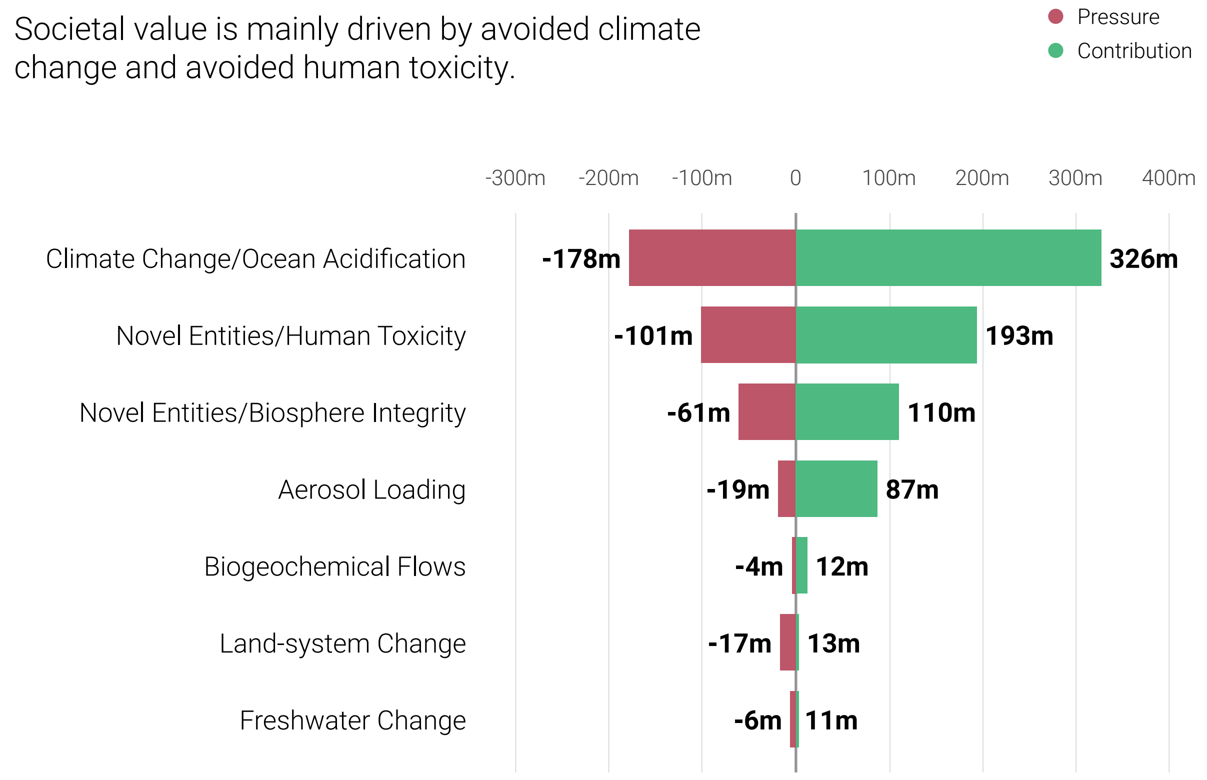
Human wellbeing impacts expressed in EUR
Climate change and ocean acidification remain the dominant category in monetary terms, driving both the largest positive impact (+EUR 326 million) and the largest negative footprint (–EUR 178 million). This reflects the scale at which portfolio companies displace carbon-intensive activities, particularly through circular material flows and food waste reduction.

When human toxicity is included, the novel entities boundary becomes substantially more prominent. The portfolio generates EUR +193 million in avoided impacts against a footprint of EUR −101 million, yielding a net position of +EUR 93 million linked to reduced human exposure to persistent pollutants and synthetic chemicals. These are pressures with direct health implications, which accounts for their prominence in the monetized results.

Aerosol loading shows one of the strongest net positions across the boundaries, with avoided impacts of EUR +87 million against a footprint of EUR −19 million.

Across the 13 portfolio companies[243] assessed, the total negative footprint amounts to approximately EUR −386 million, while avoided impacts reach EUR +752 million. This implies an avoided-to-footprint ratio of 1.9x, meaning that for every euro of planetary pressure generated, nearly two euros of societal harm are avoided. These avoided impacts translate into reduced disease burden, preserved productivity, and lower strain on public systems and infrastructure. The monetary framing makes explicit that the planetary boundaries are not only environmental thresholds, but the biophysical foundation on which human wellbeing and economic stability depend.

Figure 49
Planetary boundary pressures and contributions - Human wellbeing impact (EURm)



243. Please see Figure 56 in the Appendix for a full overview of companies included in the assesment.

Holdbart: The planetary case for saving surplus food

CASE STUDY

Holdbart at a glance
Holdbart is Norway's leading retailer of surplus food, rescuing excess products that suppliers cannot sell through conventional channels. Products that are discontinued, overstocked, nearing expiry, or have old or faulty labels are sold in Holdbart's stores and online at up to 90% discounts.

Working with Valuing Impact, we quantified Holdbart's positive and negative impacts across its full value chain, covering 2025 sales data across 26 food categories. Each kilogram of food Holdbart rescues displaces a kilogram that would otherwise need to be produced, and the avoided production, spanning farming, processing, and transportation, translates into avoided pressure across multiple planetary boundaries simultaneously. Holdbart's 2025 sales generate planetary contributions of approximately 102 million PDF·m²·yr, based on research indicating that around 90% of the food rescued by businesses in the surplus redistribution sector would otherwise go to waste entirely.

Land-system change accounts for 72% of total avoided impact, far exceeding the contribution from avoided greenhouse gas emissions alone. By keeping meat, dairy, and grain products in circulation, Holdbart avoids the agricultural land that would otherwise need to be cleared or cultivated to replace them. Climate change and ocean acidification follow, as avoided production means avoided emissions from farming, processing, and transport. Avoided production of water-intensive dairy and bottled drinks reduces pressure on freshwater systems, while reduced fertilizer and manure use contributes further avoided pressure across biogeochemical flows and novel entities.

Figure 50
Holdbart - Pressure and contributions by planetary boundary

Displacing new food production drives significant land-system contributions.

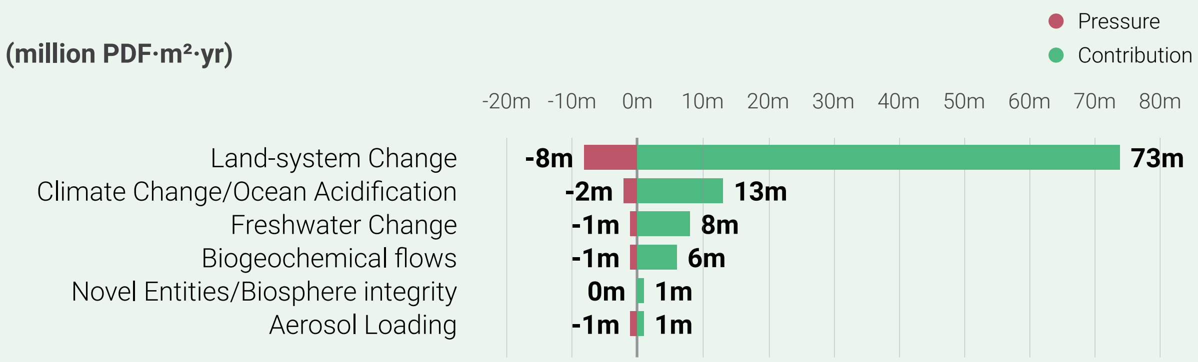
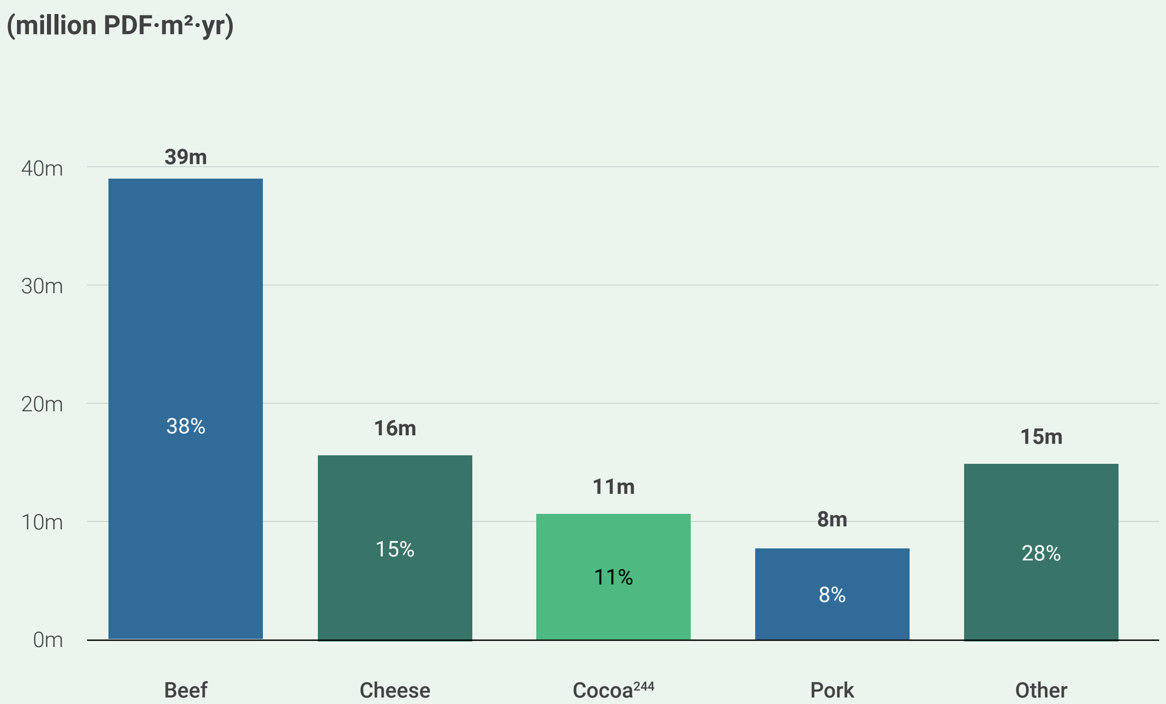


Figure 51
Holdbart - Avoided pressure by commodity

Avoiding beef production drives the majority of planetary contribution.



High-footprint food, high-impact rescue

Holdbart's avoided impact is concentrated in a small number of high-footprint categories. Four commodities account for nearly three quarters of total avoided impact, reflecting the disproportionate planetary pressure embedded in their production.

Beef accounts for the largest share, reflecting the methane emissions, land cleared for grazing, and feed crop production embedded in each kilogram, which exert pressure on climate change and land-system change boundaries simultaneously. Cheese follows, driven by the land, feed, and water demands of dairy production, where enteric methane from cattle and the volume of milk required per kilogram of cheese amplify the footprint further. Cocoa's footprint is concentrated in deforestation and soil degradation, particularly in tropical regions where expansion into forested land drives biodiversity loss alongside carbon release. Pork reflects the soy-intensive feed chains that release nitrogen and phosphorus into waterways, placing pressure on biogeochemical flow boundaries. By rescuing these commodities specifically, Holdbart's model targets the categories where each kilogram of food waste avoided yields the greatest reduction in planetary pressure.

A near-term lever within a longer-term transition

Holdbart's greatest lever is rescuing more food, and its greatest avoided impact per tonne comes from animal products and other high-footprint categories. This reflects both the environmental pressure embedded in food that already exists and the structural inefficiency of conventional food systems, where significant volumes of high-footprint production end up as waste. The longer-term system change that Summa's Sustainable Food theme points toward also involves shifting diets toward lower-impact alternatives, and the two efforts are complementary, reducing waste from today's food system while supporting the transition to a less resource-intensive one.

244. Result is based on assumptions about the average cocoa content of confectionary sold by the company

Figure 52
Summa's planetary bondaries value creation framework

 Note: Based on UN PRI Sustainable Value Creation guide

Anchoring value creation in the planetary boundaries

Driving value creation for portfolio companies and the planet requires an approach that connects science and active ownership around measurable system-level change.

Summa's investment thesis rests on the conviction that value creation and planetary boundary alignment can reinforce each other. Companies whose products and services reduce pressure on the Earth system address markets where demand is structurally growing, shaped by resource constraints, tightening regulation, and the accelerating consequences of boundary transgression. At the same time, companies that build the capabilities to manage environmental pressures across their operations and value chains can reduce costs through resource efficiency and lower their exposure to regulatory, physical, and reputational risks. Together, these dynamics unlock revenue growth, cost reduction, and risk mitigation, collectively driving multiple expansion while pushing planetary boundaries back toward safe operating spaces.

Summa's approach to realizing this potential operates across multiple reinforcing dimensions: a thematic investment strategy that selects companies positioned at the intersection of commercial opportunity and planetary need, the Via Summa active ownership model that builds the operational capabilities and strategic direction to capture that potential, impact-driven value creation programs that translate environmental priorities into concrete commercial initiatives, and the planetary boundaries assessment that quantifies where each portfolio company generates its largest positive contributions and most material negative pressures. This quantification allows Summa to direct ownership effort toward the areas where the combined potential for value creation and environmental progress is greatest, recognizing that a single well-targeted intervention can drive value across multiple levers and boundaries simultaneously.

- **Revenue growth** captures the top-line gains that follow when a company's products, services, and market positioning are aligned with planetary boundary needs, whether through new sustainable product lines that address structurally growing demand, winning tenders where sustainability performance is a scored criterion, or entering markets where environmental credentials unlock access to customers and procurement channels.
- **Cost reduction** describes how companies lower their cost base when managing planetary pressures and contributions in operations and value chains, from energy and resource efficiency gains to reduced material input costs through circular processes, lower employee turnover from purpose-driven culture, and improved access to sustainability-linked financing at lower cost of capital.
- **Risk mitigation** reflects the strategic resilience that companies build through proactive management of their most material planetary boundary pressures, including reduced regulatory exposure from early compliance, stronger supply chain continuity through diversified and circular sourcing, and lower reputational and physical climate risk.

When these three levers compound, they create the conditions for multiple expansion at exit, where quantified sustainability performance, demonstrated impact across the planetary boundaries, and alignment with structural market transitions translate into higher valuations, a wider pool of potential buyers, and a clearer long-term growth story. Critically, the same initiatives that drive commercial returns also generate the portfolio's positive contributions to the planetary boundaries, scaling the pro ducts, services, and operational improvements that reduce pressure on the Earth system.

Nutris

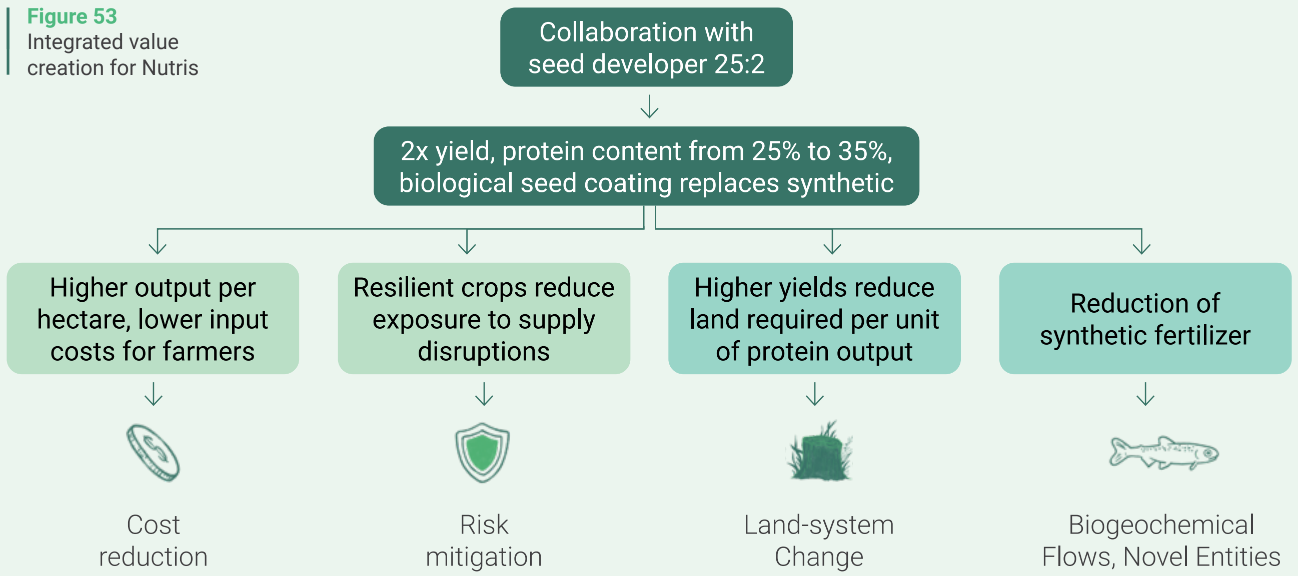
Nutris produces plant-based protein from Nordic fava beans, supplying food manufacturers with a lower-impact alternative to whey and animal-derived proteins. The business model generates positive planetary boundary impact at its core. Every ton of fava protein that displaces whey or animal protein avoids land conversion, nitrogen loading, water consumption, and greenhouse gas emissions embedded in conventional animal agriculture. In 2025, Summa initiated a collaboration between Nutris and seed developer 25:2, whose breeding platform combines machine learning, molecular biology, and controlled growth environments to develop crop varieties with enhanced yield, protein content, and resilience. Initial field trials on fava beans delivered a doubling of yield and an increase in protein content from 25% to 35%, while the biological seed coating showed potential to significantly reduce dependence on synthetic fertilizers and pesticides. The collaboration is now moving from initial trials toward broader validation across Nutris' farmer network.

If these results hold at scale, the collaboration strengthens Nutris across two value creation dimensions:

- On **cost reduction,** higher yields and increased protein density per hectare mean greater output from the same land base, while the biological seed coating removes a volatile cost line by reducing dependence on synthetic fertilizers and pesticides. For farmers, the combination of higher productivity and lower input costs stabilizes income. For Nutris, the result is a higher-quality, lower-cost supply of its core raw material, strengthening margins and competitive positioning.
- On **risk mitigation**, the collaboration reduces Nutris' exposure to supply chain disruption by building a more resilient upstream base. More resilient crop varieties lower the risk of yield loss from adverse growing conditions. The shift away from synthetic inputs reduces dependence on fertilizer and pesticide supply chains that are exposed to geopolitical disruption and tightening EU regulation of agricultural chemicals. And as Nutris deepens long-term partnerships with farmers transitioning to regenerative practices, including reduced tillage, cover cropping, and diversified crop rotations, the supply network becomes more diversified and less vulnerable to single-source disruption.

The **planetary boundary** pathways compound across both levers. Higher yields per hectare reduce pressure on land-system change. The elimination of synthetic fertilizers lowers nitrogen runoff, directly addressing the biogeochemical flows boundary. Replacing synthetic inputs with biological alternatives reduces the release of novel entities into soil and water systems. On a broader scale, analysis suggests that full adoption of regenerative practices could reduce Nutris' total environmental impact by 20–33%, confirming that the same interventions that strengthen the business also deepen its contribution to operating within planetary boundaries.

Figure 53
Integrated value creation for Nutris



oda

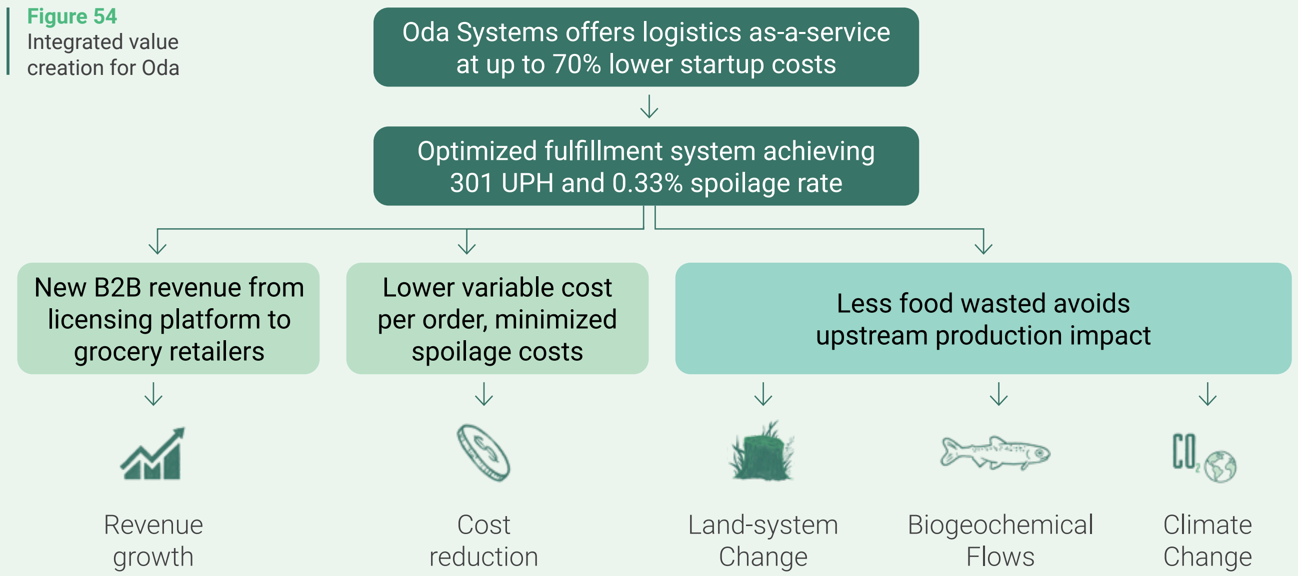
Oda operates an online grocery model built around centralized fulfillment, where a single warehouse per market replaces the fragmented inventory of dozens of physical stores. This concentration enables demand forecasting across one location rather than many, faster product turnover, and production to order for categories like baked goods. The result is a spoilage rate of 0.33%, compared to over 1% for other online grocers. The operational engine behind this performance is Oda's proprietary fulfillment system, which combines purpose-built hardware, intelligent software, and lean-inspired workflows to achieve 301 units picked per hour across end-to-end fulfillment. In August 2025, Oda launched Oda Systems, making this platform available to grocery retailers globally as a logistics-as-a-service offering.

The initiative drives value across two dimensions simultaneously:

- On **revenue growth**, Oda Systems creates an entirely new B2B revenue line by licensing the fulfillment platform to retailers seeking to launch or improve their online grocery operations. At up to 70% lower startup costs than comparable goods-to-man fulfillment systems, the platform lowers the barrier for adoption, and as online grocery penetration grows and retailers look for alternatives to building in-house infrastructure, demand is structurally expanding.
- On **cost reduction**, the high fulfillment rate directly lowers variable cost per order, the single most important unit economic driver in online grocery. Centralized demand forecasting across one warehouse rather than dozens of stores minimizes spoilage to 0.33% of operating revenue, and with it spoilage costs. As Oda Systems scales across partner retailers, higher volumes flowing through the platform generate better data for the machine learning models that drive forecasting and operational optimization.

The **planetary boundary** pathways are concentrated in the food waste mechanism. Every product that reaches a consumer instead of being discarded avoids the full upstream impact of its production. For fresh produce, dairy, and meat, this means avoided pressure on land-system change (agricultural land that did not need to be cultivated), biogeochemical flows (fertilizer that did not need to be applied), freshwater (irrigation water that was not consumed), and climate change (emissions from production and decomposition that did not occur). As Oda Systems is adopted by partner retailers, these benefits compound across a growing share of the grocery sector, extending the planetary boundary contribution beyond Oda's own operations and into the broader food system.

Figure 54
Integrated value creation for Oda



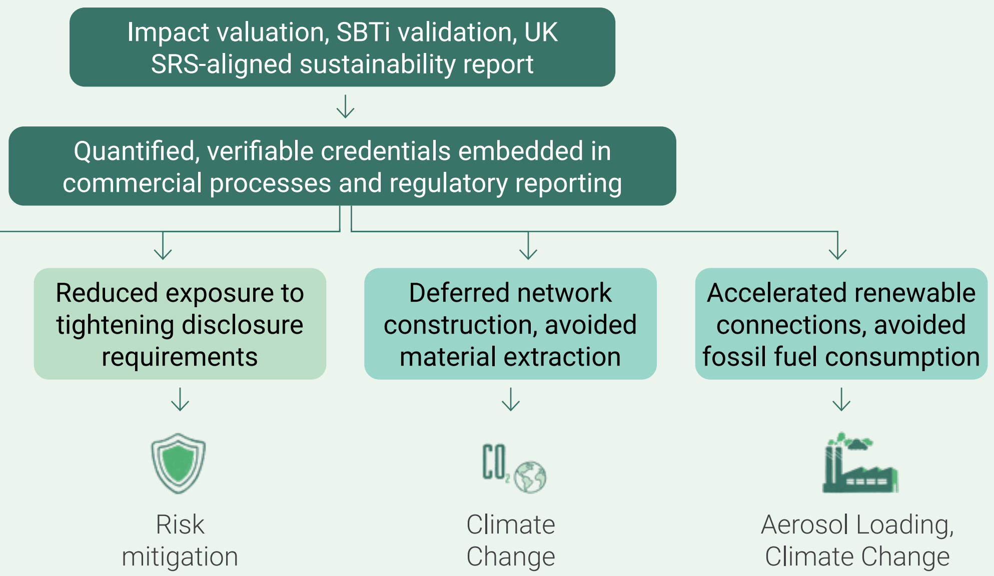
EA Technology provides monitoring and analytics solutions that help electricity network operators unlock up to 22% more capacity from existing infrastructure, avoid millions of minutes of power outages annually, and accelerate renewable energy connections. As network operators face growing pressure to demonstrate sustainable procurement, suppliers' environmental credentials are increasingly becoming a prerequisite for project bids. Since Suma's investment in October 2024, three initiatives have converted EA Technology's inherent societal value into a quantified, verifiable commercial asset. First, an independent impact valuation with Valuing Impact established that every GBP 1 of revenue generates GBP 9.60 in economic benefit and GBP 1.90 in societal wellbeing. Second, the company submitted and received validation of science-based emission reduction targets through SBTi, backed by a comprehensive carbon baseline with 90.1% activity-specific data. Third, EA Technology published its first Sustainability and Impact Report aligned with the UK Sustainability Reporting Standards.

These initiatives drive value across two dimensions.

- On **revenue growth**, EA Technology embeds these credentials into tender evaluations where network operators increasingly score suppliers on sustainability performance. The company's own report notes that sustainability progress is increasingly becoming a prerequisite for project bids. The ability to present validated targets, quantified societal impact, and standards-aligned reporting converts what was previously an intangible advantage into a measurable differentiator in winning contracts.
- On **risk mitigation**, early adoption of SBTi-validated targets, comprehensive carbon accounting, and standards-aligned reporting reduces EA Technology's exposure to tightening sustainability disclosure requirements across its operating markets. As network operators face their own regulatory obligations to demonstrate sustainable procurement, suppliers without credible environmental credentials face growing risk of exclusion from tender shortlists. By building these capabilities ahead of mandatory timelines, EA Technology reduces the risk of future contract losses while positioning itself ahead of competitors still at earlier stages of their sustainability journey.

The **planetary boundary** pathways operate through the solutions EA Technology provides. Every unit of additional capacity unlocked from existing grid infrastructure defers the need for new network construction, avoiding the associated material extraction, manufacturing emissions, and land use. By accelerating renewable energy connections and reducing fossil-backed generation requirements, the company's products contribute directly to reduced pressure on climate change and ocean acidification. And by shortening power outages that force reliance on backup diesel generation, EA Technology's fault detection and restoration solutions lower localized aerosol loading and air quality pressures.

Figure 55
Integrated value creation for EA Technology



Other value creation examples across the portfolio

These dynamics are not limited to the three case studies above. Across the portfolio, companies are generating value through initiatives that simultaneously strengthen financial performance and reduce pressure on planetary boundaries.

- NG Nordic invests in advanced sorting and recycling capabilities to convert a larger share of the roughly 4 million tons of waste it handles annually into secondary raw materials, rather than routing it to lower-value incineration or landfill. As sorting precision improves, more material enters higher-margin recovery pathways, increasing revenue per ton handled. The same shift reduces planetary boundary pressure: every ton diverted from incineration to material recovery lowers CO_2 emissions, while the company's depollution operations ensure that hazardous substances such as PFAS, PCBs, and flame retardants are safely treated rather than released into freshwater and marine systems. With 78% of revenues aligned with the EU Taxonomy and validated science-based targets for NG Group in 2025, NG Nordic's sustainability credentials also strengthen its positioning in a market where customers and regulators increasingly differentiate between providers on environmental performance.
- Axion has implemented resource efficiency measures at its Oxford facility that lower both operating costs and reduce environmental pressure. The company recovers and recycles gold from laboratory waste materials, reducing procurement costs for a high-value input while avoiding the extraction and processing impacts associated with primary gold production. A deionized water reclaim system further reduces water consumption in laboratory operations, cutting utility costs and lowering pressure on freshwater systems. These are targeted, low-capital interventions that demonstrate how operational improvements at the facility level can deliver cost reduction and reduced environmental footprint simultaneously.
- Bollegraaf designs and builds the sorting and recycling infrastructure that underpins the circular economy transition. In 2025, the company delivered 10 complete waste sorting installations, adding approximately 1 million tons per year of new processing capacity and contributing to 425 ktCO_2e in avoided emissions from the displacement of virgin materials. With 87% of revenues aligned with the EU Taxonomy under circular economy and pollution prevention objectives, Bollegraaf operates in a high-growth market, driven by mandatory recycling targets, rising recycled content requirements, and the substantial investment in sorting and recycling infrastructure that will be needed across Europe and North America over the coming decades. The combination of structural demand growth, high taxonomy alignment, and quantified avoided impact positions Bollegraaf for multiple expansion at exit, as buyers increasingly value demonstrable environmental performance alongside commercial scale.

Translating assessment into action

Summa's first planetary boundaries assessment sharpens where we can create value, scale solutions, and direct capital to drive boundaries back toward safe operating spaces.

Summa's 2025 planetary boundaries assessment provides the first comprehensive account of how the portfolio interacts with Earth systems, capturing both the pressures companies generate and the positive contributions their products and services deliver. The results affirm Summa's purpose: our portfolio companies are delivering measurable reductions in planetary boundary pressure through their core business activities, contributing to solving one of the defining challenges of our time. At the same time, the assessment makes visible where significant pressures remain and where capital and ownership effort should be directed to in order to push the planetary boundaries back to safe operating spaces. Four findings stand out.

Displacing virgin material production is the single largest source of planetary contribution across the portfolio. Every ton of waste recovered and reintegrated into secondary production avoids the extraction, processing, and emissions embedded in primary material value chains, generating reductions across climate, land use, nutrient loading, freshwater consumption, and chemical pollution simultaneously. No other mechanism in the portfolio reduces pressure across all six assessed boundaries at once. This underscores why the transition from linear to circular material systems is central to returning planetary boundaries toward safe operating spaces, and why circularity remains a central theme in Summa's thematic investment approach.

Land-system change is the largest source of pressure across the portfolio, driven almost entirely by upstream agricultural supply chains where land conversion and soil degradation remain embedded in how food is sourced and processed at scale. This concentration means that the Sustainable Food theme holds the greatest opportunity for reducing portfolio-level pressures. Innovations across the theme's investments demonstrate how this can work in practice. The shift towards regenerative agriculture at Nutris can reduce dependence on synthetic fertilizers and reverses soil degradation, surplus food redistribution at Holdbart avoids the full upstream agricultural footprint of replacement production, and centralized fulfillment at Oda cuts spoilage to a fraction of industry norms. As these models scale, the scope for compounding pressure reductions across land use, climate, nutrient loading, and freshwater systems is substantial.

The portfolio's largest emitters are also its largest contributors to climate change boundary reduction. The companies that account for the majority of reported GHG emissions, such as NG Nordic and Bollegraaf, are simultaneously the companies delivering the greatest avoided climate impact through virgin material displacement and lifecycle extension. This is not a coincidence but a structural feature of investing in sectors at the center of planetary boundary transgression. Conventional accounting methods capture only one side of this equation, which is why the planetary boundaries assessment is essential for understanding where capital is genuinely reducing pressure on Earth systems.

Commercial value creation and boundary reduction are driven by the same interventions. Higher material recovery rates, reduced food spoilage, validated decarbonization pathways, and lower input costs are simultaneously the drivers of portfolio company value creation and the mechanisms through which the portfolio reduces planetary boundary pressure. The initiatives that strengthen revenue growth, cost reduction, and risk mitigation are the same ones that reduce pressure on the boundaries, and the companies that demonstrate this alignment are the ones best positioned for multiple expansion at exit.

This assessment represents a first step in making the planetary boundaries framework practical and actionable in private markets. We will continue to refine the methodology, expand the scope of companies assessed, and deepen the integration of boundary-level insights into our investment decisions and ownership practices, with the aim of directing capital and effort toward the areas where value creation and planetary progress compound most effectively.

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Appendix

Figure 56
Pathways for avoided planetary pressures for assessed portfolio companies

Company	Positive contribution: Portfolio activities avoiding pressure on climate and the broader planetary boundaries (Scope 4)
Bollegraaf	**Avoided production of virgin materials** Avoided virgin material production (paper, aluminum, PET, HDPE, PP, glass) through automated sorting and recycling, displacing primary material extraction and processing
FAST LTA	**Avoided production of virgin materials** Avoided e-waste and manufacturing emissions through extended hardware lifespan; avoided energy consumption through storage efficiency relative to conventional solutions
Holdbart	**Avoided Food Waste** Avoided food production through reduced food waste in distribution, reducing upstream agricultural land use and associated environmental pressures
Nofitech	**Avoided feed production, avoided freshwater consumption, reduced nitrogen and phosphorus discharge** Avoided freshwater consumption, reduced nitrogen and phosphorus discharge, and avoided feed production relative to conventional aquaculture (pond and flow-through counterfactuals). Partially offset by higher energy intensity of RAS systems
STIM	**Avoided Food Production Losses & Marine Ecosystem monitoring** Avoided feed waste from reduced fish mortality, marine ecosystem monitoring and protection, displaced terrestrial protein production (salmon vs. beef/pork/chicken), avoided travel emissions from remote inspections.
TBAuctions	**Avoided production of virgin materials & avoided reprocessing impact** Avoided manufacturing impact through second-hand equipment reuse, extending product lifecycles and displacing new production
Oda	**Avoided Food Waste, Consumer Behavior Change & Avoided Food Milage** Avoided food miles and food losses leading to avoided environmental impact
Nutris	Displaced animal and other proteins on the market, and improvement of soil health and best practices for farmers
NG Nordic	**Avoided production of virgin materials & energy recovery** Displaced heat, electricity and provision of secondary material through recycling, replacing primary material production
EA Technology	**Grid optimization and avoided development Costs** Avoided capex and electricity efficiency
Tibber	**Grid optimization** Electricity use reduction through efficiency and renewable electricity
Axion	No specified pathway for avoided planetary boundary pressure
guardsix	No specified pathway for avoided planetary boundary pressure

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