

H HEURISTICS

Navigating a Changing World

Pollution, Climate Change, and Human Survivability

Strengthening Resilience Against Interacting Environmental Threats

How climate change, pollution, and ecosystem degradation compound each other — and where three pillars of resilience should intervene

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Abstract

Climate change and pollution are usually studied, financed, and negotiated as separate problems. This report argues that they are better understood as two expressions of one industrial metabolism acting on the same bodies, ecosystems, and infrastructure at once, and that the interactions between them are the main reason the margin for human survivability is narrowing faster than either threat alone would imply. It asks what would be required to keep human populations safe, healthy, and economically viable through mid-century when climate change, pollution, and ecosystem degradation compound rather than arrive one at a time.

The threats are individually large. Air pollution was linked to 7.9 million deaths in 2023 and pollution of all kinds to about 9 million a year; heat is estimated to kill roughly 546,000 people annually; observed warming reached about 1.43 °C in 2025, with current policies pointing toward roughly 2.8 °C by 2100; and seven of nine planetary boundaries are now transgressed. They are also coupled. Heat raises ozone and wildfire-smoke exposure; drought concentrates water contaminants; ecosystem loss strips away the buffers that absorb both; and cooling pollution, once removed, unmasking warming. A qualitative interaction matrix identifies heat and drought, ecosystem loss, and food-system stress as the strongest amplifiers, and ecosystems and water systems as the most amplified. An illustrative stress model shows that counting interaction terms brings the point at which combined load exceeds today's adaptive capacity forward by roughly a decade.

The burden is unequal: about nine in ten pollution deaths occur in low- and middle-income countries, 2.4 billion workers are exposed to excessive heat, and 2.1 billion people lack safely managed drinking water. The report proposes a strategy with three pillars — cutting the shared sources of climate and pollution risk, protecting people directly, and strengthening the natural and built systems that buffer them — supported by finance, governance, and data. Measures are prioritised by a double-duty test: how many threats each advances. Clean power, methane abatement, clean cooking, early warning, heat action plans, and ecosystem protection score highest and are largely proven, cost-effective, and ready to scale. The binding constraints are finance, with adaptation needs of US\$310–365 billion a year against about US\$26 billion in international public flows, and governance, with the plastics treaty unfinished. The conclusion is a priority, not a prophecy: fund, connect, and aim a response whose components already exist, before interacting threats outgrow the institutions that must manage them.

Keywords: climate change; pollution; human survivability; resilience; compound risk; air pollution; heat stress; planetary boundaries; short-lived climate pollutants; adaptation finance; early warning; double-duty investment; environmental health; interacting threats

JEL classification: Q54, Q53, Q56, I18, O13; climate and natural disasters; air and water pollution; environment and development; government policy and health; economic development and the environment

Data and method: This report synthesises institutional and peer-reviewed evidence, including the *Global Carbon Budget 2025*, the *WMO State of the Global Climate 2025*, the *UNEP Emissions Gap Report 2025* and *Adaptation Gap Report 2025*, the *State of Global Air 2025*, the *Lancet Countdown on health and climate change 2025*, the *Lancet Commission on Pollution and Health* update, the *Planetary Health Check 2025*, the ILO's 2024 report on workplace climate hazards, the WHO/UNICEF Joint Monitoring Programme 2025, IRENA's 2024 cost data, and the Global Commission on Adaptation. Every quantitative claim is attributed inline to a source with a hyperlink. Figures 1, 2, 7, 15, and 21 are conceptual schematics; Figures 3 and 5 include rounded or derived values noted in their source lines. Figures for different years and methods are not additive. Appendix A records provenance, exclusions, and caveats. The report is analytical rather than predictive.

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Executive Summary

Climate change and pollution are usually studied, financed, and negotiated as separate problems. They are better understood as two expressions of one industrial metabolism, acting on the same human bodies, the same ecosystems, and the same infrastructure at the same time — and the interactions between them are now the main reason the margin for human survivability is narrowing faster than either threat would suggest alone.

This report asks a practical question: what would it take to keep human populations safe, healthy, and economically viable through the middle of this century when climate change, pollution, and ecosystem degradation interact rather than arrive one at a time? It synthesises the most recent institutional evidence — including the [Global Carbon Budget 2025](#), the [WMO State of the Global Climate 2025](#), the [State of Global Air 2025](#), the [2025 Lancet Countdown on health and climate change](#), and the [2025 Planetary Health Check](#) — and organises it into a resilience strategy with three pillars and an enabling layer.

Key findings

- **The threats are large on their own.** Air pollution was linked to [7.9 million deaths in 2023](#); pollution of all kinds to about [9 million deaths a year](#); heat to roughly [546,000 deaths a year](#). Observed warming reached [about 1.43 °C in 2025](#), and current policies point toward [roughly 2.8 °C](#) by the end of the century.
- **They are coupled, not parallel.** Heat raises ozone and smoke exposure; ageing and under-ventilated cities concentrate both; drought concentrates water contaminants; ecosystem loss removes the buffers that would otherwise absorb each shock. In this report's qualitative matrix, heat and drought, ecosystem loss, and food-system stress are the strongest amplifiers, while ecosystems and water systems are the most amplified.
- **Ignoring interactions delays recognition of danger.** In an illustrative stress model (Figure 2), adding an interaction term brings the point at which combined load exceeds today's adaptive capacity forward by roughly a decade — from the late 2050s to the late 2040s. The numbers are schematic; the structural point is not.
- **The planetary buffer is thinning.** Seven of nine planetary boundaries are now [transgressed](#), including novel entities (synthetic chemicals and plastics), biogeochemical flows, and — as of 2025 — ocean acidification.
- **The burden is unequal.** About [92 percent of pollution deaths](#) and [90 percent of air-pollution deaths](#) occur in low- and middle-income countries; [2.4 billion workers](#) face excessive heat; [2.1 billion people](#) still lack safely managed drinking water.
- **Source control is cheap, fast, and double-duty.** Cutting fossil combustion, methane, and short-lived pollutants addresses climate and pollution together. [Renewables](#) were cheaper than the cheapest new fossil alternative for 91 percent of newly commissioned utility-scale capacity in 2024, and a [45 percent methane cut](#) could avoid nearly 0.3 °C by 2045 while preventing about 260,000 premature deaths a year.
- **Protection pays.** The [Global Commission on Adaptation](#) estimated US\$7.1 trillion of net benefits from US\$1.8 trillion of adaptation investment over 2020–2030, and [24 hours' warning](#) of a hazard can cut damage by roughly 30 percent.

- **Finance and governance are the binding constraints.** Developing countries need an estimated [US\\$310–365 billion a year](#) for adaptation by 2035 against about US\$26 billion in international public flows in 2023, and the global [plastics treaty remains unfinished](#).

Table 1. Headline indicators of interacting environmental threats

Indicator	Latest value	Year	Source
Fossil CO ₂ emissions	38.1 Gt (record)	2025	Global Carbon Budget 2025
Atmospheric CO ₂	425.7 ppm (projected)	2025	Global Carbon Budget 2025
Observed warming vs 1850–1900	≈1.43 °C	2025	WMO
Projected warming, current policies	≈2.8 °C	2100	UNEP Emissions Gap
Deaths attributed to air pollution	7.9 million	2023	State of Global Air
Deaths attributed to all pollution	≈9 million	2019	Lancet Commission update
Heat-related deaths, annual average	≈546,000	2012–21	Lancet Countdown
Planetary boundaries transgressed	7 of 9	2025	Planetary Health Check
People lacking safely managed drinking water	2.1 billion	2024	WHO/UNICEF JMP
Workers exposed to excessive heat	2.4 billion	2020	ILO
Adaptation finance need vs flows	US\$310–365bn vs US\$26bn	2035 / 2023	UNEP Adaptation Gap

Years refer to the latest data in each cited source. Estimates differ in method and scope and are not additive.

What this report recommends

The strategy is organised around three pillars — cutting the shared sources of climate and pollution risk, protecting people directly, and strengthening the natural and built systems that buffer them — supported by finance, governance, and data. The central argument is that the pillars should be sequenced and funded by their capacity to reduce more than one threat at a time. Clean power, methane control, clean cooking, early warning, heat action plans, and wetland and mangrove protection each pay in several currencies at once; they should be treated as the core of a survivability budget rather than as separate lines in climate, health, and environment ministries.

1 Introduction: Three Threats, One Survivability Question

For most of the past half-century, the environmental agenda has been divided by problem: ozone, acid rain, smog, climate, plastics, biodiversity, chemicals. Each division produced a treaty, an agency, a financing window, and a community of experts. What the evidence of the 2020s shows is that the divisions do not exist in the places where people actually live and die.

A heatwave in a polluted city is not a climate event followed by a pollution event. It is a single exposure in which high temperature raises the body's cardiovascular load while ozone and fine particles damage the lungs, power demand strains a grid that may be burning the fuels that emit the particles, and wildfire smoke may arrive from a landscape dried by the same heat. The [2025 report of the Lancet Countdown](#) tracks this convergence: 2024 was the hottest year on record, the average person was exposed to a record [16 additional health-threatening hot days](#) attributable to climate change, and heat-related mortality is estimated at about 546,000 deaths a year — roughly 1,500 a day on average — on top of air pollution that kills far more.

The scale of the combined problem is hard to hold in mind. The [State of Global Air 2025](#) attributes 7.9 million deaths in 2023 to air pollution, about one in eight deaths worldwide. The [Lancet Commission on Pollution and Health](#) put total pollution-related deaths at about 9 million a year, with toxic chemical pollution — including lead — responsible for roughly 1.8 million of them, a number the authors consider conservative. The [WMO](#) reports that 2015–2025 were the eleven warmest years on record, that ocean heat content reached its highest level in the 66-year observational record, and that Earth's energy imbalance — the surplus of heat entering the climate system — is now increasing.

1.1 Why survivability, and why now

This report uses "survivability" in a deliberately practical sense: the capacity of a human population to keep people alive, healthy, fed, sheltered, and economically viable in a given place under a given level of environmental stress. It is a spectrum, not a cliff. Most places will not become instantly uninhabitable; many will become measurably harder to live in, more costly to keep safe, and more unequal in who bears the cost. The relevant question for policy is therefore not whether civilisation survives but how many people, in how many places, lose how much of their margin of safety — and what can be done to widen it.

The timing matters for three reasons. First, the physical clock is short: the [Global Carbon Budget 2025](#) estimates that the remaining budget for a 50 percent chance of limiting warming to 1.5 °C is about 170 billion tonnes of CO₂, equivalent to roughly four years of current emissions. Second, the governance clock is uneven: the [plastics treaty](#) remains unfinished after talks in Geneva ended in August 2025 without agreement, and [COP30](#) produced a call to triple adaptation finance by 2035 whose wording was weaker than many countries sought. Third, the political clock is shifting: the [World Economic Forum's Global Risks Report 2026](#) finds attention moving toward geoeconomic confrontation even as extreme weather tops the ten-year outlook.

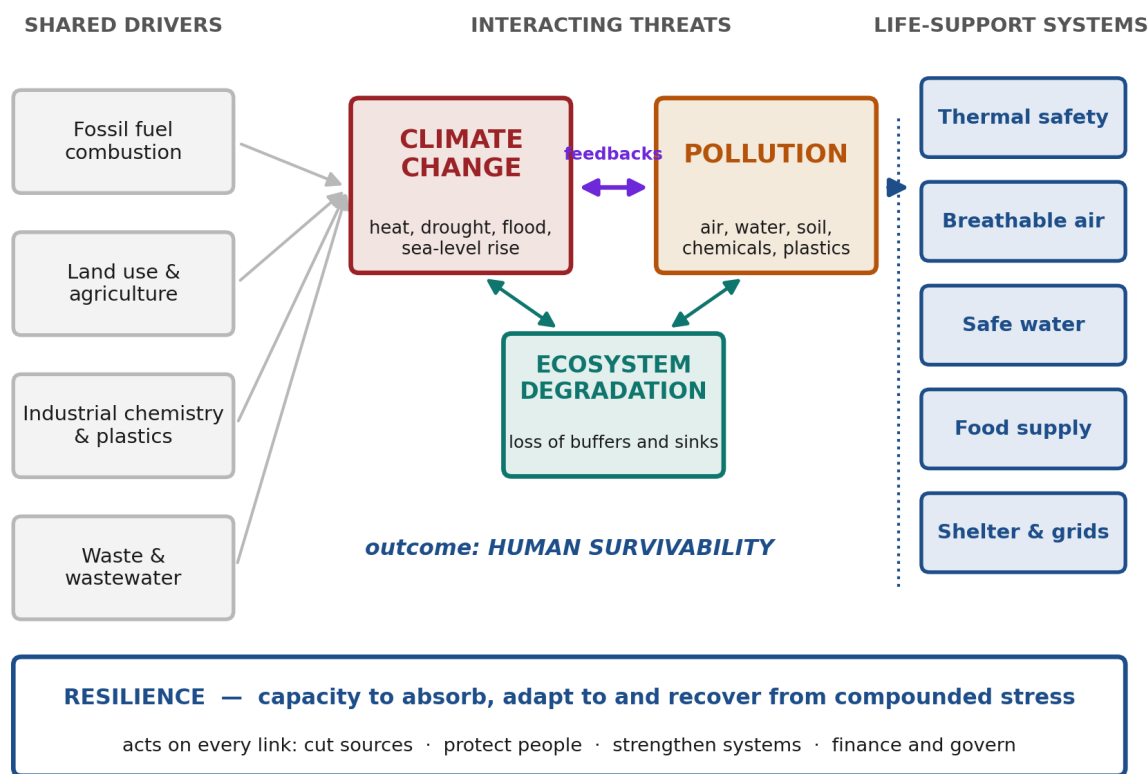


Figure 1. Conceptual framework: shared drivers act through two interacting threats — climate change and pollution — and through the ecosystem degradation both cause, on the life-support systems that determine human survivability. Resilience acts on every link.

Source: H Heuristics framework, developed throughout this report.

1.2 The argument in brief

The report makes four claims. First, climate change and pollution share their principal drivers — fossil combustion, industrial agriculture, and chemical and plastics production — so reducing the shared sources is the highest-value intervention. Second, the two threats interact through identifiable pathways, so their combined effect on human systems exceeds the sum of their separate effects. Third, the burden of that combined effect falls disproportionately on people with the least capacity to adapt. Fourth, there is a resilience strategy whose components are largely known, increasingly cheap, and in many cases already proven at scale; what is missing is integration, finance, and sequencing.

1.3 Scope, method, and limits

The report is a synthesis, not a new model. Every quantitative claim is attributed inline to an institutional or peer-reviewed source, and every figure states its source line. Three kinds of figure appear. Data figures plot published numbers directly. Derived figures apply simple arithmetic to published numbers and say so. Conceptual figures — Figures 1, 2, 7, 15, and 21 — are schematic: they illustrate structure and relative magnitude and should not be read as forecasts. Where evidence is contested, as with aerosol masking (Section 5) and rapid attribution (Section 6), the report says so, and no single estimate is treated as definitive. Appendix A lists data notes and sources.

2 A Framework for Survivability and Resilience

A framework earns its place if it changes what a decision-maker does. The one used here is built to make three things visible that single-hazard analysis hides: shared drivers, interaction terms, and the buffering capacity that stands between a stress and a human outcome.

2.1 Risk as hazard, exposure, vulnerability, and capacity

The standard risk framework used by the [IPCC](#) treats risk as the product of hazard, exposure, and vulnerability. This report adds a fourth term, adaptive capacity, because the policy lever lies there: hazards are largely set by upstream emissions and exposures by settlement patterns, but vulnerability and capacity are what institutions, finance, and infrastructure can change within a decade. A heatwave of a given intensity kills very different numbers of people depending on whether homes can be cooled, whether warnings reach the elderly, whether clinics are staffed, and whether the grid stays on.

The same logic applies to pollution. Exposure to fine particulate matter is a function of what is burned and where; the health outcome depends on baseline cardiovascular and respiratory health, access to care, and co-exposure to other stressors. The [WHO's 2021 guideline](#) for annual PM_{2.5} is 5 µg/m³; the [WHO ambient air quality database](#) reported that 99 percent of the global population breathes air that exceeds guideline limits.

2.2 Interaction terms and the margin of safety

Where two stressors act on the same system, the combined effect can be additive, sub-additive, or super-additive. Heat and air pollution on mortality, drought and water contamination on health, and ecosystem loss and flooding on property damage are examples of potentially super-additive pairs: each raises the sensitivity of the system to the other. When interaction terms are positive, models that sum single-hazard effects understate risk and, more importantly, understate how soon load will exceed capacity.

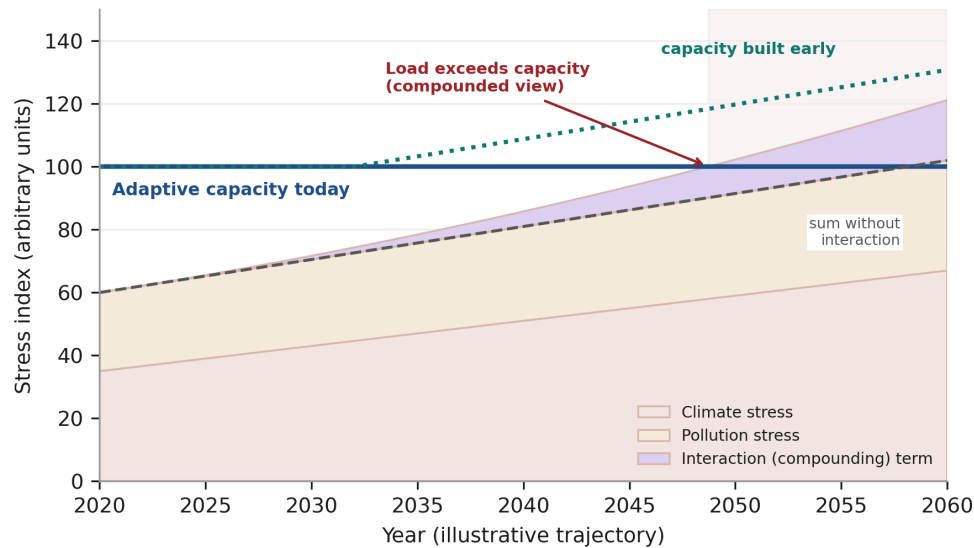


Figure 2. Illustrative stress model. Climate stress and pollution stress rise gradually; a positive interaction term accelerates the total. The compounded load crosses today's adaptive capacity roughly a decade before the simple sum does, and capacity built early can keep the margin open.

Source: H Heuristics illustrative model; indices are arbitrary and the figure is schematic, not a forecast.

Figure 2 makes this concrete. Climate stress rises linearly, pollution stress more slowly, and an interaction term grows with the square of elapsed time. The simple sum of the first two crosses a fixed capacity line in the late 2050s; the compounded total crosses in the late 2040s. Capacity that starts rising a decade from now keeps the margin open. The model is schematic; its value is to show that the timing of danger is sensitive to whether interactions are counted, and that the most robust response is to build capacity before the crossing is observed.

2.3 Three types of resilience

The strategy in Sections 10–14 draws on three complementary notions of resilience. Absorptive resilience is the ability of people and systems to take a shock without losing function — a hospital with backup power, a household with savings, a wetland that holds floodwater. Adaptive resilience is the ability to adjust behaviour and infrastructure as conditions shift — heat action plans, crop switching, cooler building codes. Transformative resilience is the ability to change the system itself so that the stress is reduced at source — the shift from combustion to electricity, from linear plastics to circular materials. The strongest portfolios combine all three; the weakest rely only on absorbing shocks that could have been prevented.

2.4 Design principles

- **Prioritise shared causes.** Where one intervention reduces several threats, it goes first.
- **Count interactions.** Appraisal should include compound and cascading effects, not only single-hazard losses.
- **Protect the most exposed first.** Marginal resilience is worth most where capacity is lowest.
- **Build before the crossing, and measure it.** Capacity takes years to create; indicators should be public and tied to budgets.

3 The Climate Threat: Where the World Stands

The climate threat is now measured, not projected. Concentrations, emissions, temperatures, ocean heat, and ice extent are at or near record levels, and the gap between current policy and the Paris temperature goals has narrowed only slightly.

3.1 Concentrations and emissions

Global fossil carbon dioxide emissions reached a record [38.1 billion tonnes in 2025](#), a 1.1 percent increase over 2024; including land-use change, total anthropogenic emissions were about 42.2 billion tonnes. Atmospheric CO₂ is projected to have averaged 425.7 parts per million in 2025, roughly 52 percent above its pre-industrial level, compared with 422.8 ppm observed in 2024. Human activity had by 2024 warmed the planet by an estimated 1.36 °C.

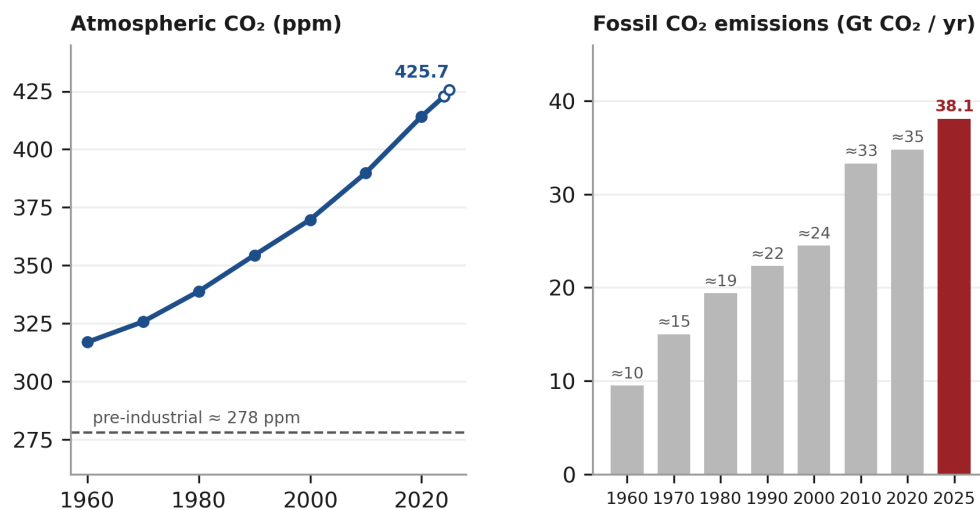


Figure 3. Atmospheric CO₂ concentration and fossil CO₂ emissions, 1960–2025. Concentration points are decadal values with the 2024 observation and 2025 projection; emission bars are rounded decadal values with the 2025 projection highlighted.

Source: NOAA Mauna Loa decadal means (rounded); Global Carbon Project series (rounded); 2024–2025 values from the [Global Carbon Budget 2025](#). Decadal values are approximate.

Concentration and emissions are different quantities. Carbon dioxide is a stock pollutant: a substantial fraction of each year's emissions persists in the atmosphere for centuries, so temperature is governed by cumulative emissions rather than the current rate. That is why the remaining budget matters and why even steep emission cuts do not quickly reduce temperature. It is also why the interaction between climate and pollution is so consequential: cutting short-lived pollutants can act quickly, whereas CO₂ cuts act on the trajectory of future warming.

3.2 Temperature, oceans, and ice

The [WMO State of the Global Climate 2025](#) places 2025 at about 1.43 °C above the 1850–1900 average — the second or third warmest year on record — and finds 2015–2025 to be the eleven warmest years in the record. Ocean heat content reached a record high, extending a streak of annual records, and the oceans

have been absorbing the equivalent of about eighteen times annual human energy use each year for two decades. For the first time the report includes Earth's energy imbalance as a headline indicator. Arctic sea ice was at or near record lows, Antarctic sea ice was the third lowest on record, and glacier melt continued.

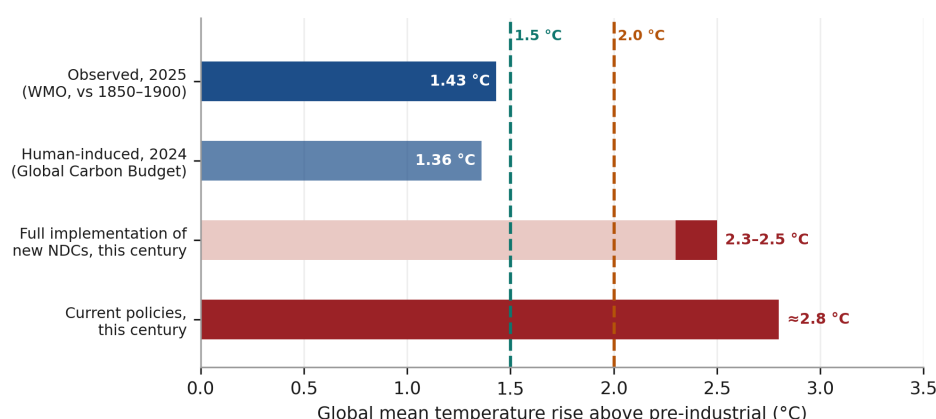


Figure 4. Observed warming and projected end-of-century warming against the Paris thresholds. Observed and human-induced warming are already close to 1.5 °C; fully implemented new national pledges point to 2.3–2.5 °C, and current policies to about 2.8 °C.

Source: [WMO State of the Global Climate 2025](#); [Global Carbon Budget 2025](#); [UNEP Emissions Gap Report 2025](#).

3.3 The policy gap

The [UNEP Emissions Gap Report 2025](#) estimates that full implementation of new national pledges would lead to 2.3–2.5 °C of warming this century, and that current policies lead to about 2.8 °C — down from 3.1 °C the year before, though methodological updates account for about 0.1 °C of the improvement and the US withdrawal from the Paris Agreement offsets another 0.1 °C. To be on a 2 °C pathway, 2030 emissions would need to be about 25 percent below 2019 levels; for 1.5 °C, about 40 percent below. The report concludes that the multi-decadal average temperature will exceed 1.5 °C at least temporarily. By 30 September 2025 only 60 Parties, covering 63 percent of emissions, had submitted new 2035 targets.

These numbers define the climate threat for this report: a world likely to exceed 1.5 °C for a period, on a path toward roughly 2.3–2.8 °C absent stronger action, and therefore committed to a harsher thermal and hydrological environment in which pollution co-exposures must be evaluated. Adaptation is no longer optional; neither is cutting the sources that drive both warming and pollution.

3.4 What warming does to the pollution problem

Warming does not merely add a heat hazard to a polluted world; it changes how pollution behaves. Higher temperatures speed the photochemistry that forms ground-level ozone; hotter, drier seasons increase wildfire smoke; lower river flows concentrate contaminants; warm, nutrient-rich water favours harmful algal growth; and extreme rainfall mobilises legacy contamination from soils, landfills, and industrial sites. Section 5 treats these pathways systematically. The climate threat is a multiplier on the pollution threat, and vice versa.

4 The Pollution Threat: A Larger and Less Visible Burden

Pollution kills more people each year than any single climate hazard, yet it receives a fraction of the attention and finance. It is also changing in composition: deaths from household and water pollution have fallen, while deaths from ambient air pollution and toxic chemicals have risen.

4.1 Air pollution

Air pollution is the largest component. The [State of Global Air 2025](#) attributes 7.9 million deaths in 2023 to air pollution; of these, 6.8 million (86 percent) were from non-communicable diseases such as heart disease, stroke, COPD, diabetes, and — newly included — dementia, to which air pollution contributed more than 625,000 deaths. Ambient fine particles accounted for about 4.9 million deaths, household air pollution from solid cooking fuels for about 2.8 million, and ground-level ozone for about 470,000; because exposures overlap, the components do not sum to the total. Ninety percent of deaths occurred in low- and middle-income countries, with India and China each exceeding two million. The figure is lower than the 8.1 million reported for 2021, but the authors attribute the drop to improved methods, not improved air; the 2021 figure has been revised to 7.6 million.

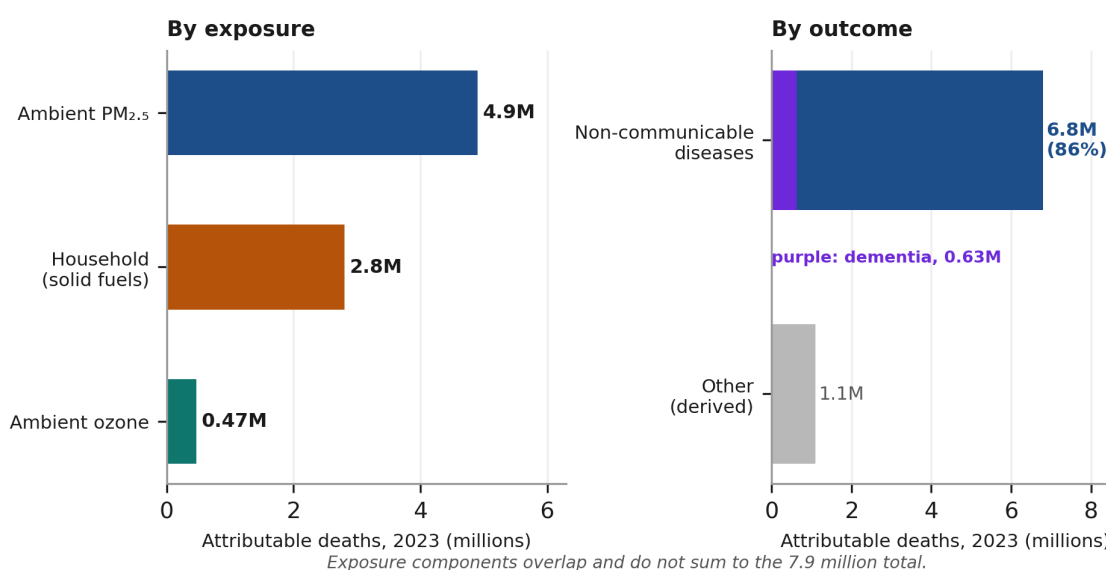


Figure 5. Deaths attributed to air pollution in 2023 by exposure and by outcome. Ambient fine particles are the largest component; non-communicable diseases account for 86 percent of the total, including more than 625,000 deaths linked to dementia.

Source: [State of Global Air 2025](#) (Health Effects Institute, IHME, NCD Alliance). "Other" is derived as total minus non-communicable.

Household air pollution remains a major, preventable component. The [IEA](#) reports that around 2 billion people worldwide still lack access to clean cooking, about 1 billion of them in Africa, and the [WHO](#) identifies household combustion of solid fuels as a leading source of indoor exposure. Clean cooking is among the clearest double-duty interventions: it cuts the exposure that kills women and children, reduces black carbon and CO₂ emissions, and relieves pressure on forests.

4.2 Water, chemicals, and plastics

Beyond air, three categories carry large and growing burdens. Water pollution and unsafe sanitation remain a major source of disease: the [WHO/UNICEF Joint Monitoring Programme](#) estimates that 2.1 billion people lack safely managed drinking water and 3.4 billion lack safely managed sanitation. Toxic chemical pollution is rising: the [Lancet Commission update](#) estimates about 1.8 million deaths, including roughly 900,000 from lead, and warns that many commercial chemicals have not been tested adequately for safety. [UNICEF and Pure Earth](#) estimated in 2020 that up to 800 million children — about one in three — have blood lead levels at or above 5 µg/dL, the level at which action is required, with nearly half in South Asia.

Plastics are the newest large-scale chemical exposure. The [Lancet Countdown on Health and Plastics](#), launched in August 2025, documents health effects from extraction through disposal and reports health-related economic losses exceeding US\$1.5 trillion a year — a figure that covers only three plastic-associated chemicals in 38 countries and so is best read as a conservative floor. The effects of microplastics themselves are still being studied and are likely underestimated.

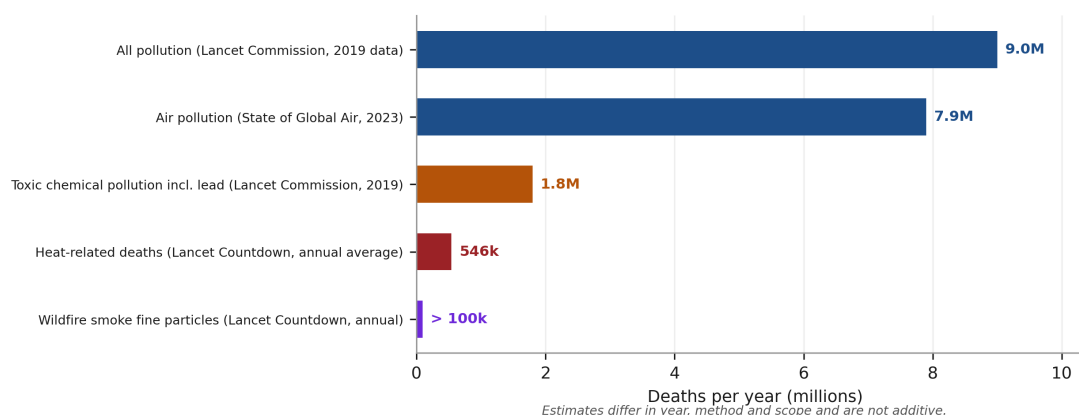


Figure 6. Scale of annual deaths attributed to selected environmental exposures. Pollution as a whole and air pollution alone exceed heat-related deaths by more than an order of magnitude; toxic chemicals, heat, and wildfire smoke are smaller but rising and poorly counted.

Source: [Lancet Commission update](#); [State of Global Air 2025](#); [Lancet Countdown 2025](#); [Finnish Meteorological Institute](#). Estimates differ in year and method and are not additive.

Table 2. The pollution portfolio: sources, burdens, and climate links

Category	Main sources	Headline burden	Climate link
Ambient air	Fossil combustion, industry, vehicles, dust, smoke	4.9m deaths from PM _{2.5} and 0.47m from ozone in 2023 (SoGA)	Shares sources with CO ₂ ; heat raises ozone; drought raises dust and smoke
Household air	Solid fuels for cooking and heating	2.8m deaths in 2023 (SoGA)	Black carbon and CO ₂ ; deforestation pressure
Water	Untreated sewage, agriculture, industry	2.1bn lack safe drinking water (JMP)	Drought concentrates; flooding spreads; heat favours algal blooms
Toxic chemicals	Lead, pesticides, industrial releases	≈1.8m deaths (Lancet)	Floods remobilise legacy contamination
Plastics	Fossil-based polymers and additives	>US\$1.5tn/yr health costs, partial (Lancet Countdown)	≈98% fossil-derived; production emits CO ₂
Wildfire smoke	Landscape fires	>100,000 deaths a year (FMI)	Fire weather lengthened by warming

Burden figures are the most recent in each cited source and differ in year and method.

4.3 The composition is shifting

Two features of the pollution burden matter for strategy. First, the shift in composition: the Lancet Commission found that deaths from household air and water pollution declined as poverty fell and services expanded, while deaths from ambient air pollution and toxic chemicals rose with industrialisation. Pollution therefore tracks development stage, and the fastest-growing economies carry the fastest-growing ambient and chemical exposures. Second, the economic cost: the Commission estimated pollution-related losses of about US\$4.6 trillion in 2019, about 6.2 percent of global economic output — a cost large enough to register in macroeconomic terms and borne largely in the same countries that face the steepest climate exposure.

5 How Pollution and Climate Change Interact

Interaction is the core of the argument. Pollution changes the climate, climate change changes pollution, and both erode the ecosystems that would otherwise buffer them. Some interactions amplify harm; one — the cooling effect of certain aerosols — complicates the simple story that cleaner is always cooler.

5.1 Pollution that warms the climate

The most important overlap is physical: the same combustion and industrial activity that emits CO₂ also emits other agents that warm the climate or damage health, or both. Methane is both a potent greenhouse gas and a precursor of ground-level ozone. The [UNEP/CCAC Global Methane Assessment](#) found that cutting human-caused methane emissions by up to 45 percent this decade would avoid nearly 0.3 °C of warming by 2045 and prevent, each year, about 260,000 premature deaths, 775,000 asthma-related hospital visits, 73 billion hours of lost labour from extreme heat, and 25 million tonnes of crop losses. Black carbon — soot — absorbs sunlight in the atmosphere and when deposited on snow, while also being a main component of the fine particles responsible for most air-pollution deaths. Tropospheric ozone is both a greenhouse gas and a respiratory irritant that damages crops.

The implication is that a large share of what is treated as "climate policy" is also air-quality policy, and vice versa. The same is true of cooling: hydrofluorocarbons used in refrigeration are potent greenhouse gases, which is why the [Kigali Amendment](#) to the Montreal Protocol is projected to avoid up to 0.5 °C of warming by 2100 if fully implemented — and roughly double that benefit if combined with better energy efficiency in cooling equipment.

5.2 The aerosol dilemma

Not all pollution warms. Sulphate aerosols reflect sunlight and cool the climate, and part of the warming already caused by greenhouse gases has been masked by sulphur pollution. As countries clean their air, that masking declines. This is the one place where the interaction between pollution and climate runs against the simple story, and it needs to be stated carefully because it is easily exaggerated.

The best-documented case is China. Estimates from several modelling approaches suggest that the roughly three-quarters decline in East Asian sulphur emissions raised global temperature by about 0.06–0.07 °C between 2007 and 2025, with uncertainty ranges of roughly 0.02–0.13 °C. The case of shipping is more contested. A 2025 multi-model study in [Atmospheric Chemistry and Physics](#) found that the IMO 2020 sulphur rules produce a physical warming response but that the global-mean temperature effect is statistically indistinguishable from zero over 2020–2040 (central estimate +0.03 °C, 5–95 percent range –0.09 to +0.19 °C), while most studies put the radiative forcing change at roughly 0.07–0.14 W/m². One group has argued for a much larger effect; that estimate lies far outside the published range and should be treated as a minority view until independently reproduced.

The policy lesson is not that clean air is a mistake. The health gains from removing fine particles are large and immediate, and the masking effect is small compared with the long-term warming driven by CO₂ and methane. The lesson is one of sequencing: air-quality improvements make deeper and faster cuts in CO₂ and methane more urgent, because the cooling offset they remove will not be replaced. A strategy that cleans the air without cutting carbon, or the reverse, is working against itself.

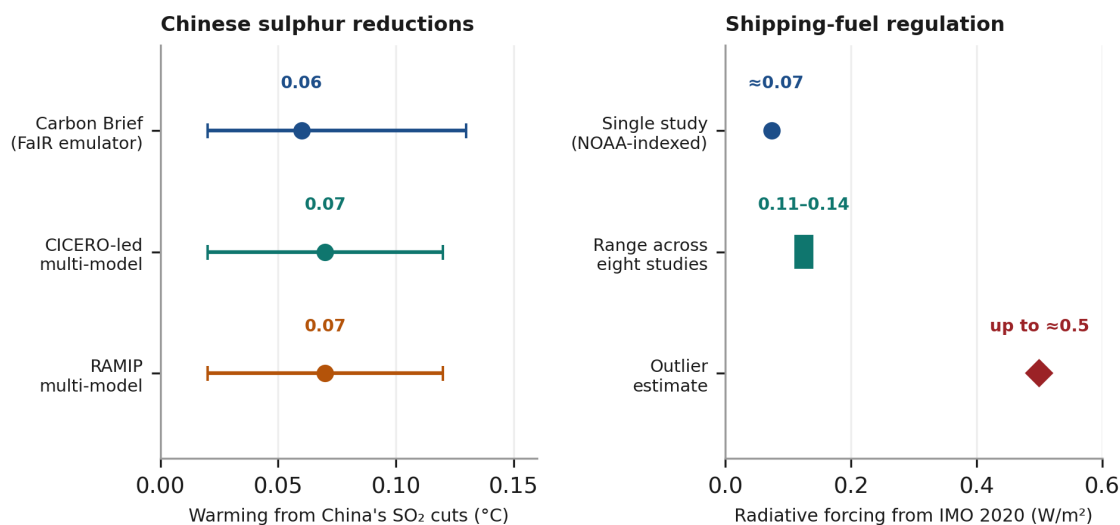


Figure 8. Estimated warming effects of removing cooling aerosols. Chinese sulphur reductions are estimated to have added roughly 0.06–0.07 °C between 2007 and 2025; estimates of the forcing change from the 2020 shipping-fuel rule cluster at 0.07–0.14 W/m², with one outlier estimate near 0.5 W/m².

Source: Carbon Brief FaIR-emulator estimate and CICERO-led and RAMIP multi-model studies as reported in secondary coverage; [Watson-Parris et al. 2025, Atmospheric Chemistry and Physics](#) and associated studies. Ranges are as published; the outlier estimate is a minority view.

5.3 Climate change that worsens pollution

The reverse pathway — climate change worsening pollution — operates through several mechanisms that are individually well established in atmospheric and hydrological science. Higher temperatures speed the photochemical reactions that form ground-level ozone, so a given quantity of precursor emissions produces more ozone in a hotter atmosphere. Hotter and drier conditions lengthen fire seasons and increase the area burned, so smoke exposure rises: the [Lancet Countdown 2025](#), drawing on modelling by the [Finnish Meteorological Institute](#), estimates that fine particles from wildfires cause over 100,000 premature deaths a year, with exposure growing because more people live in fire-prone areas. Drought reduces river flow and thereby concentrates dissolved contaminants; it also raises wind-blown dust. Extreme rainfall and flooding mobilise contaminants from soils, landfills, and industrial sites and overwhelm sanitation systems, linking climate extremes directly to the water-pollution burden in Section 7. Warmer water, with high nutrient loads, favours harmful algal blooms.

These are not marginal effects. They are the mechanism by which a changing climate converts a given level of emissions or waste into a higher level of human exposure — which is why air-quality standards, water-treatment capacity, and waste systems designed for the past climate will progressively under-perform.

5.4 A matrix of amplification

To summarise how the main stressors reinforce one another, Figure 7 presents a qualitative interaction matrix. Rows are the amplifying stressor and columns the amplified one; entries run from 0 (negligible) to 3 (strong). The ratings are H Heuristics' qualitative judgement, synthesising the mechanisms described in this section and the sources cited throughout; they are not measurements, and the exercise is meant to expose structure.

	Heat & drought	Air pollution	Water pollution & scarcity	Chemicals & plastics	Ecosystem loss	Food-system stress	
Heat & drought		3	3	2	3	3	Σ 14
Air pollution	2		1	1	2	2	Σ 8
Water pollution & scarcity	0	0		1	3	2	Σ 6
Chemicals & plastics	1	1	3		3	2	Σ 10
Ecosystem loss	3	2	3	1		3	Σ 12
Food-system stress	2	2	3	2	3		Σ 12
	Σ 8	Σ 8	Σ 13	Σ 7	Σ 14	Σ 12	

Figure 7. Qualitative interaction matrix among six stressors. Row sums show how strongly each stressor amplifies others; column sums show how strongly each is amplified. Heat and drought, ecosystem loss, and food-system stress are the strongest amplifiers; ecosystem loss, water pollution and scarcity, and food-system stress are the most amplified.

Source: H Heuristics qualitative assessment synthesising the cited literature. Scale: 0 negligible, 1 weak, 2 moderate, 3 strong. Schematic, not measured.

Two patterns stand out. First, heat and drought is the strongest amplifier: it raises ozone and smoke exposure, concentrates water pollutants, and stresses ecosystems and food systems simultaneously. Second, ecosystems and water systems are the most amplified — they absorb inputs from nearly every other stressor — which makes protecting and restoring them a high-leverage form of resilience. Figure 7 also shows that the matrix is asymmetric: water pollution amplifies few other stressors but is amplified by many, so it is a good barometer of cumulative stress.

Table 3. Principal interaction pathways between pollution and climate change

Pathway	Mechanism	Evidence	Direction
Methane → ozone	Methane is a precursor of ground-level ozone	45% cut avoids ≈ 0.3 °C and $\approx 260,000$ deaths/yr (GMA)	Pollution → climate and health
Aerosol masking	Sulphate aerosols reflect sunlight; cleaner air removes the offset	≈ 0.06 – 0.07 °C from China's cuts; shipping effect not distinguishable from zero in one multi-model study (ACP)	Pollution control → warming
Heat → ozone	Warmer air speeds ozone photochemistry	Established atmospheric chemistry	Climate → pollution
Fire weather → smoke	Heat and dryness lengthen fire seasons	$>100,000$ deaths/yr (FMI / Lancet Countdown)	Climate → pollution
Drought and flood → water	Low flows concentrate; floods mobilise contaminants	2.1bn lack safe drinking water (JMP)	Climate → pollution
Ozone → crops	Ozone damages crop tissue and cuts yields	Wheat 7.2%, soybean 6.7% global yield loss (CCAC)	Pollution → food
Plastics → climate	$\approx 98\%$ of plastic is fossil-derived	(Lancet Countdown)	Pollution → climate

Pathways are established mechanisms; magnitudes vary by region and are cited where quantified.

6 Heat, Air, and the Human Body

The body is where the interactions converge. Heat loads the cardiovascular system; fine particles and ozone damage the lungs and vessels; and the two together, in people who are old, sick, poor, or working outdoors, produce a risk far greater than either alone.

6.1 The heat toll

The [Lancet Countdown 2025](#) estimates that heat-related deaths average about 546,000 a year, and that the rate has risen 23 percent since the 1990s. In 2024, the hottest year on record, the average person worldwide experienced a record 16 extra days of health-threatening heat attributable to climate change, and infants and people over 65 faced over 20 heatwave days per person — a roughly fourfold increase over two decades. [A University of Sydney summary](#) of the report notes that the most vulnerable groups experienced an all-time high of 20 heatwave days. The report also finds that governments spent an estimated US\$956 billion on fossil fuel subsidies in 2023, and that fifteen countries accounting for more than 90 percent of CO₂ emissions spent more on those subsidies than on their national health budgets.

6.2 Physiological limits are lower than assumed

For years, the discussion of lethal heat rested on a theoretical limit of 35 °C wet-bulb temperature, the point at which the body cannot shed heat even at rest in shade. Experimental work at Penn State has shown that the practical limits are well below this figure. In laboratory tests of young, healthy adults doing light activity, [critical wet-bulb temperatures](#) averaged about 30.5 °C in humid conditions (30–31 °C) and ranged from 25 to 28 °C in hot, dry conditions — well below 35 °C in every case. The lead researchers noted that older people, people taking medications, and other vulnerable groups would be expected to have lower tolerance still.

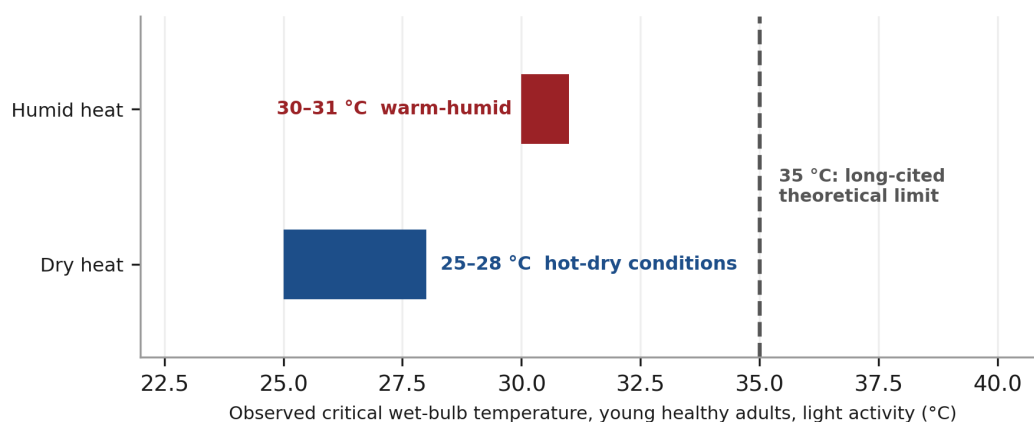


Figure 9. Observed critical wet-bulb temperatures in young healthy adults with light activity are well below the long-cited 35 °C limit — 30–31 °C in warm-humid conditions and 25–28 °C in hot-dry conditions. Older and medically vulnerable people would be expected to have lower limits.

Source: [Penn State research summary](#) (Vecellio et al., 2022).

The policy implication is that thresholds for heat warnings, workplace limits, and building standards need to be set against the physiology of vulnerable people, not the theoretical limit of the healthy; and that the

number of person-days above dangerous thresholds will rise faster than average temperature suggests, because the distribution of exposure is skewed toward the hottest and most humid places.

6.3 Heat and pollution together

Heat and air pollution act through overlapping physiological pathways — cardiovascular strain, respiratory inflammation, and dehydration — so co-exposure is more dangerous than either alone. The same hot, still, sunny days that raise ozone also coincide with peak electricity demand, and where electricity is generated by combustion, peak cooling demand raises emissions of the precursors of both ozone and particles. Wildfire smoke adds a further layer: heat dries the landscape, and the smoke then arrives in cities already stressed by heat. A person with chronic heart or lung disease — a large share of the older population in every region — may be pushed over a threshold by the combination while remaining safe under either alone.

6.4 The workplace as a front line

The [ILO's 2024 report on safety and health in a changing climate](#) estimates that about 2.4 billion of the world's 3.4 billion workers — 70.9 percent, up from 65.5 percent in 2000 — are exposed to excessive heat at some point in their work. It attributes about 19,000 deaths and roughly 23 million occupational injuries a year to excessive heat, estimates that 1.6 billion workers are exposed to solar ultraviolet radiation and 1.6 billion to workplace air pollution, and attributes up to 860,000 work-related deaths among outdoor workers each year to workplace air pollution. A [related ILO analysis](#) finds more workers than ever losing the fight against heat stress. Part of the increase in exposure reflects a larger workforce rather than higher temperatures, but the direction is clear: the people who build, farm, and deliver in the open air carry the interaction of heat and pollution on their bodies and their incomes.

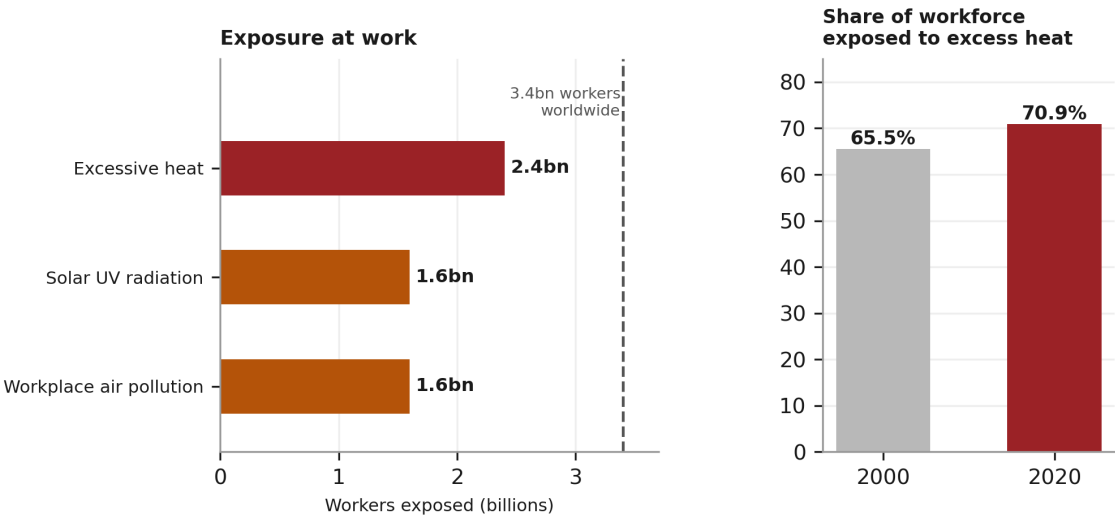


Figure 10. Workers exposed to climate-related hazards (left) and the share of the global workforce exposed to excessive heat in 2000 and 2020 (right). More than two-thirds of the world's workers are now exposed to excessive heat at some point in their work.

Source: [ILO, Ensuring safety and health at work in a changing climate \(2024\)](#); figures refer to 2020 exposure estimates.

6.5 A compound event in practice: Europe, summer 2025

A rapid attribution analysis by researchers at the London School of Hygiene & Tropical Medicine and Imperial College London illustrates the scale of compound heat in a high-income setting. It estimated about [24,400 heat-related deaths across 854 European cities](#) in summer 2025, of which about 16,500 — roughly two-thirds — were attributable to climate change, compared with a counterfactual world 1.3 °C cooler. The country estimates attributable to climate change ranged from about 4,600 in Italy to about 1,100 in the UK. The analysis is a rapid assessment that had not been peer reviewed at publication, so the figures are preliminary; but they are consistent in order of magnitude with the Lancet Countdown's longer-run estimates and show that heat mortality is not confined to low-income settings.

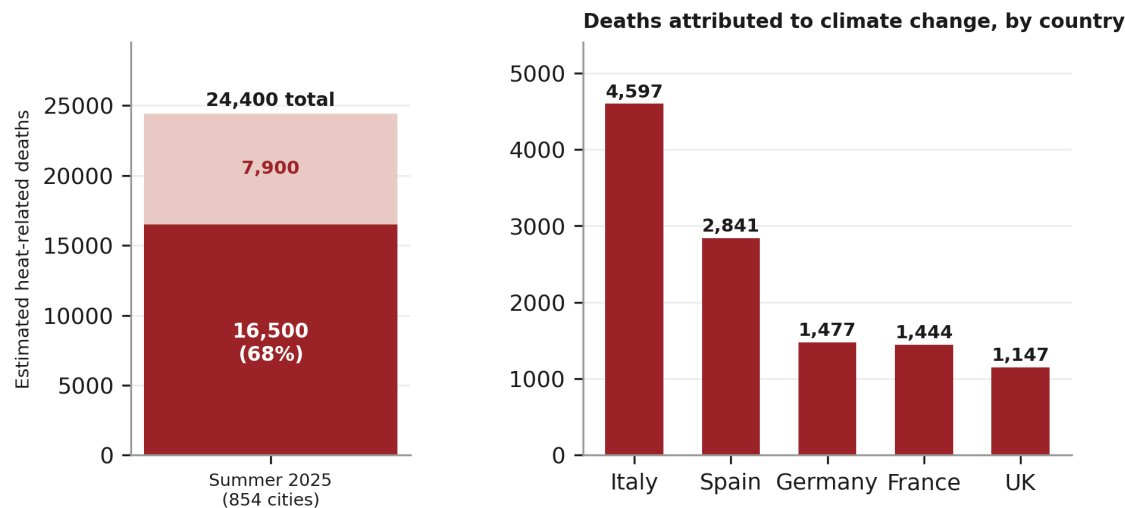


Figure 11. Estimated heat-related deaths in 854 European cities, summer 2025 (left), and deaths attributed to climate change in the five countries with the largest estimates (right). A rapid attribution estimate, not yet peer reviewed at publication.

Source: [LSHTM / Imperial College London rapid analysis \(2025\)](#). Preliminary estimates.

7 Water, Food, and Livelihoods

Water and food are where interacting environmental stress becomes a household and national economic problem. Contaminated or scarce water, ozone- and heat-damaged crops, and exposure-limited labour all reduce what people can produce, earn, and keep.

7.1 Water: scarcity and contamination together

Water is the clearest case in which scarcity and pollution are the same problem. The [WHO/UNICEF Joint Monitoring Programme](#) estimates that 2.1 billion people lack safely managed drinking water, including 106 million who drink directly from untreated surface sources, and that 3.4 billion lack safely managed sanitation, including 354 million who practise open defecation; 1.7 billion lack basic hygiene services at home. Safely managed drinking water coverage rose from 50 to 60 percent between 2015 and 2024, but people in least developed countries are more than twice as likely to lack basic services as people elsewhere, and in fragile settings coverage is 38 percentage points lower.

Climate change acts on those gaps from both ends. Drought reduces dilution and forces people toward unsafe sources; floods overwhelm latrines and treatment plants and spread pathogens; and warmer water speeds microbial growth. The result is that climate-driven extremes act through water as a multiplier on the contamination burden, and the places with the lowest baseline coverage are the places with the least capacity to respond.

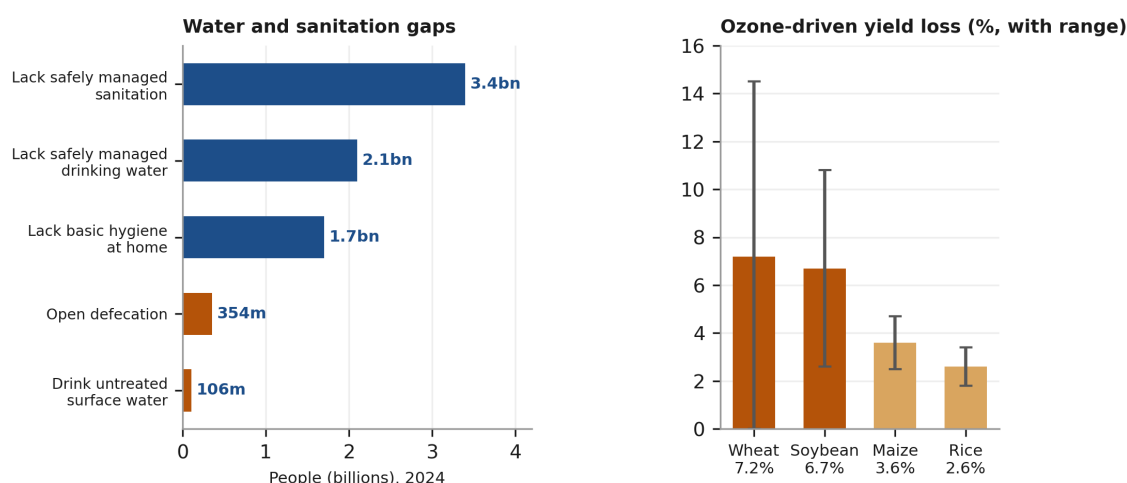


Figure 12. Water and sanitation gaps in 2024 (left) and estimated present-day global yield losses to ground-level ozone for four staple crops, with uncertainty ranges (right). Lower error bars are truncated at zero.

Source: [WHO/UNICEF JMP 2025](#); [CCAC summary of a multi-method ozone-crop reanalysis](#). Crop-loss values are central estimates with published uncertainty.

7.2 Food: ozone, heat, and yield

Food systems feel the interaction through yields. Ground-level ozone damages crop tissue and reduces photosynthesis. A [multi-method reanalysis summarised by the Climate and Clean Air Coalition](#) estimates present-day global yield losses of about 7.2 percent for wheat, 6.7 percent for soybean, 3.6 percent for maize, and 2.6 percent for rice, with wide uncertainty — particularly for wheat (± 7.3 points) and soybean

(± 4.1 points). Regional losses can be much larger in intensively farmed, polluted regions such as the wheat belts of India and China. The same analysis notes that rising CO₂ partly offsets ozone damage by reducing plant uptake, which is a reminder that the interaction runs in more than one direction and cannot be reduced to a single sign.

Heat compounds the ozone effect. The [Global Commission on Adaptation](#) warned that without adaptation, climate change could reduce global agricultural yields by as much as 30 percent by 2050, with the world's 500 million small farms most affected. Drought, heat stress during critical growth stages, soil degradation, and water contamination all act on the same fields. For households that depend on those fields, a bad season is not only an income shock; it is a nutrition shock that reduces child growth and educational outcomes, and so feeds directly into the human-capital channel through which environmental stress becomes a long-run development loss.

7.3 Livelihoods, debt, and the transmission to the economy

The livelihoods channel runs through labour, assets, and public finance. Outdoor workers lose productive hours and health to heat and workplace air pollution (Section 6). Assets are lost to floods and storms. And governments of the most exposed countries face the fiscal consequence: a disaster raises spending and cuts revenue at the same time as debt service rises. [UNCTAD](#) documents the scale of developing-country public debt, which has grown to record levels, leaving little fiscal room to invest in resilience before a shock and less to recover after one. This is the macro-financial form of the interaction: the same countries with the highest exposure to heat, pollution, and flood have the narrowest fiscal space to respond.

Lead exposure illustrates the long-run human-capital cost. [UNICEF and Pure Earth](#) estimate that up to 800 million children have blood lead levels at or above 5 $\mu\text{g/dL}$, a level the WHO says may be associated with decreased intelligence, behavioural problems, and learning difficulties; Bangladesh alone accounts for an estimated 35.5 million affected children. Exposures of this kind lower lifetime earnings and productivity long after the pollution source has been removed.

8 Ecosystems and Planetary Boundaries

Ecosystems are the shock absorbers of the human system. Forests, wetlands, mangroves, soils, and oceans filter pollutants, store carbon, buffer floods, and regulate temperature. They are also the part of the system that interacting threats degrade most thoroughly, and the part for which the loss is hardest to reverse.

8.1 The 2025 planetary health check

The [2025 Planetary Health Check](#), from the Potsdam Institute for Climate Impact Research and the Stockholm Resilience Centre, finds that seven of the nine planetary boundaries are now transgressed: climate change, biosphere integrity, land-system change, freshwater change, biogeochemical flows, novel entities, and — newly counted in 2025 — ocean acidification. Only stratospheric ozone depletion and atmospheric aerosol loading remain within the safe zone. All seven transgressed boundaries show trends of increasing pressure. Ocean surface pH has fallen by about 0.1 units since the start of the industrial era, a 30–40 percent increase in acidity, driven mainly by fossil fuel burning.

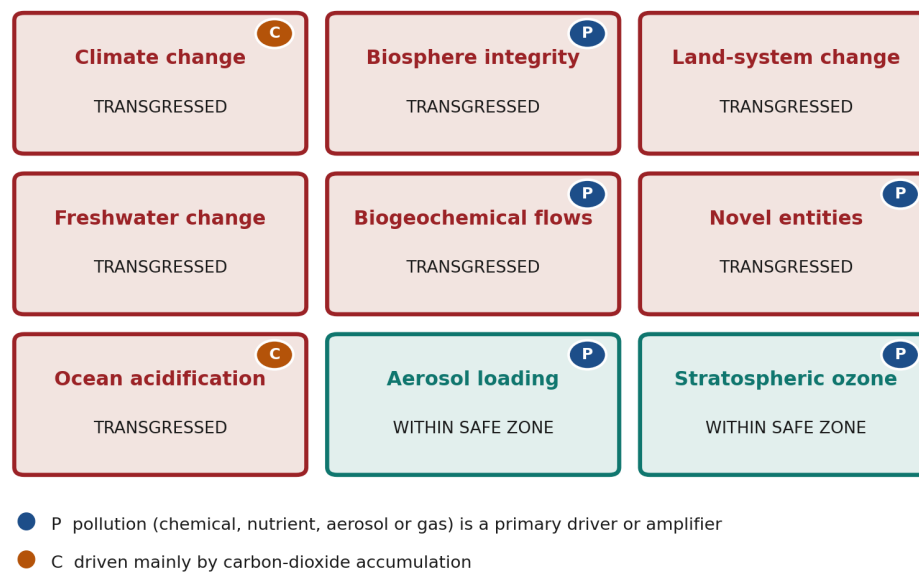


Figure 13. Status of the nine planetary boundaries, 2025. Seven are transgressed; ozone and aerosols remain within the safe zone. Markers show boundaries where pollution is a primary driver or amplifier (P) or where carbon-dioxide accumulation is the main driver (C).

Source: [Planetary Health Check 2025](#) (PIK / Stockholm Resilience Centre); markers are H Heuristics classification.

Pollution is directly implicated in several of these. Biogeochemical flows — nitrogen and phosphorus — are a form of agricultural pollution; novel entities are synthetic chemicals, plastics, and other human-made materials released faster than they can be assessed; aerosol loading is air pollution in the form of particles; and ocean acidification is the oceanic expression of CO₂ accumulation. Climate change is a boundary in its own right and a driver of change in several of the others. The boundaries are therefore not an alternative list to climate and pollution; they are the same threats seen from the perspective of the Earth system.

8.2 The ozone precedent and what it shows

The two boundaries that remain safe offer the most useful lesson. The ozone layer and aerosol loading were pushed toward their limits by industrial chemistry and air pollution, and international action — the Montreal Protocol and national air-quality policy — has turned both. The Planetary Health Check's lead authors cite the decline in aerosol pollution and the healing of the ozone layer as evidence that the direction of global development can be reversed. The mechanism is instructive: a clearly identified substance, a binding agreement with finance and compliance machinery, and available substitutes. Those three conditions are the template for the harder cases of methane, plastics, and chemicals.

8.3 Buffers worth protecting

Intact ecosystems provide protection at a cost far below that of engineered substitutes. Research on the [global flood-protection benefits of mangroves](#) found that mangroves provide flood protection worth more than US\$65 billion a year and that, without them, about 15 million more people would be flooded annually; more than 45 coastal stretches of 20 km each receive over US\$250 million a year in flood-protection benefits. Wetlands filter nutrients and sediments, forests regulate local temperature and humidity, soils store carbon and water, and coral and seagrass systems dissipate wave energy. Each of these buffers is degraded by the same pollution and warming that it would otherwise absorb — which is why ecosystem protection appears in the strategy in Section 13 as resilience infrastructure, not as a separate conservation agenda.

The [WEF Global Risks Report 2026](#) reflects the same view among risk professionals: biodiversity loss and ecosystem collapse is the risk whose severity score worsens most between the two-year and ten-year horizons, and critical changes to Earth systems ranks among the top three long-term risks.

9 Who Bears the Risk: Vulnerability and Inequality

The burden of interacting environmental threats falls where capacity is lowest. The pattern holds for pollution deaths, heat exposure, water access, and lead poisoning, and it is the strongest argument for ordering resilience investment by vulnerability rather than by economic size.

9.1 Geographic concentration

The geographic skew is stark. About [92 percent of pollution-related deaths](#) occur in low- and middle-income countries, and [90 percent of air-pollution deaths](#), with India and China each exceeding two million in 2023. Nearly half of the children with elevated blood lead levels [live in South Asia](#). The [IPCC](#) estimates that roughly 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change. The overlap of these geographies is the key structural fact: the regions with the highest pollution burdens are also the regions with the steepest projected exposure to heat and flood, the lowest baseline service coverage, and the tightest fiscal constraints.

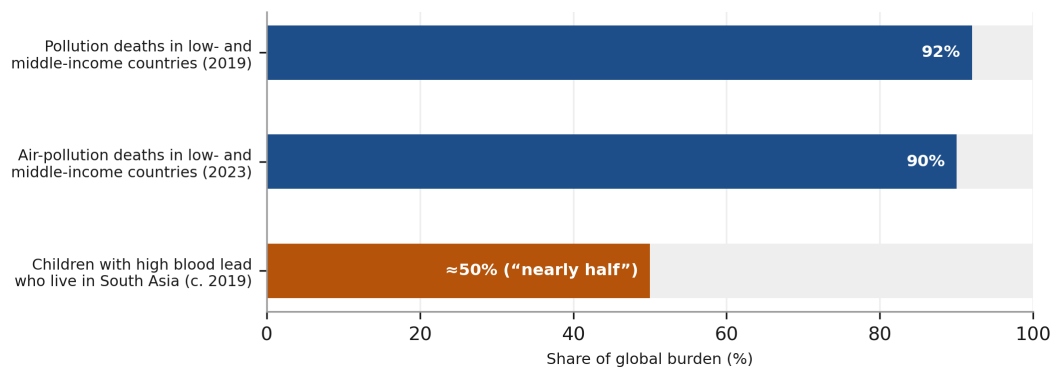


Figure 14. Concentration of the pollution burden in low- and middle-income countries and in South Asia. Nine in ten air-pollution deaths and more than nine in ten pollution deaths occur in low- and middle-income countries; nearly half of children with high blood lead live in South Asia.

Source: [Lancet Commission update](#); [State of Global Air 2025](#); [UNICEF / Pure Earth](#).

9.2 Who within countries

Within countries, risk concentrates by age, occupation, income, and place. Older adults are the main victims of heat and of air-pollution-linked non-communicable disease, including dementia. Infants and young children are most sensitive to lead, indoor smoke, and heat. Outdoor and informal workers receive the highest exposures and the least protection. Households in informal settlements often combine poor housing, no cooling, unreliable water, and proximity to industrial and waste sources. Women and children bear the burden of household air pollution.

Table 4. Groups at elevated risk from interacting environmental threats

Group	Principal exposures	Why risk is elevated	Evidence
Older adults	Heat, fine particles, ozone, smoke	Chronic disease and reduced thermoregulation	Over 20 heatwave days per person in 2024; 625,000 dementia deaths linked to air pollution (Lancet Countdown, SoGA)
Infants and children	Heat, lead, household smoke, unsafe water	Developing organs; higher intake per body weight	Up to 800m children with high blood lead (UNICEF)
Outdoor and informal workers	Heat, UV, workplace air pollution	Exposure with limited protection or recourse	2.4bn exposed to heat; up to 860,000 deaths from workplace air pollution (ILO)
Households using solid fuels	Household air pollution	Combustion indoors, often by women and children	2.8m deaths in 2023 (SoGA)
People in fragile and least developed countries	Unsafe water, compound disasters	Low service coverage and weak institutions	38-point coverage gap in fragile settings (JMP)
Coastal and flood-exposed communities	Floods, storm surge, contamination	Exposure and weak infrastructure	Mangrove loss would add 15m people flooded a year (UCSC)

Illustrative, not exhaustive. Evidence is from the cited sources; groups overlap.

9.3 Why equity is a resilience variable, not only a value

Ordering action by vulnerability is not only fair; it is efficient. The marginal benefit of a unit of resilience is highest where baseline capacity is lowest: a cooling centre, a clean cookstove, a household water filter, or an early-warning message does more good for a person with none than for a person with several. And the global systems that all people depend on — food, trade, public health, and security — are only as resilient as their most stressed nodes. Shocks that begin in the most exposed regions become global through migration, price, and disease. The ethical and the strategic arguments point in the same direction.

10 A Strategy for Resilience: Architecture and Priorities

If the threats share causes and interact, the response should share levers and be sequenced by how many threats each lever reduces. The architecture proposed here has three pillars — cut shared sources, protect people, strengthen systems — and an enabling layer of finance, governance, and data.

10.1 The three pillars and the enabling layer

The first pillar acts on the flow: it reduces the emission and release of the substances that drive both warming and pollution. The second acts on exposure and vulnerability: it protects people directly from the hazards that remain. The third acts on the buffers: it protects and rebuilds the natural and built systems that absorb shocks before they reach people. Under all three runs an enabling layer — finance that reaches where it is needed, governance that integrates what is currently separate, data that makes compound risk visible, and institutional capacity to deliver. The pillars map onto the three types of resilience in Section 2: transformative, adaptive, and absorptive.

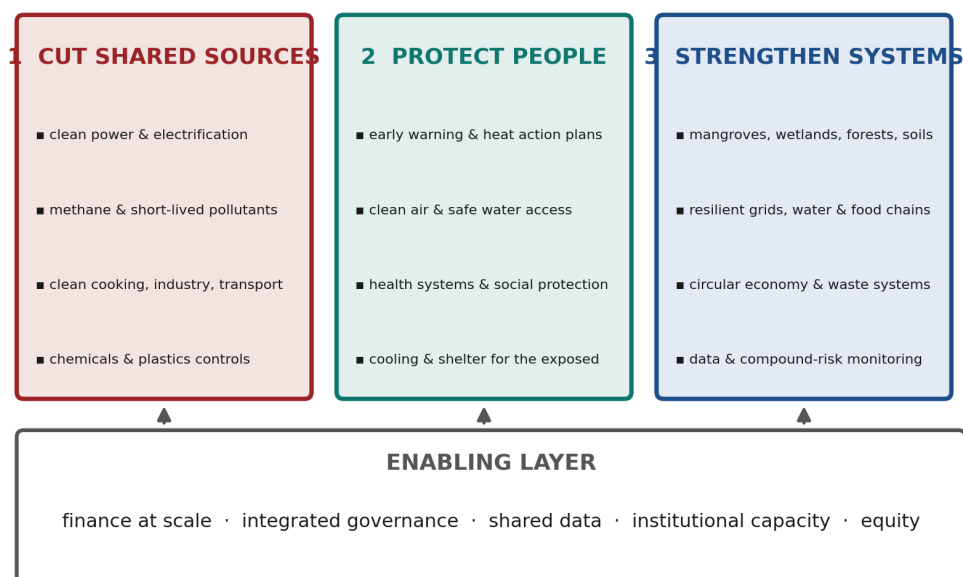


Figure 15. Strategy architecture: three pillars acting on sources, people, and systems, supported by an enabling layer of finance, governance, data, capacity, and equity.

Source: H Heuristics framework.

10.2 The double-duty test

With limited finance and political attention, the question is how to order action. This report proposes a simple filter, the double-duty test: for each candidate measure, ask how many of the following it advances — reducing greenhouse gases, reducing pollution exposure, reducing vulnerability to heat, flood, or water stress, and protecting ecosystems. A measure that scores on three or four should be prioritised over one that scores on one, other things equal. The test does not replace cost-benefit analysis; it corrects a bias in ministry-by-ministry budgeting, in which cross-cutting returns go uncounted.

Table 5. The double-duty portfolio: measures that advance several goals at once

Measure	Climate	Pollution / health	Adaptation	Evidence
Clean power and electrification	●	●	○	91% of new renewable capacity cheaper than new fossil in 2024 (IRENA)
Methane abatement	●	●	○	≈0.3 °C avoided by 2045; ≈260,000 deaths/yr prevented (GMA)
Clean cooking	●	●	○	≈2bn people without access; 2.8m household-air deaths (IEA , SoGA)
Efficient, low-HFC cooling	●	○	●	Kigali: up to 0.5 °C avoided by 2100 (CCAC)
Early-warning systems		○	●	24 hours' notice cuts damage ≈30% (UN)
Heat action plans		○	●	≈1,190 deaths/yr avoided in Ahmedabad (Hess et al.)
Mangrove and wetland protection	○	○	●	>US\$65bn/yr flood benefit (UCSC)
Chemical and plastic controls	○	●		≈1.8m chemical deaths; >US\$1.5tn/yr plastics costs (Lancet , Countdown)

Marks show primary benefit (●) and secondary benefit (○) as assessed by H Heuristics from the cited evidence. Evidence figures are from the sources cited.

10.3 Sequencing: three tiers

The strategy is sequenced in three tiers. Tier 1 contains measures that are already cost-effective, proven, and double-duty: renewable power and electrification, methane abatement, clean cooking, early warning, heat action plans, and clean-air enforcement. They should be funded and deployed immediately and at scale. Tier 2 contains measures that require institutional change and larger finance but have strong evidence: ecosystem protection and restoration, resilient grids and water systems, health-system strengthening, and workplace protection. Tier 3 contains the harder transformations — chemicals governance, circular plastics, and industrial decarbonisation — whose pace depends on international agreement and technology cost declines. The tiers overlap in time but not in priority: the effort lost by waiting to complete Tier 3 is far greater than the effort needed to start Tier 1.

10.4 Principles for implementation

- **Local first.** Heat action plans, early-warning delivery, and clean-air enforcement succeed or fail at municipal and community level; national and international finance should be designed to reach that level.
- **Integrated appraisal.** Projects should be appraised on their full set of benefits, including health and avoided damages, not only on the budget line of the sponsoring ministry.
- **Avoid maladaptation.** Measures should not reduce one risk while raising another — for example, cooling powered by dirty electricity.
- **Measure and publish.** Indicators should be public, comparable, and tied to accountability (Section 15).

11 Pillar One: Cut the Shared Sources

The most cost-effective way to reduce interacting threats is to reduce what causes more than one of them. The technology to do so is now, in most power markets, cheaper than the alternative.

11.1 Clean power and electrification

Fossil combustion is the largest shared source of CO₂ and of the particles and ozone precursors that account for most air-pollution deaths. The cost case for replacing it has changed decisively. According to the [IRENA Renewable Power Generation Costs in 2024 report](#), 91 percent of newly commissioned utility-scale renewable capacity delivered power at lower cost than the cheapest new fossil-fuel alternative; solar PV was 41 percent cheaper and onshore wind 53 percent cheaper than the lowest-cost new fossil option, with average costs of about US\$0.043 per kWh for solar and US\$0.034 per kWh for onshore wind. Utility-scale battery storage costs have fallen by about 93 percent since 2010, to about US\$192 per kWh in 2024, and renewables helped avoid an estimated US\$467 billion in fossil-fuel costs in 2024.

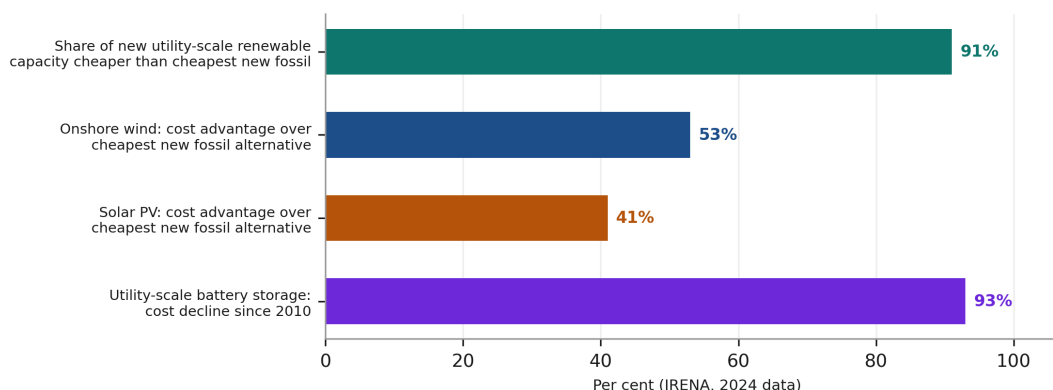


Figure 16. Competitiveness of renewable power in 2024: the share of new utility-scale renewable capacity that undercut the cheapest new fossil alternative, the cost advantage of onshore wind and solar PV, and the decline in battery storage costs since 2010.

Source: [IRENA, Renewable Power Generation Costs in 2024](#).

These are cost comparisons for new capacity, not for the existing fleet, and solar's levelised cost rose slightly in 2024 owing to financing costs and market factors — a reminder that the cost of capital is part of the cost of clean power (Section 14). The strategic point is that for new generation the economic case now supports prevention, and that replacing coal and gas combustion also removes the particle and ozone-precursor emissions that drive Section 4's air-pollution deaths. Electrification of transport, cooking, and industrial heat extends the benefit to tailpipes, kitchens, and furnaces.

11.2 Methane and short-lived pollutants

Methane abatement is among the best double-duty measures available, because the benefit is fast, large, and shared by climate, health, and food. The [Global Methane Assessment](#) found that up to a 45 percent cut in human-caused emissions this decade is achievable, that about 30 percent could come from readily available measures by 2030 — mostly in the fossil-fuel sector, where leaks and venting are easiest to locate and fix — and that the benefits far outweigh the costs. The [Global Methane Pledge](#), launched in 2021,

commits participating countries to cut methane emissions by 30 percent by 2030 from 2020 levels. Cooling is the second short-lived lever: the [Kigali Amendment](#) to the Montreal Protocol phases down hydrofluorocarbons and, if fully implemented, avoids up to 0.5 °C of warming by 2100; paired with efficiency gains in cooling equipment the benefit could roughly double.

11.3 Air-quality policy that works: Beijing

Large reductions in fine-particle pollution are achievable within a decade. Under the Clean Air Action Plan (2013–2017) and the Blue Sky Action Plan (2018–2020), Beijing's annual PM_{2.5} concentration fell to 30 µg/m³ in 2022 — [down 66.5 percent from 2013](#), when it averaged about 89.5 µg/m³ — according to the city's own monitoring. The [University of Chicago's Air Quality Life Index](#) notes that Beijing's 2013 level was roughly 17 times the WHO's then-safe level, that the national plan targeted a 34 percent cut in Beijing, and that the wider Beijing–Tianjin–Hebei region cut particulates by 53.1 percent between 2013 and 2021. Attribution of the decline to specific policies is contested, and one synthetic-control study credits the regional programme with only a portion of it; but the order of magnitude is not in doubt. Beijing's air nevertheless remains six times above the [WHO annual guideline](#) of 5 µg/m³, showing how far the standard is from current practice even in a success case.

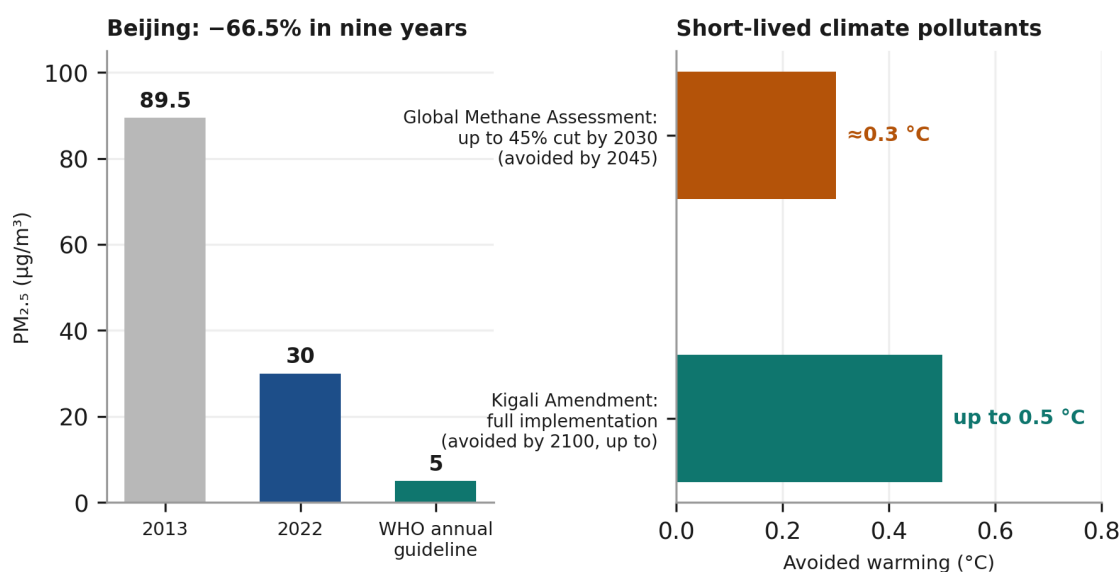


Figure 17. What source control has delivered and could deliver. Left: Beijing's annual PM_{2.5} fell from about 90 µg/m³ in 2013 to 30 µg/m³ in 2022, still six times the WHO guideline. Right: avoided warming from methane abatement and from full implementation of the Kigali Amendment.

Source: Beijing municipal monitoring as reported by [China Daily](#) and [AQLI](#); WHO; [Global Methane Assessment](#); [Kigali Amendment summary](#). Avoided-warming values are upper-end or central estimates as published.

11.4 Clean cooking

Clean cooking is the clearest example of a measure whose primary benefit is health and whose climate and ecosystem benefits are substantial. The [IEA](#) reports that around 2 billion people worldwide still cook with polluting fuels and that the number of Africans without access has continued to grow, reaching about 1 billion; its roadmap argues that the gap could be closed in 15 years at the pace other developing economies have achieved. Replacing solid-fuel cooking removes the household-air-pollution exposure that accounted

for about 2.8 million deaths in 2023, cuts black-carbon and CO₂ emissions, and reduces pressure on forests and on the time of women and children who collect fuel. It is a Tier 1 measure on every criterion.

11.5 Chemicals and plastics

Chemicals and plastics are the area in which the shared source is least controlled. The Lancet Commission's estimate of 1.8 million deaths from toxic chemical pollution — likely an undercount because most manufactured chemicals have not been assessed — and the Lancet Countdown on Health and Plastics' estimate of more than US\$1.5 trillion a year in health-related losses from only three plastic chemicals in 38 countries indicate a large, growing, and poorly measured burden. About 98 percent of plastics are made from fossil fuels, so plastics are also a climate issue. The international response is incomplete: the [INC-5.2 plastics treaty talks in Geneva](#) ended in August 2025 without agreement, the chair resigned, and the [INC-5.3 session in February 2026](#) elected a new chair, Julio Cordano of Chile, but held no substantive negotiations; by June 2026 [negotiators remained deadlocked](#). Pending an international agreement, national and regional measures — chemical-of-concern restrictions, extended producer responsibility, design standards, and lead-exposure programmes — are the practical Tier 3 starting point.

11.6 Sequencing air cleanup with carbon cuts

The aerosol dilemma of Section 5 argues for pairing, not delaying. Air-quality gains should proceed, because the health benefits are immediate and large; but because the cooling offset provided by sulphate aerosols will not be replaced, those gains should be accompanied by deeper and faster cuts in CO₂ and methane. Concretely, national plans should be framed as joint clean-air and climate plans with shared targets, shared monitoring, and shared finance, so that progress on one cannot be bought at the expense of the other.

12 Pillar Two: Protect People Directly

Even with strong source control, warming and pollution will continue for decades. The second pillar protects the people who are exposed now: warning them, cooling them, giving them clean air and water, and making sure health and social-protection systems can absorb the shock.

12.1 Early warning

Early warning is among the highest-return resilience investments. The [UN Secretary-General](#) has cited the Global Commission on Adaptation's finding that just 24 hours' notice of an impending hazardous event can reduce damage by 30 percent, and [UN-Water](#) reports the Commission's estimate that spending US\$800 million on such systems in developing countries would avoid losses of US\$3–16 billion per year. The Early Warnings for All initiative aims to cover everyone on Earth. The estimate is that of the Commission and is not a controlled study, but the direction and order of magnitude are consistent across the literature: warnings that reach people and trigger action are cheap relative to the damage they prevent.

For interacting threats, warning systems should be multi-hazard: a heat alert should include ozone and smoke forecasts, and a flood warning should include water-safety advice. Systems built hazard by hazard will miss the compound events that cause the largest losses.

12.2 Heat action plans and cooling access

Heat action plans coordinate forecasting, public alerts, targeted outreach to vulnerable people, cooling spaces, work-hour adjustments, and health-system preparedness. The best-studied example is Ahmedabad, India, which launched South Asia's first plan after a deadly 2010 heatwave. A [pilot evaluation by Hess and colleagues](#) found that the plan was associated with an estimated 1,190 avoided heat-related deaths a year, comparing mortality in 2014–2015 with a 2007–2010 baseline; [the plan's sponsors](#) report a rounded figure of about 1,100. As a before-and-after evaluation without a control group the estimate is uncertain, but it indicates what a low-cost coordinated plan can achieve.

Cooling access is the structural complement. The risk is maladaptation: air-conditioning raises electricity demand, and where power is fossil-based raises emissions of both CO₂ and air pollutants, while refrigerants can be potent greenhouse gases. The strategy is therefore to promote passive and efficient cooling — shade, reflective roofs, ventilation, efficient equipment — with low-HFC refrigerants under the Kigali phase-down, powered by clean electricity.

12.3 Clean air and safe water

Direct exposure reduction complements source control. Household and community measures — clean-cooking transitions, indoor air filtration in schools and clinics during smoke and pollution episodes, point-of-use water treatment, safe sanitation, and lead-source remediation — deliver protection within months rather than decades. The [JMP report](#) shows the scale of the water gap: 2.1 billion people without safely managed drinking water. Because climate extremes raise the risk of contamination, water-safety planning — from source protection to storage — should be built into climate adaptation plans from the start.

12.4 Health systems and workplaces

Health systems are the last line of absorptive capacity. Hospitals and clinics need continuous power and cooling; they need staff trained to recognise heat illness and pollution-related acute events; and they need surveillance that links exposures to outcomes so that early signals are not lost. Workplaces are the second front: the [ILO](#) shows that 2.4 billion workers are exposed to excessive heat, and its recommendations — heat-stress standards, scheduling and rest, shade, water, and protective equipment, enforced and extended to informal workers — are inexpensive relative to the injuries, deaths, and lost output they address. Social protection is the financial counterpart: transfers and insurance triggered by heat or disaster let households absorb a shock without selling assets.

12.5 The return on protection

The best-known estimate of aggregate returns is that of the [Global Commission on Adaptation](#), which found that investing US\$1.8 trillion globally in five areas — early warning, climate-resilient infrastructure, dryland agriculture, mangrove protection, and water-resources resilience — from 2020 to 2030 could generate US\$7.1 trillion in net benefits, with benefit-cost ratios of 2:1 to 10:1 and in some cases higher. The ratio of about four to one excludes the co-benefits from reduced pollution exposure that many of the measures also deliver.

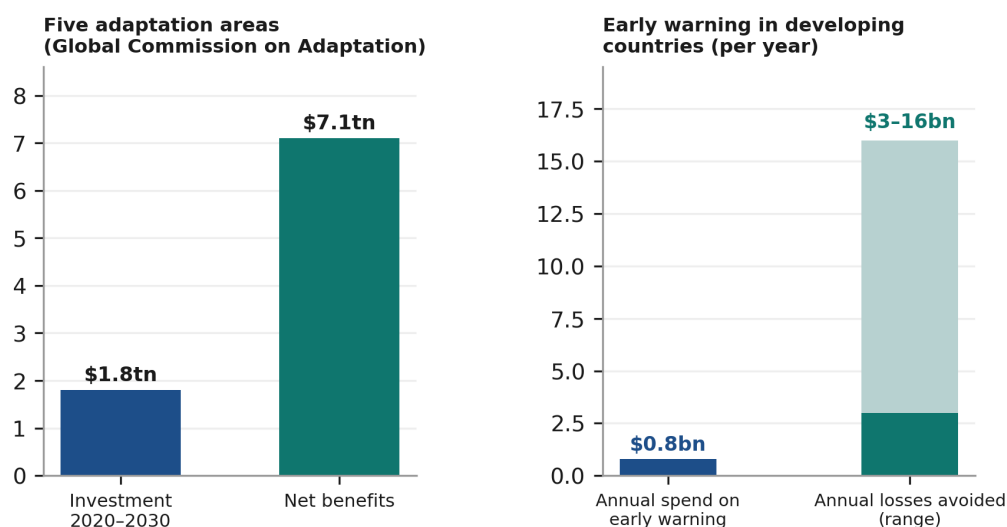


Figure 18. Returns on adaptation investment. Left: US\$1.8 trillion invested in five areas over 2020–2030 is estimated to yield US\$7.1 trillion in net benefits. Right: US\$0.8 billion a year on early warning in developing countries is estimated to avoid US\$3–16 billion a year of losses.

Source: [Global Commission on Adaptation, Adapt Now \(2019\)](#); [UN Secretary-General remarks \(2022\)](#) and [UN-Water](#). Estimates are the Commission's.

13 Pillar Three: Strengthen Systems and Ecosystems

The third pillar rebuilds the buffers. Ecosystems, infrastructure, and information systems determine how much of a shock reaches people, and they are the cheapest form of resilience where they still exist.

13.1 Nature-based buffers

Mangroves, wetlands, forests, and soils provide protection that engineered substitutes can match only at great cost. The [mangrove research](#) quantifies flood-protection benefits above US\$65 billion a year and 15 million fewer people flooded; the Global Commission on Adaptation named mangrove protection as one of its five highest-return investment areas. Wetlands filter nutrients and slow floodwater; urban trees and green space lower local temperatures and filter some particles; soil carbon and water retention buffer drought. Each is also a pollution-control service, which is why the nature-based pillar belongs in the same strategy as the first two rather than in a separate conservation budget. The principal risk is treating restoration as one-off planting rather than as protection of whole functioning systems.

13.2 Resilient infrastructure and energy

Every protection measure in Pillar Two — cooling, clinics, water treatment, warning systems — depends on reliable power and communications. Grid resilience is therefore a survivability issue, not only an economic one. Distributed generation and storage allow critical facilities to ride through outages; decentralised systems can supply clinics, water pumps, and cooling centres where grids are weak. A general principle of resilient design — and one reason the Global Commission on Adaptation named resilient infrastructure among its five investment areas — is that building resilience in at the design stage is cheaper than retrofitting after failure. For interacting threats, the key design criterion is whether a facility can keep working during the compound event — a heatwave with smoke, a flood with contamination — rather than during the single hazard it was designed for.

13.3 Circular systems and waste

Waste is the systems-level expression of the chemicals and plastics problem. Where collection is absent, waste is burned or dumped, producing particle and toxic emissions and blocking drainage; where plastic production grows unchecked, the burden of pollution and emissions grows with it. Circular systems — design for reuse and repair, extended producer responsibility, reliable collection and sorting, and safe disposal — reduce both the demand for fossil feedstock and the flow of pollutants. The point for strategy is that waste infrastructure is part of climate and pollution resilience, and that it is financed locally while the benefits are shared globally.

13.4 Data, monitoring, and compound-risk analysis

Systems cannot be managed that cannot be seen. Existing monitoring is organised by hazard and agency, so compound events appear in the data only after the fact. A resilience data layer would combine meteorological, air-quality, hydrological, and health data at city and district scale; would report compound indices — heat with ozone and smoke, flood with water contamination — in near real time; and would be open enough to let health systems and employers act on it. Models of the kind sketched in Section 2 can then be calibrated against observed outcomes. The Lancet Countdown and the WMO's annual state-of-

climate reporting are models of what indicator-based monitoring can achieve; the missing step is to extend them to compound exposures and to place them in public decision cycles.

Table 6. Synergies and trade-offs to manage

Measure	Synergy	Trade-off or risk	How to manage it
Cleaner air through sulphur cuts	Large, immediate health gains	Loss of aerosol cooling (ACP)	Pair with faster CO ₂ and methane cuts
Air-conditioning	Reduces heat deaths	Power demand; refrigerant leakage	Efficiency; Kigali; clean power; passive cooling
Biomass cookstoves	Cut fuel use and smoke if clean-burning	Residual particle emissions	Prioritise clean fuels and electricity
Hard flood defences	Reduce flood losses	Cost; loss of natural buffers	Combine with mangroves and wetlands
Early warning	Cuts damage ≈30%	Fails without last-mile delivery	Community protocols; multi-hazard design

H Heuristics analysis drawing on the evidence cited in Sections 5–13.

14 Finance and Governance: The Enabling Layer

The measures in Sections 11–13 are known and in most cases affordable. What separates them from deployment is finance that reaches the right places and governance that connects what is currently separate. Both are lagging the evidence.

14.1 The adaptation finance gap

The scale of the shortfall is documented in the [UNEP Adaptation Gap Report 2025](#), "Running on Empty". Using modelled costs, developing countries need about US\$310 billion a year for adaptation by 2035; extrapolating from their national plans raises the figure to about US\$365 billion. International public adaptation finance flows were about US\$26 billion in 2023, down from US\$28 billion in 2022, so needs are 12 to 14 times current flows and the gap is US\$284–339 billion a year. The Glasgow goal of doubling adaptation finance from 2019 levels to about US\$40 billion by 2025 will not be met if current trends continue. In 2022–2023 debt instruments made up an average of 58 percent of international public adaptation finance even though 70 percent was concessional — a pattern that adds to the debt burden of countries already constrained.

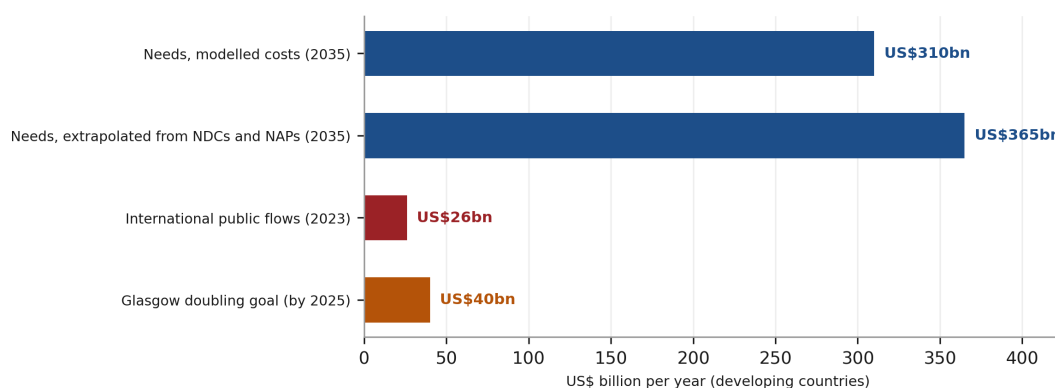


Figure 19. The adaptation finance gap. Developing-country adaptation needs of US\$310–365 billion a year by 2035 are 12 to 14 times current international public flows of about US\$26 billion (2023); the Glasgow goal of about US\$40 billion by 2025 is also unlikely to be met.

Source: [UNEP Adaptation Gap Report 2025](#).

The newer multilateral commitments narrow the gap only partly. The New Collective Quantified Goal agreed at [COP29](#) calls for at least US\$300 billion a year by 2035 for climate action in developing countries — a floor the Adaptation Gap Report judges insufficient. The [COP30 outcome in Belém](#) called for tripling adaptation finance by 2035, but the wording was hortatory rather than binding, the baseline year was dropped, and developing countries had pressed unsuccessfully for 2030. Negotiators also finalised a package of about 59–60 indicators for the Global Goal on Adaptation, though the final list was shortened and weakened compared with the technical experts' draft.

14.2 Subsidies, debt, and the cost of capital

Three structural features of the financial system work against resilience. First, fossil-fuel subsidies: the [Lancet Countdown 2025](#) reports that governments spent an estimated US\$956 billion on them in 2023, and

that fifteen countries accounting for more than 90 percent of global CO₂ emissions spent more on those subsidies than on their national health budgets. Redirecting even a fraction would fund much of the adaptation gap. Second, debt: [UNCTAD](#) documents record levels of developing-country public debt, which limits fiscal space for resilience before a shock and recovery after one. Third, the cost of capital: for clean-power projects in many developing countries, financing costs are a larger part of total cost than in advanced economies, which — as the IRENA 2024 data on solar's slight cost increase suggests — can offset technology cost declines. Lowering the cost of capital through guarantees, blended finance, and multilateral lending is therefore a resilience policy, not only a development one.

14.3 Governance: lessons from what has worked

The international architecture on these issues has strengths and gaps. The Montreal Protocol, adopted in 1987, is the clearest success: a defined set of substances, binding phase-out schedules, a financial mechanism, and available substitutes. The result is that stratospheric ozone is one of only two planetary boundaries still within the safe zone, and the Kigali Amendment extended the same model to hydrofluorocarbons. The Paris Agreement sets temperature goals through nationally determined contributions but has no comparable compliance mechanism, and the Emissions Gap Report shows the resulting shortfall. The Global Methane Pledge and the Global Framework on Chemicals are newer and largely voluntary; the plastics negotiations are deadlocked.

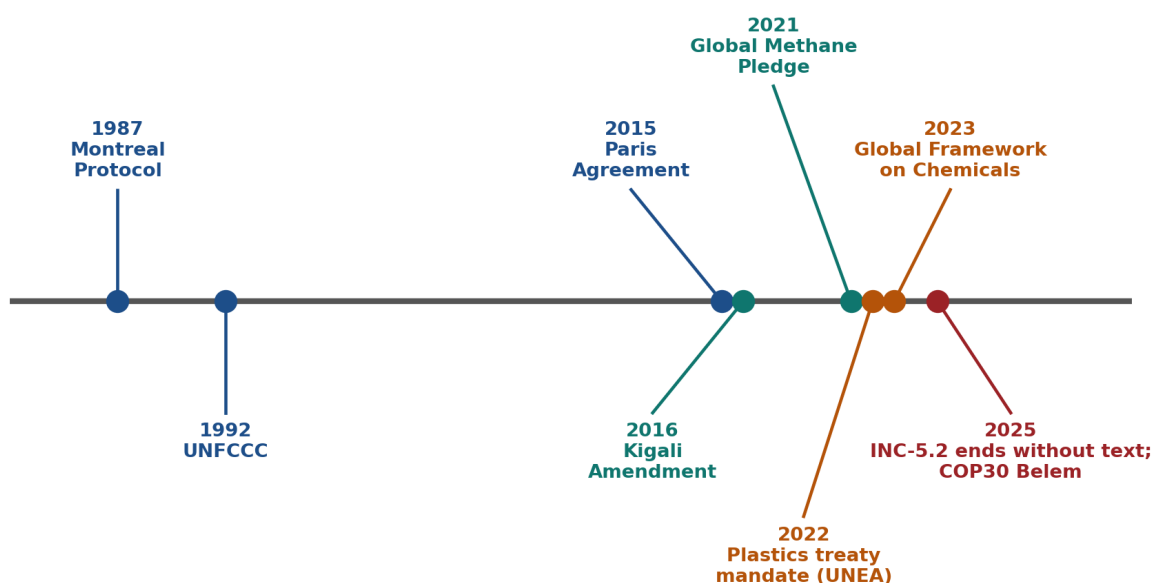


Figure 20. *The architecture of agreements. The ozone and hydrofluorocarbon regimes (blue and teal) combine binding obligations with finance; newer climate, methane, chemicals, and plastics instruments are more recent, more voluntary, or unfinished.*

Source: H Heuristics compilation; see [UNEP Ozone Secretariat](#), [Global Methane Pledge](#), [INC-5.2](#), [INC-5.3](#), and [COP30](#).

Table 7. Status of the main international instruments relevant to interacting threats

Instrument	Scope	Status	Key gap
Montreal Protocol / Kigali	Ozone-depleting substances; HFCs	Ozone boundary within safe zone (PHC); Kigali avoids up to 0.5 °C (CCAC)	Energy efficiency of cooling
Paris Agreement / NDCs	Greenhouse gases	2.3–2.5 °C with new NDCs; ≈2.8 °C on current policies	Compliance; ambition gap
Global Methane Pledge	Methane	Voluntary 30% cut by 2030	Verification; enforcement
COP30 adaptation outcome	Adaptation finance	Call to triple finance by 2035; baseline dropped	Binding targets; baseline
Plastics treaty (INC)	Plastic pollution	Deadlocked; new chair elected Feb 2026	Production limits; chemicals
Global Framework on Chemicals	Chemicals and waste	Adopted 2023; largely voluntary	Binding obligations; finance

Status as of October 2026 according to the cited sources; check official sites for updates.

14.4 Recommendations for finance and governance

- **Fund double-duty first.** Multilateral and national budgets should rank measures by the number of threats each reduces (Table 5) and report health and avoided-damage benefits alongside emissions.
- **Shift adaptation finance toward grants and concessional terms.** With debt instruments at 58 percent of international public adaptation flows, more of the money should not add to the debt of the countries it is meant to help.
- **Redirect subsidies.** Phase down fossil-fuel subsidies and recycle a defined share into clean energy, early warning, and health-system resilience.
- **Integrate plans.** National climate, clean-air, water, and chemical plans should share targets, monitoring, and budgets, and National Adaptation Plans should include compound-risk assessment.
- **Complete the unfinished treaties.** Seek a plastics agreement with production and chemical provisions; meanwhile use national and regional measures.

15 Roadmap and Monitoring, 2026–2050

A strategy without a schedule and a scoreboard is a statement of intent. This section sets out a three-phase roadmap and a monitoring dashboard drawn from indicators that already exist.

15.1 A three-phase roadmap

The roadmap has three phases. **Build (2026–2030)** is the cheapest window to create capacity: deploy Tier 1 measures at scale, finish the early-warning build-out, adopt integrated clean-air and climate plans, and fix the finance architecture. **Scale (2030–2040)** extends protection and source control across all high-exposure regions, restores and protects ecosystem buffers, and completes the chemicals and plastics regimes. **Sustain and adapt (2040–2050)** maintains and upgrades the system through the period in which interacting stress is expected to be greatest, and adjusts as observations accumulate. The phases correspond to the danger window in Figure 2: the investment that matters most is the investment made before the crossing.

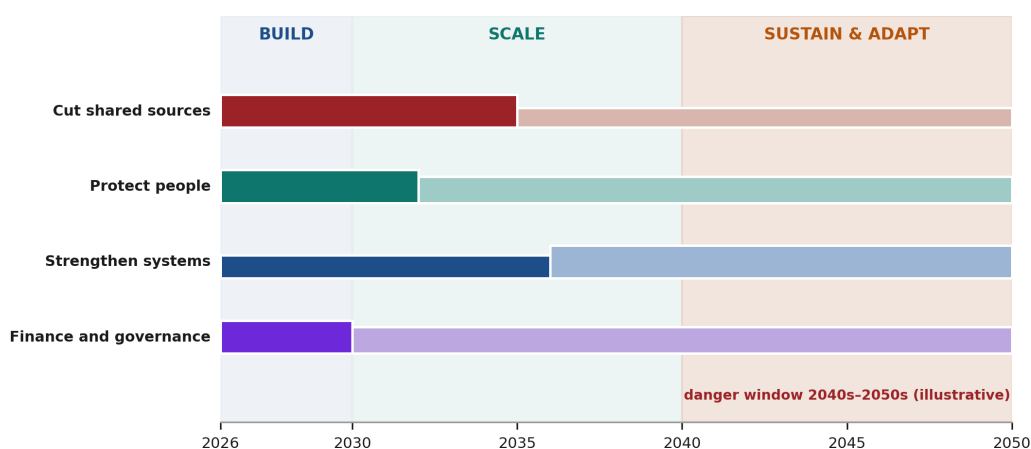


Figure 21. Conceptual roadmap, 2026–2050. Source control, protection, systems, and enabling-layer streams are front-loaded in the Build phase, extended at scale in the following decade, and sustained through the illustrative danger window of the 2040s and 2050s.

Source: H Heuristics framework. Conceptual; timings are indicative.

Table 8. Roadmap milestones

Phase	Source control	Protection	Systems and enabling layer
Build 2026–2030	Emissions on a path to about 25% (2 °C) or 40% (1.5 °C) below 2019 by 2030 (UNEP); 30% methane cut (GMP); clean-cooking acceleration	Multi-hazard early warning for all at risk; heat action plans in major cities; workplace heat standards (ILO)	Integrated clean-air and climate plans; compound-risk monitoring; grant-heavy adaptation finance
Scale 2030–2040	Power systems largely clean; HFC phase-down on schedule; chemical-of-concern restrictions	Universal safe water and clean cooking; adaptive social protection; adaptation finance tripled by 2035 (COP30)	Mangrove and wetland protection at scale; resilient grids; plastics regime in force
Sustain 2040–2050	Residual fossil sources eliminated where feasible	Adjust standards as observations accumulate; maintain cooling and health capacity	Regular reassessment of boundaries and indicators; continuous learning

Milestones that cite a source come from that source's commitments or estimates; others are H Heuristics proposals.

15.2 A monitoring dashboard

The dashboard below uses indicators that are already published, so no new data system is needed to start. The point is to place them in public decision cycles — annual budget reviews, national planning, and international stocktakes — and to report them together so that compound risk is visible.

Table 9. Survivability dashboard: baseline indicators and direction of travel

Indicator	Baseline	Direction / reference	Source
Fossil CO ₂ emissions	38.1 Gt (2025)	Down; –25% / –40% vs 2019 by 2030 for 2 °C / 1.5 °C	GCB , UNEP
Population exposed above WHO PM _{2.5} guideline	99% (2022 database)	Down toward 5 µg/m ³ annual	WHO
Air-pollution deaths	7.9 million (2023)	Down	SoGA
Heat-related deaths	≈546,000 a year	Down	Lancet Countdown
Workers exposed to excessive heat	70.9% (2020)	Down, with standards extended	ILO
Safely managed drinking water	60% of people (2024)	Up; 2.1bn without	JMP
People without clean cooking	≈2 billion	Down to zero	IEA
Planetary boundaries transgressed	7 of 9 (2025)	Stop and reverse	PHC
Adaptation finance, developing countries	US\$26bn (2023)	Up to US\$310–365bn need by 2035; triple by 2035	UNEP AGR , COP30

Baselines are the latest values in the cited sources. Targets are stated only where they come from the cited source; otherwise the direction of travel is shown.

15.3 Risks to the strategy

Four risks deserve explicit attention. Policy reversal: the US withdrawal from the Paris Agreement already offsets a measurable fraction of recent progress in projected warming. Aerosol surprises: if aerosol cooling proves larger than central estimates, the climate benefits of air cleanup will be partly offset in the near term, raising the urgency of CO₂ and methane cuts. Finance shortfalls: with international adaptation finance at 7

to 8 percent of estimated need, the shortfall is the largest risk to Pillar Two. Data gaps: compound exposures are poorly measured, so true interaction effects may be larger or smaller than assumed.

15.4 What would change this analysis

The report's central claims are falsifiable, and it is useful to say what evidence would weaken them. If epidemiological studies show that heat and air pollution act sub-additively on mortality at realistic exposure levels, the interaction term in Figure 2 would shrink and the case for compound appraisal would weaken. If the aerosol effect is much larger than the 0.06–0.07 °C estimated for China's cuts, the sequencing advice in Section 11.6 would need to be strengthened. If the double-duty portfolio proves more costly than estimated in the cited sources, the ranking in Table 5 would change. The strategy is robust to such updates because its core components are justified on single-threat grounds as well.

16 Conclusion: Widening the Margin

The evidence of the 2020s does not support a story of imminent collapse, and it does not support complacency. It supports a narrower, more actionable conclusion: the margin of safety for human populations is narrowing faster than the sum of individual threats would suggest, the narrowing is concentrated in the places least able to afford it, and the response that would widen it is largely known.

The report began with a single question: what would it take to keep human populations safe through the middle of this century when climate change, pollution, and ecosystem degradation interact? The answer has four parts. First, understand the threats as coupled. Heat raises ozone and smoke; drought concentrates contaminants; ecosystems lose the capacity to buffer both; and cooling pollution, once removed, unmasks warming. Appraisals that count each threat separately understate risk and understate how soon load exceeds capacity.

Second, act first on the shared sources. Clean power is now the cheapest new generation in most markets; methane abatement is a fast, double-duty lever; clean cooking removes the largest household exposure; and the success of the Montreal Protocol shows that binding, financed, substitutable regimes work. Third, protect people directly and now. Early warning, heat action plans, clean air and water, workplace standards, and health and social-protection systems are inexpensive relative to the losses they avert, and they pay off whether or not the worst climate outcomes materialise. Fourth, rebuild the buffers and the enabling layer: protect mangroves and wetlands, harden power and water systems, close the finance gap, redirect subsidies, and connect the data.

Five priorities for the next five years

- **Adopt the double-duty test** in climate, health, environment, and finance budgets so that measures advancing several goals are funded first.
- **Build multi-hazard early warning and heat action plans** in every high-exposure city and district, with last-mile delivery and clear protocols.
- **Accelerate clean power, methane abatement, and clean cooking** — the Tier 1 measures — as joint climate and clean-air programmes.
- **Protect and restore ecosystem buffers** — mangroves, wetlands, forests, and soils — as resilience infrastructure, with durable governance.
- **Close the finance and governance gaps:** grants-heavy adaptation finance, subsidy reform, and a plastics and chemicals regime that covers production.

The window is open but not indefinite. The investments that matter most are the ones made before the crossing, when they are cheapest and the options are widest. The conclusion of this report is therefore a priority, not a prophecy: the task for the rest of this decade is to fund, connect, and aim a response whose components already exist, before the interacting threats outgrow the capacity of the institutions that must manage them.

Appendix A: Data Notes and Source Index

This appendix records how each figure was produced, what was excluded, and where every cited source can be found.

A.1 Figure provenance

Table A1. Figure provenance and type

Figure	Type	Notes
1 Framework	Conceptual	H Heuristics framework
2 Stress and capacity	Conceptual	Illustrative functional forms; indices arbitrary
3 CO ₂ and emissions	Data (rounded)	Decadal values rounded; 2024–2025 from the Global Carbon Budget
4 Warming	Data	WMO, Global Carbon Budget, UNEP Emissions Gap Report
5 Air-pollution deaths	Data / derived	State of Global Air 2025; “other” = total minus NCD
6 Scale of deaths	Data	Different years and methods; not additive
7 Interaction matrix	Conceptual	Qualitative H Heuristics assessment
8 Aerosol masking	Data	As reported in secondary coverage of multi-model studies
9 Wet-bulb thresholds	Data	Vecellio et al. 2022; young healthy adults, light activity
10 Workers exposed	Data	ILO 2024; 2020 estimates
11 Europe summer 2025	Data	Rapid attribution; not peer reviewed at publication
12 Water and food	Data	JMP 2025; CCAC summary of ozone-crop reanalysis
13 Planetary boundaries	Data	PIK / SRC 2025; P and C markers are H Heuristics classification
14 Concentration of burden	Data	“Nearly half” plotted as ≈50%
15, 21 Strategy and roadmap	Conceptual	H Heuristics frameworks
16–20 Cost, source control, returns, finance, timeline	Data	IRENA 2024; Beijing monitoring; GCA; UNEP Adaptation Gap

Data = published values plotted directly; Derived = simple arithmetic on published values; Conceptual = schematic, not a forecast.

A.2 Exclusions and caveats

- A reported figure of 154,000 wildfire-smoke deaths in 2024 could not be confirmed and is not used; the report uses the confirmed estimate of over 100,000 a year.
- A figure for the decline in solar PV costs since 2010 could not be confirmed against the 2024 IRENA report and is not used; the report uses the confirmed 2024 competitiveness and battery-cost figures.
- The Lancet Countdown 2025 report is summarised in secondary sources with differing figures for the rise in heat mortality since the 1990s; the report uses the WHO summary (23 percent) and the 546,000 annual average.

- Figures for pollution deaths (2019), air-pollution deaths (2023), and heat deaths (2012–2021) come from different studies, years, and methods and are not additive.
- The 2013 and 2022 Beijing values come from municipal monitoring as reported in the press; attribution to specific policies is contested.
- The Ahmedabad estimate is from a pilot before-and-after evaluation without a control group.
- Where secondary coverage of a primary source was used to confirm a number, the primary source should be consulted for exact definitions and uncertainty ranges.

A.3 Source index

- **Climate and carbon:** [Global Carbon Budget 2025](#); [WMO State of the Global Climate 2025](#) and [press release](#); [UNEP Emissions Gap Report 2025](#); [IPCC Sixth Assessment Report: Synthesis](#).
- **Air pollution and health:** [State of Global Air 2025](#); [Lancet Countdown 2025](#), [WHO summary](#), and [University of Sydney summary](#); [Lancet Commission on Pollution and Health update](#) and [news summary](#); [WHO ambient air quality fact sheet](#); [WHO household air pollution fact sheet](#); [WHO air-quality database announcement](#); [FMI wildfire-smoke estimate](#).
- **Heat, work, and attribution:** [Penn State wet-bulb research](#); [ILO, safety and health in a changing climate](#); [ILO on heat stress](#); [LSHTM / Imperial rapid analysis](#).
- **Water, food, and chemicals:** [WHO/UNICEF JMP 2025](#); [CCAC summary of ozone and crop yields](#); [UNICEF / Pure Earth on lead](#); [Lancet Countdown on Health and Plastics](#).
- **Planetary boundaries and ecosystems:** [Planetary Health Check 2025](#) and [site](#); [mangrove flood-protection research](#); [WEF Global Risks Report 2026](#) and [summary](#).
- **Pollution–climate interactions:** [UNEP/CCAC Global Methane Assessment](#); [Global Methane Pledge](#); [Kigali Amendment benefits](#); [Watson-Parris et al. 2025 \(ACP\)](#); [UNEP Ozone Secretariat](#); [Climate and Clean Air Coalition](#).
- **Solutions and cases:** [IRENA Renewable Power Generation Costs in 2024](#); [IEA clean cooking](#); [Beijing PM_{2.5} \(China Daily\)](#); [AQLI on China's air-quality action plan](#); [Ahmedabad Heat Action Plan evaluation](#); [Ashden profile](#).
- **Adaptation and finance:** [UNEP Adaptation Gap Report 2025](#); [Global Commission on Adaptation, Adapt Now](#) and [WRI release](#); [UN Secretary-General on Early Warnings for All](#); [UN-Water](#); [COP29 outcome](#); [COP30 outcomes](#); [UNCTAD, A World of Debt](#).
- **Plastics treaty:** [INC-5.2 explainer](#); [INC-5.3 chair election](#); [Mongabay, June 2026](#).