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World scientists' warning to humanity: a third notice

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Executive summary

Life on Earth is in a planetary emergency driven by escalating human pressures and the crossing of multiple planetary boundaries. Climate change, biodiversity loss, pollution, land degradation, and resource depletion are intensifying and placing increasing strain on the natural systems that support life. These pressures are already affecting food, water, health, and economic stability in many parts of the world, most severely for those who contributed least to causing them. Many of the actions needed to address this emergency would also improve daily life for billions of people. Reducing fossil fuel use, restoring ecosystems, cutting pollution, and expanding access to basic services can lead to cleaner air and water, healthier populations, and more secure food and energy systems. We identify six broad areas where major transformations are needed, including a rapid shift away from fossil fuels, increased protection and restoration of nature, aligning economic systems with planetary limits, reduced overconsumption in wealthy societies, transitions to sustainable food systems, and greater social and gender equity through improved access to education, healthcare, and basic services. Progress in all of these areas will depend on just and effective governance, renewed international cooperation, and shifts in societal values and norms that support more sustainable relationships with each other and with nature. Humanity has the knowledge, tools, and resources needed to rapidly reduce environmental pressures while improving human well-being.

Introduction

Humanity has pushed the Earth system beyond the conditions that have supported life and civilization for millennia (Xu et al. 2020). After reviewing available scientific evidence, and with the support of more than XXXXX scientist signatories worldwide, we conclude that life on Earth has entered a planetary emergency (box 1). The challenge is no longer only to avert crises but to limit their impacts through rapid mitigation while strengthening resilience across communities and ecosystems. We warn that without rapid transformative change, both the living world and the human societies that depend on it are increasingly at risk.

This letter to humanity is not only about preventing catastrophe. It is about unlocking one of the greatest opportunities in human history to redesign human systems in ways that contribute to restoring critical functions of the Earth and enhance well-being and safety for all. This letter reflects a shared responsibility and moral obligation of scientists to speak out. The first World Scientists' Warning to Humanity in 1992 and the second warning in 2017 documented escalating environmental degradation (Union of Concerned Scientists 1992, Ripple et al. 2017). Now, a decade after the second warning, this third warning reflects continued deterioration and narrowed margins for corrective action.

This warning is directed to governments, financial institutions, corporations, and citizens worldwide. It comes at a moment when environmental and social crises are interacting, accelerating, and reinforcing one another (Pörtner et al. 2023, Fletcher et al. 2024, PBScience 2025). This emergency is unfolding amid declining institutional capacity, the erosion of scientific authority, escalating geopolitical conflicts, and weakening multilateral cooperation. These risks are not distant or theoretical. They are already affecting billions of people and undermining the conditions that support human well-being and socioeconomic stability worldwide.

This systemic planetary crisis is not just a story of risk and loss. It is also a story of opportunity to build a more resilient, equitable, and prosperous future. Decisive transformative actions to stabilize the climate, restore ecosystems, reduce pollution, and transform food systems would deliver substantial benefits. Focused investments could provide universal access to clean energy services, prevent millions of premature deaths, and lift hundreds of millions of people out of hunger and poverty (UNEP 2025).

In this third warning, we assess the vital signs of the

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Box 1. Declaration of a planetary emergency. This declaration forms part of the "World Scientists' Warning to Humanity: A Third Notice" and is endorsed by the undersigned scientists. A public-facing version of this declaration is available for individual endorsement and signing by citizens worldwide, allowing members of the public to acknowledge the planetary emergency described by the scientific community.

We, the undersigned, recognize that Earth is now in a state of planetary emergency. Climate change, biodiversity loss, land and freshwater degradation, pollution, and unsustainable production and consumption are destabilizing the Earth system that supports all life. These interconnected crises are driven largely by the scale and intensity of human activities. The scientific evidence for this emergency is clear, compelling, and growing. The planetary emergency is no longer a future threat. It is unfolding now. Increasing risks of large-scale and potentially irreversible Earth system changes, including cascading tipping points, threaten the stability of natural systems and human societies.

The planetary emergency persists not because of a lack of knowledge, but because human systems have failed to align with physical and ecological limits. Continued delay increases the risk of irreversible harm, with consequences falling most heavily on those who have contributed least and on future generations. Addressing this emergency will require responsibility, fairness, and transformative change at the scale of civilization, including fundamental shifts in how societies produce and consume resources and relate to the natural world. At the same time, decisive action offers an opportunity to improve human health, security, equity, and resilience while helping restore the stability of the Earth system on which civilization depends. Without deep, coordinated, and timely action, the planetary emergency will intensify, with consequences that could shape life on Earth for centuries. By endorsing this declaration, we acknowledge both the severity of this emergency and our shared responsibility to support urgent, science-informed actions that protect the foundations of life on Earth.

human enterprise, the planetary boundaries of the Earth system, and the scale of transformation now required to reduce the risk of the most severe outcomes for human societies and for the rest of life on Earth. This warning is more than a scientific assessment. It is a call to action at a moment of converging evidence and imminent peril.

Vital signs of the human enterprise

Human activity continues to strain the Earth system, as reflected by multiple indicators trending in concerning directions (figure 1). Global fossil fuel use and carbon dioxide emissions continue to rise, driving global warming (figure 1a, 1b). Conversely, for the first time in over a century of coal-dominated power generation, renewables have surpassed coal globally, marking a major clean-energy milestone (figure 1c).

Pressures on ecosystems persist, leading to ongoing biodiversity loss, forest degradation, increasing zoonotic diseases, and rising freshwater withdrawals, despite some expansion of protected areas (figure 1i-l, 1o). The size of the global economy continues to grow (figure 1d). The erosion of environmental safeguards in major economies directly undermines the capacity for effective and just climate action and ecosystem protection, as does the rising number of armed conflicts (figure 1e). Humans and ruminant livestock dominate global mammal biomass (supplemental figure S1). Rising meat consumption and growing ruminant livestock numbers increase pressures on land, biodiversity, climate, freshwater, and nutrient cycles, alongside continued stress on marine fisheries (figure 1f-h). At the same time, highly unequal wealth accumulation, income and consumption patterns mean the most affluent people and countries account for a disproportionate share of global resource use and environmental impacts, while continued, though slowing, population growth increases aggregate demand for food, water, energy, and materials (Samways 2022; figure 1m-p).

Planetary boundaries

The accelerated rate of global warming is very likely a first sign of a planet losing resilience (Foster and Rahmstorf 2026). Scientifically, this comes as no surprise given that humanity has crossed multiple planetary boundaries, the biophysical limits defining Earth's safe operating space (Rockström et al. 2024). Seven of nine key boundaries have been crossed, including those related to climate change, biosphere integrity, land-system change, freshwater change, biogeochemical flows of nitrogen and phosphorus, novel entities such as human-made chemicals, and most recently, ocean acidification (supplemental figure S2). The consequences of these transgressions are severe. For example, climate-driven ocean warming has triggered widespread coral bleaching and mortality, threatening marine biodiversity and the roughly

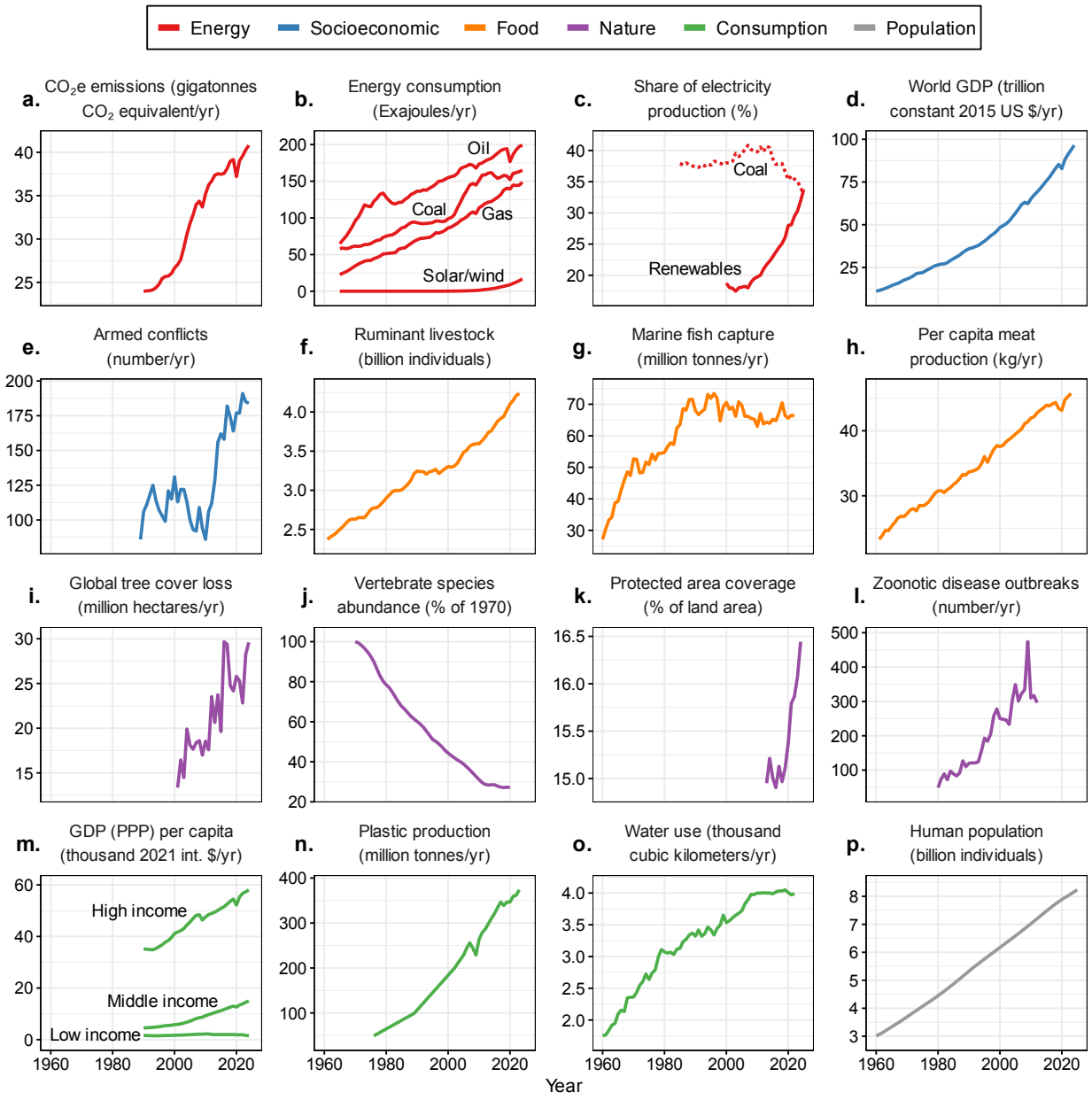

Figure 1. Global vital signs of the human enterprise. Time series of environment-related human activities. Abbreviations correspond to carbon dioxide (CO_2), gross domestic product (GDP), purchasing power parity (PPP), and international (int.). Sources and details about each variable are provided in supplemental file S3.

500 million people who depend on coral reefs for food or livelihoods (Hoegh-Guldberg et al. 2019).

The simultaneous exceedance of most planetary boundaries also implies increased risk of nonlinear change, cascading impacts, and potentially irreversible Earth system shifts such as a hothouse Earth trajectory driven by feedback loops and tipping points (supplemental figure S3). Global mean 20-year average temperature is likely to exceed the Paris limit of 1.5 °C soon, increasing the risk of triggering additional climate impacts and Earth-system responses (Cannon 2025). Critical tipping thresholds for the Greenland and West Antarctic ice sheets may have already been exceeded, whereas boreal permafrost, mountain glaciers, and the Amazon rainforest could tip soon (Ripple et al. 2026). Importantly, crossing such thresholds may commit the Earth system to long-term and potentially

irreversible transformations that unfold gradually, meaning that current conditions can mask growing instability and that the most severe consequences may occur long after the triggering processes begin (Armstrong McKay et al. 2022).

Only two of the nine planetary boundaries have not been breached: stratospheric ozone depletion and atmospheric aerosol loading (figure S2). The partial recovery of the ozone layer demonstrates that rapid, coordinated, science-based global action can reverse severe environmental damage (Haas 2019). This demonstrates that humanity can act decisively when political will aligns with scientific evidence.

Responsibility and equity

Climate change, biodiversity loss, and pollution are interconnected and mutually reinforcing manifestations of ecological overshoot (Ripple et al. 2024, Romanello et al. 2025). The drivers of this destabilization are concentrated in high-income nations, powerful industries, and economic systems that prioritize short-term profit and continuous growth, reinforced by societal values and institutions that equate progress with material expansion (Hickel et al. 2022). Yet those who have contributed least often face the greatest risks and harms, reflecting structural injustices that both drive and exacerbate these challenges (Deivanayagam et al. 2023). This is partly due to the marginalization of Indigenous Peoples and local communities, who steward much of the world's biodiversity (Reyes-García et al. 2026). A just response to the planetary emergency must therefore align responsibility for action with contributions to environmental harm, while prioritizing the protection of those who are most vulnerable (Gupta et al. 2023). High-income nations, the wealthiest people, and large corporations generate the largest environmental impacts and possess the greatest capacity to act (Chancel 2022). They also increasingly shift the burdens of ecological damage through global supply chains onto distant and less politically empowered regions and societies (Hoang and Kanemoto 2021).

Transformations

We identify six core transformations spanning energy systems, ecosystems, economies, consumption patterns, food systems, and social justice (for details, see box 2). Implementing these transformations depends not only on advances in ecological and Earth-system science but also on social, institutional, and behavioral change (IPBES 2024). Transformative change also requires shifts in societal values and worldviews that shape relationships between people and nature (Pascual et al. 2023). Research on social tipping points shows that when norms shift and institutions align, relatively small but committed groups can catalyze rapid societal change (Chenoweth 2021).

Humanity has entered a decisive period in which the risks of exceeding Earth-system limits are profound, whereas the opportunities to improve human well-being and planetary stability remain significant. We are no longer approaching a planetary emergency. We are living inside it. Scientific knowledge and evidence-based decision-making must guide responses, alongside shifts in social norms, values, and institutions that recognize the deep interconnectedness of all living systems and humanity's dependence on nature (Díaz et al. 2019, Pascual et al. 2023). Recognizing the importance of Indigenous, local, and traditional knowledge systems together with scientific understanding will be essential for building more inclusive and effective responses (Deivanayagam et al. 2023). The choices made in the coming years will determine whether humanity stabilizes the Earth system and secures a livable future for people and the rest of life on Earth.

Supplemental files

See supplemental file S1 for a list of signatories. These signatories endorse this warning as individuals and not as representatives of their affiliated institutions. All XX of the language translations are provided in supplemental file S2. Because of space limitations, we are unable to provide a comprehensive overview of all major potential threats to humanity such as artificial intelligence (AI), nuclear risk, and global pandemic threats (see box S1). See Table S1 for a list of 61 narrowly focused scientists' warning journal articles on various topics published since 2017 by members of the Alliance of World Scientists.

Project website and other resources

The documentary film, The Scientist's Warning, can be viewed at https://www.youtube.com/watch?v=byXGCPo-80w. To view the Alliance of World Scientists website, go to https://scientistswarning.forestry.oregonstate.edu. Scientists may sign this third warning to humanity using this form: https://forms.gle/BAfifGWesmoYjKzi7.

Acknowledgements

We thank 300 members of the Alliance of World Scientists who offered ideas on how to shape this third warning to humanity; see table S2 for a summary of their ideas.

Box 2. Six transformations to stabilize the Earth system. These mutually reinforcing transformations outline pathways to reduce environmental pressures while improving human well-being and resilience.

Energy

Fossil fuel extraction and use are incompatible with stabilizing the climate system and must be rapidly phased out (Wolf et al. 2025). Achieving this goal requires a just and globally coordinated transition toward renewable energy systems that operate within planetary limits while minimizing environmental and social impacts. Reducing energy demand in the Global North is also essential. Accelerating the transition to clean energy would reduce emissions while delivering major co-benefits including cleaner air, improved public health, greater energy security, and lower long-term energy costs.

Nature

Protecting and restoring nature is essential for Earth-system stability and human well-being. Immediate protection of remaining intact ecosystems, combined with large-scale restoration and regeneration of degraded lands, rivers, and oceans, can help recover biodiversity and reestablish key ecological processes (IPBES 2019). Effective stewardship must also recognize Indigenous Peoples as rights holders, support Indigenous and local governance systems, and ensure that affected local communities are heard. Healthy ecosystems provide essential contributions to people including food, clean water, climate regulation, disaster protection, and cultural and health benefits for societies worldwide.

Economy

Aligning economic systems with planetary limits requires moving beyond development models that depend on continual expansion of material and energy use (Kallis et al. 2025). Current economic systems prioritize continued growth in production and consumption despite mounting environmental risks (Jones et al. 2026). Alternative approaches that instead prioritize human well-being, social equity, and environmental sustainability offer pathways to reduce pressures on the Earth system. Economies oriented toward well-being rather than perpetual expansion can maintain high quality of life while lowering inequality and ecological impacts.

Consumption

Overconsumption by affluent nations and individuals is a dominant driver of global environmental pressures, accounting for a disproportionate share of resource use, emissions, and material extraction (Wiedmann et al. 2020). Addressing this imbalance requires both behavioral changes and structural reforms that encourage sustainable lifestyles and reduce excessive demand for energy and materials. Meeting basic needs for all people while moderating consumption among the most affluent can substantially reduce environmental pressures. Such shifts can also improve human well-being while reducing resource use and strengthening social equity (Vogel et al. 2021).

Food

Food systems are major contributors to environmental change, generating roughly one-third of global greenhouse gas emissions while exerting large pressures on land, freshwater, nutrient cycles, and biodiversity (Rockström et al. 2025). Transforming food systems represents one of the most immediate opportunities to reduce environmental impacts. Shifts toward whole-food plant-based diets, reductions in food loss and waste, and wider adoption of sustainable and regenerative agricultural practices can substantially lower emissions and resource use while supporting biodiversity and ecosystem health. These changes can also improve public health, enhance food security, and support more resilient and equitable food systems.

Social Justice

Advancing social justice through universal access to education, healthcare, housing, and basic services is central to building resilient and sustainable societies (Gupta et al. 2023). Hundreds of millions of people, particularly women and girls, still lack access to secondary education, quality healthcare, and reproductive autonomy. Expanding these opportunities improves well-being, strengthens resilience to environmental change, and contributes to voluntary stabilization of population growth. Societies with greater equity, education, and access to basic services are consistently more capable of sustaining long-term environmental stewardship and collective action.

References cited

Armstrong McKay DI, Staal A, Abrams JF, Winkelmann R, Sakschewski B, Loriani S, Fetzer I, Cornell SE, Rockström J, Lenton TM. 2022. Exceeding 1.5 C global warming could trigger multiple climate tipping points. *Science* 377: eabn7950.

Cannon AJ. 2025. Twelve months at 1.5 °C signals earlier than expected breach of Paris Agreement threshold. *Nature Climate Change* 15: 266–269.

Chancel L. 2022. Global carbon inequality over 1990–2019. *Nature Sustainability* 5: 931–938.

Chenoweth E. 2021. Civil Resistance: What Everyone Needs to Know. Oxford University Press.

Deivanayagam TA et al. 2023. Envisioning environmental equity: climate change, health, and racial justice. *The Lancet* 402: 64–78.

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SH, Chan KM, et al. 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science* 366.

Fletcher C, Ripple WJ, Newsome T, Barnard P, Beamer K, Behl A, Bowen J, Cooney M, Crist E, Field C, et al. 2024. Earth at risk: An urgent call to end the age of destruction and forge a just and sustainable future. *PNAS nexus* 3: pgae106.

Foster G, Rahmstorf S. 2026. Global warming has accelerated significantly. *Geophysical Research Letters* 53: e2025GL118804.

Gupta J, Liverman D, Prodani K, Aldunce P, Bai X, Broadgate W, Ciobanu D, Gifford L, Gordon C, Hurlbert M, et al. 2023. Earth system justice needed to identify and live within Earth system boundaries. *Nature Sustainability* 1–9.

Haas PM. 2019. Robust ozone governance offers lessons for mitigating climate change. *One Earth* 1: 43–45.

Hickel J, O'Neill DW, Fanning AL, Zoomkawala H. 2022. National responsibility for ecological breakdown: a fair-shares assessment of resource use, 1970–2017. *The Lancet Planetary Health* 6: e342–e349.

Hoang NT, Kanemoto K. 2021. Mapping the deforestation footprint of nations reveals growing threat to tropical forests. *Nature Ecology & Evolution* 5: 845–853.

Hoegh-Guldberg O, Hutchings P, Kingsford M, Hoegh-Guldberg O. 2019. Coral reefs in a changing world. *The Great Barrier Reef: Biology, Environment and Management* 143.

IPBES. 2019. Global Assessment Report on Biodiversity and Ecosystem Services. IPBES Secretariat.

IPBES. 2024. Thematic Assessment Report on the Underlying Causes of Biodiversity Loss and the Determinants of Transformative Change and Options for Achieving the 2050 Vision for Biodiversity of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Transformative Change Assessment). O'Brien K, Garibaldi L, and Agrawal A. (eds.). IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.11382215.

Jones M et al. 2026. IPBES Business and Biodiversity Assessment: Summary for Policymakers.

Kallis G, Hickel J, O'Neill DW, Jackson T, Victor PA, Raworth K, Schor JB, Steinberger JK, Ürge-Vorsatz D. 2025. Post-growth: the science of wellbeing within planetary boundaries. *The Lancet Planetary Health* 9: e62–e78.

Pascual U, Balvanera P, Anderson CB, Chaplin-Kramer R, Christie M, González-Jiménez D, Martin A, Raymond CM, Termansen M, Vatn A, et al. 2023. Diverse values of nature for sustainability. *Nature* 620: 813–823.

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

Pörtner H-O, Scholes R, Arneth A, Barnes D, Burrows M, Diamond S, Duarte C, Kiessling W, Leadley P, Managi S, et al. 2023. Overcoming the coupled climate and biodiversity crises and their societal impacts. *Science* 380: eabl4881.

Reyes-García V et al. 2026. Indigenous Peoples and local communities as agents of transformative change for sustainability. *Communications Earth & Environment* 7: 102.

Ripple WJ, Wolf C, Newsome TM, Galetti M, Alamgir M, Crist E, Mahmoud MI, Laurance WF. 2017. World scientists' warning to humanity: A second notice. *BioScience* 67: 1026–1028.

Ripple WJ, Wolf C, Rockström J, Richardson K, Wunderling N, Gregg JW, Westerhold T, Schellnhuber HJ. 2026. The risk of a hothouse Earth trajectory. *One Earth* 9.

Ripple WJ, Wolf C, van Vuuren DP, Gregg JW, Lenzen M. 2024. An environmental and socially just climate mitigation pathway for a planet in peril. *Environmental Research Letters* 19: 021001.

Rockström J, Donges JF, Fetzer I, Martin MA, Wang-Erlandsson L, Richardson K. 2024. Planetary boundaries guide humanity's future on Earth. *Nature Reviews Earth & Environment* 5: 773–788.

Rockström J, Thilsted SH, Willett WC, Gordon LJ, Herrero M, Hicks CC, Mason-D'Croz D, Rao N, Springmann M, Wright EC, et al. 2025. The EAT–Lancet

Commission on healthy, sustainable, and just food systems. *The Lancet* 406: 1625–1700.

Romanello M, Walawender M, Hsu S-C, Moskeland A, Palmeiro-Silva Y, Scamman D, Smallcombe JW, Abdullah S, Ades M, Al-Maruf A, et al. 2025. The 2025 report of the Lancet Countdown on health and climate change: climate change action offers a lifeline. *The Lancet* 406: 2804–2857.

Samways D. 2022. Population and sustainability: Reviewing the relationship between population growth and environmental change. *The Journal of Population and Sustainability* 6: 15–41.

[UNEP] United Nations Environment Programme. 2025. Global Environment Outlook 7: A future we choose – Why investing in Earth now can lead to a trillion-dollar benefit for all. Nairobi. (https://wedocs.unep.org/handle/20.500.11822/49014).

United Nations. 2024. World Population Prospects 2024: Summary of Results. (Report no. UN DESA/POP/2024/TR/NO. 9). United Nations.

Union of Concerned Scientists. 1992. World Scientists' Warning to Humanity.

Vogel J, Steinberger JK, O'Neill DW, Lamb WF, Krishnakumar J. 2021. Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning. *Global Environmental Change* 69: 102287.

Wiedmann T, Lenzen M, Keyßer LT, Steinberger JK. 2020. Scientists' warning on affluence. *Nature communications* 11: 1–10.

Wolf S et al. 2025. Scientists' warning on fossil fuels. *Oxford Open Climate Change* 5: kgaf011.

Xu C, Kohler TA, Lenton TM, Svenning J-C, Scheffer M. 2020. Future of the human climate niche. *Proceedings of the National Academy of Sciences* 117: 11350–11355.

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