The Science Behind the Climate Emergency

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GLOSSARY

Acronyms

AR6 IPCC's Sixth Assessment cycle consists of one four part assessment report (AR6) with three Working Group Reports, and a Synthesis Report (SYR), and several special reports (SRs). AR6 is the most recent assessment published by the IPCC on climate change science, impacts, and mitigation strategies.

AR6 SR15 Special Report on Global Warming of 1.5°C by authors from the three working groups of the IPCC Sixth Assessment on the impacts of global warming of 1.5 degrees Celsius above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (published October 2018).

The first-order draft underwent expert review between 31 July–24 September 2017; the second-order draft underwent expert and government review between 8 January–25 February 2018; and the final draft underwent final review from 4 June–29 July 2018. The literature submission cut-off was on 1 November 2017.

AR6 SRCCL Special Report on Climate Change and Land by authors from the three working groups of the IPCC Sixth Assessment on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystem (published August 2019).

The first-order draft underwent expert review between 11 June–5 August 2018; the second-order draft underwent expert and government review between 19 November 2018–14 January 2019; and the final draft underwent final review from 29 April–19 June 2019. The literature submission cut-off was on 28 October 2018.

AR6 SROCC Special Report on the Ocean and Cryosphere in a Changing Climate by authors from the three working groups of the IPCC Sixth Assessment Report on how the ocean and cryosphere have and are expected to change with ongoing global warming, the risks and opportunities these changes bring to ecosystems and people, and mitigation, adaptation and governance options for reducing future risks (published September 2019).

The first-order draft underwent expert review between 4 May–29 June 2018; the second-order draft underwent expert and government review between 16 November 2018–11 January 2019; and the final draft underwent final review from 14 June–9 August 2019. The literature submission cut-off was on 15 October 2018.

AR6 SYR Synthesis Report of the IPCC Sixth Assessment (published March 2023). The IPCC panel approved the draft outline during its 52nd Session between 24–28 February 2020. This report underwent an extensive review and negotiation process with governments and observer organizations.

AR6 WG1 Working Group I Contribution to the IPCC Sixth Assessment Report on the physical science basis (published August 2021).

The first-order draft underwent expert review between 29 April–23 June 2019; the second-order draft underwent expert and government review between 2 March–5 June 2020; and the final draft underwent final review from 4 May–20 June 2021. The literature submission cut-off was on 31 January 2021.

AR6 WG2	Working Group II Contribution to the IPCC Sixth Assessment Report on impacts, adaptation, and vulnerability (published February 2022). The first-order draft underwent expert review between 18 October–13 December 2019; the second-order draft underwent expert and government review between 4 December 2020–29 January 2021; and the final draft underwent final review from 1 October–26 November 2021. The literature submission cut-off was on 1 November 2020.
AR6 WG3	Working Group III Contribution to the IPCC Sixth Assessment Report on mitigation strategies and its potentials (published April 2022). The first-order draft underwent expert review between 13 January–8 March 2020; the second-order draft underwent expert and government review between 18 January–14 March 2021; and the final draft underwent final review from 29 November 2021–30 January 2022. The literature submission cut-off was on 14 December 2020.
CH_4	Methane
CO_2	Carbon dioxide
GHG	Greenhouse gas
GWP	Global warming potential
HFCs	Hydrofluorocarbons
IACtHR	Inter-American Court of Human Rights
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and the Caribbean
LULUCF	Land use, land use change, and forestry
N_2O	Nitrous oxide
O_3	Tropospheric ozone
REDD+	Reducing emissions from deforestation and forest degradation in developing countries

Terms

1.5°C guardrail The scientific consensus is that limiting global temperature increases to a maximum of 1.5°C above pre-industrial levels is the only way to avoid the most severe impacts of climate change, slow self-perpetuating feedback loops, and avoid or at least delay irreversible tipping points. Keeping the limit of 1.5°C temperature rise within reach requires cutting both CO_2 and non-CO_2 pollutants, as well as protecting existing carbon sinks.

Afforestation The practice of planting new forests on lands that were previously unforested.

Carbon neutrality *See* net zero emissions. Can refer to net zero CO_2 or net zero GHG, which is sometimes referred to as climate neutrality. Carbon neutrality does not slow the rate of warming in the near term unless it includes substantial methane reduction.

Carbon sink Anything that absorbs more carbon dioxide than it emits (i.e., removes and stores carbon dioxide from the atmosphere). Examples of natural carbon sinks include oceans, forests, peat bogs, mangroves, seagrass beds, kelp forests, salt marshes and swamps.

Carbon source Anything that releases more carbon dioxide than it absorbs. Examples of carbon sources include emissions associated with fossil fuel extraction and combustion and deforestation.

Methane source Anything that releases more methane than it absorbs. Over a period of 20 years, methane is over 80 times stronger at warming the planet than CO_2. Therefore, sources of methane have a strong impact on the planet's temperature in the near term. Examples of sources of methane are gas venting in oil fields and leaks in gas pipelines, decomposition of organic waste in low-oxygen conditions, and enteric fermentation from cattle.

Intergovernmental Panel on Climate Change (IPCC) The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and endorsed by a UN General Assembly resolution in 1988. The IPCC prepares a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change and the social and economic impact of climate change. Since its inception, the IPCC has prepared six Assessment Reports. IPCC authors and reviewers are volunteers selected under an established process. The IPCC currently has 195 members. Reports undergo interactive review processes of commenting and revision before final publication. The Summary for Decisionmakers is negotiated by governments before publication. It is important to note that due to the established process the IPCC reports do not reflect the latest science. All IPCC reports undergo two stages of review. A First Order Draft is reviewed by experts. Following the expert review, authors develop a Second Order Draft based on the comments received. This draft then undergoes a second review by both governments and experts. Authors will prepare a Final Draft based on the comments received during the second review. The Final Draft is distributed to governments at the time of the final government review of the Summary for Policymakers. Note that the cut-off date for submitted literature is usually a month before the Second Order Draft review, which is usually at least a year before the final version is published. By the time of publication, the analysis is at least a year out of date. For the Synthesis Report, which integrates key findings from the three

	Working Group reports, the analysis is several years out of date, as it does not reflect new science since the publication of the Working Group reports.
Irrecoverable carbon	Carbon stored in natural systems that "are vulnerable to release from human activity and, if lost, could not be restored by 2050."[1]
Linear v. non-linear impacts	Linear impacts increase roughly in proportion to increases in warming, *i.e.*, they scale with warming: a bit more warming causes a bit more impact. Non-linear impacts are different: a bit more warming can trigger self-amplifying feedbacks that are disproportionate to the extra warming, and may also push regional or global climate systems across tipping points that result in a change of state. These changes may occur abruptly and can be irreversible, like stepping off a cliff. Note, for some tipping points that are triggered at a specific temperature, the impacts may play out over decades and even centuries. For example, once warming exceeds 1.6°C for multiple years, the Greenland Ice Sheet will be committed to irreversible melting. If all of Greenland melted, it would contribute 5–7 meters of sea level rise over centuries or millennia. Non-linear impacts such as tipping points are generally not well represented in climate models nor in economic models used to assess the risks of climate change. The *accelerating rate of warming* may trigger the tipping points earlier than expected.
Net zero emissions vs. Zero emissions	Net zero emissions are achieved when anthropogenic emissions of greenhouse gases are balanced by removals over a specified period. When multiple gases are involved, the quantification depends on the climate metric used (such as global warming potential, global temperature change potential) and on the time period specified. Conversely, "zero emissions" means no emission of GHGs, without the compensating carbon dioxide or GHG removal. Unlike net zero emissions, which only require that any emitted anthropogenic emissions are balanced by removing an equal quantity of anthropogenic greenhouse gases from the atmosphere, zero emissions require that no anthropogenic greenhouse gases are emitted at all.
Overshoot	Global warming that temporarily breaches 1.5°C above pre-industrial levels. Even with overshoot, some impacts could still be irreversible, even if global warming is reduced. IPCC AR6 defines global warming as the average global temperature over the preceding 10-year compared with pre-industrial conditions (1.20°C for 2014–2023[2]), whereas SR1.5 defined global warming "as the average of a 30-year period centered on the current year, assuming the recent rate of warming continues."[3] Annual global temperature, as opposed to the 10-year or 30-year average, is "more likely than not" to exceed 1.5°C for at least one year between 2023 and 2027 according to the UK Met Office.[4]
Paris Agreement	The Paris Agreement is an international treaty on climate change adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." It does this primarily by allowing parties to set their own "nationally determined contributions" to climate mitigation.

Proforestation	The practice of enabling continuous forest growth, preserving mature forests, and allowing forests to regenerate absent human intervention to achieve their full ecological potential of maximum carbon sequestration. Proforestation strategies include preventing timbering and active forest management.
Reforestation	The practice of repopulating an existing forest by planting new specimens.
Self-perpetuating feedbacks	Also referred to as "positive feedbacks" or "self-reinforcing feedbacks," they describe conditions where the outputs of a system are returned as amplified inputs in a circular cause-and-effect relationship. In the climate context, self-perpetuating feedbacks cause additional warming beyond the initial warming (e.g., loss of Arctic sea ice reduces reflectivity, which in turn increases warming, which then cause more sea ice to melt), creating a loop whereby the planet increasingly warms itself.
Short-lived climate pollutants (SLCPs), or "super pollutants"	SLCPs are non-CO_2 pollutants that have a relatively short atmospheric lifespan but are more powerful than CO_2 at warming the planet. SLCPs include **methane**, a powerful greenhouse gas; **tropospheric ozone**, a greenhouse gas and secondary pollutant formed by the interaction of sunlight with nitrogen oxides, volatile organic compounds, and methane; **hydrofluorocarbons**, powerful greenhouse gases that are non-ozone-depleting substitutes for chlorofluorocarbons and hydrochlorofluorocarbons; and **black carbon**, which is not a greenhouse gas but a powerful climate-warming aerosol and air pollutant. Nitrous oxide is a super pollutant but is not short lived.
Tipping point	A critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly. *See also*, "Linear vs. non-linear" impacts.
UN Framework Convention on Climate Change (UNFCCC)	The **United Nations Framework Convention on Climate Change** is a convention of 198 States formed in 1992 as a framework for international cooperation on addressing the global threat of climate change through mitigation and adaptation measures. The Paris Agreement was negotiated and implemented under its umbrella. Art. 2 of the UNFCCC states that "The ultimate objective … is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[5]

I. SUMMARY

Climate change poses an existential threat to humankind. The intertwined nature of climate change and human rights becomes apparent as we witness the adverse effects on various dimensions of human life. To address the climate emergency, we must slow down the rate of warming as much as possible as quickly as possible. Only a dual strategy to reduce both non-carbon dioxide super climate pollutants *and* carbon dioxide (CO_2) can keep global temperatures within safe limits and protect human rights for present and future generations.

The climate emergency is a challenge of *temperature, tipping points, and time*.

Temperature. *The temperature of Earth is too hot at today's 1.2°C of warming* above pre-industrial levels. Linear impacts already are imposing tremendous damage that violate human rights; and self-perpetuating feedback loops—where the Earth warms itself—will soon push the planet past a series of tipping points that impose abrupt non-linear impacts that are irreversible, catastrophic, and will cause massive human rights violations.[i] The rise in temperature is driven by both the escalating emissions of carbon dioxide and the emissions of non-carbon dioxide super climate pollutants, especially methane; the reduction in emissions of reflective air pollutants; the destruction of forests and carbon sinks; and the loss of the reflective capacity of Arctic snow and ice.

Tipping Points. *Tipping points are just ahead and will cause irreversible and potentially catastrophic impacts.* Study of the planet's history reveals that regional and global climate systems can shift states, sometimes abruptly. A recent assessment finds that exceeding 1.5 °C increases the likelihood of triggering or committing to six self-perpetuating climate tipping points.[6] The non-linear way in which these shifts occur makes them difficult to represent in climate models. Some abrupt system shifts are projected in climate models, with a cluster of six abrupt shifts between 1°C and 1.5°C of warming and another eleven between 1.5°C and 2°C,[7] as confirmed by two IPCC Special Reports.[8] The goal under the Paris Agreement is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."

Time. Without fast action to slow warming, *we are likely to exceed the 1.5°C guardrail by the end of the decade.*[9] The urgency of the climate crisis is evident as the window of opportunity to prevent massive and abrupt human rights violations is shrinking to the end of the decade.

Slowing down the rate of warming in the near term is paramount, and it requires immediate and focused action. Cutting super climate pollutants can avoid nearly four times more warming by 2050 than strategies targeting CO_2 alone and halve the rate of warming compared to a reference scenario with limited climate mitigation and when accounting for the reduction in reflective particles that mask warming as a result of decarbonization strategies that phase out fossil fuel use.[10] Previous studies have found that we can avoid up to 0.6°C of warming by 2050 (not accounting

[i] Linear impacts increase roughly in proportion to increases in warming, *i.e.*, they scale with warming: a bit more warming causes a bit more impact. Non-linear impacts are different: a bit more warming pushes the planet past a series of tipping points with impacts that are disproportionate to the extra warming. These abrupt non-linear impacts are like stepping off a cliff. Note, for some tipping points that are triggered at a specific temperature, the impacts may play out over decades and even centuries. This is expected to be the case, for example, with the Greenland Ice Sheet. The accelerating rate of warming may trigger the tipping points earlier than expected.

for unmasking) and keep the 1.5°C guardrail within reach with limited overshoot, but only by cutting the non-CO_2 super climate pollutants—methane (CH_4), hydrofluorocarbons (HFCs), tropospheric (or ground level) ozone (O_3), and black carbon aerosols. For comparison, aggressive decarbonization that reaches net zero CO_2 by 2050 could avoid about 0.2°C by 2050, not accounting for the unmasking that results as sulfates co-emitted with burning fossil fuels are reduced.[11]

There are solutions available for the Americas to tackle the climate emergency that will help keep a limit of 1.5°C temperature rise within reach, limit overshoot to the shortest time possible, and that will show other countries outside the region what they should do to protect the climate. Sector-specific actions to mitigate super climate pollutants, protect forests and other sinks, and decarbonize the energy system must be deployed quickly and at scale.

Climate change is a fast-moving problem that cannot be solved with slow-moving solutions. As Nobel Laureate Dr. Mario Molina stated, "Speed must become the key measure of all climate mitigation strategies: a speedy reduction of global warming before it leads to further, self-reinforcing climate change feedbacks and tipping points; a speedy deployment of mitigation actions and technologies; and getting this all up to scale in a speedy manner. And let us be clear: By 'speed,' we mean measures—including regulatory ones—that can begin within two-to-three years, be substantially implemented in five-to-10 years, and produce a climate response within the next decade or two."[12]

II. THE GLOBAL CLIMATE EMERGENCY

A. Temperature, Tipping Points, and Time

The climate emergency is about temperature, tipping points, and time. The Earth is already too hot at today's 1.2°C of observed warming above the pre-industrial level,[13] with linear impacts currently imposing tremendous damage; and there is too little time before self-perpetuating feedback loops—where the Earth warms itself—push the planet past a series of tipping points that impose abrupt non-linear impacts that are irreversible and catastrophic. The climate of the Earth will push millions and eventually billions of people out of the corridor of life where civilization has evolved.[14] The Secretary General of the UN has categorized the climate emergency as an existential threat for humankind.[15]

Scientific evidence shows that we are already in a state of planetary emergency, where both the risk and urgency of the emergency are acute.[16] The current climate impacts at 1.2°C of warming are largely linear impacts that worsen proportionally with warming, but with emerging regional "non-linear" surprises.[17] These include more frequent and more severe weather extremes[18] like record-breaking heatwaves,[19] droughts,[20] fires,[21] rainfall,[22] and flooding.[23]

At 1.2°C, we're already in the temperature range where we may be triggering non-linear, abrupt and potentially irreversible tipping points. Exceeding 1.5°C increases the risk of triggering a cluster of six[24] to 11[25] self-perpetuating climate tipping points that are anticipated between 1.5°C and 2°C, including the loss of the Greenland Ice Sheet and the West Antarctic Ice Sheet.[26] Together, the ice sheets of Greenland and West Antarctica would lock in 10 meters of sea level rise over the coming centuries if their approaching tipping thresholds are crossed.[27]

There is scientific evidence that the Greenland Ice Sheet already is nearing a tipping point, suggesting “substantially enhanced melting in the near future.”[28] The melting Greenland Ice Sheet is already the largest single contributor to the rate of global sea level rise.[29] When all of Greenland melts, it would contribute 5–7 meters of sea level rise.[30] While the complete loss of the Greenland Ice Sheet may take millennia, the rate of future melt, and hence rate of sea level rise, depends “strongly on the magnitude and duration of the temperature overshoot.”[31] On the opposite end of the planet, significant warming of ocean waters around West Antarctica will be locked in at 1.5°C of warming, and will likely accelerate the collapse of the ice sheet.[32]

In addition, self-perpetuating feedback loops are further accelerating warming. Loss of the Arctic’s reflective snow and ice, which is being replaced with darker ocean and land that absorbs rather than reflects incoming solar radiation, contributing to “Arctic amplification,” where the Arctic is warming at four times the global average, further accelerating global warming.[33] The Arctic could be sea ice free in September within 10 to 15 years.[34] In the extreme case when all Arctic sea ice is lost for the sunlit months, as could happen as early as mid-century,[35] it will add the equivalent of 25 years of current climate emissions.[36] Loss of land-based snow and ice could double this.[37] A similar “regime shift” may be underway in the Antarctic,[38] given the record low sea ice extents observed in the past three years (2022 to 2024).[39]

Another feedback loop is the destruction of the Amazon forest, which is shifting from a “sink” that pulls carbon dioxide out of the atmosphere and stores it safely in its biomass and soil, to a “source” of carbon dioxide emissions when trees are cut or burned.[40] There is a risk that when 20 to 25% of the Amazon is destroyed, the forest will enter a death spiral and turn into a savanna with devastating impacts on the region and the world.[41] If all of the carbon stored in the Amazon were released, the planet could warm by an additional 0.25°C.[42]

B. The Carbon Budget

Another way of looking at the climate challenge is to consider the carbon budget that scientists calculate remains before we crash through the 1.5°C guardrail. The most recent update integrating AR6 data reduced the carbon budget to 250 billion tonnes of CO_2 for a 50:50 chance of keeping warming to 1.5°C, from the beginning of 2023, and assumes that between 2020–2050 methane emissions are cut in half, nitrous oxide emissions are reduced 25%, and sulfate emissions are reduced by 77%.[43] Failing to meet the methane and nitrous oxide reductions would reduce the remaining carbon budget. Inclusion of sulfate reductions that would be expected to occur alongside reduced use of fossil fuels accounts for unmasking. While this budget includes some carbon-climate feedbacks,[44] poorly constrained and non-linear feedbacks[45] (including permafrost emissions due to limited process models) and tipping points are not accounted for directly but could be considered based on choice of likelihood for meeting target temperature (with a higher percentage hedging against these risks).[46]

At current emission levels, this approximately 250 $GtCO_2$ budget would run out in mid-2029.[47] According to Carbon Brief, for a high-emission country such as the UK, its share of the carbon budget will run out in 2 years.

C. Existential Threat from Tomorrow's 1.5°C to 2°C

Beyond 1.5°C, many climate impacts are predicted to become non-linear, abrupt, irreversible, and catastrophic.[48] Surpassing tipping points will trigger self-perpetuating feedback loops with the risk of a "hothouse" climate state where billions of people live in places that become too hot for human habitation.[49] The "hothouse climate state" resembles "planetary states that were last seen several millions of years ago" and would make much of the globe inhospitable to humans and many species.[50] The 1.5°C guardrail aims to keep warming to a "safe and just corridor" of life to ensure a stable climate system and reducing exposure to risks.[51] The Earth Commission, a global team of scientists, have begun to quantify these safe and just Earth system boundaries, which include limiting warming to 1.5°C to remain within safe boundaries to avoid climate tipping points.[52] The IPCC confirmed the critical importance of maintaining the temperature limit to 1.5°C and estimated that under current trends, this temperature guardrail would be passed by the early 2030s.[53] However, with continuing record climate emissions the rate of warming is predicted to increase from 0.2°C per decade to 0.25–0.32°C per decade over the next 25 years.[54] In this case, temperatures "will reach 1.5°C in the 2020s and 2°C before 2050."[55]

The window for effective mitigation to remain under 1.5°C, slow self-perpetuating feedbacks, and avoid or at least delay irreversible tipping points is quickly shrinking to the end of the decade.[56]

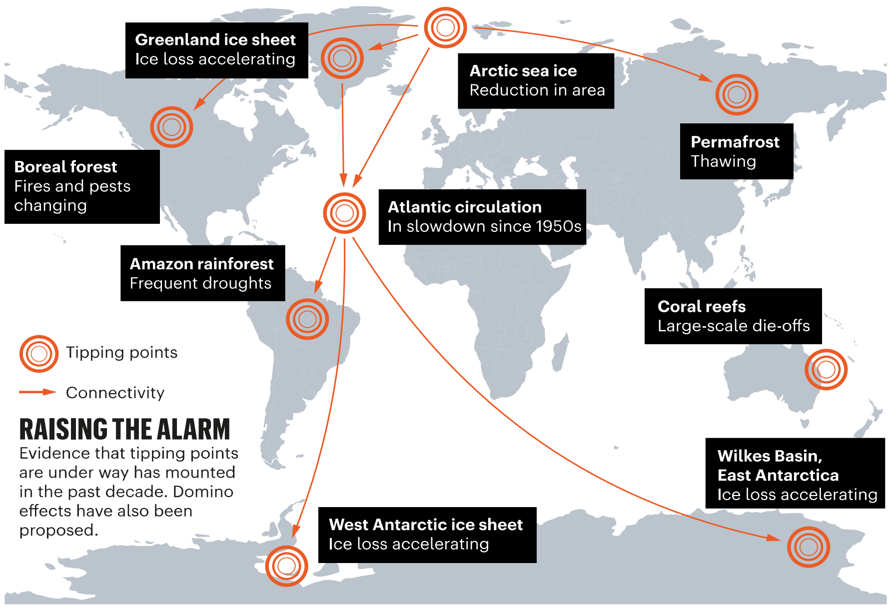
Between 1.5°C and 2°C, a cluster of six[57] to 11[58] tipping points or abrupt shifts are predicted to be triggered, including loss of Arctic summer sea ice, loss of the West Antarctic and Greenland Ice Sheets, boreal forest ecosystem shifts, permafrost carbon release, and coral reef loss. Current levels of warming may already be enough to tip the Greenland and West Antarctic Ice Sheets, coral reefs, and cause abrupt thaw of regional permafrost.[59] At 2°C of warming, the risks of triggering "relatively large, abrupt and sometimes irreversible" tipping points becomes high, according to the IPCC's 6th Assessment Report (AR6).[60] Other undiscovered tipping points may exist, as current models are limited and often omit processes, such as those related to permafrost thaw and other biogeochemical feedbacks.[61]

In addition, domino-like interactions among these tipping points are projected to lower thresholds and increase the risk of triggering a global cascade of tipping points (

Figure II-1).[62] For example, the fates of the Greenland and West Antarctica Ice Sheets are linked: tipping of either ice sheet could tip the other,[63] and could also trigger a shutdown of the Atlantic meridional overturning circulation (AMOC),[64] a branch of the global ocean conveyor belt. The addition of freshwater from melting ice sheets in both Greenland and West Antarctica changes the mechanics of the conveyor belt,[65] which could force the already-weakening[66] AMOC to shut off.[67] Given the AMOC's role in circulating life-sustaining water, warmth, and nutrients in the Atlantic,[68] a complete shutdown would result in catastrophic impacts,[69] occurring at speeds beyond societies' capacities to adapt.[70]

In sum, the cluster of interacting tipping points presents extreme risks to human systems, including the risks of financial and societal destabilization and increased potential for conflict and mass migrations, with grave and irreversible consequences for human rights.[71]

Figure II-1. Climate Tipping Points



Source: Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE, 575(7784): 592–595.

III. ADDRESSING THE CLIMATE EMERGENCY

Successfully addressing the climate emergency *now* requires that States select and implement fast mitigation solutions that provide the most avoided warming to prevent surpassing 1.5°C;[72] slow self-perpetuating feedbacks and avoid tipping points that worsen climate impacts;[73] and protect the most vulnerable people and ecosystems[74] from heat, drought, flooding, and other extremes that will dramatically worsen with every increment of additional warming.[75]

A. The Marathon: Decarbonization Is Critical But Cannot Slow Near-Term Warming Nor Prevent Non-Linear Abrupt Impacts

Decarbonizing the energy system and achieving net-zero emissions is critical for stabilizing the climate and keeping temperatures below 1.5°C by the end of this century. However, even if all CO_2 emissions were reduced to zero today, the planet will not return to pre-industrial levels because a significant percent of CO_2 lingers in the atmosphere for centuries,[76] and near-term warming could be accelerated due to unmasking of warming as sulfate aerosols are reduced unless accompanied by strong and sustained reductions in super climate pollutants.

The IPCC's AR6 and more recent studies confirm that cutting fossil fuel emissions—the main source of CO_2—by decarbonizing the energy system, in isolation, actually accelerates warming in the next decade.[77] Burning fossil fuels emits not only CO_2 but also sulfate aerosols, which act to cool the climate. These cooling sulfates fall out of the atmosphere fast when fossil fuel use ceases, while much of the CO_2 lasts much longer, thus leading to relatively higher warming for the first decade or two.[78]

The marathon to decarbonize in the longer term is essential for the stability of the climate system, but the sprint to reduce super pollutants must occur immediately to reduce the likelihood of exceeding 1.5°C,[79] prevent human rights violations from the worst of climate impacts, and build resilience.

B. The Sprint: Cutting Super Climate Pollutants and Implementing Nature-Based Solutions Can Quickly Reduce Near-Term Warming

Cutting super climate pollutants can avoid nearly four times more warming by 2050 than strategies targeting CO_2 alone compared to a reference scenario with limited climate mitigation and when accounting for the reduction in reflective particles that mask warming as a result of decarbonization strategies that phase out fossil fuel use.[80] Previous studies have found that fast cuts to the short-lived climate pollutants (SLCPs), or super climate pollutants, could avoid up to 0.6°C of warming by 2050 and up to 1.2°C by 2100.[81] This would reduce projected warming in the Arctic by two-thirds, the rate of global warming by half, and avoid or at least delay self-perpetuating feedbacks and irreversible tipping points.[82] Progress in reducing growth in HFC emissions through agreement of the Kigali Amendment to the Montreal Protocol agreed in 2016 mean that we are on track to achieve about 0.1°C of the avoided warming by 2050. Solutions that reduce SLCPs also reduce food waste, energy waste, and air pollution.[83]

According to the IPCC, SLCPs account for around half of today's global warming, contributing to rising sea levels and more frequent and extreme climatic events, and harming human health, food security, and biodiversity.[84]

The SLCPs are methane (CH_4), black carbon (soot), tropospheric ozone (O_3, "smog"), and hydrofluorocarbons (HFCs, or refrigerants).[85] These SLCPs are tens to thousands of times more powerful than CO_2 at warming the planet, but they are short-lived—meaning that they remain in the atmosphere for only a few days to a few years, whereas CO_2 can remain for hundreds of years. Reducing these pollutants provides almost immediate benefits to climate change and human health.

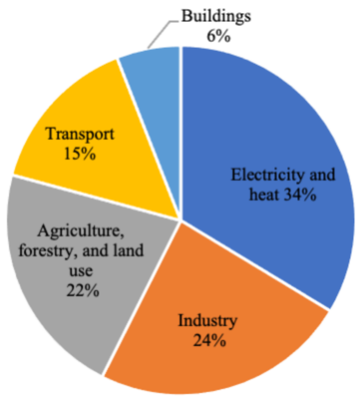
Other fast mitigation strategies to help reach near-term and long-term climate targets include protecting and expanding nature-based "carbon sinks," which are natural features like oceans or forests that absorb and store carbon from the atmosphere.[86] These nature-based solutions also provide many co-benefits to people and ecosystems,[87] such as improving water storage, providing food and livelihoods, and improving air quality.

IV. THE HUMAN CAUSES OF CLIMATE CHANGE

A. Global Causes of Climate Change

Of the current 1.2°C of warming since pre-industrial levels,[88] the emissions of CO_2 and other greenhouse gases (GHGs) from human activities are responsible for approximately 1.14°C.[89] Global GHG emissions continue to rise, with the average annual GHG emissions reaching the highest records in the last decade.[90] The continuing emissions have pushed the atmospheric concentrations of GHGs to new records every year, including for CO_2, CH_4, and N_2O.[91]

Figure IV-1. Major Sources of Global GHG Emissions



Major sources of global GHG emissions are from the energy sector (34%), industry (24%), agriculture, forestry, and land use (AFOLU) (22%), transport (15%), and buildings (6%). *Source:* Dhakal S., Minx J. C., Toth F. L., Abdel-Aziz A., Figueroa Meza M. J., Hubacek K., Jonckheere I. G. C., Kim Y.-G., Nemet G. F., Pachauri S., Tan X. C., & Wiedmann T. (2022) *Chapter 2: Emissions Trends and Drivers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., *et al.* (eds.).

With respect to the super climate pollutants, 50–65% of global methane emissions come from anthropogenic sources in three main sectors: energy production (35%),[92] agriculture (40%),[93] and waste (20%),[94] with biomass burning and biofuels as additional sources.[95]

HFCs have increased globally by 18% from 2016 to 2020.[96] More than 75% of total HFC emissions come from stationary air conditioners and industrial/commercial refrigerators.[97]

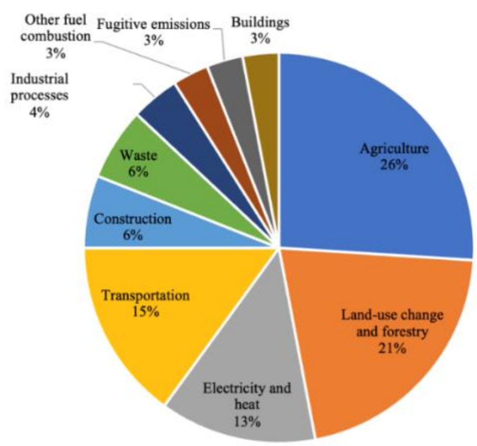
Black carbon is not a greenhouse gas, but a powerful climate-warming aerosol that is a component of fine particulate matter (specifically, $PM_{2.5}$) that enters the atmosphere through the incomplete combustion of fossil fuels, as well as biofuels and biomass.[98] It has a global warming impact up to 1,500 times stronger than CO_2 per unit of mass.[99] Black carbon is challenging to quantify because of limited global-scale observations.[100]

Tropospheric ozone is not directly emitted but is a product of atmospheric reactions with precursor pollutants, notably methane and other volatile organic compounds and nitrogen oxides. Global tropospheric ozone levels increased by less than 40% from pre-industrial to 2005, driven by increases in precursor pollutants.[101] In addition to contributing to warming, it is responsible for millions of premature deaths,[102] billions of dollars' worth of crop losses annually,[103] and weakening of carbon sinks.[104]

B. Causes of Climate Change in the Americas

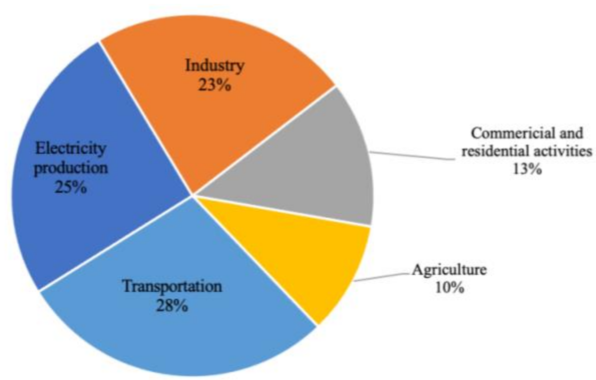
Since 1990, Latin America and the Caribbean (LAC) have contributed 11% of global GHG emissions growth[105] and in 2019, LAC contributed merely 8.1% of global GHG emissions.[106] The energy sector accounts for 43% of emissions in LAC, which is below the world average of 74%; while agriculture and land use and forestry combined account for 45% of emissions, compared to the world average of 14%.[107] The land-use sector also plays a crucial role in the region's GHG emissions. Deforestation, primarily driven by agricultural expansion, is a major source.[108] Additionally, the industrial sector contributes to the region's emissions, particularly through the production of cement, steel, and chemicals.[109]

Figure IV-2. Major Sources of GHG Emissions in LAC



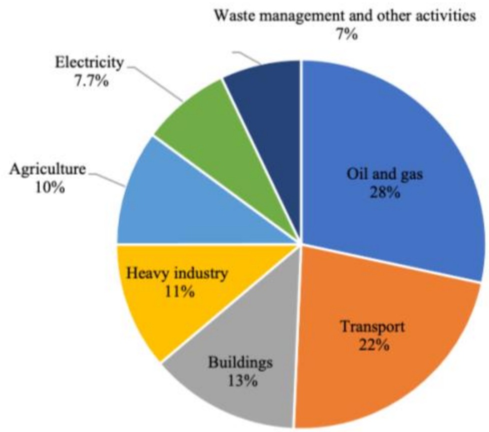
Major sources of GHG emissions in LAC are agriculture (26%), land-use change and forestry (21%), transportation (15%), electricity (13%), waste and construction (12%), with the remaining emissions from other activities such as industrial processes and fugitive emissions (13%). *Source:* World Bank Group (2022) A ROADMAP FOR CLIMATE ACTION IN LATIN AMERICA AND THE CARIBBEAN 2021-2025, 3 (Figure 2).

Figure IV-3. Major Sources of GHG Emissions in Canada



Major sources of GHG emissions in Canada are oil and gas (28%), transport (22%), buildings (13%), heavy industry (11%), agriculture (10%), and electricity (7.7%), with the remaining emissions from waste management and other activities (7%). *Source:* Environment and Climate Change Canada (2020) CANADA'S NATIONAL REPORT ON BLACK CARBON AND METHANE CANADA'S THIRD BIENNIAL REPORT TO THE ARCTIC COUNCIL, Figure ES-6.

Figure IV-4. Major Sources of GHG Emissions in the U.S.



Major sources of GHG emissions in the U.S. are transportation (28%), electricity production (25%), industry (23%), commercial and residential activities (13%), and agriculture (10%). *Source:* United States Environmental Protection Agency (28 April 2023) *Sources of Greenhouse Gas Emissions*.

The U.S. and Canada have historically contributed significantly more GHG emissions and bear far greater responsibility for the climate emergency. The U.S. has contributed the most to global warming, and is responsible for 20% of historical global CO_2 emissions between 1850–2021.[110] In 2021, the U.S. contributed to 11% of the world's GHG emissions (equivalent to the EU and Russia's combined emissions share).[111] The U.S. is also currently the world's second-largest GHG emitter.[112] Canada is responsible for 2.6% of historical CO_2 emissions between 1850–2021.[113] In 2021, Canada contributed to 1.56% of global GHG emissions.[114]

Of the countries in the Americas, the other top historical emitters include Brazil (4th highest, 5%).[115] Much of Brazil's historical warming contribution is attributed to deforestation in the late 19th and 20th centuries by settlers, and less from fossil fuel emissions.[116]

For cumulative CO_2 emissions in the Americas between 1990–2020, the U.S. contributed the largest share of the countries in the Americas (60%), followed by Brazil (14%), Canada (8.3%), Mexico (4.8%), and Venezuela (2.9%).[117]

For methane emissions, North America contributed to 11.9% of global methane emissions in 2022, with the energy sector comprising the largest emissions source.[118] Central and South America contributed 10.8% of global methane emissions in 2022, with the agriculture sector comprising the largest emissions source.[119] In the Americas, the top 2022 methane emitters were the U.S. (39.42%), Brazil (24.72%), Mexico (0.07%), Argentina (0.07%), and Canada (0.06%).[120] For cumulative methane emissions in the Americas between 1990–2020, the U.S. contributed the largest share (36%), followed by Brazil (21%), Venezuela (12%), Mexico (6.8%), Argentina (6.6%), and Canada (4.7%).[121]

C. Overview of Super Climate Pollutants by Sector

The sectors that are sources of CO_2 emissions are also sources of super climate pollutants across the Americas. Agriculture, transport, and domestic and commercial refrigeration produce the largest emissions of methane, black carbon, particulate matter (PM), and HFCs in LAC, the U.S., and Canada.[122] As super climate pollutants are also air pollutants, reducing them presents an opportunity to address both public health, food security, and climate change issues. For example, mitigating emissions of super pollutants can reduce warming in LAC by 0.9°C by 2050.[123] It can also reduce premature mortality in LAC from $PM_{2.5}$ by at least 26% annually and avoid 3–4 million tons of staple crops each year.[124] Solutions to reduce super climate pollutants are set out in Section VI.

i. Energy

The energy sector, through the production of fossil fuels, is the third largest source of methane emissions in the LAC region, accounting for about 18% of the total methane emissions in 2019.[125] Methane is emitted when it is vented and incompletely flared during production and when it leaks from pipes and containers during storage and transportation. Natural gas production from LAC represented about 5% of the total world production in 2020, with Argentina, Mexico, Trinidad & Tobago, Brazil, Venezuela, and Colombia accounting for the majority of production in 2021.[126] Recent studies have shown that methane emissions from oil and gas production in Mexico are two times higher than estimated in the country's GHG inventory, due to venting of associated gas at well sites and leaks from storage and transportation facilities.[127]

Methane emissions from the oil and gas industry can be reduced by almost 75% at an overall saving, given the average natural gas prices from 2017 to 2021.[128] Yet, even if the value of captured gas is not taken into account, most available abatement measures could be implemented at the cost of US$ 15/tCO_2e.[129] Some examples of cost-effective mitigation measures include implementing leak detection and repair programs, installing vapor recovery units, and replacing leaky equipment.[130]

In the U.S., the energy sector accounts for 56% of methane emissions.[131] A study conducted by the Environmental Defense Fund found that methane emissions in the U.S. from 2012 to 2018 were 60% higher than those emissions reported by the U.S. Environmental Protection Agency (EPA).[132] This was due to the EPA underestimating methane emissions from abnormal activities such as venting.[133] In Canada, the energy sector accounted for 58% of methane emissions.[134]

ii. Transportation

The combustion of fossil fuels in transportation is a significant source of black carbon emissions in LAC.[135] Over the past decade, the region experienced among the highest motorization rates in the world, reaching 201 vehicles per 1,000 inhabitants on average in 2015, while facing a decrease in the quality and productivity of public transit systems.[136] The transportation sector currently accounts for the highest energy consumption in the LAC region and is almost entirely dependent on fossil fuels.[137] Mexico, Argentina, Brazil, and Venezuela represent the highest emissions of black carbon from the transportation sector.[138]

The transportation sector in the U.S. accounts for about 52% of national black carbon emissions, and diesel engines contribute about 90% of the transportation black carbon emissions.[139] Transportation and mobile equipment is by far the largest source of black carbon in Canada, accounting for 56% of total emissions in 2021. Diesel engines contribute about 45% of total emissions.[140]

iii. Agriculture

The agriculture sector is a major source of super climate pollutants in LAC. It is the region's largest source of methane emissions, accounting for 61% in 2019,[141] with livestock and rice cultivation accounting for more than half of sectoral methane emissions. In Latin America alone, the livestock subsector is responsible for 70% of agricultural methane emissions.[142]

In the U.S. and Canada, agriculture plays a less significant, but still important role in methane emissions. In the U.S., agriculture makes up 27% of methane emissions,[143] and in Canada, it also makes up 27% of methane emissions.[144]

Biomass burning has been implemented across LAC as an alternative to waste treatment, wherein agricultural and forest residues are burned to produce electricity.[145] Biomass burning produces black carbon and deteriorate air quality in the region.[146] Black carbon from biomass burning in South America has been traced all the way to the Antarctic Peninsula and the Southern Ocean.[147] In many countries, bioenergy with the potential for carbon capture and storage (BECCS) is categorized as carbon-neutral, because it is argued that the carbon dioxide emissions are offset by replanting trees to replace the carbon sinks that are being cut down and burned, with immediate emissions of carbon dioxide. However, BECCS is not carbon-neutral for several decades, if ever, as the carbon emissions from cutting and burning trees will not be offset for decades to centuries.[148] Large-scale bioenergy will also diminish biodiversity,[149] harm human health,[150] threaten water and food supplies,[151] and perpetuate environmental injustice.[152]

iv. Waste

The waste sector is the second largest source of methane emissions in Latin America and the Caribbean, accounting for 20% of emissions from the region.[153] Methane is produced when organic waste in landfills is decomposed by methane-producing bacteria. The Inter-American Development Bank estimates that the region will produce 296 million tons of municipal solid waste by 2030, over half of which is expected to be organic.[154] 56% of countries in the region dispose of their waste in sanitary landfills with limited implementation of biogas capture systems and 40% in inadequate disposal sites.

Waste accounts for 17% of methane emissions in the U.S.,[155] and 18% of methane emissions in Canada.[156] Municipal solid waste (MSW) landfills are the third-largest source of human-related methane emissions in the U.S., accounting for approximately 14.3% of these emissions in 2021. The methane emissions from MSW landfills in 2021 were approximately equivalent to the GHG emissions from nearly 23.1 million gasoline-powered passenger vehicles driven for one year or the CO_2 emissions from nearly 13.1 million homes' energy use for one year.[157]

v. Cooling

HFCs are alternatives for ozone-depleting substances and are mainly used as refrigerants for cooling and air conditioners.[158] Unlike other substances controlled under the Montreal Protocol, HFCs do not deplete the ozone layer but are GHGs that are several thousand times more powerful than CO_2 in contributing to global warming.[159]

In LAC, 80% of HFC emissions come from Argentina, Brazil, and Mexico.[160] HFC emissions in the region are composed mostly of HFC-134a and HFC-152.[161] As temperatures begin to rise, so will demand for cooling. 48.8 million people in LAC are at a high risk of having no access to sustainable cooling.[162] The urban poor are at the highest risk, increasing by 500,000 people between 2020 and 2021.[163] Moreover, with a growing population, and increasing income and living standards, the region is expected to increase its stock of air conditioners sixfold by 2050.[164] This projected rise in necessity and demand could not only increase potential emissions of HFCs but increasing stocks of air conditioning and other cooling equipment could also strain energy grids.[165]

The Inter-American Development Bank estimates that energy intensity (the amount of energy consumed per unit of GDP) in LAC decreased by 0.8%, compared to a world average decrease of 2.1% annually.[166] Minimum energy performance standards for cooling lag by 30% behind main manufacturers and would need to increase by 67% to meet the standards set by the United Nations Environment Program.[167] Improving energy efficiency in lighting, refrigeration, air conditioning, and motors could save the region 20% in electricity consumption.[168]

The U.S., together with the EU, accounts for 80% of HCFC emissions from Annex 1 countries, and Canada, together with Australia, Russia, and Japan account for the remaining 20% from Annex 1 countries.[169] The most common HCFC in use today in the U.S. is HCFC-22 or R-22, a refrigerant still used in existing air conditioners and refrigeration equipment.[170]

D. The Contribution of Deforestation and Land Use to Climate Change

Forests and other forms of vegetation are essential parts of the carbon cycle, as they serve as "carbon sinks" to absorb CO_2 from the atmosphere and store it over time. Degradation of forests and other carbon sinks, therefore, contributes to global warming by decreasing the amount of carbon stored in the carbon sink.[171] Deforestation combined with global warming risks causing self-perpetuating feedbacks and crossing tipping points.[172]

Loss of forests and other carbon sinks contributes to warming by both depriving the atmosphere of a carbon sink and contributing to the release of carbon from the soil and decomposition. Deforestation combined with global warming risks enhancing warming self-perpetuating feedbacks and crossing ecosystem tipping points such as the loss of the Amazon.[173] Halting the destruction of our forests and other carbon sinks, such as mangroves and seagrasses, so they continue to store carbon and do not turn into sources of CO_2 can provide fast mitigation, while also protecting biodiversity.[174]

Under current warming trends, the global land-based carbon sink, which now mitigates about 30% of carbon emissions and has avoided 0.4°C of warming since 1900,[175] could be cut by half as early as 2040 as increasing temperatures reduce photosynthesis and speed up respiration,[176] the biological energy-yielding process that produces carbon dioxide and water as byproducts.

Earth's ecosystems are estimated to contain 139 billion metric tons of "irrecoverable carbon," defined as carbon stored in natural systems that "are vulnerable to release from human activity and, if lost, could not be restored by 2050."[177] The highest concentrations of irrecoverable carbon are in the Amazon, with additional reserves globally in boreal forests, mangroves, and peatlands.[178] Human activities, such as deforestation, slash and burn fires, agricultural expansion, as well as associated climate impacts such as droughts, flood, and changes in precipitation, all threaten these carbon stores.

Massive deforestation across LAC, caused by the expansion of agriculture, growth of cities, timber harvesting, and other human activities, depletes forests and other land-based carbon sinks, such as wetlands, mangroves, prairies, and other ecosystems. Halting the destruction of forests and other natural carbon sinks in the region, such as mangroves and seagrasses, so they continue to store carbon and do not turn into carbon sources can provide fast mitigation and also protect biodiversity.[179] If all of the carbon (10 years' worth of human emissions) stored in the Amazon were released, the planet could warm by 0.3°C.[180] In addition, the destruction of these natural ecosystems through deforestation and land use practices impacts a wide spectrum of rights, explained further below.

The feedback between climate change and land use change, including deforestation, is projected to threaten the Amazon and its effectiveness as a carbon sink—in the last decade alone, the southern Amazon has become a net carbon source, largely due to climate change and deforestation.[181] Between 1991–2022, the average temperature increase in LAC increased by about 0.2°C per decade (compared to about 0.1°C per decade between 1961–1990).[182]

The Amazon forest is already within the bounds of its estimated tipping point, 20–40% of complete loss,[183] with 20% destroyed completely and an additional 6% beyond repair absent human intervention.[184] Continued deforestation and drying of vegetation and soils in the Amazon under high-emissions scenarios could result in up to a 50% loss in forest cover by 2050.[185] Further, changes to the global water cycle may be pushing the Amazon to a tipping point.[186] The combination of drier conditions, deforestation, and warming have been reducing Amazon forest resilience since 2000, increasing the risk of dieback, the point where rainforest will turn to savanna.[187] With increased deforestation, including from fires, greater disturbances, and higher temperatures, there is a point beyond which the Amazon rainforest would be difficult to reestablish,[188] with recent measurements suggesting that the southeastern area of the Amazon has already shifted to a net carbon source as tree mortality increases and photosynthesis decreases.[189] In 2023, the Amazon River Basin (83% of which is rainforest) entered what has been called "the most extreme" drought in the historical record, marked by 120-year low water levels in many of the river's tributaries.[190] Droughts strain the resilience of the forest and could trigger a tipping point.[191]

The U.S. and Canada also have significant forest cover. Almost one-third of the U.S. is forested. U.S. forests were a net carbon sink in 2021, sequestering 794 MMT CO_2 equivalents (or 216 MMT of carbon) that year.[192] This represented an offset of 13% of GHG emissions. However, these forests are at risk from an increased rate of wildfires, with studies attributing a rise in wildfires in the Western U.S. to human-caused global warming.[193]

Canada ranks as the country with the third-largest forest area in the world.[194] Despite this, forests have not acted as a carbon sink in Canada since 2001, with Canada's managed forests being a net contributor of roughly 78 megatonnes of emissions in 2016 alone.[195] The emissions result from logging practices such as clear-cutting of old-growth forests and slash burning, as well as the increasing impact of climate change including pine-beetle outbreaks and wildfires.[196]

E. Contribution of Destroying Ocean Sinks to Climate Change

Ocean carbon sinks are areas of the ocean that absorb and store carbon dioxide from the atmosphere as part of the natural carbon cycle. Like forests, the absorption of carbon dioxide by the ocean mitigates the impacts of climate change by reducing the amount of carbon dioxide in the atmosphere. According to the U.S. National Oceanic and Atmospheric Administration (NOAA), the ocean absorbs about 30% of the CO_2 that is released in the atmosphere. As a result of the increase in CO_2 global emissions, the ocean acidity has increased by approximately 30%, the seawater has warmed by 0.88°C, and the Atlantic Meridional Overturning Circulation has slowed by approximately 15%.[197] Without the ocean, the Earth would be 36°C hotter.[198]

In addition to being important carbon sinks, around 3 billion people depend upon the world's marine ecosystems for their food security, economy, and culture.[199] In LAC, the ocean plays a critical role in absorbing and storing carbon dioxide. The Caribbean has extensive coral reefs, seagrass beds, and mangroves, which are all highly effective at storing carbon. Protecting and restoring these ecosystems can help to increase carbon storage in the region's ocean.

In South America, the Amazon River plays a significant role in carbon storage in the region's ocean, as it brings large amounts of organic carbon to the ocean through runoff.[200] However, deforestation and land-use change in the Amazon basin (outlined above) pose a risk to this carbon storage potential.[201] In the Central American sub-region, while mangroves offer significant potential for carbon storage, which are highly effective at sequestering carbon, they are threatened by deforestation, coastal development, and aquaculture. Overall, the opportunities for carbon storage in oceans in LAC are significant, but there are also risks that need to be addressed to fully realize this potential.

In the U.S., coastal blue carbon habitats are estimated to sequester 4.8 million metric tons of CO_2 annually.[202] The U.S. announced in 2021 to conserve 30% of its lands and waters by 2030 (through its 30x30 initiative).[203] Within the U.S., several states are incorporating blue carbon ecosystems within their GHG inventories, collaborating with NOAA through creating marine and coastal protected areas, including the National Estuarine Research Reserves and National Marine Sanctuaries. In 2019, NOAA incorporated coastal blue carbon in the EPA's U.S. Greenhouse Gas Inventory, and in 2020, the U.S. became the first country in the world to add blue carbon from coastal seagrasses, mangroves, and salt marshes to its national greenhouse gas inventory.[204]

Likewise, Canada's (the country with the world's longest coastline) coastal ecosystems, including the ocean, salt marshes, seagrass meadows, kelp forests, and marine soft sediments, are critical carbon sinks.[205]

Overfishing poses one of the greatest threats to ocean health. Overfishing threatens the resiliency of marine ecosystems, to the effects of climate change on ocean waters, and added warming compromises the ability of marine organisms to repopulate.[206] For example, young yellowtail flounder off southern New England and the Mid-Atlantic coasts of the U.S. require "cold pools" to survive, yet the rate of warming for waters off the northeastern U.S. is among the highest in the world.[207] Despite some success in repopulating certain fish stocks, in the U.S., 48 stocks are known to be overfished, meaning that the population sizes are low enough to jeopardize the stock's ability to sustain its maximum sustainable yield.[208]

V. CLIMATE IMPACTS IN THE AMERICAS

At the current 1.2°C warming, LAC is already experiencing major climate-related events that are directly and indirectly impacting the human rights protected by the Inter-American system. Further warming will multiply and magnify these rights violations. If global warming goes beyond 1.5°C, these impacts will significantly escalate in scale and severity. However, climate impacts will have differentiated consequences throughout the region based on numerous geographical, economic, cultural, and political factors. Many individuals and groups' adaptation needs will be lower under the 1.5°C limit.[209] Strategies that address climate change impacts without appropriately focusing on the social and economic drivers of vulnerability that enable the impacts of climate change to unequally and unjustly violate and erode the rights of certain persons and communities seriously imperil many of the fundamental rights in the Inter-American system. Climate mitigation and adaptation efforts need to take into account the needs of these groups to avoid human rights violations and ensure a transition that is just, equitable, and sustainable.

Table 1. Climate Impacts Summary[ii]

Impacts		Current Impacts	Future Projected Impacts
Infections and deaths resulting from climate-related diseases	Global	39,503,684 million deaths in 2019[210]	3.4 million deaths per year by end of century[211]
	LAC	16.52 million cases of dengue between 2010-2019[212]	260% rise in dengue by mid-century[213]
	U.S. & Canada	642,602 cases of mosquito, tik, and flea borne diseases between 2004-2016 (USA)[214]	9,900 cases of Lyme disease annually by end of century (Canada)[215]
Deaths resulting from extreme temperatures	Global	Over 5 million a year (2000-2019)[216]	Increase of between 100% and 1000% in the rate of excess mortality due to extreme heat by end of century[217]
	LAC	200,055 people annually (2000-2019)[218]	
	U.S. & Canada		Heat-related mortality is projected to be more than double by the 2050s and triple by the 2080s from the current levels in major Canadian cities[219] 7,300 additional deaths by the 2030s and 16,000 by the 2050s (USA)[220]
Exposure to extreme heat	Global	0.7 billion people-days/year exposed to extreme heat in urban areas alone[221]	1.28 billion people by end of century[222]
	LAC	16.64 million people-days/year from 1983–2016[223]	Increase in extremely hot days of 5-10 times by mid-century (South America)[224]
	U.S. & Canada	3.18 million people-days/year from 1983–2016[225]	107 million people by mid-century (USA)[226]
Work hours lost due to extreme heat	Global	133.6 billion work hours in 2018[227]	362-1091 billion hours[228]
	LAC	$22 billion in lost income in 2021 (South America)[229]	
	U.S. & Canada		1.8 billion hours (USA)[230]
Air pollution exposure	Global	7.28 billion people exposed to PM 2.5[231]	14% of the overall increase in ozone related mortality by end of century[232] 6.6 million deaths from air pollution by 2050[233]
	LAC	500 million people[234]	
	U.S. & Canada	Over 103 million people exposed to ozone smog (USA)[235]	
Internal displacement	Global	23.7 million people in 2021[236]	1.2 billion people by 2050[237]
	LAC	1.7 million people in 2021 (LAC, U.S., & Canada)[238]	10.6 million people by 2050[239]

[ii] Note that the extent of these future projected impacts will vary depending on the scale of the global temperature increase, the extent to which States can adapt to climate change, and any further potential escalation of the climate emergency caused by the crossing of key tipping points or other developments.

Impacts		Current Impacts	Future Projected Impacts
	U.S. & Canada		
Reduction in crop yield	Global		10% by 2050, 25% by 2100[240]
	LAC		19% reduction in bean crops by 2050, 17.2% reduction in maize by 2050[241] 30% fall in overall plantation yields by 2050 (the Caribbean)[242]
	U.S. & Canada		7% reduction in corn, 9% reduction in soybean by mid-century (USA)[243]
Direct damages from climate disasters	Global		
	LAC		$100 billion annually by 2050[244]
	U.S. & Canada	$1.1 trillion (2013–2022) (USA)[245] $18 billion (2010–2019) (Canada)[246]	$14.5 trillion over 50 years (USA)[247]
Loss of GDP	Global		65% of GDP by end of century[248]
	LAC	1.7% of GDP annually[249]	16% of GDP by end of century[250]
	U.S. & Canada	0.8% of GDP in 2021 (Canada)[251]	2.5% of GDP by 2050 and 1-4% of GDP annually by end of century (USA)[252]

A. Summary of Impacts in Latin America and the Caribbean

Throughout the LAC region, climate impacts are already causing food and water insecurity, migration and displacement, disruption of livelihoods, significant physical and mental health issues, and severe economic losses.

According to the IPCC AR6 regional report for the LAC region, climate change will likely convert existing risks in the region into severe key risks. Key risks include:

1. Risk of food insecurity due to droughts;
2. Risk to people and infrastructure due to floods and landslides;
3. Risk of water insecurity due to declining snow cover, shrinking glaciers, and rainfall variability;
4. Risk of increasing epidemics, particularly of vector-borne diseases;
5. Cascading risks overwhelming public service systems;
6. Risk of large-scale changes and biome shifts in the Amazon;
7. Risks to coral reef ecosystems; and
8. Risks to coastal socio-ecological systems due to sea level rise (SLR), storm surges, and coastal erosion.[253]

Warming beyond 1.5°C will have devastating impacts throughout LAC, particularly for the most vulnerable areas and communities. For example, a 1.5°C increase alone would increase the population affected by floods in Colombia, Brazil, and Argentina by 100–200%, in Ecuador by 300%, and in Peru by 400%.[254]

Warming beyond 1.5°C is expected to have significant impacts on islands in the Caribbean, and urgent action is needed to mitigate these impacts and support the region's resilience and adaptation efforts.[255] As global temperatures rise, thermal expansion and melting glaciers and ice sheets will lead to sea level rise. This will have significant impacts on low-lying islands in the Caribbean, which are already experiencing flooding and erosion from sea level rise.[256] Increased sea level rise will likely also exacerbate storm surges and coastal flooding. Climate change will also increase the intensity and frequency of extreme weather events such as hurricanes, tropical storms, and floods.[257] Furthermore, higher temperatures are expected to lead to increased evaporation rates, which could exacerbate water and food insecurity issues in the Caribbean.[258] Many islands in the region already face water shortages, and this could worsen under a warmer climate.[259] The Caribbean is already prone to these events, and they will become more severe under a warmer climate, leading to increased damage to infrastructure and property, as well as loss of life.

The impacts of land use change, particularly deforestation, fires, and other climate change impacts have direct impacts to human health, ecosystems, food security, livelihoods, and carbon sinks in the region.[260] Specifically, projected impacts in LAC include rising food insecurity from droughts; rising water insecurity from melting snow and glacier ice (e.g., in the high Andes), and from rainfall variability; risk to people and infrastructure from floods and landslides; risk to health due to an increase in vector-borne diseases; significant physical and cultural risks to the Amazon; and risk to coastal systems from sea level rise and coastal erosion, among other projected impacts.[261]

Between 2000–2019, LAC was the second most disaster-prone region in the world, with 152 million people affected by 1,205 disasters, including floods, storms, earthquakes, droughts, landslides, wildfires, and extreme heat.[262] Attribution studies can now link climate change to specific extreme weather events and the damage they cause.[263] This expanding body of scientific and historical evidence in climate attribution strengthens the legal basis for redressing harms.

According to AR6 WGI, "[i]t is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s... with *high confidence* that human-induced climate change is the main driver of these changes."[264] In high-emission scenarios, week-long periods of record-breaking high temperatures are two to seven times more probable in 2021–2050 and three to 21 times more probable in 2051–2080, compared to the last three decades—events that would be nearly impossible absent anthropogenic warming.[265] Additionally, night-time fire intensity has increased globally by 7.2% in the last two decades due to rising temperatures, causing more intense, longer-lasting, and larger fires.[266]

A number of impacts for the region are of particular importance in understanding how human rights are affected by the onset of climate change in the region and these are addressed below.

B. Summary of Impacts in the U.S. and Canada

The U.S. and Canada are also experiencing dramatic impacts as a result of climate change. These impacts are disproportionately affecting vulnerable members of each country's societies, in particular those from coastal indigenous communities. While both countries have access to greater resources to engage in climate mitigation and adaptation than the LAC region, the economic impact of climate change is and will significantly deplete the resources of two of the world's largest economies. The impacts of climate change on the U.S. and Canada illustrate that even countries in the global north cannot escape the effects of climate change on human rights.

According to the IPCC AR6 regional report on North America, "without limiting warming to 1.5°C, key risks to North America are expected to intensify rapidly by mid-century (high confidence). These risks will result in irreversible changes to ecosystems, mounting damages to infrastructure and housing, stress on economic sectors, disruption of livelihoods, and issues with mental and physical health, leisure, and safety. Immediate, widespread, and coordinated implementation of adaptation measures aimed at reducing risks and focused on equity have the greatest potential to maintain and improve the quality of life for North Americans, ensure sustainable livelihoods and protect the long-term biodiversity, and ecological and economic productivity, in North America."[267]

Extreme heat and hurricanes have already caused a high rate of fatalities across the U.S. and Canada, as well as costing billions of dollars in damages. The impacts of Hurricane Irma and Hurricane Maria were particularly devastating, with thousands of fatalities occurring in the U.S. territory of Puerto Rico alone.[268] As the rate and scale of climate disasters increase, so too will the economic resources needed to mitigate and adapt to these disasters. Climate change-induced economic losses could cost the U.S. economy US$14.5 trillion over the next 50 years.[269] This in turn hampers the capacity of U.S. and Canada to use their greater economic power as a force to foster global climate cooperation.

The U.S. and Canada are also experiencing a rise in floods, droughts, and glacier loss, which is damaging the lives and livelihoods of coastal communities, as well as destroying homes and important indigenous cultural sights.

While the U.S. and Canada are wealthy nations, there remain areas of poverty and deprivation, particularly in subsistence-based fishing communities.[270] Coastal erosions, ocean acidification, and a rise in extreme weather events hamper these communities' capacity to exercise their personal, social, economic, and cultural rights. Damage to the economies of the U.S. and Canada is also disproportionate to lower-income communities, leading to a rise in inequality and loss of social and economic opportunities.[271]

The IPCC AR6 report predicts that key risks in North America are expected to intensify rapidly by mid-century. These include an increase in climate hazards such as wildfires and heatwaves, an increase in health risks including vector-borne diseases, damage to the food production capacity of the region, and escalating climate-change impacts on marine, freshwater, and terrestrial ecosystems.[272] The U.S. government could spend between an additional US$25–128 billion annually on just six types of Federal expenditure: coastal disaster relief, flood insurance, crop insurance, healthcare insurance, wildland fire suppression, and flooding at Federal facilities by the end of the century.[273]

C. Economic and Health Impacts of Climate Change

The International Monetary Fund's 2022 World Economic Outlook Report urges policymakers to establish credible and irreversible climate policies and states that the costs of transitioning would be "dwarfed by the innumerable long-term costs of inaction."[274]

However, when evaluating the economic impacts of climate change, it is important to highlight the limitations of the current climate finance models. Climate models do not accurately depict the future or the financial implications.[275]

The latest assessment of climate finance models finds that models do not include tipping points, feedback loops, sea level rise, heat stress, food supply disruptions, cascade effects, or adaptation costs.[276] The assessment press release states that "[t]his severely limits the usefulness of the models to business leaders and policy makers, who may reasonably believe these models effectively capture risk levels, unaware that many of the most severe climate impacts have not been considered."[277] The following information should be considered understanding that these projections are implausibly conservative if we surpass 1.5°C.

Loss of GDP. Cambridge Econometrics quantified a 65% negative impact on global GDP in a business-as-usual (BAU) scenario with 4°C warming by 2100. The authors stated that "[t]hese large damage estimates are likely to understate the true losses, since our method is based on the observed relationship between temperature and economic output, and we focus only on the impacts of gradual warming on productivity. They do not account for tipping points or other unprecedented changes in the climate system."[278]

Climate-related extreme events have already cost double-digit percentages of GDP in some cases.[279] In rankings of the impacts of extreme weather events from 2000 to 2019 in terms of economic losses as a share of GDP, eight of the top 20 countries are in the Caribbean.[280] Between 1970–2021, reported climate-, weather-, and water-related disasters costed countries in the Americas $2 trillion.[281] By 2050, climate change damages could cost US$100 billion annually to the LAC region.[282]

Poverty, Food and Water Insecurity. Climate shocks reduce the income of the poorest 40% by more than double the average of the LAC population and could push an estimated 2.4–5.8 million people in the region into extreme poverty by 2030.[283] Plantations in the Caribbean are predicted to fall up to 30% by 2050.[284] Lower yields would have negative consequences in a number of areas, such as growth in output and investment in agriculture, the external sector, poverty reduction, and food security. There is also evidence of a present and future increase in water scarcity, further increasing poverty in the region.[285]

Continued climate inaction will lead to a loss of 900,000 job opportunities every year in the U.S. for the next 50 years due to climate damages.[286] In Canada, low-income households could see income losses of 12% should global temperatures rise by 2°C. [287]

Extended droughts, changing precipitation, and land-use change exacerbate food insecurity in LAC, and rising food prices and socioeconomic factors can hinder further access to healthy diets in the region.[288] In South America, which comprises 66% of the LAC population,[289] 168.7 million people experience moderate or severe food insecurity.[290] This figure will only increase as climate change puts further pressure on food systems,[291] underscoring the need to reduce warming in the near term to reduce the impacts of climate change on food security in LAC.

Rising sea levels trigger saltwater intrusion that can impede access to safe drinking water and poses one of the biggest threats to freshwater systems.[292] In the Caribbean, water demand is already exceeding supply, which is further exacerbated by severe drought made worse by global warming.[293] Despite increased rainfall observances, some places in LAC still experience water insecurity—between 2014 and 2016, Brazil experienced a water crisis, when the main water reservoir of Sao Paulo reached only 5% of its 1.3 billion m^3 capacity.[294]

Health and Access to Healthcare. Climate change impacts are accelerating and disproportionately affecting the health of vulnerable populations in LAC. Failure to act expediently to reduce warming costs lives: of all heat-related deaths, between 20% (Argentina) and 77% (Ecuador) can be attributed to human-caused climate change in LAC.[295] The changing environment also increases the likelihood of infectious diseases such as dengue.[296] Between 2000–2009 and 2010–2019, dengue cases almost tripled (6.78 million to 16.52 million) in LAC.[297] Air pollution exacerbated COVID-19 hospitalization and death rates in LAC.[298] Poor sanitation conditions in low-income countries can exacerbate health risks and result in more deaths in the region absent further climate, environmental, and economic action, underscoring the need to act immediately to reduce warming in the near term.[299]

D. The Implications of Vulnerability in LAC

Vulnerable groups in the LAC are disproportionately impacted by climate change in the ways detailed below. The implications of vulnerability to climate impacts already pose human rights threats and challenge a just transition both in terms of mitigation and adaptation.

Indigenous People. Indigenous people in Latin America are particularly vulnerable to the impacts of climate change due to their reliance on natural resources for their livelihoods and deep cultural connections to the land. According to the World Bank, 24% of the region's Indigenous population lives in extreme poverty (2.7 times more than non-Indigenous people), and they are disproportionately affected by climate change.[300] Climate change threatens the culture, livelihood, and safety of Indigenous communities.[301] Sea level rise, biodiversity loss, and other climate change impacts further exacerbate the loss of Indigenous languages.[302]

Indigenous people in LAC are already more likely to experience higher poverty, lower employment, and limited access to education, health services, and decision-making processes.[303] This is further exacerbated by climate change impacts that worsen these vulnerabilities and impose additional vulnerabilities due to Indigenous communities' dependence on the natural environment for cultural and physical survival.[304] Many Indigenous communities in LAC are also forced to live in climate risk-prone areas such as low-lying coastlines and floodplains.[305] However, Indigenous people, while comprising only 5% of the global population, protect 80% of the biodiversity in the planet (particularly women).[306]

Women and Gender-minorities. Climate impacts disproportionately affect women and gender minorities in LAC. In LAC, women experience higher levels of food insecurity and poverty compared to men.[307] Women and gender minorities also have a more difficult time migrating in South America due to a lack of social networks that are more available to men, and therefore are more likely to remain in areas experiencing climate change impacts.[308] Existing gender-based inequalities, combined with environmental degradation, also exacerbate gender-based violence such as domestic violence, forced marriage, human trafficking, forced prostitution, and hate crimes.[309]

Children and Youth. Children and youth face disproportionate health impacts caused by a rapidly warming world. For example, air pollution has a disproportionate impact on youth, with 98% of children in low-and middle-income countries breathing polluted air,[310] killing one in ten children or permanently stunting children's development.[311] In the LAC region, 105 million children are already exposed to air pollution.[312] If the planet reaches 2.4°C of warming at 2050, as compared to 1.7°C, 370 million more children will be exposed to long-lasting heatwaves.[313]

Elderly. Older adults (65 and older) are disproportionately vulnerable to the health impacts associated with climate change and weather extremes."[314] Older people are particularly vulnerable to heat exposure, and climate change is projected to increase the risk of heat exposure. In LAC, climate change is already increasing heat exposure for the elderly.[315] From 2012–2021, on average, adults above 65 were exposed to 12.3 million more person-days of heatwaves each year, as compared to a 1995–2005 baseline.[316] In almost all countries in South America, the number of heat-related deaths has increased continuously among people over 65 since the year 2000.[317] The number of heat-related deaths increased by 160% on average in the 2017–2021 period compared to the 2000–2004 period.[318] Older people are also vulnerable to climate change because they are particularly vulnerable to disease, air quality, wildfire smoke, heatwaves, and other compounding issues caused by the climate emergency.[319]

Poor and Economically Marginalized Communities. Climate impacts worsen underlying triggers that harm the economy and are disproportionately felt by impoverished communities. Every year, 150,000 to 2.1 million people experience extreme poverty due to natural disasters in LAC—by 2030, this number could rise to 5.8 million people a year, mostly due to health-related impacts of climate change.[320] For those living in more impoverished areas, there is a higher likelihood of experiencing debilitating climate impacts, exacerbated by poor living conditions, lack of public services and resources, and nearby polluting sites.[321] Inequality in the region also interrelates with poverty to make poor communities highly vulnerable to the impacts of climate change. Limited access to resources due to structural socioeconomic inequality makes it much harder for poor communities to access adaptation options.[322]

Migration, Displacement & Climate Refugees. Extreme weather events induced by global warming amplify social, economic, and environmental factors that induce mass migration and population displacement. There is an upward trend of internal climate migration in Latin America, Sub-Saharan Africa, and South Asia, with the potential to surpass over 143 million migrants by 2050.[323] In Mexico and Central America, internal climate migrants could double between 2020 and 2050.[324] Under a more climate-friendly scenario that meets the Paris Agreement's 1.5°C temperature limit, a scenario that is still possible with immediate and deep cuts to super climate pollutants, as described in Section VI, there would be up to 87% fewer climate migrants in Latin America compared to a business-as-usual scenario.[325]

Climate change is inducing mass cross-border displacements in the Americas. For example, in 2017, Hurricanes Irma and Maria prompted the Bahamans and Antigua and Barbuda's island of Barbuda to implement island-wide mandatory evacuations, and caused over 135,000 Puerto Ricans to migrate to the U.S.[326] There is a dearth of regional agreements on how to address and prevent displacement in the Americas, including protocols for managing displacement from both rapid-onset disasters, such as hurricanes, as well as slower-onset climate effects that render current settlement areas uninhabitable, such as settlements on eroding coastlines in the Caribbean.[327]

Climate refugees face further discrimination and violence in many countries when seeking asylum.[328] This is compounded by governments failing to identify or categorize climate-displaced people, hindering climate refugees' access to protection and migration.[329] Recognizing and ensuring protections for climate refugees as a distinct vulnerable class of citizens is critical to ensuring climate justice.

In addition to generating increased migration and climate refugees, the impacts of climate change can disproportionately affect current refugees and displaced peoples.[330] For example, nearly 2.5 million Venezuelans have migrated to Colombia and another 2 million in Chile, Ecuador, and Peru,[331] and face additional vulnerabilities such as economic hardship, sexual exploitation, recruitment into armed groups or street gangs, intimidation, lack of good job opportunities, limited access to health care, and xenophobia.[332]

Climate & Environmental Defenders. Climate and environmental activists are more likely to face violence and criminalization for their activism. Since 2012, Global Witness found that at least 1,700 land and environmental defenders were killed protecting their land and resources.[333] In Brazil, 85% of these killings happened in the Amazon, intensifying following the election of former President Bolsonaro. The main drivers of these attacks are land inequality, violent conflict over land, corruption by land grabbers, shrinking civic protection, and a culture of corporate impunity that allows corporate power supported by government policies to perpetuate the climate and biodiversity crisis and kill environmental defenders.[334] Climate and environmental activists are also criminalized by being charged with coercion, trespassing, and other criminal offenses to justify police action, or burdened with SLAPP suits[iii] by corporate power players to dissuade activism.[335]

VI. SOLUTIONS IN THE AMERICAS TO TACKLE THE CLIMATE EMERGENCY

Tackling the climate emergency expeditiously and effectively in the Americas will require coordinated responses at the regional, national, and sub-national levels. Solutions are multifaceted and require mitigation of super climate pollutants, decarbonization, and the protection and restoration of carbon sinks simultaneously to keep the planet below the 1.5°C safe temperature limit. Moreover, allocating resources to ensure wide-scale mitigation, adaptation, and resilience-building is fundamental, since a lack of financing and weak implementation capacity present serious obstacles in the region and exacerbate impacts to communities and ecosystems.[336] A combination of critical actions that mitigate super climate pollutants, decarbonize, and protect carbon sinks are the only way to stop future and ongoing rights violations.

A. Sector-Specific Actions to Immediately and Substantially Mitigate Super Climate Pollutants and Decarbonize in LAC

[iii] SLAPP suits, or strategic lawsuits against public participation, are civil complaints intended to intimidate and silence people or organizations who speak out on public issues. *See generally* Cornell Law School, *SLAPP suit*.

States must implement economy-wide solutions that target high-polluting sectors like energy, transport, and waste. Taking these proven mitigation actions, with adequate capacity-building and regional coordination, offer additional opportunities and benefits for the region, including near-term improvements in the quality of life of the population, job creation, and improved sustainable development.[337]

Box 1. Key SLCP Mitigation Actions for LAC

- Incorporating best practices or upgrading best available technologies in industrial processes, such as reducing flaring in the oil and gas industry;
- Seeking maximum ambition to implement all commitments under the atmospheric treaties, such as ensuring the full or accelerated phasedown of hydrofluorocarbons (HFCs) while incorporating maximum energy efficiency measures in the cooling sector;
- Incorporating measures into large-scale infrastructure programmes of public authorities like the waste sector, such as capturing and using methane emissions from landfills;
- Implementing sustainable, low-emission solutions to reduce black carbon emissions, such as providing alternative, non-motorized transport options and freight management in the transport sector;
- Changing practices, some of which are embedded in cultural, economic and social traditions, for domestic cooking and heating, agriculture and artisanal industries; and
- Implementing "natural" climate solutions, such as proforestation, improved land management, and conservation of forests, wetlands, seagrass beds, and other natural sinks.

Energy

- Ensure the deployment of best available technologies to stop leaks and prohibiting venting in the oil and gas sector;[338]
- Stop waste of energy by capturing methane rather than flaring it;
- Divestment from fossil fuel;
- Accelerate the transition to renewable energy by investing in renewables; and
- Search for data on offshore wind energy and harnessing the energy of waves.

Agriculture

- Improving and changing agricultural practices like implementing different grazing and breeding strategies and feed for livestock;
- Several cost-effective solutions have been found to reduce the production of N_2O emissions including the use of new technologies in agricultural processes;[339] and
- Stop agricultural burning.

Waste

- Upgrading solid waste and wastewater treatment;[340]
- Reducing food waste, diverting organic waste from landfills, and improving landfill management;[341] and
- Developing infrastructure for sustainable cold chains to reduce organic waste diverted into landfills.

Transportation

- Rapidly introducing strict emissions standards of new vehicles and

eliminating high emitting vehicles with full enforcement; and
- Promote and transfer to electrification in transport.

Buildings
- Improve energy efficiencies for multiple sectors, including buildings and infrastructure, both through retrofitting and through use energy efficient technology in new infrastructure;
- Eliminating gas in new construction and phasing out leaky gas stoves;[342]
- Shifting to clean energy for electrification and heating, including incentives to promote solar panel installation and battery storage technologies;
- Switching to clean cooking equipment to reduce black carbon;[343]
- Switching to cleaner heating method to reduce methane and black carbon;[344]
- Replacing or retrofitting cooling technology used in refrigeration and air conditioning;[345] and
Updating or adopting minimum energy performance standards for cooling equipment and strengthening laws against importing cooling equipment that do not comply with standards in exporting countries.

B. Sector-Specific Actions to Immediately and Substantially Mitigate Super Climate Pollutants and Decarbonize in the United States and Canada

As high-income countries and disproportionately high contributors to current and historic GHG emissions, Canada and the United States must take urgent action to counter the climate crisis. The range of pollutants (SLCPs, nitrous oxide, and carbon dioxide) and polluting industries necessitates the simultaneous implementation of multiple solutions. The United States and Canada have the capacity to lead the development of new technologies to increase energy efficiency, increase carbon capture technology, and ensure a just transition. Addressing the climate emergency in Canada and the U.S. requires urgent action across a variety of sectors and across the private sector and every level of government.

The U.S. and Canada must focus on developing technologies to transition to a zero-carbon future while targeting key pollutant sectors such as energy, transportation, waste, and agriculture. These mitigation actions provide opportunities for the U.S. and Canada to emerge as leaders in sustainable development, create jobs, and ensure a just transition.

Box 2. Key SLCP Mitigation Actions for the U.S. and Canada

- Exploring potential for developing needed technologies, such as clean hydrogen, renewable energy, and carbon capture strategies;
- Changing financial incentives, including by removing subsidies for fossil fuels, divesting public funds from fossil fuels, and incentivizing the development of more sustainable technology;
- Incorporating best practices or upgrading the best available technologies in industrial processes, particularly in the energy sector;
- Retrofitting infrastructure, buildings, and technology to reduce emissions and improving energy efficiency across all sectors;
- Exploring natural climate solutions by practicing sustainable land management and protecting carbon sinks;
- Managing emissions from waste and agriculture; and
- Eliminate loopholes in mandated emissions reporting.

Energy

- Remove subsidies for fossil fuels and divest public funds from fossil fuels;
- Eliminate loopholes for mandated emissions reporting, including for emissions from start-up, shut-down, and malfunction events of major power producers;
- Limit methane emissions in the oil and gas sector, including through introducing regulations that limit emissions from venting and leaks;[346]
- Support the development of renewable energy, such as by diversifying supply chains, exploring potential from small modular reactors, and supporting biogenic, low-carbon fuel innovations;[347]
- Expand the blue and green hydrogen supply, support growth in biofuels and sustainable aviation fuels,[348] and invest in clean hydrogen by creating demand for low-carbon hydrogen and developing hydrogen end-use technologies;[349]
- Regulate wood-burning appliances to address black carbon emissions;[350]
- Replace natural gas sources with zero-carbon energy sources, especially in the power, manufacturing, chemicals, and building sectors;[351] and
- Expand renewables by investing in the renewables supply chain, expanding the grid, securing access to adequate land for renewable deployment, and installing renewables.[352]

Negative Emissions Technology

- Explore nature-based solutions by restoring habitats, protecting carbon sinks, and adopting Indigenous practices and other sustainable land management practices;[353]
- Support development of new carbon capture, utilization, and storage (CCUS) technologies.[354] This includes improving biological carbon capture with geological storage, including bioenergy with carbon capture and storage (BECCS) and ocean fertilization,[355] and improving and investing in non-biological technologies, including enhanced rock weathering and direct air capture;[356]

- Establish carbon capture hubs in key locations, such as the Gulf Coast and the Midwest;[357] and
- Explore options to remove methane from the atmosphere, including through catalytic chemical oxidation, augmentation of atmospheric sinks, and microbial removal by methanotrophs.[358]

Buildings and infrastructure

- Adopt export restrictions on cooling equipment below the energy efficiency standards and Montreal Protocol obligations of the exporter country;
- Invest in improving energy efficiencies for multiple sectors, including buildings and infrastructure, both through retrofitting and through developing new technology;[359]
- Reduce emissions from existing facilities and infrastructure, including through retrofitting, electrification, and carbon capture;[360]
- Implement building codes to reduce the emissions intensity of commercial and residential infrastructure, including from heating, cooling, and electricity use; and
- Introduce government standards for purchasing requiring that the government purchases only zero-emissions goods and services in categories for which this is possible.[361]

Transportation

- Implement stricter vehicle emissions standards such as requiring diesel particulate filters;
- Promote electrification in transport by providing support and investment into infrastructure, including by updating electricity grids to support electric cars, investing in electric buses and rail systems,[362] and investing in electric vehicles;[363] and
- Address black carbon emissions from transportation by supporting faster turnover for diesel vehicles.[364]

Agriculture

- Develop solutions for reducing N_2O emissions from agricultural processes, such as precision farming, nitrogen inhibitors, and plant-growth promoting bacteria;[365]
- Invest in improving energy efficiency in the agriculture sector;[366] and
- Take measure to reduce consumption of animal products, including investing in alternative protein, promoting low meat diets, and providing access to plant-based alternatives.[367]

Waste

- Mitigate methane emissions from agriculture sources such as enteric fermentation;[368]
- Incentivize organic waste diversion from landfills;[369] and
- Mitigate methane emissions from municipal solid waste landfills,[370] including through adopting regulations requiring methane controls on landfills.[371]

C. Protecting and Restoring Carbon Sinks in the Americas

Saving land carbon sinks in the Americas requires a multi-pronged strategy of protecting forests in the region by preventing deforestation and restoring sinks through proforestation measures.[372]

Box 3. Key Actions to Protect and Restore Carbon Sinks in the Americas

- Establishing land rights for Indigenous and local communities;
- Implementation of zoning measures to reduce encroachment of developed land;
- Establishing protected land reserves and promoting forest protection and proforestation;
- Protecting threatened wetlands;
- Preserving existing peatlands and restoring degraded peatlands;
- Restoring coastal 'blue carbon' ecosystems; and

Efforts to protect land-based carbon sinks must begin with recognizing Indigenous land rights and incorporating Indigenous land management strategies such as silvopasture and regenerative agriculture.[373] Indigenous and local community solutions could help restore a significant portion of this carbon storage potential, as Indigenous and local communities steward at least 22% of global forest carbon, consisting of areas that hold 80% of the planet's biodiversity.[374] In the Amazon alone, forests managed by Indigenous people sequestered 340 million metric tons of carbon annually between 2001–2021.[375] Research has shown that establishing land rights for Indigenous and local communities tend to lower deforestation rates and carbon emissions, while deforestation rates are higher in areas where this right is not secured.[376]

For example, between 2000–2012, deforestation in the Brazilian Amazon occurred only in 0.6% of lands protected by Indigenous communities compared to 7.0% of non-Indigenous lands.[377] Further, due to land management and environmental defending practices, forests in the Brazilian Amazon stewarded by Indigenous communities contain 36% more carbon per hectare than non-Indigenous lands in the Brazilian Amazon.[378] In the Brazilian Amazon alone, Indigenous lands and government-protected areas could prevent 27.2 million hectares of deforestation by 2050, saving 12 billion tonnes of CO_2 (which is equal to around three years worth of CO_2 emissions from all countries in Latin America and the Caribbean).[379]

In addition, measures to protect ocean sinks include restoring coastal 'blue carbon' ecosystems.[380] In the last decade, ocean and land ecosystems have sequestered 52% of anthropogenic CO_2 emissions—however, this may not account for other coastal ecosystems.[381] For example, mangroves sequester carbon at a rate ten times greater than tropical rainforests annually.[382] Reducing mangrove deforestation rates could sequester up to 55–61% more carbon.[383] Therefore, protecting existing coastal, terrestrial, and ocean sinks is critical for fast mitigation.

The High-Level Panel for a Sustainable Ocean Economy, a multilateral group comprising representatives from 14 oceanic countries, estimates that by 2050 ocean-based climate mitigation and carbon storage options could make up 21% of the emissions reductions needed to limit global warming to 1.5°C.[384] This equates to more than all current global emissions from coal-fired power plants worldwide.

Another strategy to preserve sinks is through deployment of REDD+, or reducing emissions from deforestation and forest degradation in developing countries. REDD+ projects may include the sustainable management of tropical forests and conservation and enhancement of forest carbon stocks,[385] and have already resulted in a reduction of 11 billion tons of CO_2 emissions across 14 countries as of 2022.[386] Countries can obtain results-based payments from a variety of sources including public and private, bilateral and multilateral, and others.[387] These sources include the Green Climate Fund, the Government of Norway, Government of Germany, Programa REM Colombia – Vision Amazonia, and Central African Forest Initiative.[388]

Common safeguards prior to deploying a REDD+ project include free, prior and informed consent of communities residing within or near the target project, recognition of rights over land and resources, and good-faith consultation between States and forest-dependent communities.[389] This is because REDD+ projects may interfere with the communities' (typically Indigenous Peoples and local communities) access to forests and forest resources,[390] displace communities,[391] exacerbate land conflicts,[392] and may ultimately commercialize a forest as an emissions reductions project, rather than utilize other benefits from that natural resource.[393] The UN Declaration on the Rights of Indigenous Peoples emphasize the importance of Indigenous Peoples' roles in forest management, and notes that REDD+ safeguards require "full and effective participation of ... indigenous peoples and local communities," further implying the need for free, prior and informed consent in REDD+ projects.[394]

D. Effective Mitigation of CO_2 and Super Climate Pollutants Is Essential to Give LAC Time to Adapt, Build Resilience, and Protect Rights

Implementing these mitigation actions will help avoid the worst impacts of climate change while giving States the time and material resources to design and implement equitable, fair, and sustainable adaptation actions to help people and communities face the unavoidable impacts.

ANNEX A: DETAILED IMPACTS IN THE AMERICAS

A. Weather Changes and Extreme Weather Events

Heatwaves. Absent fast action, in LAC, massive heatwave events will likely continue to increase in frequency and intensity, particularly in places closer to the equator. In 2021 and 2022, several countries in LAC reported record-breaking temperature highs.[395] Between 2016–2020, several countries experienced a rise in the mean number of days exposed to heatwaves (compared to 1986–2005), including by 9.3 days in Colombia, 11.2 days in Honduras, and 15.2 days in Suriname.[396] The World Weather Attribution, an initiative launched with climate scientists to explain how recent weather events have intensified due to climate change, confirmed that climate change made the record-breaking early season heat in Argentina and Paraguay 60 times more likely, which caused an increase in power outages, wildfires, heat-related deaths, and decreases in harvests and labor productivity.[397] These heatwaves increased wildfires in Argentina and Paraguay by 283% and 258% at the beginning of 2022.[398] The report further confirms that similar heatwaves will only increase in frequency and intensity with added global warming.[399] The best and fastest way to cut the rate of warming in the near term is reducing super climate pollutant emissions, as discussed in Section II *supra*.

In the U.S., heatwaves are occurring more often than they used to in major cities. Their frequency has increased steadily, from an average of two heat waves per year during the 1960s to six per year during the 2010s and 2020s.[400] In Canada, extreme heat killed almost 600 people in British Colombia in 2021, and there has been a significant rise in wildfires.[401] In 2021, the Pacific Northwest region, encompassing the U.S. states of Oregon and Washington and the Canadian Provinces of British Columbia and Alberta, experienced a record-breaking heatwave. The impacts of this event were catastrophic, including hundreds of attributable deaths across the Pacific Northwest, mass mortalities of marine life, reduced crop and fruit yields, river flooding from rapid snow and glacier melt, and a substantial increase in wildfires—the latter contributing to landslides in the months following.[402]

According to AR6 WGI, "[i]t is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s…. with high confidence that human-induced climate change is the main driver of these changes."[403] Current impacts of climate change have already made extreme heatwaves in the LAC region 60% likely, if global temperatures rise by 2°C heatwaves in the region will become four times as severe––this severity would be impossible absent Anthropocene warming.[404] Additionally, extreme temperatures already increased risk of wildfire dangers to extreme risk levels that last on average 7–10 days longer.[405] Extreme heat threatens lives, health, water security, and food security.

Hurricanes and Cyclones. In 2021, LAC experienced a higher-than-average number of tropical cyclones that caused about US$80 billion in damages to people and infrastructure.[406] This was the sixth year in a row where the Atlantic hurricane season was higher than average.[407] The rising intensity and frequency of extreme weather events trigger displacement in the region, with Peru, Colombia, and Guatemala experiencing the largest average displacements caused by extreme hurricanes.[408] These weather events emphasize the need to address climate change as quickly and effectively as possible.

In the U.S., in 2021, there were 20 separate billion-dollar weather and climate disasters. The total cost for these events was $145 billion, making this the third most costly year on record, behind 2017 and 2005. 2021 was the seventh consecutive year in which 10 or more billion-dollar disaster events occurred in the U.S.[409] In 2017, Hurricane Maria caused the longest blackout in U.S. history and led to 2,975 fatalities in the U.S. territory of Puerto Rico.[410] Hurricane Irma, which also struck in 2017, led to the destruction of 25% of buildings in the Florida Keys and 65% were significantly damaged.[411] In Canada, Hurricane Fiona (later downgraded to Storm Fiona) caused widespread damage to infrastructure and led to $660 million in insured damages alone.[412] Increased hurricane frequency alone could drive up U.S. spending on coastal disaster response between $22 billion and $94 billion annually by the end of the century.[413]

Precipitation. Mean precipitation is projected to change significantly, increasing in Northwest South America and Southeast South America, and decreasing in Northeast South America and Southwest South America.[414] Increased rainfall triggers flooding and landslides, affecting thousands of people and causing further damage. However, decreased rainfall affects water supplies and reduces agricultural productivity and revenues.[415] In 2019 alone, flooding caused most of the 1.5 million forced displacements in the Americas.[416] The World Bank estimates that, without concerted action, by 2050, more than 17 million people in Latin America and the Caribbean could be forced to relocate to escape the slowly evolving effects of climate change.[417] The risks of additional water crises from increased or decreased precipitation highlight the need for fast climate action. In 2022, Central and Eastern Mexico experienced precipitation 40–60% below normal levels, while Northwest Mexico was 40% above normal.[418]

In the U.S., over the entire period from 1910 to 2020, the portion of the country experiencing extreme single-day precipitation events increased at a rate of about half a percentage point per decade.[419] In Canada, two days of intense precipitation in British Colombia in 2021 led to the loss of at least five lives, cut the city of Vancouver off entirely from the rest of Canada by road and rail, and made this the costliest natural disaster in the province's history.[420]

Droughts. The frequency and intensity of droughts have increased in LAC, resulting in 3.5 million people needing humanitarian assistance in the Dry Corridor region of Central America alone.[421] The Dry Corridor entered its fifth consecutive drought year in 2019 and is projected to increase in duration by 12–30%, intensity by 17–42%, and frequency by 21–42% by the end of the century.[422] In 2022, 30% of Mexico experienced moderate to extreme drought, and 68% of Puerto Rico experienced moderate to severe drought.[423] By May 2022, over half (56%) of Mexico experienced moderate to exceptional drought.[424] In the Amazon, extreme drought caused an increase in fire events, increasing the conversion of rainforest to savannah.[425] In 2022, Chile entered the 14th year of its megadrought, the longest and most severe drought in the country in over a thousand years.[426] Hydropower is currently responsible for 50% of the electricity in Latin America, additionally, water is a key input for other forms of power generation.[427] Water scarcity will likely lead to electrical shutdowns primarily in urban areas, as seen already when Venezuela could not operate the Guri Dam, the second largest hydroelectric center in the world, in the midst of a drought.[428] For the last year, Argentina—a top global exporter of soy, and corn—has been experiencing the worst drought in over 60 years, impacting its crop production and exacerbating its inflation and economic crisis.[429] The impact of the drought on the country balances of payment is an example of what can the region expect on the link between extreme whether events and economics. Similar losses have already been felt in Brazil and Paraguay, which experienced up to a 70% loss in Soybean production and a 43% loss in maize production; the loss caused by the year-long drought in Uruguay cost the agricultural and cattle sector US$ 56 million.[430] The increase in frequency and intensity of droughts indicates the severity of the need for intensive climate action.

In the U.S., the increase in heat and reduction of snow under climate change have amplified recent hydrological droughts (severe water shortages) in California, the Colorado River Basin, and the Rio Grande. In California, the higher temperatures intensified the 2011–2016 drought, which had been initiated by years of low precipitation, causing water shortages to ecosystems, cities, farms, and energy generators.[431] In Canada, climate change contributed to an extreme drought in British Colombia in 2015 that was unusual in terms of its severity, extent, and impacts. In Alberta, the same drought conditions led the government to declare the Province an Agricultural Disaster Area.[432] The implications of these droughts have far-reaching impacts in light of the outsized influence of the U.S. and Canada on the global economy.

B. Oceans and Coastal Areas

LAC is particularly vulnerable to the impacts of climate change due to its dependence on coastal ecosystems for food and livelihoods. Rising sea levels, ocean acidification, and extreme weather events are causing damage to coastal infrastructure, displacement of communities, and loss of biodiversity.

Sea Level Rise. Over the last three decades, sea level has increased at a higher rate than the global level in the South Atlantic and will continue to rise in the oceans surrounding the region. Sea levels have risen by 2.21 mm per year along South American Pacific coasts, 3.23 mm per year along coastlines in the tropical North Atlantic, Central America, and southern Caribbean, 3.60 mm per year along coastlines in the subtropical North Atlantic and the Gulf of Mexico, and 3.66 mm per year along South American Atlantic coasts.[433] (In comparison, the global mean sea level rise between 1993–2022 averaged 3.4 mm per year.[434]) Increased sea level rise will cause further coastal flooding events in low-lying areas and coastal erosion. In low-lying islands in the Caribbean and coastal cities, sea level rise poses several risks, including to livelihoods, agriculture, aquaculture, and economies. These risks highlight the need for decisive, quick, and effective climate action.

The U.S. and Canada are also vulnerable to the impacts of climate change on the coast. Subsistence-based fishing communities, like those in Alaska, are at risk from the nutrition, infrastructure, economic, and health consequences to language, education, and the communities themselves as coastal areas continue to be affected. There is more than a trillion dollars' worth of real estate along the U.S. coastline, all of which is at risk from damage and degradation.[435] In Canada, northern coastal communities, many of which are Indigenous, have experienced some of the most rapid climate change globally, and projected changes for the region will continue to be significant.[436]

Ocean Acidification. GHG emissions and associated warming temperatures are also altering ocean chemistry, increasing seawater acidity, with devastating impacts on marine life in the LAC region. Throughout the Caribbean, and in colder waters of the Pacific all the way to Patagonia, ocean acidification is impacting the ability of organisms, such as shellfish and corals, to build shells and skeletons, which will severely undermine regional food security and livelihoods. These effects are exacerbated by overfishing, pollution, ocean warming, and reduced oxygen levels. The region relies heavily on the sea for food and livelihoods, and without significant reductions in emissions, the consequences will be catastrophic. Rising temperatures, ocean acidification, and other climate change impacts are leading to coral reef degradation in the Caribbean.

In the U.S., ocean acidification also poses a severe threat to the biodiversity of ecologically sensitive areas such as the Alaska coastline.[437] In Canada, the country's cold coastal waters may be particularly prone to acidification due to the natural occurrence of undersaturated waters at shallow depths (Pacific coast), or large freshwater input (Arctic coast).[438] In the Northeast Pacific Ocean for example, the saturation horizon is naturally shallow – as little as 100 meters below the surface. Scientists expect the saturation depth to become shallower as global atmospheric CO_2 concentrations increase over the coming century, putting organisms close to the surface at risk from ocean acidification.[439]

Coral Reefs. Coral reefs provide critical ecosystem services, including protection from storm surges and waves, and support for fisheries and tourism. Their loss will have significant economic and ecological impacts on the Americas generally. Even if global warming is constrained to a 1.5°C increase, 70–90% of warm-water coral reefs will die off; that number increases to near if not total die-offs as temperatures climb to 2°C.[440] The living cover of Caribbean reef-building corals has declined by more than 80% in the last 50 years.[441] As coral reefs support 25% of our ocean's marine life, mass die-offs of coral reefs will result in food insecurity for most of the world, especially coastal populations.[442]

Coral reefs also serve as a natural buffer for shorelines against waves, storm surges, floods, and erosion, providing protection for millions of people in the U.S. alone who live in coastal areas that will experience more severe impacts without coral reefs protection.[443] An estimated 1 billion people worldwide benefit from the ecosystem services provided by coral reefs, including food, coastal protection, and income from tourism and fisheries.[444] Beyond protection and food security, coral reefs provide a large economic benefit through tourism, in some cases accounting for a third of GDP in the Caribbean and as much as 80% in the Maldives.[445] The loss of coral reefs will result in economic loss as much as US$375 billion annually as a result of loss of tourism and destruction from flooding and other storm events.[446]

Coastal Degradation. Coastal erosion is one of the major impacts of climate change in the coastal areas of the LAC region. The rising sea levels and increased frequency and intensity of storms are causing the loss of beaches, cliffs, and coastal wetlands.[447] The erosion of coastlines is threatening the infrastructure, such as homes, roads, and ports, and is also affecting the livelihoods of local communities that depend on tourism and fisheries. A combination of natural and human factors causes the erosion of coastlines. Natural factors include wave action, tides, and currents, while human factors include coastal development, sand mining, and deforestation. Coastal erosion has significant economic and social impacts. It reduces the value of coastal properties, affects tourism revenue, and leads to the displacement of communities. The loss of coastal wetlands, such as mangrove forests, also reduces the protection they provide against storm surges and flooding.[448] Many measures, including GHG mitigation, financing for adaptation infrastructure, and protection of mangroves and wetlands, would significantly reduce impacts and protect coastal communities.[449]

C. Glaciers and Mountains

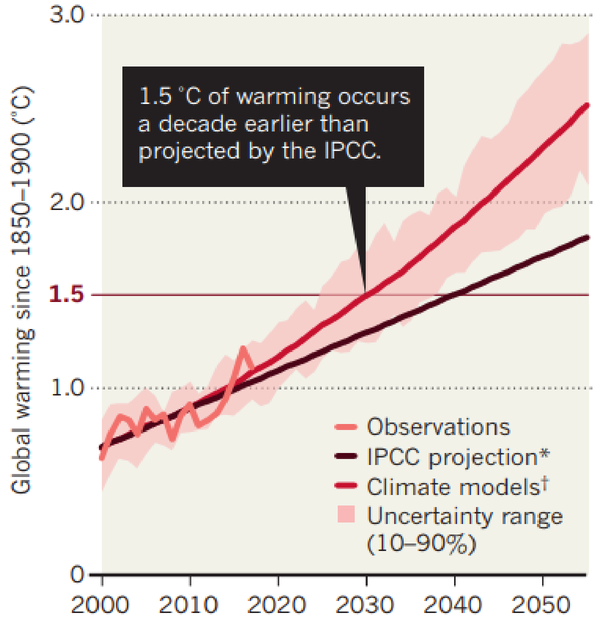
Ice Loss. Global sea levels are rising at an accelerating rate due to glacier and ice melt from anthropogenic warming.[450] Between 1992–1999 and 2010–2019, the rate of glacier and ice sheet loss increased by a factor of four, and along with glacier mass loss, was the majority contributor to sea level rise between 2006–2018,[451] threatening 900 million people living in low-lying coastal areas—one out of every ten people on Earth.[452] Since the 1980s, glaciers in the Andes have decreased by 30–50% overall, with the Southeastern Andes experiencing the highest loss of glacier mass worldwide.[453] Decreased water supplies from glacier retreat will result in negative socioeconomic impacts, such as affecting fruit production in Argentina.[454] In South America, ice fields in Patagonia are the largest bodies of ice outside of Antarctica in the Southern Hemisphere and are quickly losing volume, triggering floods and changing river ecosystems.[455] Non-climate drivers are exacerbating the vulnerability of low-lying coastal communities' exposure to sea level rise and extreme sea level events.[456]

Rapid cuts in emissions are critical to avoid further ice loss, and, as discussed in Section II *supra*, reducing super climate pollutant emissions is the best and fastest way to cut the rate of warming in the near term—fast cuts can reduce the rate of sea level rise by 18% by 2050.[457]

Annex B: Climate Change in Figures: Emissions, Impacts, Solutions, and Benefits

A. The Need for Fast Action on Super Climate Pollutants

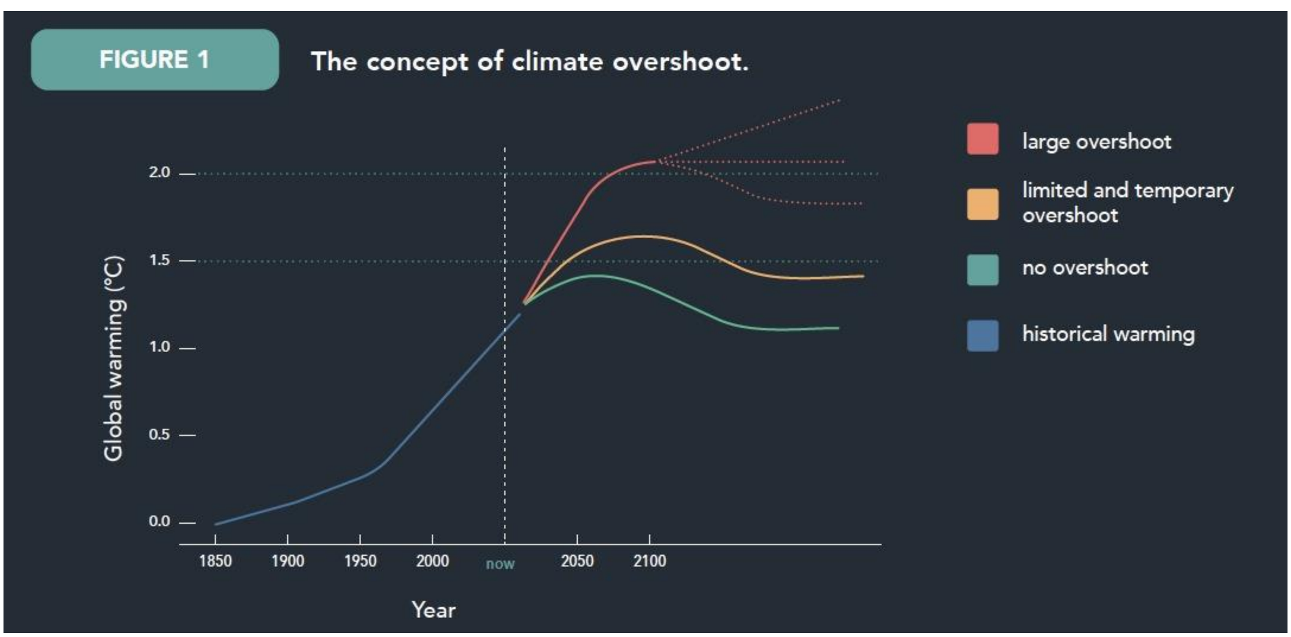
Figure 1. Temperature Trajectory Towards Breaching the 1.5°C Guardrail



*Trend for 2001–15 extended with a constant rate of 0.2 °C per decade, as per IPCC special report. †Ten-year average, 37 climate models for the RCP8.5 scenario (IPCC Fifth Assessment, 2014).

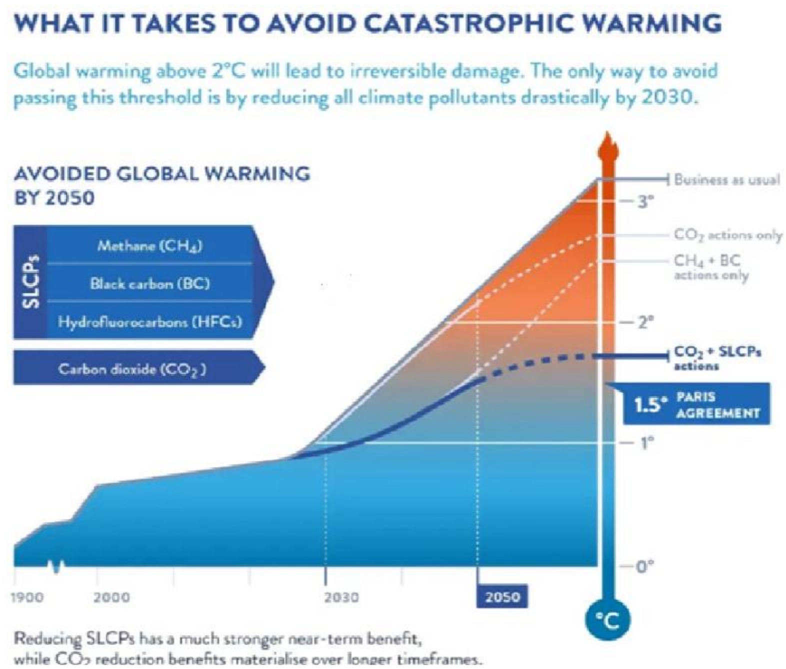
Source: Xu Y., Ramanathan V., & Victor D. (2018) *Global warming will happen faster than we think*, Comment, NATURE 564(7734): 30–32.

Figure 2. The Concept of Climate Overshoot



Source: Climate Overshoot Commission (2023) REDUCING THE RISKS OF CLIMATE OVERSHOOT, 27.

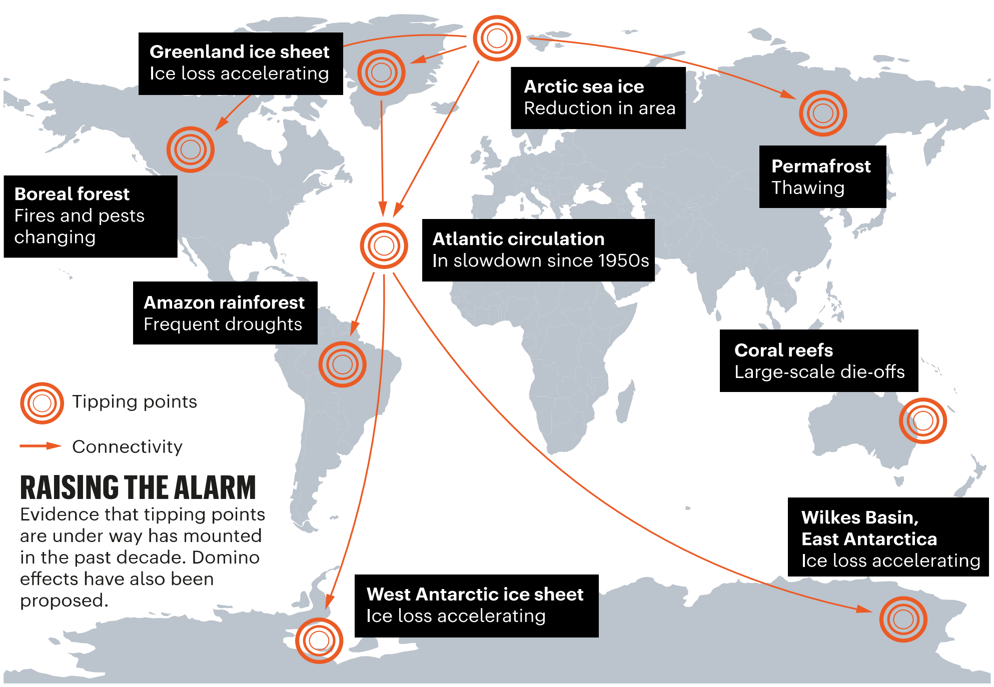
Figure 3. Temperature Consequences of Delayed SLCP Mitigation



Source: Climate & Clean Air Coalition, *What are short-lived climate pollutants?*, SLCP Infographics (*last visited* 8 September 2023).

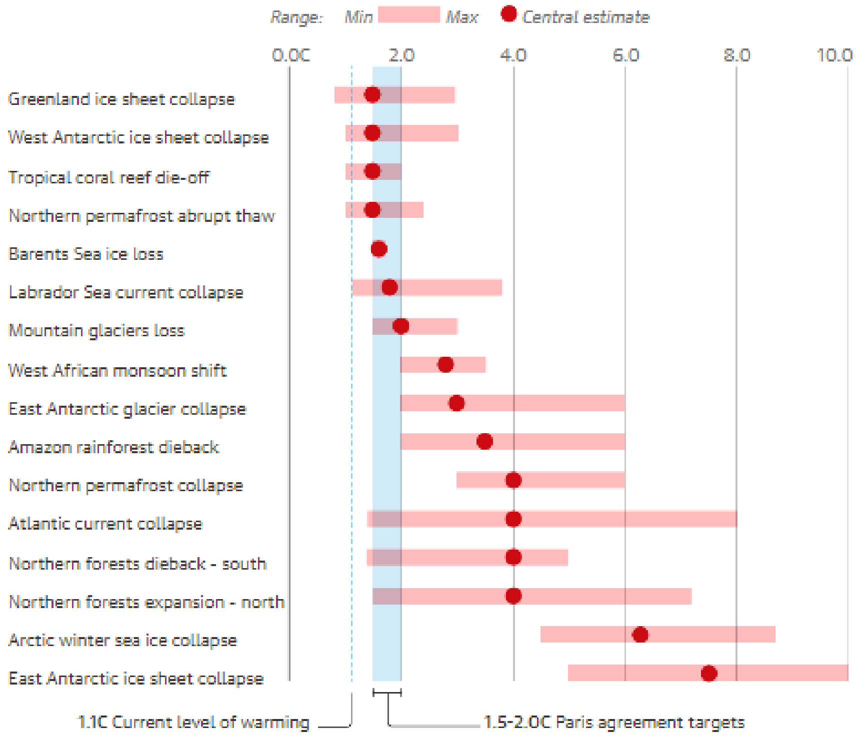
B. Climate Tipping Points

Figure 4. Critical Climate Tipping Points



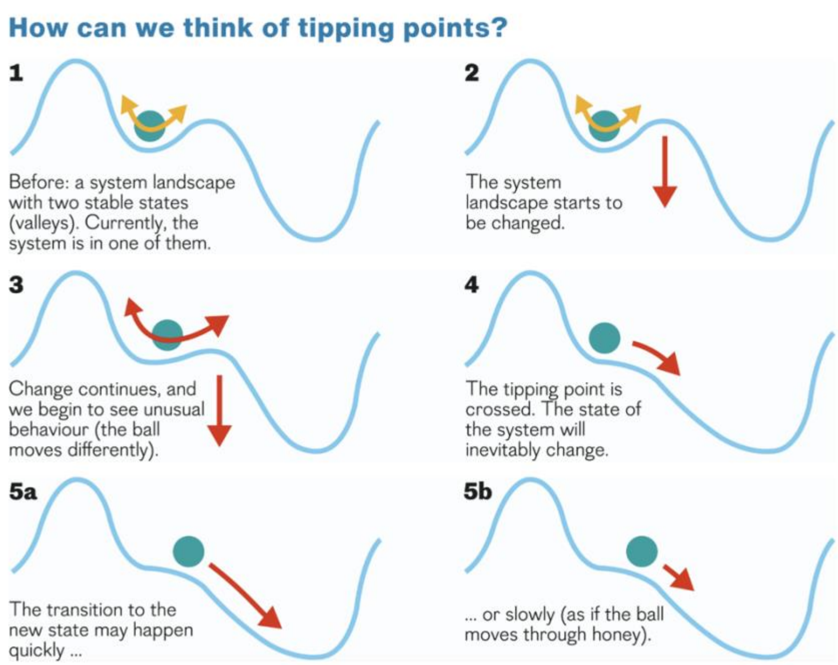
Source: Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE, 575(7784): 592–595.

Figure 5. Range of Global Heating to Trigger Tipping Points



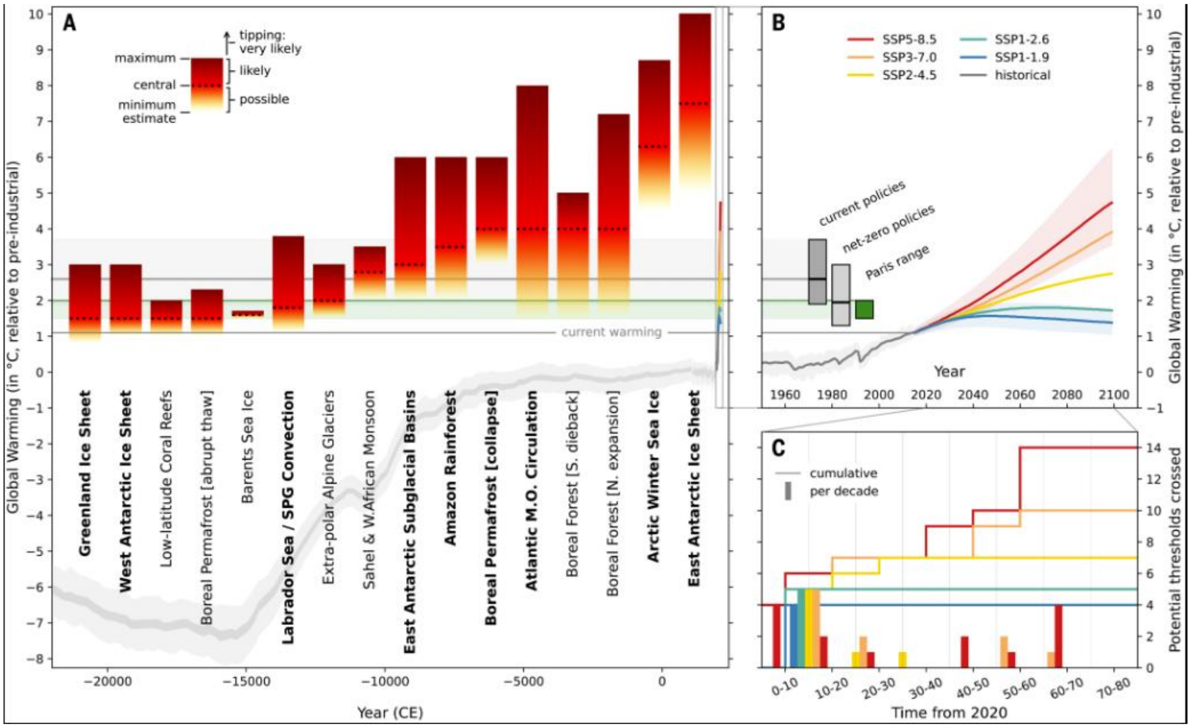
Source: Carrington D. (2022) *World on brink of five 'disastrous' climate tipping points, study finds*, THE GUARDIAN.

Figure 6. Understanding Tipping Points



Source: Rockström J. (2023) *Tipping Points and Feedback Loops, in* THE CLIMATE BOOK: THE FACTS AND THE SOLUTIONS, Thunberg G. (ed.), 36.

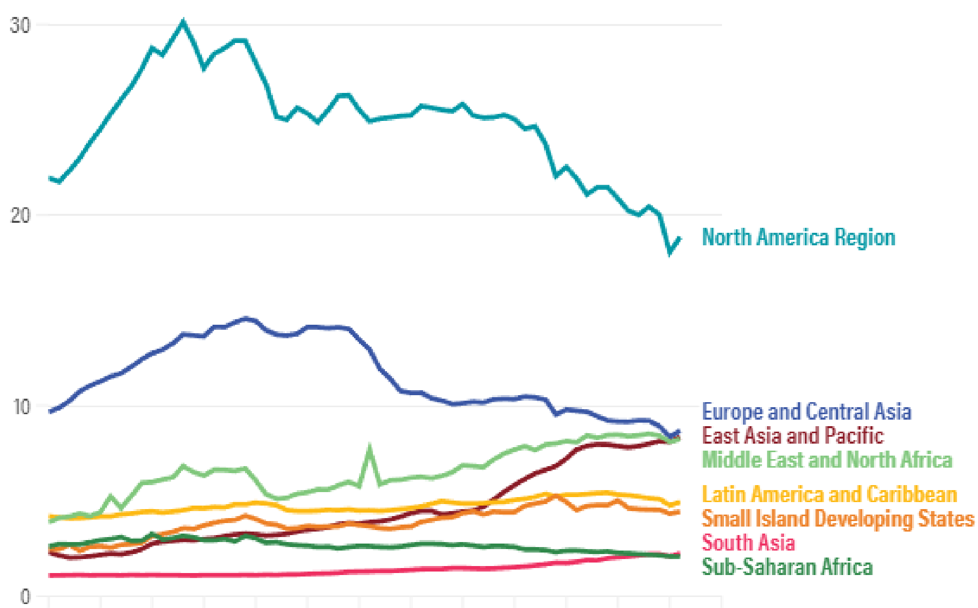
Figure 7. Temperature Limits Causing Tipping Points



Source: Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5 °C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, Figure 2.

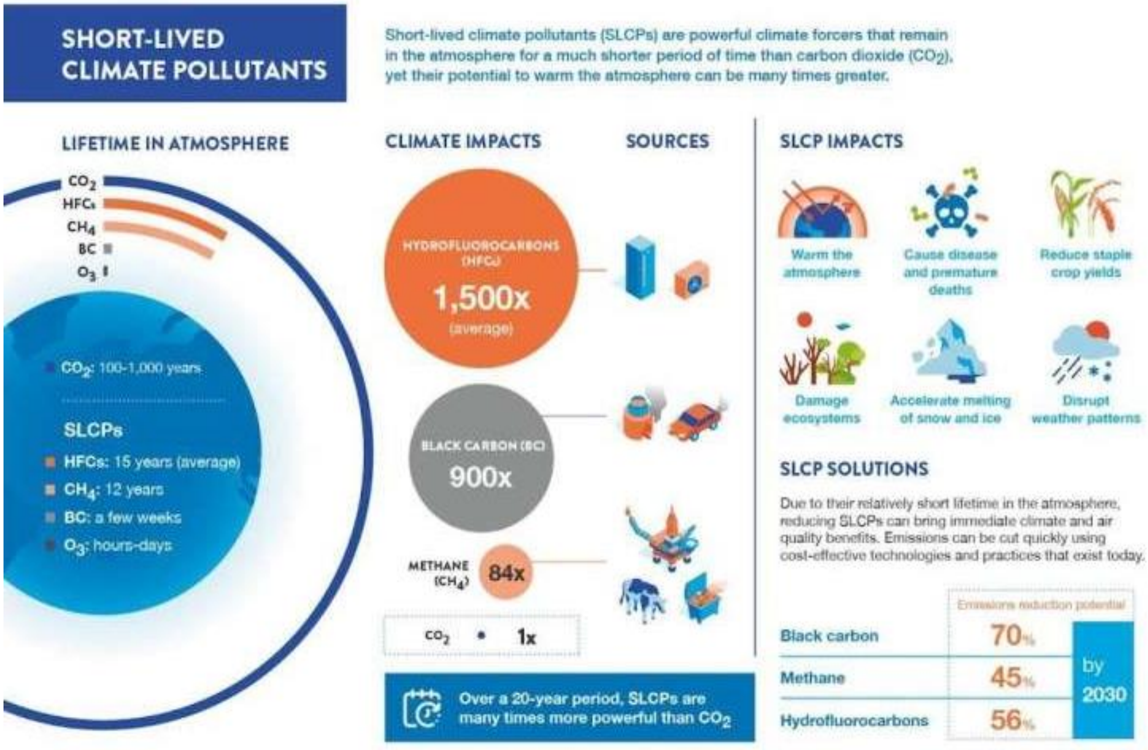
C. Sources of Greenhouse Gas Emissions

Figure 8. Greenhouse Gas Emissions per Sector, LAC v. World



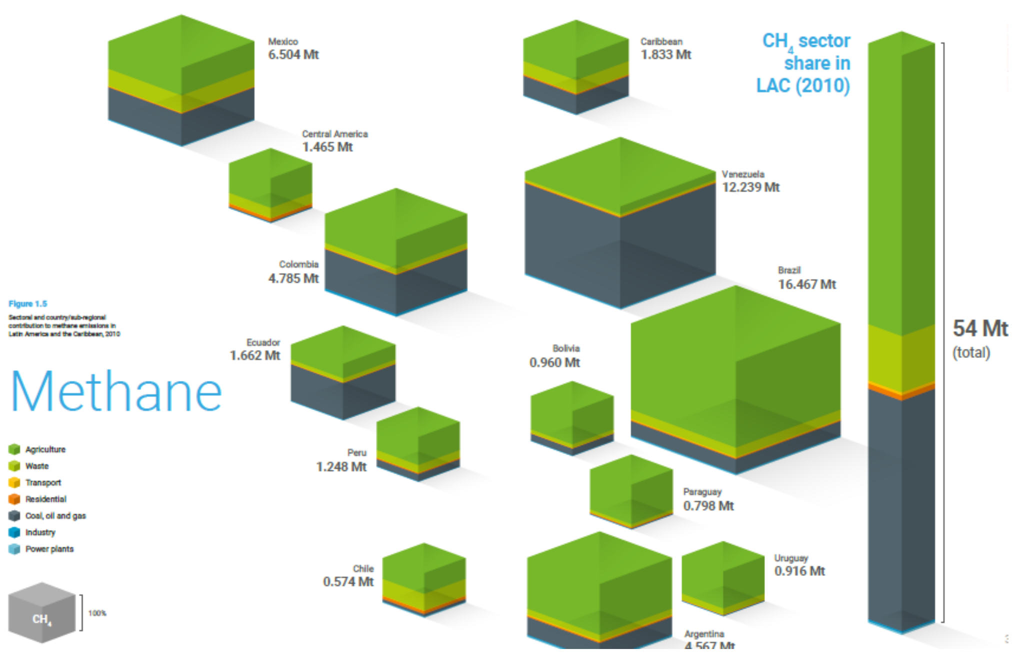
Source: Vigna L. & Friedrich J. (8 May 2023) *9 Charts Explain Per Capita Greenhouse Gas Emissions by Country*, World Resources Institute Insights.

Figure 9. Overview of Short-Lived Climate Pollutants



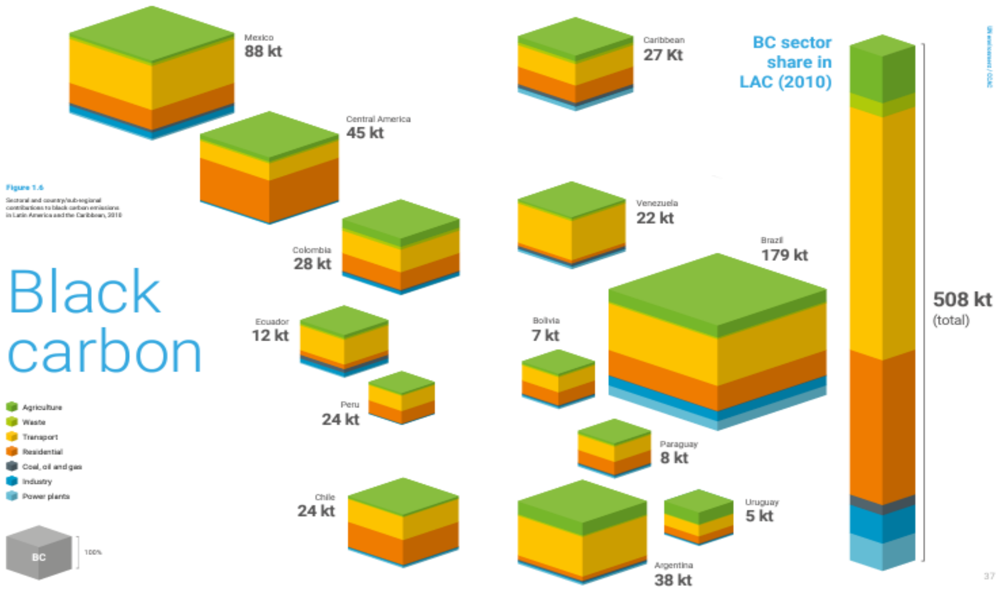
Source: Climate & Clean Air Coalition, [*What are short-lived climate pollutants?*](), SLCP Infographics (*last visited* 8 September 2023).

Figure 10. Sources of Methane Emissions, LAC



Source: Climate & Clean Air Coalition (2018) [*Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean*]().

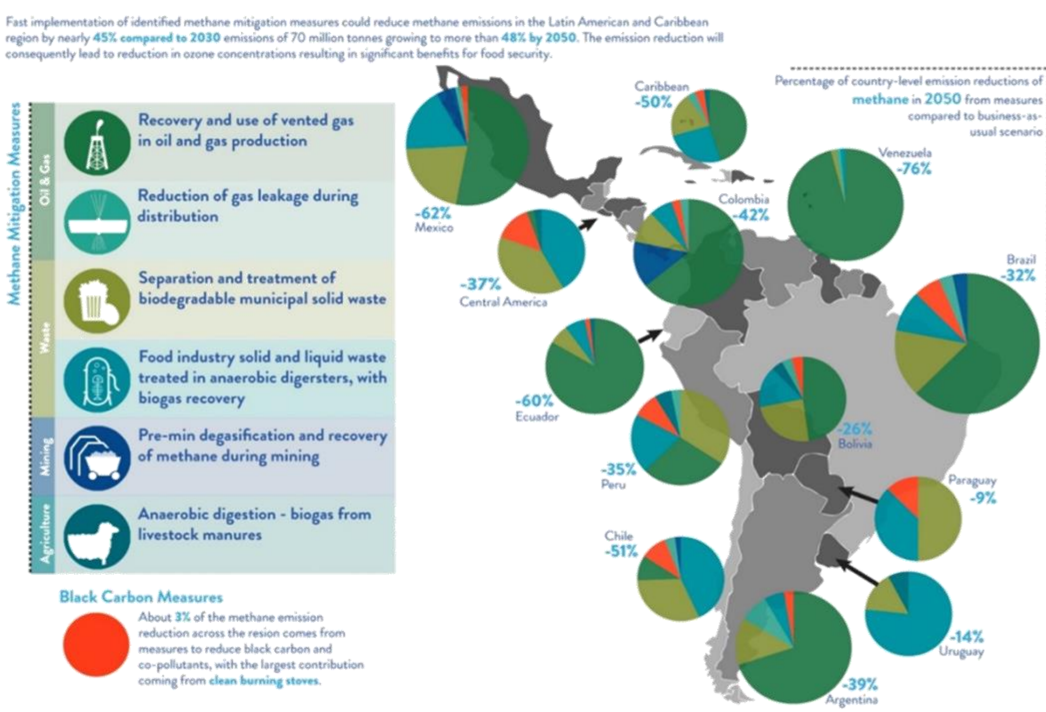
Figure 11. Sources of Black Carbon Emissions, LAC



Source: Climate & Clean Air Coalition (2018) [*Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean*].

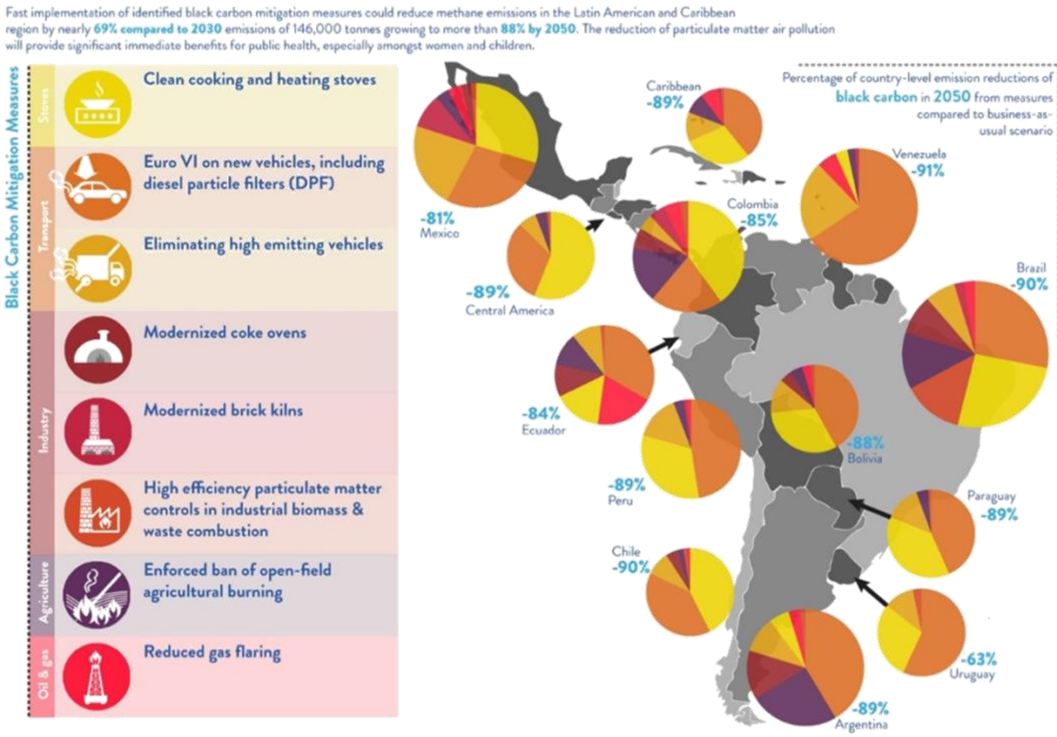
D. Examples of Super Climate Pollutant Mitigation Measures

Figure 12. Methane Mitigation Measures and Potential Reductions



Source: Climate & Clean Air Coalition (2018) [*Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean*].

Figure 13. Black Carbon Measures and Potential Reductions



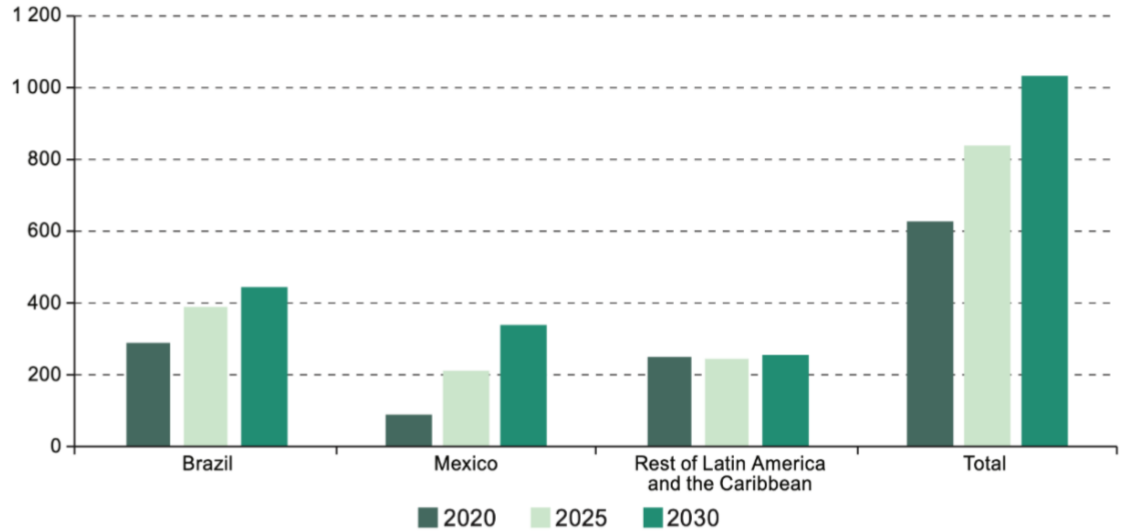
Source: Climate & Clean Air Coalition (2018) *Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean*.

E. Examples of Super Climate Pollutant Mitigation Measures

Figure 14. Annual Benefits of SLCP Mitigation by 2030

Source: United States Agency for International Development (2022) *Short-Lived Climate Pollutants & USAID's Climate Strategy: Achieving Fast Mitigation*.

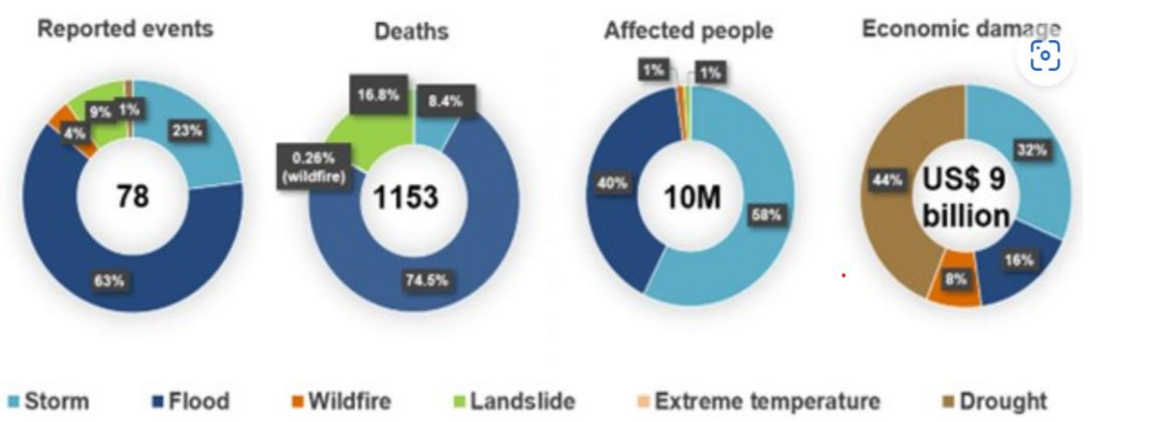
Figure 15. Potential Jobs Created through Energy Transition, 2020–2030 (thousand jobs created)



Source: United Nations Economic Commission for Latin America and the Caribbean & International Labour Organization (2018) EMPLOYMENT SITUATION IN LATIN AMERICA AND THE CARIBBEAN: *ENVIRONMENTAL SUSTAINABILITY AND EMPLOYMENT IN LATIN AMERICA AND THE CARIBBEAN*, Nº 19 LC/TS.2018/85.

F. Climate Risks and Vulnerabilities in LAC

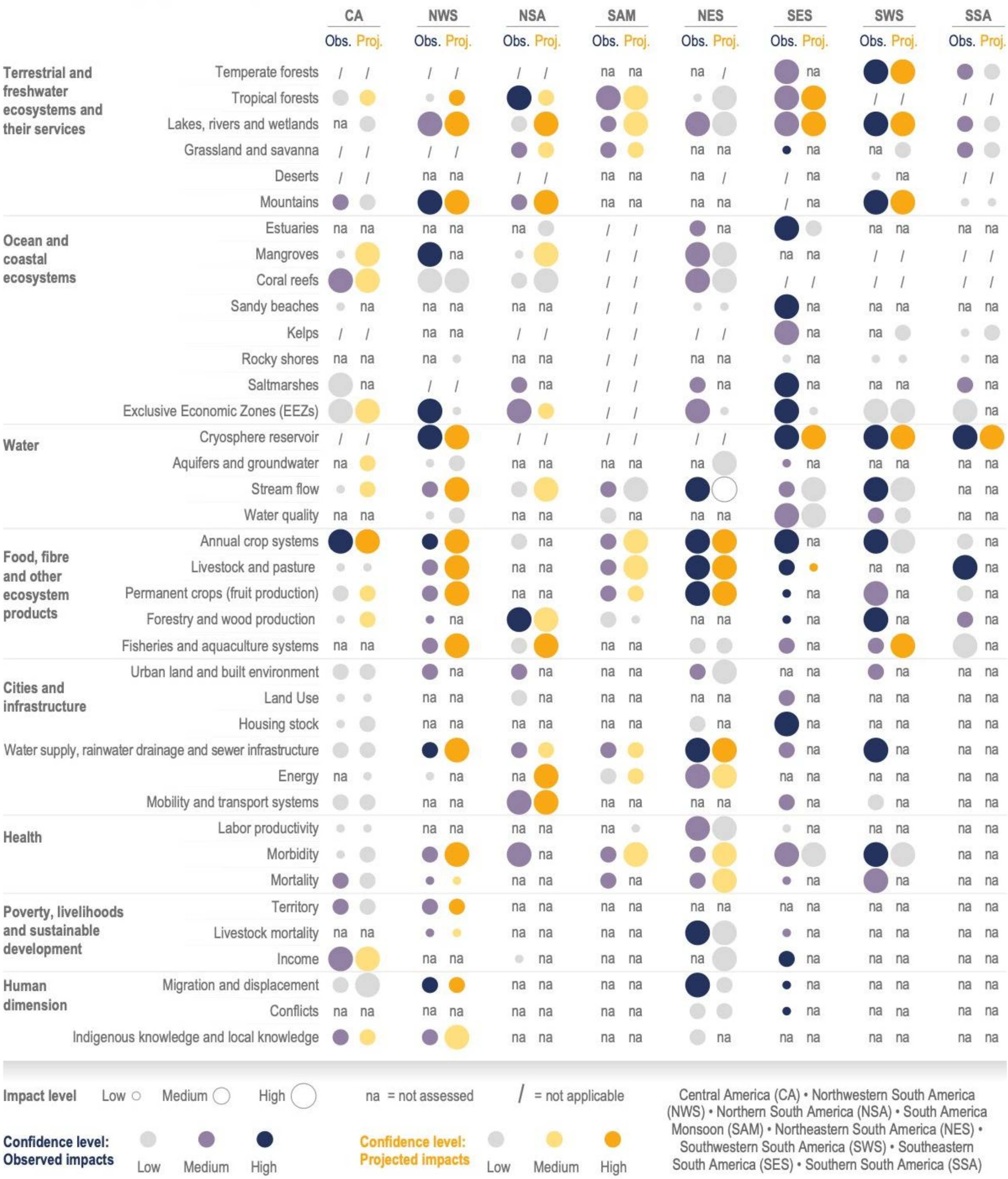
Figure 16. Weather, Climate, and Water-related Disasters in LAC



Weather, climate and water-related disasters in Latin America and the Caribbean in 2022. Impact numbers for some disaster occurrences may be lacking due to data unavailability. Source: CRED EM-DAT

Source: World Meteorological Organization (2023) *Climate change vicious cycle spirals in Latin America and the Caribbean*.

Figure 17. Observed and Projected Climate Impacts for Central and South America



Fuente: Castellanos E., *et al.* (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.).

Figure 18. Observed and Projected Hazards in Central and South America, Current Levels v. 2–4°C Increase

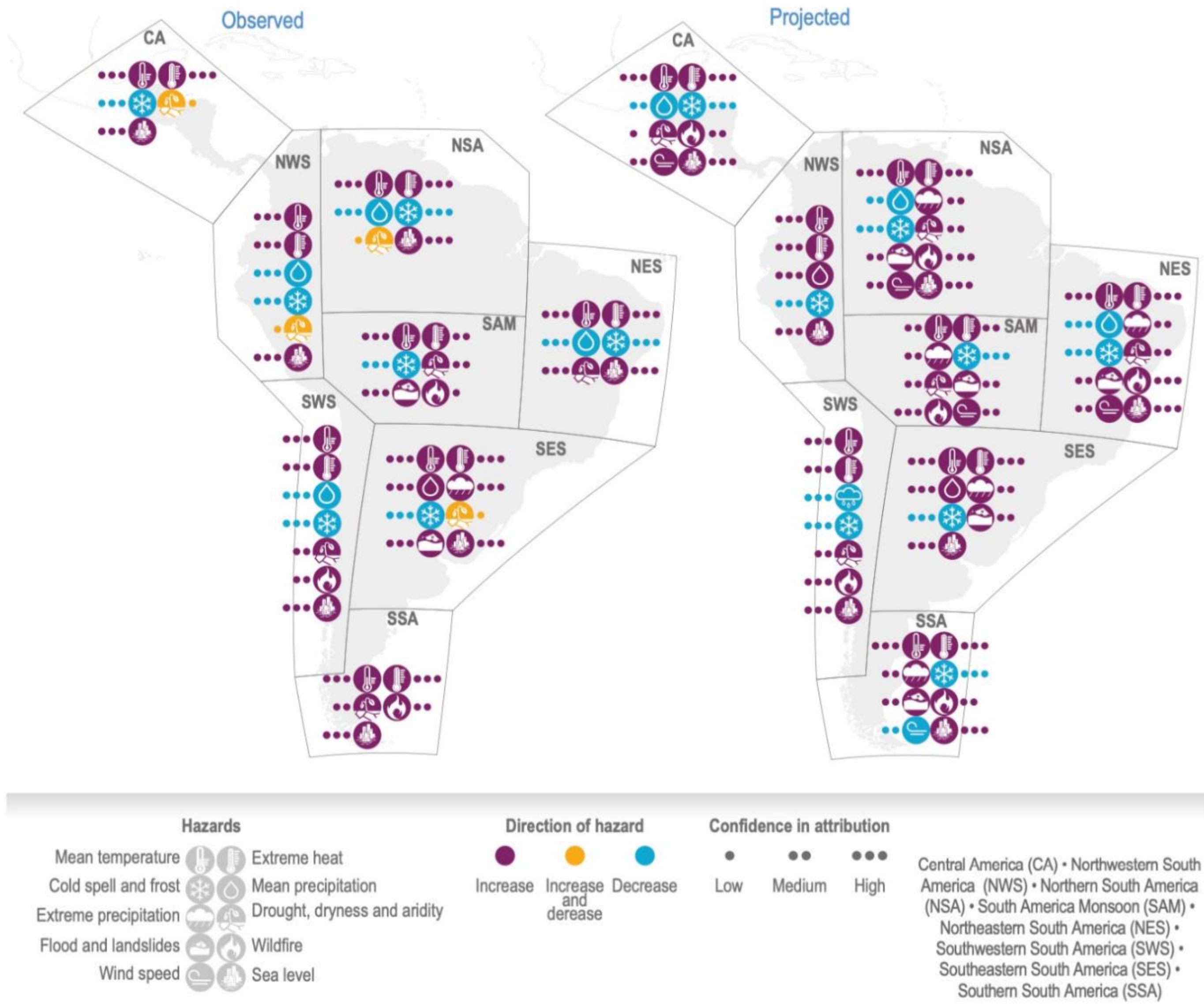
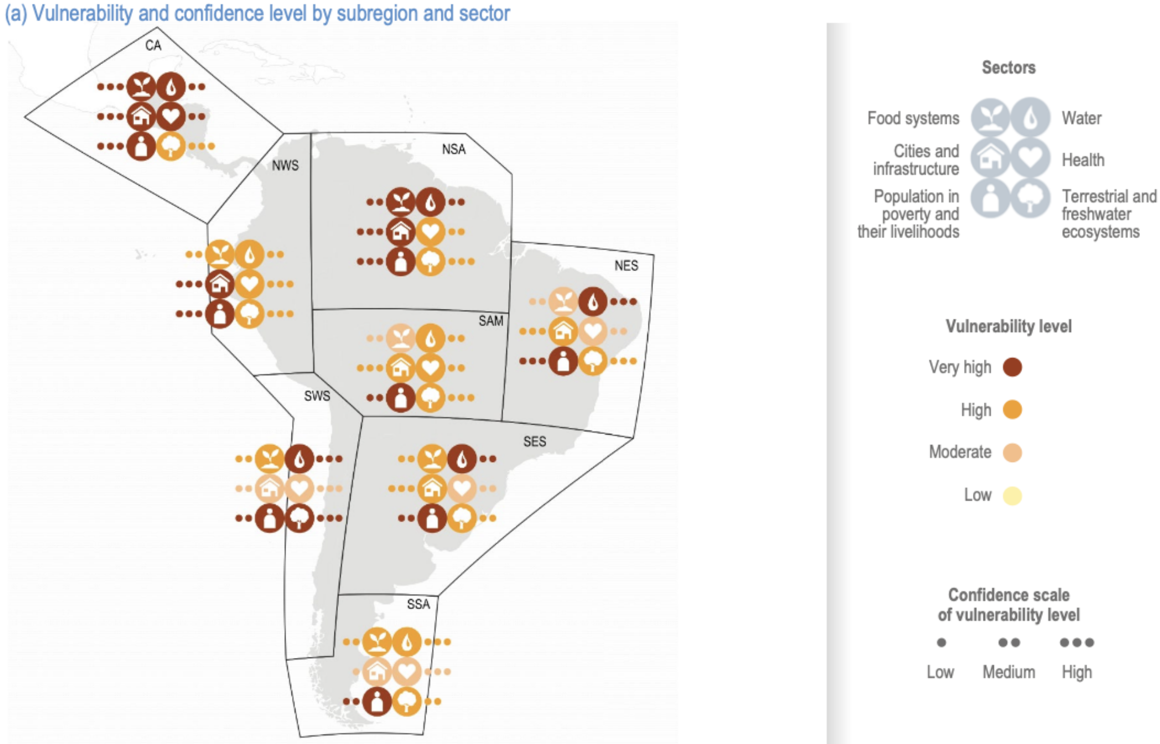


Figure 12.6 | Observed trends (WGI AR6 Tables 11.13, 11.14, 11.15) (Seneviratne et al., 2021) and summary of confidence in direction of projected change in climatic impact drivers, representing their aggregate characteristic changes for mid-century for RCP4.5, SSP3-44 4.5 and SRES A1B scenarios, or above within each AR6 region, approximately corresponding (for CIDs that are independent of SLR) to global warming levels between 2°C and 2.4°C (WGI AR6 Table 12.6) (Ranasinghe et al., 2021).

Fuente: Castellanos E., *et al.* (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.).

Figure 19. Vulnerabilities in LAC per Sector

(a) Vulnerability and confidence level by subregion and sector



(b) References used and vulnerability level attributed by subregion and sector

Sectors	CA	NES	NSA	NWS	SAM	SES	SSA	SWS
Food systems	4,6,9,11, 14,19,21, 27,35, 40,47	6,9,16, 21,22,27, 35,47	6,9,11,14, 19,21,27, 35,45,47	6,14,19,21 ,22,27,35, 40,45	6,21,27, 35,47	6,9,14,2 1,22,27, 35,47	6,14,21, 22,27,35, 39,47	6,14,21, 22,27,35, 39,40, 45
Cities and infrastructure	5,35	5,31,25	5,35	5,35	5,35	5,35	5,35	5,35
Population in poverty and their livelihoods	7,15,10, 12,13,23 ,25,40	10,12,13 ,15,17,2 5,28,49	10,12,13, 15,17,25, 28,33	10,12,13, 15,25,40	10,12,13, 15,17,25	10,12,13, 15,17,25, 28	10,12,13, 15,25	10,12,13, 15,25,40, 44
Water	26,35,41	26,35,48, 49,50	24,26,35	24,26,35	24,26,35	24,26,35, 41	24,26,35, 39	24,26,35, 39
Health	20,30,35	20,30,35 ,50	20,30,35	20,30,35	20,30,35	20,30,35	20,30,35	20,30,35
Terrestrial and freshwater ecosystems	29,35,38	2,29,32, 35,37,38 42	2,29,35, 37,38	2,8,24, 29,35,3 7,38	2,29,35, 37,38	29,35,38	24,29,35, 38	3,18,24, 29,35,38 ,46

Central America (CA) • Northwestern South America (NWS) • Northern South America (NSA) • South America Monsoon (SAM) • Northeastern South America (NES) • Southwestern South America (SWS) • Southeastern South America (SES) • Southern South America (SSA)

Figure 12.7 | Sectoral distribution of vulnerability levels to climate change for sub-regions. The vulnerability levels are based on studies that include: (a) databases with climate-change vulnerability indexes by country and sector, (b) studies that apply climate-change vulnerability indexes by sector at the local, national, regional or global scale, and (c) studies that define some vulnerability level based on the authors' expert judgment.

Panel (a) shows the vulnerability and confidence levels for each sub-region.

Panel (b) indicates the references used and the level of vulnerability by sub-region. The numbers within the table indicate the reference used for the assessment in the following order: (1) Aitken et al. (2016); (2) Anderson et al. (2018b); (3) Bañales-Seguel et al. (2018); (4) Bouroncle et al. (2017); (5) CAF (2014); (6) Carrão et al. (2016); (7) Donatti et al. (2019); (8) Eguiguren-Velepucha et al. (2016); (9) FAO (2020a); (10) FAO (2020b); (11) FAO (2021a); (12) FAO (2021b); (13) FAO (2021c); (14) FAO et al. (2021); (15) FAO and ECLAC (2020); (16) Ferreira Filho and Moraes (2015); (17) Filho et al. (2016); (18) Fuentes-Castillo et al. (2020); (19) FSIN and Global Network Against Food Crisis (2021); (20) Global Health Security Index (2019); (21) Godber and Wall (2014); (22) Handisyde et al. (2017); (23) Hannah et al. (2017); (24) Immerzeel et al. (2020); (25) Inform Risk Index (2021); (26) Koutroulis et al. (2019); (27) Krishnamurthy et al. (2014); (28) Lapola et al. (2019a); (29) Li et al. (2018); (30) Lin et al. (2020); (31) Mansur et al. (2016); (32) Martins et al. (2017); (33) Menezes et al. (2018); (34) Nagy et al. (2018);35) ND-Gain (2020); (36) Northey et al. (2017); (37) Olivares et al. (2015); (38) Pacifici et al. (2015); (39) Qin et al. (2020); (40) Romeo et al. (2020); (41) Liu and Chen (2021); (42) Silva et al. (2019b); (43) Soto Winckler and Del Castillo Pantoja (2019); (44) Soto et al. (2019); (45) Tomby and Zhang (2019); (46) Venegas-González et al. (2018b); (47) Yeni and Alpas (2017); (48) Marengo et al. (2017); (49) Bedran-Martins et al. (2018); (50) Confalonieri et al. (2014a). Detailed methodology can be found in SM12.2.

Fuente: Castellanos E., *et al.* (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.).

Figure 20. Climate Risks in Central and South America for Temperature Increase Above 2°C

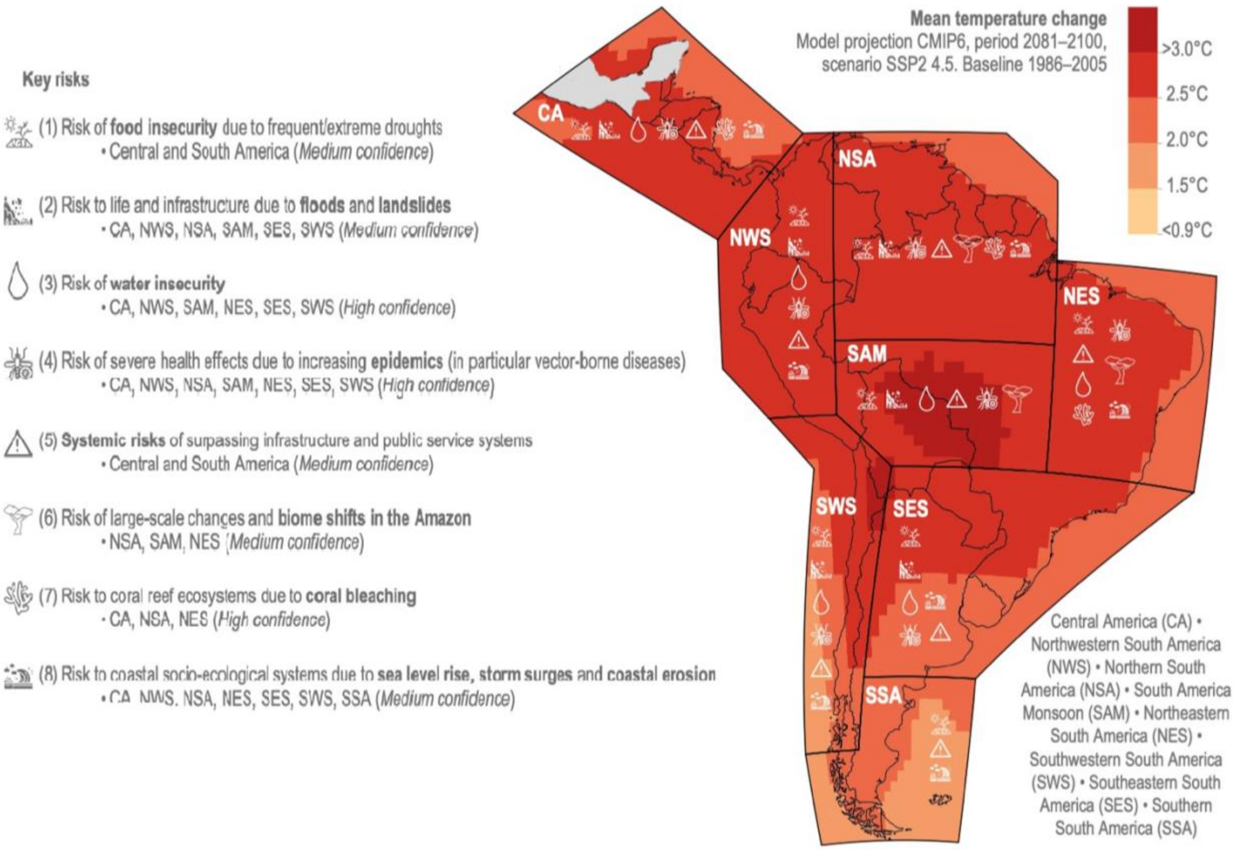
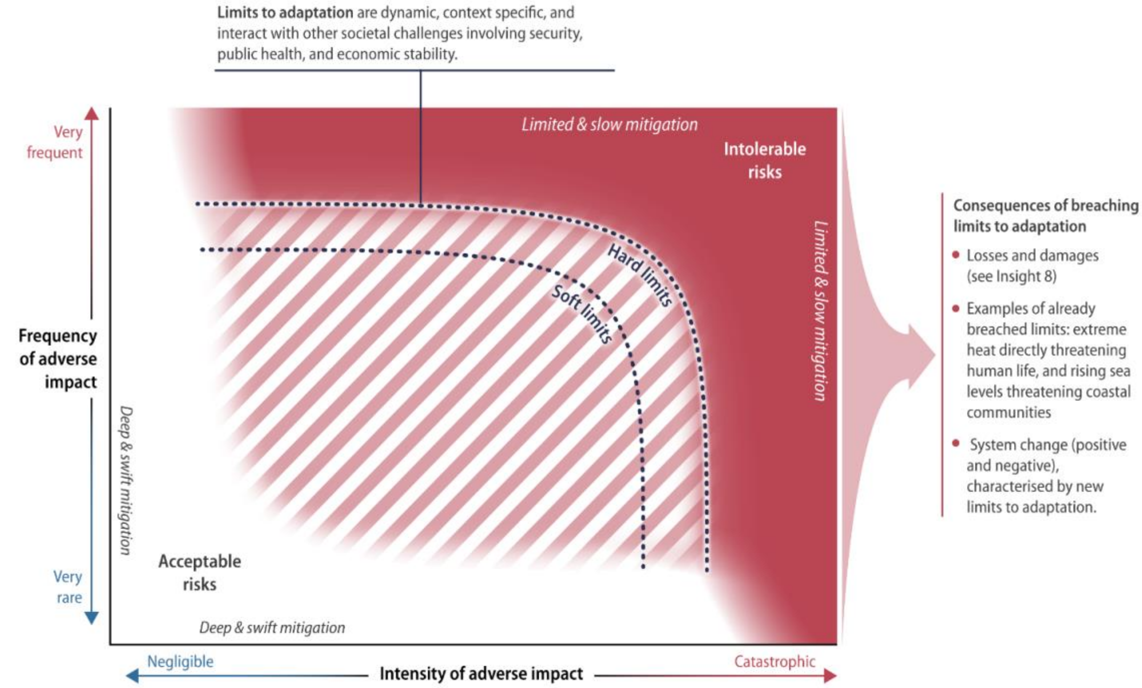


Figure 12.11 | Synthesis of key risks for the CSA region. The base map indicates the mean temperature change between the SSP2 4.5 scenario using CMIP6 model projections for 2081–2100 and a baseline period of 1986–2005 (WGI AR6 Atlas, Gutiérrez et al., 2021).

Fuente: Castellanos E., *et al.* (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.).

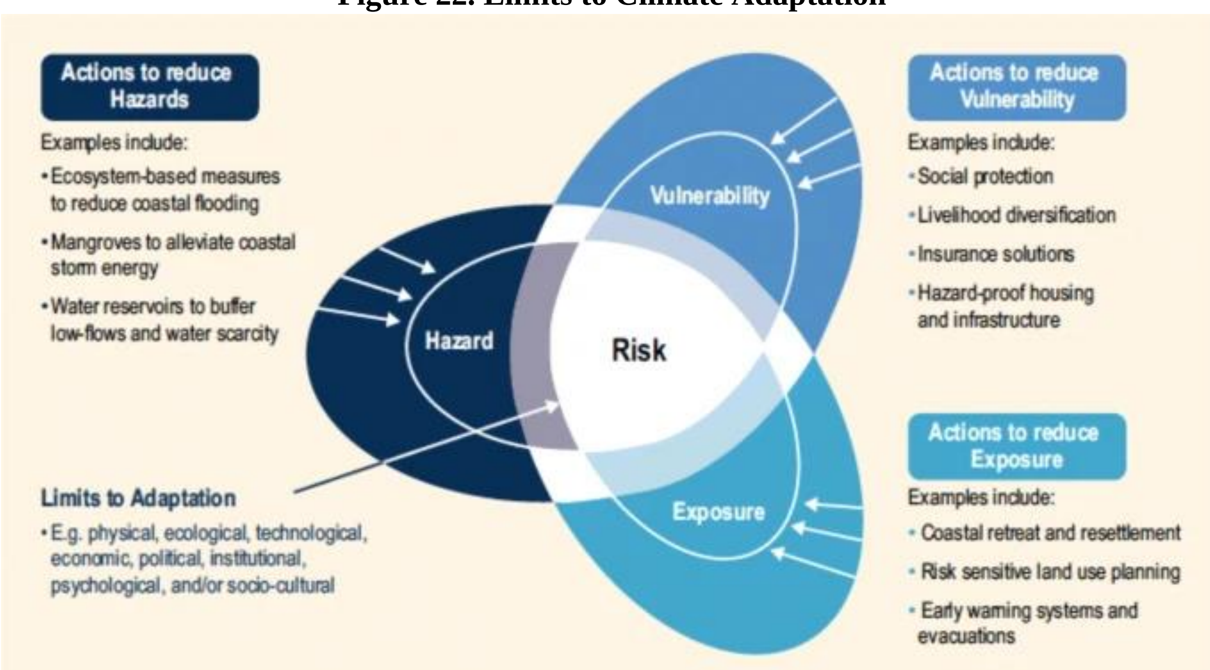
G. Climate Change Adaptation in Figures

Figure 21. Limits of Climate Adaptation



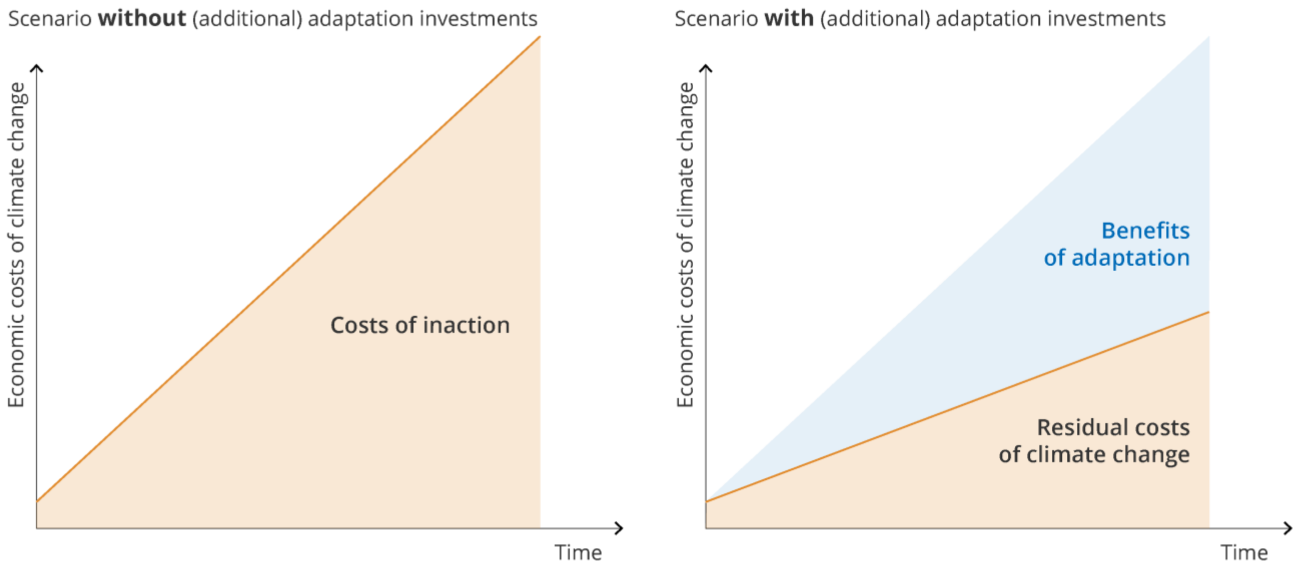
Source: 10 New Insights from Climate Science (2022) *Questioning the myth of endless adaptation*.

Figure 22. Limits to Climate Adaptation



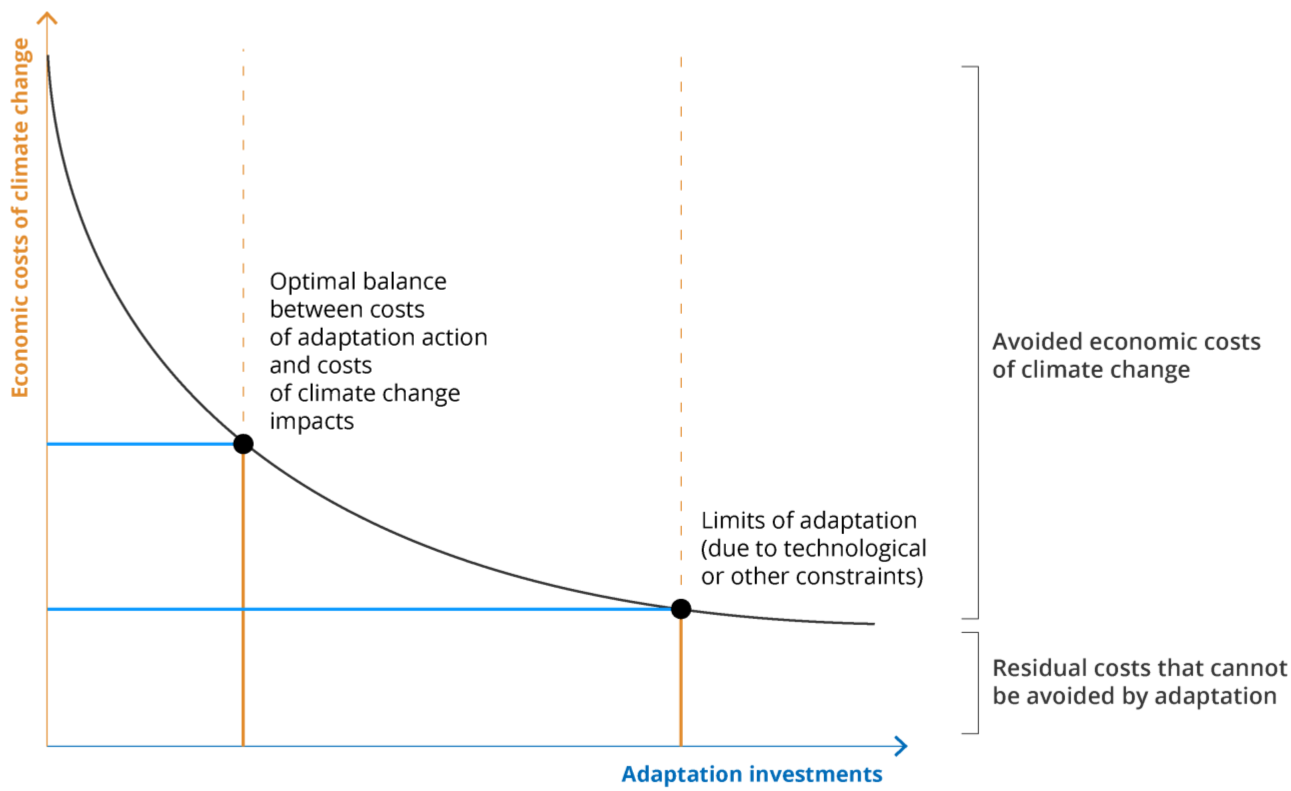
Source: Mechler R., *et. al.* (2020) *Loss and Damage and limits to adaptation: recent IPCC insights and implications for climate science and policy*, SUSTAIN. SCI. 15: 1245–1251, 1249.

Figure 23. Costs of Inaction v. Benefits of Adaptation



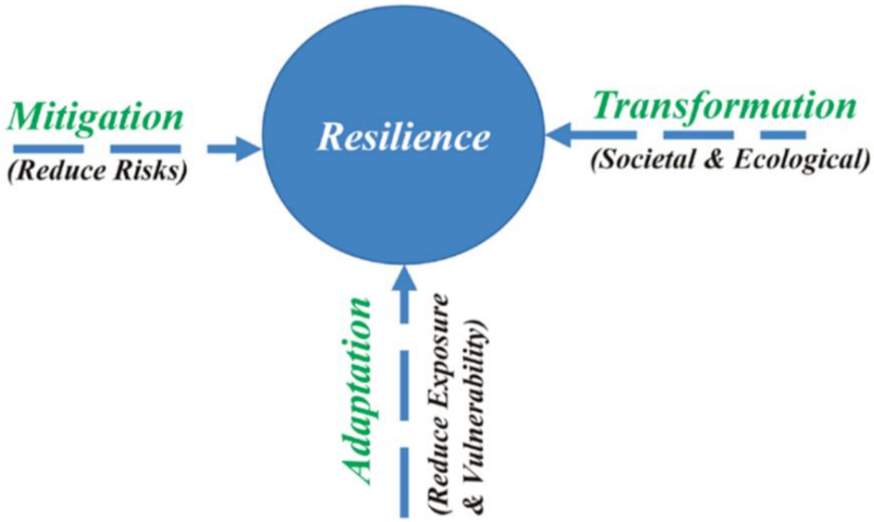
Source: European Environment Agency (2023) [*Assessing the costs and benefits of climate change adaptation*].

Figure 24. Link Between Adaptation Investments and the Economic Costs of Climate Change



Source: European Environment Agency (2023) [*Assessing the costs and benefits of climate change adaptation*].

Figure 25. The Three Pillars of Resilience



Source: Ramanathan V. & von Braun J. (eds.), *Resilience of People and Ecosystems under Climate Stress*, Proceedings of a Conference Held at Casina Pio IV, Vatican City, 13-14 July 2022, Libreria Editrice Vaticana: Vatican City.

H. Videos

Explanations of tipping points and the catastrophic risks to the climate system

How 16 Tipping Points Could Push Our Entire Planet Into Crisis | World Economic Forum

Climate Tipping Points by Tim Lenton | YouTube

How Close Are We to a Climate Change Tipping Point? | YouTube

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The limits of adaptation

"We're coming closer to limits of adaptation" Climate researcher Johan Rockström | YouTube

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Explanation of causes of climate change: CO_2 and non-CO_2 pollutants and importance of carbon sinks

Project Drawdown presents the Drawdown Roadmap: The Science Behind the Roadmap | YouTube

The Benefits of Reducing Short-lived Climate Pollutants | Drew Shindell, Climate & Clean Air Coalition | Youtube

Climate Resilience: Why, When and How? | Professor V. Ramanathan | The Pontifical Academy of Sciences

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[1] Goldstein A., Noon M. L., Ledezma J. C., Roehrdanz P. R., Raghav S., McGreevey M., Stone C., Shrestha S., Golden Kroner R., Hole D., & Turner W. (2021) IRRECOVERABLE CARBON: THE PLACES WE MUST PROTECT TO AVERT CLIMATE CATASTROPHE, Conservation International, 7 ("'Irrecoverable carbon' refers to the vast stores of carbon in nature that are vulnerable to release from human activity and, if lost, could not be restored by 2050 — when the world must reach net-zero emissions to avoid the worst impacts of climate change... There are high concentrations of irrecoverable carbon in the Amazon (31.5 Gt), the Congo Basin (8.1 Gt), and New Guinea (7.3 Gt). Other important irrecoverable carbon reserves are located in the Pacific Northwest of North America, the Valdivian forests of Chile, the mangroves and swamp forests of Guyana, the peatlands of Northern Scotland, Niger Delta's mangroves, Cambodia's Tonle Sap Lake, the Scandinavian and Siberian boreal forests, and the eucalyptus forest of Southeast Australia, among others."). *See also* Goldstein A., *et al.* (2020) *Protecting irrecoverable carbon in Earth's ecosystems*, NAT. CLIM. CHANGE 10(4): 287–295; *and* Noon M. L., Goldstein A., Ledezma J. C., Roehrdanz P. R., Cook-Patton S. C., Spawn-Lee S. A., Wright T. M., Gonzalez-Roglich M., Hole D. G., Rockström J., & Turner W. R. (2021) *Mapping the irrecoverable carbon in Earth's ecosystems*, NAT. SUSTAIN. 5: 37–46.

[2] World Meteorological Organization (2024) STATE OF THE GLOBAL CLIMATE 2023, 3 ("The ten-year average 2014–2023 global temperature is 1.20±0.12°C above the 1850–1900 average, the warmest 10-year period on record.").

[3] Forster P. M. … Zhai P. (2023) *Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence*, EARTH SYSTEM SCIENCE DATA 15(6): 2295–2327, 2295 ("The indicators show that human-induced warming reached 1.14 [0.9 to 1.4] C averaged over the 2013–2022 decade and 1.26 [1.0 to 1.6] ˚C in 2022."); 2309 ("AR6 defined the current human-induced warming relative to the 1850–1900 baseline as the decade average of the previous 10-year period (see AR6 WGI Chap. 3). …SR1.5 defined current human-induced warming as the average of a 30-year period centred on the current year, assuming the recent rate of warming continues (see SR1.5 Chap. 1). This definition is currently almost identical to the present-day single-year value of human-induced warming, differing by about 0.01 °C (see results in Sect. 7.4); the attribution assessment in SR1.5 was therefore provided as a single-year warming. This section also updates the SR1.5 single-year approach by providing a year 2022 value.").

[4] World Meteorological Organization (2023) WMO GLOBAL ANNUAL TO DECADAL CLIMATE UPDATE, 2 ("The annual mean global near-surface temperature for each year between 2023 and 2027 is predicted to be between 1.1°C and 1.8°C higher than the average over the years 1850-1900. • The chance of global near-surface temperature exceeding 1.5°C above preindustrial levels for at least one year between 2023 and 2027 is more likely than not (66%). It is unlikely (32%) that the five-year mean will exceed this threshold.").

[5] United Nations (1992) UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, art. 2 ("The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner").

[6] Here we distinguish between abrupt shifts, as in Drijfhout *et al*. (2015), and the more restrictive definition of "core climate tipping points" defined by Armstrong McKay *et al.* (2022) as "when change in part of the climate system becomes (i) selfperpetuating beyond (ii) a warming threshold as a result of asymmetry in the relevant feedbacks, leading to (iii) substantial and widespread Earth system impacts." *See* Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS [West Antarctic Ice Sheet] and GrIS [Greenland Ice Sheet] tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF [low-latitude coral reefs], and North Atlantic

subpolar gyre / Labrador-Irminger Sea convection abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST [Global Mean Surface Temperature] returns below 1.5°C within an uncertain overshoot time (likely decades) (94). … The chance of triggering CTPs [Climate tipping points] is already non-negligible and will grow even with stringent climate mitigation (SSP1-1.9 in Fig. 2, B and C). Nevertheless, achieving the Paris Agreement's aim to pursue efforts to limit warming to 1.5°C would clearly be safer than keeping global warming below 2°C (90) (Fig. 2). Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC [North Atlantic subpolar gyre / Labrador-Irminger Sea convection] collapse is crossed. The likelihood of triggering AMOC [Atlantic Meridional Overturning Circulation] collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C. A cluster of abrupt shifts occur in ESM [Earth System Models] at 1.5 to 2°C (19). Although not tipping elements, ASSI [Arctic Summer Sea Ice] loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C."); *and* Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 42 ("Risks associated with large-scale singular events or tipping points, such as ice sheet instability or ecosystem loss from tropical forests, transition to high risk between 1.5°C–2.5°C (*medium confidence*) and to very high risk between 2.5°C–4°C (*low confidence*). The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with further warming (*high confidence*).").

[7] Drijfhout S., Bathiany S., Beaulieu C., Brovkin V., Claussen M., Huntingford C., Scheffer M., Sgubin G., & Swingedouw D. (2015) *Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models*, PROC. NAT'L. ACAD. SCI. 112(43): E5777–E5786, E5777 ("Abrupt transitions of regional climate in response to the gradual rise in atmospheric greenhouse gas concentrations are notoriously difficult to foresee. However, such events could be particularly challenging in view of the capacity required for society and ecosystems to adapt to them. We present, to our knowledge, the first systematic screening of the massive climate model ensemble informing the recent Intergovernmental Panel on Climate Change report, and reveal evidence of 37 forced regional abrupt changes in the ocean, sea ice, snow cover, permafrost, and terrestrial biosphere that arise after a certain global temperature increase. Eighteen out of 37 events occur for global warming levels of less than 2°, a threshold sometimes presented as a safe limit."). *See also* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, REV. GEOPHYS. 61(e2021RG000757): 1–81, 48 ("Earth system elements that this review indicates are at higher risk of crossing critical thresholds or undergoing substantial changes in response to warming this century under moderate (RCP4.5) emissions scenarios include loss of Arctic summer sea ice, loss of portions of the GIS, loss of portions of the West Antarctic Ice-sheet, Amazon rainforest dieback, boreal forest ecosystem shifts, some permafrost carbon release, and coral reef loss (Figure 14). In contrast, methane release from marine methane hydrates and strato-cumulus cloud deck evaporation will likely require longer timescales and higher emissions forcing in order to occur at large scales, while disruptions of tropical monsoons may be contingent on large shifts in other Earth system components and are unlikely to occur as a direct response to changes in aerosol forcing or land cover (see Section 2.6). Critical thresholds for weakening of the AMOC remain unclear and a transition of this system to a different state may not occur this century (see Section 2.1). While the GIS and WAIS may transgress critical thresholds this century (see Section 2.3), timescales of ice loss may require many centuries to millennia to run to completion (Bakker et al., 2016; Clark et al., 2016; Golledge et al., 2015; Huybrechts & De Wolde, 1999)."); Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE 575(7784): 592–595, 593 ("A further key impetus to limit warming to 1.5 °C is that other tipping points could be triggered at low levels of global warming. The latest IPCC models projected a cluster of abrupt shifts between 1.5 °C and 2 °C, several of which involve sea ice. This ice is already shrinking rapidly in the Arctic...."); Arias P. A., *et al.* (2021) *Technical Summary*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), TS-71–TS-72 ("It is *likely* that under stabilization of global warming at 1.5°C, 2.0°C, or 3.0°C relative to 1850–1900, the AMOC will continue to weaken for several decades by about 15%, 20% and 30% of

its strength and then recover to pre-decline values over several centuries (*medium confidence*). At sustained warming levels between 2°C and 3°C, there is limited evidence that the Greenland and West Antarctic Ice Sheets will be lost almost completely and irreversibly over multiple millennia; both the probability of their complete loss and the rate of mass loss increases with higher surface temperatures (*high confidence*). At sustained warming levels between 3°C and 5°C, near-complete loss of the Greenland Ice Sheet and complete loss of the West Antarctic Ice Sheet is projected to occur irreversibly over multiple millennia (*medium confidence*); with substantial parts or all of Wilkes Subglacial Basin in East Antarctica lost over multiple millennia (*low confidence*). Early-warning signals of accelerated sea-level-rise from Antarctica, could possibly be observed within the next few decades. For other hazards (e.g., ice sheet behaviour, glacier mass loss and global mean sea level change, coastal floods, coastal erosion, air pollution, and ocean acidification) the time and/or scenario dimensions remain critical, and a simple and robust relationship with global warming level cannot be established (*high confidence*)... The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with climate change (*high confidence*). It is *very unlikely* that gas clathrates (mostly methane) in deeper terrestrial permafrost and subsea clathrates will lead to a detectable departure from the emissions trajectory during this century. Possible abrupt changes and tipping points in biogeochemical cycles lead to additional uncertainty in 21st century atmospheric GHG concentrations, but future anthropogenic emissions remain the dominant uncertainty (*high confidence*). There is potential for abrupt water cycle changes in some high-emission scenarios, but there is no overall consistency regarding the magnitude and timing of such changes. Positive land surface feedbacks, including vegetation, dust, and snow, can contribute to abrupt changes in aridity, but there is only *low confidence* that such changes will occur during the 21st century. Continued Amazon deforestation, combined with a warming climate, raises the probability that this ecosystem will cross a tipping point into a dry state during the 21st century (*low confidence*)."); *and* Lee J.-Y., Marotzke J., Bala G., Cao L., Corti S., Dunne J. P., Engelbrecht F., Fischer E., Fyfe J. C., Jones C., Maycock A., Mutemi J., Ndiaye O., Panickal S., & T. Zhou (2021) *Chapter 4: Future Global Climate: Scenario-Based Projections and Near-Term Information*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 4-96 (Table 4.10 lists 15 components of the Earth system susceptible to tipping points).

[8] *See* Hoegh-Guldberg O., *et al.* (2018) *Chapter 3: Impacts of 1.5°C of Global Warming on Natural and Human Systems*, *in* GLOBAL WARMING OF 1.5 °C, *Special Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 262 ("Tipping points refer to critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible. An understanding of the sensitivities of tipping points in the physical climate system, as well as in ecosystems and human systems, is essential for understanding the risks associated with different degrees of global warming. This subsection reviews tipping points across these three areas within the context of the different sensitivities to 1.5°C versus 2°C of global warming. Sensitivities to less ambitious global temperature goals are also briefly reviewed. Moreover, an analysis is provided of how integrated risks across physical, natural and human systems may accumulate to lead to the exceedance of thresholds for particular systems. The emphasis in this section is on the identification of regional tipping points and their sensitivity to 1.5°C and 2°C of global warming, whereas tipping points in the global climate system, referred to as large-scale singular events, were already discussed in Section 3.5.2. A summary of regional tipping points is provided in Table 3.7."); *and* Abram N., *et al.* (2019) *Chapter 1: Framing and Context of the Report*, *in* THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *Special Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.), 1-81 ("While some aspects of the ocean and cryosphere might respond in a linear (i.e., directly proportional) manner to a perturbation by some external forcing, this may change fundamentally when critical thresholds are reached. A very important example for such a threshold is the transition from frozen water to liquid water at around 0 ºC that can lead to rapid acceleration of ice-melt or permafrost thaw (e.g., Abram et al., 2013; Trusel et al., 2018). Such thresholds often act as tipping points, as they are associated with rapid and abrupt changes even when the underlying forcing changes gradually (Figure 1.1a, 1.1c). Tipping elements include, for example, the collapse of the ocean's large-scale overturning circulation in the Atlantic (Section 6.7), or the collapse of the West Antarctic Ice Sheet though a process called marine ice sheet instability (Cross-Chapter Box 8 in Chapter 3; Lenton, *et al*. 2008). Potential ocean and cryosphere tipping elements form part of the scientific case for efforts to limit climate warming to well below 2ºC (IPCC, 2018).").

[9] Hansen J. E., Sato M., Simons L., Nazarenko L. S., Sangha I., Kharecha P., Zachos J. C., von Schuckmann K., Loeb N. G., Osman M. B., Jin Q., Tselioudis G., Jeong E., Lacis A., Ruedy R., Russell G., Cao J., & Li J. (2023*)* *Global warming in the pipeline*, OXF. OPEN CLIM. CHANGE 3(1): 1–33, 21 ("With current policies, we expect climate forcing for a few decades post-2010 to increase 0.5–0.6 W/m^2 per decade and produce global warming of at least +0.27°C per decade. In that case, global warming will reach 1.5°C in the 2020s and 2°C before 2050 (Fig. 24). Such acceleration is dangerous in a climate system that is already far out of equilibrium and dominated by multiple amplifying feedbacks." … Figure 25 caption reads "Edges of the predicted post-2010 accelerated warming rate (see text) are 0.36 and 0.27°C per decade."). *See also* Xu Y., Ramanathan V., & Victor D. G. (2018) *Global warming will happen faster than we think*, Comment, NATURE 564(7734): 30–32, 30–31 ("But the latest IPCC special report underplays another alarming fact: global warming is accelerating. Three trends—rising emissions, declining air pollution and natural climate cycles—will combine over the next 20 years to make climate change faster and more furious than anticipated. In our view, there's a good chance that we could breach the 1.5 °C level by 2030, not by 2040 as projected in the special report (see 'Accelerated warming'). The climate-modelling community has not grappled enough with the rapid changes that policymakers care most about, preferring to focus on longer-term trends and equilibria."). *See also* Climate & Clean Air Coalition (2014) TIME TO ACT TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS, 25 (Figure: SLCP Climate Benefits, Avoided global warming [showing that the avoided global warming from rapid implementation of SLCP mitigation measures is 0.6°C by 2050]). Since the Xu, Ramanathan, and Victor Comment was published, the IPCC has updated its estimate for when 1.5 °C will be exceeded: *see* Arias P. A., *et al.* (2021) *Technical Summary*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), TS-9 ("Timing of crossing 1.5°C global warming: Slightly different approaches are used in SR1.5 and in this Report. SR1.5 assessed a likely range of 2030 to 2052 for reaching a global warming level of 1.5°C (for a 30-year period), assuming a continued, constant rate of warming. In AR6, combining the larger estimate of global warming to date and the assessed climate response to all considered scenarios, the central estimate of crossing 1.5°C of global warming (for a 20-year period) occurs in the early 2030s, ten years earlier than the midpoint of the likely range assessed in the SR1.5, assuming no major volcanic eruption. (TS.1.3, Cross-Section Box TS.1)").

[10] Dreyfus G. B., Xu Y., Shindell D. T., Zaelke D., & Ramanathan V. (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22): 1–8, 1, 5, 6 ("Aggressive decarbonization to achieve net-zero CO_2 emissions in the 2050s (as in the decarb-only scenario) results in weakly accelerated net warming compared to the reference case, with a positive warming up to 0.03 °C in the mid-2030s, and no net avoided warming until the mid-2040s due to the reduction in co-emitted cooling aerosols (Figure 3a). By 2050, decarbonization measures result in very limited net avoided warming (0.07°C), consistent with Shindell and Smith, but rise to a likely detectable 0.25°C by 2060 and a major benefit of 1.4°C by 2100 (Table S5). In contrast, pairing decarbonization with mitigation measures targeting CH_4, BC, HFC, and N_2O (not an SLCP due to its longer lifetime) independent from decarbonization are essential to slowing the rate of warming by the 2030s to under 0.3°C per decade (Table 1, Figure 3b), similar to the 0.2°C to 0.25°C per decade warming prior to 2020. Recent studies suggest that rate of warming rather than level of warming controls likelihood of record-shattering extreme weather events. By 2050, the net avoided warming from the targeted non-CO_2 measures is 0.26°C, almost 4 times larger than the net benefit of decarbonization alone (0.07°C) (Table S5)."; "These non-CO_2 targeted measures when combined with decarbonization can provide net cooling by 2030 and reduce the rate of warming from 2030 to 2050 by about 50%, roughly half of which comes from methane, significantly larger than decarbonization alone over this time frame."; "Moreover, decarbonization alone increases the warming rate in the near term (Table 1). Notably, the warming rate in the decarbonization scenario would not drop below the current rate of warming until the 2040s (Fig. 3B). Pairing decarbonization with measures targeting SLCP slows the rate of warming a decade or two earlier than decarbonization alone.").

[11] Xu Y. & Ramanathan V. (2017) *Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes*, PROC. NAT'L. ACAD. SCI. 114(39): 10315–10323, 10321 ("The SP [super pollutant] lever targets SLCPs. Reducing SLCP emissions thins the SP blanket within few decades, given the shorter lifetimes of SLCPs (weeks for BC to about 15 years for HFCs). The mitigation potential of the SP lever with a maximum deployment of current technologies … is about 0.6 °C by 2050 and 1.2 °C by 2100 (SI Appendix, Fig. S5B and Table S1)."). *See also* Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr

A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived climate forcers*, in CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 821 ("Across the SSPs, the collective reduction of CH_4, ozone precursors and HFCs can make a difference of global mean surface air temperature of 0.2 with a very likely range of [0.1–0.4] °C in 2040 and 0.8 with a very likely range of [0.5–1.3] °C at the end of the 21st century (comparing SSP3-7.0 and SSP1-1.9), which is substantial in the context of the Paris Agreement. Sustained methane mitigation, wherever it occurs, stands out as an option that combines near- and long-term gains on surface temperature (*high confidence*) and leads to air quality benefits by reducing surface ozone levels globally (*high confidence*)."); and Dreyfus G. B., Xu Y., Shindell D. T., Zaelke D., & Ramanathan V. (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22): 1–8, 5 ("Aggressive decarbonization to achieve net-zero CO_2 emissions in the 2050s (as in the decarb-only scenario) results in weakly accelerated net warming compared to the reference case, with a positive warming up to 0.03 °C in the mid-2030s, and no net avoided warming until the mid-2040s due to the reduction in co-emitted cooling aerosols (Figure 3a). By 2050, decarbonization measures result in very limited net avoided warming (0.07°C), consistent with Shindell and Smith, but rise to a likely detectable 0.25°C by 2060 and a major benefit of 1.4°C by 2100 (Table S5).").

[12] Molina M., Ramanathan V., & Zaelke D. (2 April 2020) *Best path to net zero: Cut short-lived super-pollutants*, BULLETIN OF THE ATOMIC SCIENTISTS ("Speed must become the key measure of all climate mitigation strategies: a speedy reduction of global warming before it leads to further, self-reinforcing climate change feedbacks and tipping points; a speedy deployment of mitigation actions and technologies; and getting this all up to scale in a speedy manner. And let us be clear: By "speed," we mean measures—including regulatory ones—that can begin within two-to-three years, be substantially implemented in five-to-10 years, and produce a climate response within the next decade or two."). *See also* Molina M., Zaelke D., Sarma K. M., Andersen S. O., Ramanathan V., & Kaniaru D. (2009) *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*, Proc. Nat'l. Acad. Sci. 106(49): 20616–20621, 20616 ("Current emissions of anthropogenic greenhouse gases (GHGs) have already committed the planet to an increase in average surface temperature by the end of the century that may be above the critical threshold for tipping elements of the climate system into abrupt change with potentially irreversible and unmanageable consequences. This would mean that the climate system is close to entering if not already within the zone of "dangerous anthropogenic interference" (DAI). Scientific and policy literature refers to the need for "early," "urgent," "rapid," and "fast-action" mitigation to help avoid DAI and abrupt climate changes. We define "fast-action" to include regulatory measures that can begin within 2–3 years, be substantially implemented in 5–10 years, and produce a climate response within decades. We discuss strategies for short-lived non-CO_2 GHGs and particles, where existing agreements can be used to accomplish mitigation objectives. Policy makers can amend the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs) with high global warming potential. Other fast-action strategies can reduce emissions of black carbon particles and precursor gases that lead to ozone formation in the lower atmosphere, and increase biosequestration, including through biochar. These and other fast-action strategies may reduce the risk of abrupt climate change in the next few decades by complementing cuts in CO_2 emissions.").

[13] World Meteorological Organization (2024) STATE OF THE GLOBAL CLIMATE 2023, 3 ("The ten-year average 2014–2023 global temperature is 1.20±0.12°C above the 1850–1900 average, the warmest 10-year period on record."). *See also* Met Office, *Indicators of Global Warming* (*last visited* 13 March 2024) ("Despite differences between them, there is a clear consensus among indicators centred on 2022 (Table 1) that the current magnitude of surface warming is approximately 1.2°C to 1.3°C and substantially higher than suggested by the average temperature over the last 10 or 20 years of approximately 1.1°C and 1.0°C, respectively."). *See* Copernicus Climate Services (9 January 2023) *2022 was a year of climate extremes, with record high temperatures and rising concentrations of greenhouse gases* (*last visited* 11 June 2023) ("2022 was the 5th warmest year – however, the 4th-8th warmest years are very close together. The last eight years have been the eight warmest on record. The annual average temperature was 0.3°C above the reference period of 1991-2020, which equates to approximately 1.2°C higher than the period 1850-1900. Atmospheric carbon dioxide concentrations increased by approximately 2.1 ppm, similar to the rates of recent years. Methane concentrations in the atmosphere increased by close to 12 ppb, higher than average, but below the last two years' record highs. La Niña conditions persisted during much of the year, for the third year in a row"); National

Aeronautics and Space Administration (12 January 2023) *NASA Says 2022 Fifth Warmest Year on Record, Warming Trend Continues*; ***and*** National Oceanic and Atmospheric Administration (12 January 2022) *2022 was world's 6th-warmest year on record*.

[14] Rockström J., *et al.* (2021) *Identifying a Safe and Just Corridor for People and the Planet*, EARTH'S FUTURE 9(4): 1–7, 1 ("Human development depends on safeguarding the stability of the planet (Steffen et al., 2018; Xu et al., 2020). Current human activities, especially of high consuming wealthy societies, are threatening the stability of Earth's life support systems and its capacity to support our future well-being in the Anthropocene (Steffen, Broadgate, et al., 2015). Simultaneously, key human development needs remain, including attaining the UN Sustainable Development Goals for all by 2030, and ensuring continued human well-being for a world population of possibly 10 billion people in 2050. Addressing these challenges requires a full integration of people's lives and the planet's stability.").

[15] Guterres A. (15 May 2018) *Remarks at Austrian World Summit*, United Nations, Speeches ("Climate change is, quite simply, an existential threat for most life on the planet – including, and especially, the life of humankind.").

[16] Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE, 575(7784): 592–595, 594 ("In our view, the clearest emergency would be if we were approaching a global cascade of tipping points that led to a new, less habitable, 'hothouse' climate state[11]. Interactions could happen through ocean and atmospheric circulation or through feedbacks that increase greenhouse-gas levels and global temperature. Alternatively, strong cloud feedbacks could cause a global tipping point[12,13].We argue that cascading effects might be common. Research last year[14] analysed 30 types of regime shift spanning physical climate and ecological systems, from collapse of the West Antarctic ice sheet to a switch from rainforest to savanna. This indicated that exceeding tipping points in one system can increase the risk of crossing them in others. Such links were found for 45% of possible interactions[14]. In our view, examples are starting to be observed. … If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us. We need to change our approach to the climate problem. … In our view, the evidence from tipping points alone suggests that we are in a state of planetary emergency: both the risk and urgency of the situation are acute…."). *See also* Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS and GrIS tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF, and abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST returns below 1.5°C within an uncertain overshoot time (likely decades) (94).").

[17] Dennis B. & Dance S. (31 July 2023) *It's not just hot. Climate anomalies are emerging around the globe*, THE WASHINGTON POST ("But some events were so abnormal that they sent a wave of consternation through the scientific community. Antarctic sea ice is at a historically low level for this time of year, according to federal data. Sea surface temperatures across the North Atlantic have been "off the charts," Europe's Copernicus Climate Change Service reported, noting that the figures set records for this time of year "by a very large margin." Water temperatures off the coast of South Florida rose to unfathomable levels in recent days, leading scientists to fear for the fate of the only living coral barrier reef in the continental United States.¶ "On the one hand, we knew these things were going to happen. These have been the predictions for a long time," said Claudia Tebaldi, a scientist at the Pacific Northwest National Laboratory. ¶ And yet, she said, "this year, in particular, has seemed so extreme. … The size of the anomalies is surprising." ¶ For years, climate scientists have detailed again and again the many impacts that are likely as the world grows steadily hotter, such as more intense storms, more torrential rainfall, fast-rising seas and melting ice caps. ¶ But they also have been unequivocal that with more warming comes the possibility of unforeseen consequences — of rapid changes, irreversible collapses and other feedback loops.¶ More than a decade ago, a study from the National Academies of Sciences, Engineering and Medicine found that while many aspects of climate change and its effects "are expected to be approximately linear and gradual," that won't always be the case. ¶ "It is clear that the risk of

surprises can be expected to increase with the duration and magnitude of the warming," the authors wrote. ¶ That reality seems to be playing out.").

[18] Xu Y. & Ramanathan V. (2017) *Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes*, PROC. NAT'L. ACAD. SCI. 114(39): 10319–10323, 10320 ("Box 2. Risk Categorization of Climate Change to Society. … [A] 2 °C warming would double the land area subject to deadly heat and expose 48% of the population. A 4 °C warming by 2100 would subject 47% of the land area and almost 74% of the world population to deadly heat, which could pose existential risks to humans and mammals alike unless massive adaptation measures are implemented, such as providing air conditioning to the entire population or a massive relocation of most of the population to safer climates. … This bottom 3 billion population comprises mostly subsistent farmers, whose livelihood will be severely impacted, if not destroyed, with a one- to five-year megadrought, heat waves, or heavy floods; for those among the bottom 3 billion of the world's population who are living in coastal areas, a 1- to 2-m rise in sea level (likely with a warming in excess of 3 °C) poses existential threat if they do not relocate or migrate. It has been estimated that several hundred million people would be subject to famine with warming in excess of 4 °C (54). However, there has essentially been no discussion on warming beyond 5 °C. Climate change-induced species extinction is one major concern with warming of such large magnitudes (>5 °C). The current rate of loss of species is ~1,000-fold the historical rate, due largely to habitat destruction. At this rate, about 25% of species are in danger of extinction in the coming decades (56). Global warming of 6 °C or more (accompanied by increase in ocean acidity due to increased CO_2) can act as a major force multiplier and expose as much as 90% of species to the dangers of extinction (57). The bodily harms combined with climate change-forced species destruction, biodiversity loss, and threats to water and food security, as summarized recently (58), motivated us to categorize warming beyond 5 °C as unknown??, implying the possibility of existential threats."). *See also* Xu C., Kohler T. A., Lenton T. M., Svenning J.-C., & Scheffer M. (2020) *Future of the human climate niche*, PROC. NAT'L. ACAD. SCI. 117(21): 11350–11355, 11350 ("Here, we demonstrate that for millennia, human populations have resided in the same narrow part of the climatic envelope available on the globe, characterized by a major mode around ~11 °C to 15 °C mean annual temperature (MAT). …We show that in a business-as-usual climate change scenario, the geographical position of this temperature niche is projected to shift more over the coming 50 y than it has moved since 6000 BP. … Specifically, 3.5 billion people will be exposed to MAT ≥29.0 °C, a situation found in the present climate only in 0.8% of the global land surface, mostly concentrated in the Sahara, but in 2070 projected to cover 19% of the global land (Fig. 3). … For instance, accounting for population growth projected in the SSP3 scenario, each degree of temperature rise above the current baseline roughly corresponds to one billion humans left outside the temperature niche, absent migration (*SI Appendix*, Fig. S14)."); Watts N., *et al.* (2021) *The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises*, THE LANCET 397(10269): 129–170, 129 ("Vulnerable populations were exposed to an additional 475 million heatwave events globally in 2019, which was, in turn, reflected in excess morbidity and mortality (indicator 1.1.2). During the past 20 years, there has been a 53.7% increase in heat-related mortality in people older than 65 years, reaching a total of 296 000 deaths in 2018 (indicator 1.1.3). The high cost in terms of human lives and suffering is associated with effects on economic output, with 302 billion h of potential labour capacity lost in 2019 (indicator 1.1.4). India and Indonesia were among the worst affected countries, seeing losses of potential labour capacity equivalent to 4–6% of their annual gross domestic product (indicator 4.1.3).").

[19] Zachariah M., Philip S., Pinto I., Vahlberg M., Singh R., Otto F., Barnes C., & Kimutai J. (2023) *Extreme heat in North America, Europe and China in July 2023 made much more likely by climate change* ("In line with what has been expected from past climate projections and IPCC reports these events are not rare anymore today. North America, Europe and China have experienced heatwaves increasingly frequently over the last years as a result of warming caused by human activities, hence the current heat waves are not rare in today's climate with an event like the currently expected approximately once every 15 years in the US/Mexico region, once every 10 years in Southern Europe, and once in 5 years for China. ● Without human induced climate change these heat events would however have been extremely rare. In China it would have been about a 1 in 250 year event while maximum heat like in July 2023 would have been virtually impossible to occur in the US/Mexico region and Southern Europe if humans had not warmed the planet by burning fossil fuels."). Note also the record-breaking June 2021 heatwave in the Pacific Northwest (U.S. and Canada) would have been virtually impossible absent human-caused climate change and would have been much less detrimental to human health. *See* Philip S. Y., *et al.* (2021) *Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada*, WORLD WEATHER ATTRIBUTION, 2 ("Also, this heatwave was

about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today."); *and* Newburger E. (1 July 2021) *Historic heat wave linked to hundreds of deaths in Pacific Northwest and Canada*, CNBC ("Dr. Jennifer Vines, Multnomah County's health officer, said the preliminary cause of death was hyperthermia, an abnormally high body temperature resulting from an inability of the body to deal with heat. Many of the dead were found alone and without air conditioning…. "While it is too early to say with certainty how many of these deaths are heat related, it is believed likely that the significant increase in deaths reported is attributable to the extreme weather B.C. has experienced," Lapointe said in a statement."). In Western Europe, global warming made the 2019 heatwaves up to 100 times more likely. *See* Vautard R., *et al.* (2020) *Human contribution to the record-breaking June and July 2019 heatwaves in Western Europe*, ENVIRON. RES. LETT. 15(9): 094077, 1–9, 5 ("For the France average, the heatwave was an event with a return period estimated to be 134 years. As for the June case, except for HadGEM-3A, which has a hot and dry bias, the changes in intensity are systematically underestimated, as they range from 1.1 °C (CNRM-CM6.1) to 1.6 °C (EC-EARTH). By combining information from models and observations, we conclude that the probability of such an event to occur for France has increased by a factor of at least 10 (see the synthesis in figure 3). This factor is very uncertain and could be two orders of magnitude higher. The change in intensity of an equally probable heatwave is between 1.5 degrees and 3 degrees. We found similar numerical results for Lille, with however an estimate of change in intensity higher in the observations, and models predict trend estimates that are consistently lower than observation trends, a fact that needs further investigation beyond the scope of this attribution study. We conclude for these cases that such an event would have had an extremely small probability to occur (less than about once every 1000 years) without climate change in France. Climate change had therefore a major influence to explain such temperatures, making them about 100 times more likely (at least a factor of ten).").

[20] Dahl K. A., Abatzoglou J. T., Phillips C. A., Ortiz-Partida J. P., Licker R., Merner L. D., & Ekwurzel B. (2023) *Quantifying the contribution of major carbon producers to increases in vapor pressure deficit and burned area in western US and southwestern Canadian forests*, ENVIRON. RES. LETT. 18(6): 064011, 1–11, 2 ("Vapor pressure deficit (VPD)—a measure of atmospheric water demand defined as the difference between the amount of water vapor in the air and the amount of water vapor that air would hold at saturation—has emerged as a key metric linking climate change and burned area (BA) due to its role in regulating ecosystem water dynamics (Grossiord et al 2020, Clarke et al 2022). Through the lens of regional wildfire risk, rising VPD ultimately translates to a greater likelihood that fuels will ignite and carry fire across a landscape. More than two-thirds of the observed summertime increase in VPD in the western US has been attributed to anthropogenic warming (Zhuang et al 2021). In turn, the increase in summertime VPD has driven increases in fuel aridity in the region, resulting in nearly a doubling of BA in western US forests during 1984–2015 (Abatzoglou and Williams 2016). Regionally, there is a strong and established interannual relationship between VPD and BA across forested subregions of the western US and southwestern Canada (Abatzoglou et al 2018, Williams et al 2019, Whitman et al 2022). In flammability-limited ecosystems like forests, area burned is exponentially related to VPD (Juang et al 2022).").

[21] Night-time fire intensity has increased globally in the last two decades due to rising temperatures, causing more intense, longer-lasting, and larger fires. *See* Balch J. K., Abatzoglou J. T., Joseph M. B., Koontz M. J., Mahood A. L., McGlinchy J., Cattau M. E., & Williams A. P. (2022) *Warming weakens the night-time barrier to global fire*, NATURE 602: 442–448, 442 ("Night-time provides a critical window for slowing or extinguishing fires owing to the lower temperature and the lower vapour pressure deficit (VPD). However, fire danger is most often assessed based on daytime conditions[1,2], capturing what promotes fire spread rather than what impedes fire. Although it is well appreciated that changing daytime weather conditions are exacerbating fire, potential changes in night-time conditions—and their associated role as fire reducers—are less understood. Here we show that night-time fire intensity has increased, which is linked to hotter and drier nights. Our findings are based on global satellite observations of daytime and night-time fire detections and corresponding hourly climate data, from which we determine landcover-specific thresholds of VPD (VPD_t), below which fire detections are very rare (less than 95 per cent modelled chance). Globally, daily minimum VPD increased by 25 per cent from 1979 to 2020. Across burnable lands, the annual number of flammable night-time hours—when VPD exceeds VPD_t—increased by 110 hours, allowing five additional nights when flammability never ceases. Across nearly one-fifth of burnable lands, flammable nights increased by at least one week across this period. Globally, night fires have become 7.2 per cent more intense from 2003 to 2020, measured via a satellite record. These results reinforce the lack of night-time relief that wildfire suppression teams have experienced

in recent years. We expect that continued night-time warming owing to anthropogenic climate change will promote more intense, longer-lasting and larger fires."); *discussed in* Dickie G. (19 July 2022) *Steamy nights in European heatwave worsen health and fire risks – experts*, REUTERS.

[22] The eastern coast of South Africa saw extreme flooding in 2022, which affected 40,000 people and caused US $1.57 billion in property damage. A recent study shows that the probability of such extreme rainfall in the region has doubled due to human-induced climate change. *See* Pinto I., *et al.* (2022) *Climate change exacerbated rainfall causing devastating flooding in Eastern South Africa*, WORLD WEATHER ATTRIBUTION: 1–21, 2 ("40,000 people were impacted by the rainfall and subsequent floods- 435 deaths were reported from the affected areas, 55 injured and 54 people missing (Government of South Africa, 2022a). At least 13,500 houses were damaged or destroyed - among these, over 4,000 homes in informal settlements in eThekwini Metropolitan Municipality were destroyed, leaving 6278 people homeless and 7245 people in shelters (Ibid.). 630 schools were affected in the KZN province in the impacted areas, and 124 schools damaged, thus impacting around 270,000 students (Government of South Africa, 2022b). Critical infrastructure such as bridges and roads were also severely damaged, including two major highways (IFRC, 2022), and the mobile phone infrastructure of KwaZulu-Natal saw 400 towers impacted due to power outages and flooded fibre conduiting (Tech Central, 2022). In addition, large parts of Durban were left without electricity and water for days due to damage to water treatment and power plant stations (IFRC, 2022). The overall property damage is estimated around 17 billion rand/US$1.57 billion (IOL, 2022a)."; "…the probability of an event such as the rainfall that resulted in this disaster has approximately doubled due to human-induced climate change. The intensity of the current event has increased by 4-8%.").

[23] For example, the catastrophic flooding that inundated a third of Pakistan in 2022 was very likely made more severe by climate change, increasing rainfall, glacier melt, and extending a La Niña event in the Pacific for a rare third year. *See* Clarke B., Otto F., & Harrington L. (5 September 2022) *Pakistan floods: What role did climate change play?*, THE CONVERSATION ("Clues as to the role of climate change can also come from aspects that contributed to this disaster. There are three main factors. ¶ First, extreme rainfall. A warmer atmosphere holds more moisture. For every degree the atmosphere warms it can hold about 6%-7% more moisture, which often results in more rain falling during the most extreme events (south Asia has warmed around 0.7°C since 1900). Had this event happened in a world where carbon dioxide concentrations were instead at pre-industrial levels, the rains probably would have been less intense. ¶ Second, the monsoon itself, which is highly complex and variable. It forms in south Asia in the summer, when air over land warms faster than air over the sea, which creates a flow of air onto the land. The winds bring great volumes of moisture that precipitate into deluges when they meet higher ground, especially the Himalayas. ¶ Unusual monsoon rains over Pakistan have some predictability. They occur when multiple phenomena coincide, including a La Niña event in the Pacific and large meanders in the high-altitude jet stream, as was the case in both 2010 and this year. ¶ There is emerging evidence that this confluence of factors may occur more regularly as the climate changes. If such trends continue, then flooding in Pakistan and other simultaneous extremes across the northern Hemisphere will happen more often in the future. ¶ Pakistan also experienced extended and brutal heatwaves in May and June this year, which were amplified by climate change. This heat amplified the monsoonal "thermal low"—a low-pressure system created by hot air rising rapidly—which greatly enhanced the flow of moisture-laden air onto southern Pakistan. ¶ Third, Pakistan has more than 7,000 glaciers in its northern mountainous regions. As these glaciers melt, their waters contribute to the flooding. This melting is driven to a large degree by climate change and is especially prominent this year as a result of the heatwave."); Otto F. E. L., Zachariah M., Saeed F., Siddiqi A., & Shahzad K. (2022) *Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan*, WORLD WEATHER ATTRIBUTION, 3 ("However, for the 5-day rainfall extreme, the majority of models and observations we have analysed show that intense rainfall has become heavier as Pakistan has warmed. Some of these models suggest climate change could have increased the rainfall intensity up to 50% for the 5-day event definition."); *and* Trenberth K. (15 September 2022) *2022's supercharged summer of climate extremes: How global warming and La Niña fueled disasters on top of disasters*, THE CONVERSATION.

[24] These six tipping points, shown in **Figure** Error! Main Document Only.**,** are the Greenland ice sheet, West Antarctic ice sheet, low-latitude (warm water) coral reefs, abrupt permafrost thaw, abrupt loss of Barents Sea winter ice, and collapse of the subpolar gyre (SPG) overturning circulation in the Labrador Sea. *See* Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M.

(2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS [West Antarctic Ice Sheet] and GrIS [Greenland Ice Sheet] tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF [low-latitude coral reefs], and North Atlantic subpolar gyre / Labrador-Irminger Sea convection abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST [Global Mean Surface Temperature] returns below 1.5°C within an uncertain overshoot time (likely decades) (94). … The chance of triggering CTPs [Climate tipping points] is already non-negligible and will grow even with stringent climate mitigation (SSP1-1.9 in Fig. 2, B and C). Nevertheless, achieving the Paris Agreement's aim to pursue efforts to limit warming to 1.5°C would clearly be safer than keeping global warming below 2°C (90) (Fig. 2). Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC [North Atlantic subpolar gyre / Labrador-Irminger Sea convection] collapse is crossed. The likelihood of triggering AMOC [Atlantic Meridional Overturning Circulation] collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C. A cluster of abrupt shifts occur in ESM [Earth System Models] at 1.5 to 2°C (19). Although not tipping elements, ASSI [Arctic Summer Sea Ice] loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C.").

[25] Here we distinguish between abrupt shifts, as in Drijfhout *et al*. (2015), and the more restrictive definition of "core climate tipping points" defined by Armstrong McKay *et al.* (2022) as "when change in part of the climate system becomes (i) selfperpetuating beyond (ii) a warming threshold as a result of asymmetry in the relevant feedbacks, leading to (iii) substantial and widespread Earth system impacts." For description of the eleven abrupt shifts, *see* Drijfhout S., Bathiany S., Beaulieu C., Brovkin V., Claussen M., Huntingford C., Scheffer M., Sgubin G., & Swingedouw D. (2015) *Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models*, PROC. NAT'L. ACAD. SCI. 112(43): E5777–E5786, E5777, E5784 ("Abrupt transitions of regional climate in response to the gradual rise in atmospheric greenhouse gas concentrations are notoriously difficult to foresee. However, such events could be particularly challenging in view of the capacity required for society and ecosystems to adapt to them. We present, to our knowledge, the first systematic screening of the massive climate model ensemble informing the recent Intergovernmental Panel on Climate Change report, and reveal evidence of 37 forced regional abrupt changes in the ocean, sea ice, snow cover, permafrost, and terrestrial biosphere that arise after a certain global temperature increase. Eighteen out of 37 events occur for global warming levels of less than 2°, a threshold sometimes presented as a safe limit."; 11 abrupt shifts are shown between 1.0–1.5°C in "Fig. 4. Abrupt shifts as a function of global temperature increase. Shown are the number of abrupt climate changes occurring in the CMIP5 database for different intervals of warming relative to the preindustrial climate.").

[26] Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS [West Antarctic Ice Sheet] and GrIS [Greenland Ice Sheet] tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF [low-latitude coral reefs], and North Atlantic subpolar gyre / Labrador-Irminger Sea convection abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST [Global Mean Surface Temperature] returns below 1.5°C within an uncertain overshoot time (likely decades) (94). … The chance of triggering CTPs [Climate tipping points] is already non-negligible and will grow even with stringent climate mitigation (SSP1-1.9 in Fig. 2, B and C). Nevertheless, achieving the Paris Agreement's aim to pursue efforts to limit warming to 1.5°C would clearly be safer than keeping global warming below 2°C (90) (Fig. 2). Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC [North Atlantic subpolar gyre / Labrador-Irminger Sea convection] collapse is crossed. The likelihood of triggering AMOC [Atlantic Meridional Overturning Circulation] collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C. A cluster of abrupt shifts occur in ESM [Earth System Models] at 1.5 to 2°C (19). Although not tipping

elements, ASSI [Arctic Summer Sea Ice] loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C.").

[27] Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 9, 12 ("With about 1.2°C of global warming compared to pre-industrial levels, we are getting dangerously close to the temperature thresholds of some major tipping points for the ice sheets of Greenland and West Antarctica. Crossing these would lock in unavoidable long-term global sea level rise of up to 10 metres."; "Table 1.2.1: Summary of evidence for tipping dynamics, key drivers and biophysical impacts in each system considered in this chapter" [see column on biophysical impacts for Greenland and West Antarctic ice sheets].). For higher estimates of sea-level rise based on Earth's past climate, *see* International Cryosphere Climate Initiative (2023) STATE OF THE CRYOSPHERE REPORT 2023 – TWO DEGREES IS TOO HIGH, 12 ("Because of the existence of these thresholds, when temperatures reached 2°C above pre-industrial in the Earth's past, sea levels peaked at around 12–20 meters higher than present-day levels. During the height of the Pliocene 3 million years ago, when CO2 levels were comparable to today and temperatures stabilized at 2–3°C higher than pre-industrial, sea levels may have peaked at around 20 meters higher than today's.19,20,26,40 Such extensive sea level rise would be catastrophic for today's coastal communities — yet we are currently on track for even higher temperature peaks than those that drove these past sea level rises.").

[28] Boers N. & Rypdal M. (2021) *Critical slowing down suggests that the western Greenland Ice Sheet is close to a tipping point*, Proc. Nat'l. Acad. Sci. 118(21): 1–7, 1 ("A crucial nonlinear mechanism for the existence of this tipping point is the positive melt-elevation feedback: Melting reduces ice sheet height, exposing the ice sheet surface to warmer temperatures, which further accelerates melting. We reveal early-warning signals for a forthcoming critical transition from ice-core-derived height reconstructions and infer that the western Greenland Ice Sheet has been losing stability in response to rising temperatures. We show that the melt-elevation feedback is likely to be responsible for the observed destabilization. Our results suggest substantially enhanced melting in the near future.").

[29] King M. D., Howat I. M., Candela S. G., Noh M. J., Jeong S., Noël B. P. Y., van den Broeke M. R., Wouters B., & Negrete A. (2020) *Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat*, Comm. Earth & Env't.: 1–7, 1 ("The Greenland Ice Sheet is losing mass at accelerated rates in the 21st century, making it the largest single contributor to rising sea levels. Faster flow of outlet glaciers has substantially contributed to this loss, with the cause of speedup, and potential for future change, uncertain.").

[30] Fox-Kemper B., *et al.* (2021) *Chapter 9: Ocean, Cryosphere and Sea Level Change*, ***in*** Climate Change 2021: The Physical Science Basis, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.*(eds.), 1308–1309, 1302 ("[T]he main uncertainty related to high-end sea-level rise is "when" rather than "if" it arises: the upper limit of 1.02 m of *likely* sea-level range by 2100 for the SSP 5-8.5 scenario will be exceeded in any future warming scenario on time scales of centuries to millennia (*high confidence*), but it is uncertain how quickly the long-term committed sea level will be reached (Section 9.6.3.5). Hence, global-mean sea level might rise well above the *likely* range before 2100, which is reflected by assessments of ice-sheet contributions based on structured expert judgment (Bamber et al., 2019) leading to a 95th percentile of projected future sea-level rise as high as 2.3 m in 2100 (Section 9.6.3.3)… High-end sea-level rise can therefore occur if one or two processes related to ice-sheet collapse in Antarctica result in an additional sea-level rise at the maximum of their plausible ranges (Sections 9.4.2.5, 9.6.3.3; Table 9.7) or if several of the processes described in this box result in individual contributions to additional sea-level rise at moderate levels. In both cases, global-mean sea-level rise by 2100 would be substantially higher than the assessed *likely* range, as indicated by the projections including *low confidence* processes reaching in 2100 as high as 1.6 m at the 83rd percentile and 2.3 m at the 95th percentile (Section 9.6.3.3)."; "While ice-sheet processes in whose projection there is *low confidence* have little influence up to 2100 on projections under SSP1-1.9 and SSP1-2.6 (Table 9.9), this is not the case under higher emissions scenarios, where they could lead to GMSL rise well above the *likely* range. In particular, under SSP5-8.5, *low confidence* processes could lead to a total GMSL rise of 0.6-1.6 m over this time period (17th-83rd percentile range of p-box including SEJ- and MICI-based projections), with 5th-95th percentile projections extending to 0.5-2.3 m (*low confidence*)."). *See also* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, Rev. Geophys.

61: 1–81, 19–20 ("As mentioned above, reduction of the GIS will likely require a millennium. Yet the weakening of ice shelf buttressing directly accelerates ice flow and discharge independent of MISI and MICI processes, with immediate implications for observed rates of sea-level rise. Consequently, under our current best understanding, Greenland and Antarctic ice-sheet collapse cannot be considered an abrupt or fast phenomenon in which most sea level impacts manifest within decades. Nevertheless, ice-sheet losses may contribute to regional sea level rise under RCP8.5 and worst-case scenarios that reaches 1–2 m for many cities globally by 2100, seriously threatening existing communities and infrastructure (Trisos et al., 2022). Over longer timescales, sustained high rates of global sea-level rise (>1 cm/yr by 2200, with further acceleration to up to a couple centimeters per year beyond) may broadly strain coastal adaptation efforts (Oppenheimer et al., 2019). At the same time, models indicate that strong climate mitigation may avert significant fractions of potential sea-level rise and prevent ice-sheet collapse across large regions. In several modeling studies the RCP2.6 scenario prevents collapse of the WAIS (Bulthuis et al., 2019; DeConto & Pollard, 2016) and may reduce the Antarctic contribution to global sea level rise by 2100 to 13 cm (Edwards et al., 2021).... Although significant uncertainties remain regarding the precise temperature thresholds that could trigger ice-sheet collapse, research to date suggests that aggressive climate mitigation could limit risks from ice-sheet instabilities (Table 4).").\

[31] Robinson A., Calov R., & Ganopolski A. (2012) *Multistability and critical thresholds of the Greenland ice sheet*, NAT. CLIM. CHANGE 2(6): 429–432, 429 ("Recent studies have focused on the short-term contribution of the Greenland ice sheet to sea-level rise, yet little is known about its long-term stability. The present best estimate of the threshold in global temperature rise leading to complete melting of the ice sheet is 3.1 ºC (1.9–5.1 ºC, 95% confidence interval) above the preindustrial climate, determined as the temperature for which the modelled surface mass balance of the present-day ice sheet turns negative. Here, using a fully coupled model, we show that this criterion systematically overestimates the temperature threshold and that the Greenland ice sheet is more sensitive to long-term climate change than previously thought. We estimate that the warming threshold leading to a monostable, essentially ice-free state is in the range of 0.8–3.2 ºC, with a best estimate of 1.6 ºC. By testing the ice sheet's ability to regrow after partial mass loss, we find that at least one intermediate equilibrium state is possible, though for sufficiently high initial temperature anomalies, total loss of the ice sheet becomes irreversible. Crossing the threshold alone does not imply rapid melting (for temperatures near the threshold, complete melting takes tens of millennia). However, the timescale of melt depends strongly on the magnitude and duration of the temperature overshoot above this critical threshold."). *See also* Bochow N., Poltronieri A., Robinson A., Montoya M., Rypdal M., & Boers N. (2023) *Overshooting the critical threshold for the Greenland ice sheet*, NATURE 622(7983): 528–536, 528, 530 ("Our results show that the maximum GMT and the time span of overshooting given GMT targets are critical in determining GrIS stability. We find a threshold GMT between 1.7 °C and 2.3 °C above preindustrial levels for an abrupt ice-sheet loss. GrIS loss can be substantially mitigated, even for maximum GMTs of 6 °C or more above preindustrial levels, if the GMT is subsequently reduced to less than 1.5 °C above preindustrial levels within a few centuries. However, our results also show that even temporarily overshooting the temperature threshold, without a transition to a new ice-sheet state, still leads to a peak in SLR of up to several metres."; "A reduction in temperature from ad 2100 to ad 2200 leads to a mitigation of the ice loss, depending on the convergence temperature reached (Fig. 2). Regardless of the peak temperature in ad 2100, a convergence temperature increase of 1.5 °C GMT above preindustrial (ΔTJJA = 1.3 °C) by ad 2200 or lower leads to a stable ice sheet, with the equivalent of less than 1 m long-term SLR contribution in simulations with both models (Fig. 2a,b).").

[32] Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 17 ("Substantial ocean warming and ice shelf basal melting is committed in the Amundsen Sea over the 21st Century, which will likely accelerate the retreat of several key WAIS outlet glaciers including the Thwaites and Pine Island glaciers (Naughten et al. 2023)."), *discussing* Naughten K. A., Holland P. R., & De Rydt J. (2023) *Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century*, NAT. CLIM. CHANG. 13(11): 1222–1228, 1223–1224 ("Future warming and melting are markedly stronger than historical trends, with ensemble mean future warming trends ranging from 0.8 to 1.4 °C per century (Extended Data Table 1) compared with the historical mean of 0.25 °C per century. Even under the most ambitious mitigation scenario, Paris 1.5 °C, the Amundsen Sea warms three times faster than in the twentieth century. … The Paris 1.5 °C, Paris 2 °C and RCP 4.5 trends are all statistically indistinguishable, assessed in any combination, for both warming and melting. Only RCP 8.5, the most extreme scenario, is distinct from the others. This result suggests that climate mitigation has limited power to prevent ocean warming which controls sea-level rise from the WAIS and

that internal climate variability presents a larger source of uncertainty than future greenhouse gas emissions. … Therefore, while mitigation of the worst-case climate change scenario still has the potential to reduce Amundsen Sea warming, it will probably not make a difference for several decades. By this time, the impact on some glacier basins of the WAIS could be irreversible, even if ocean temperatures then returned to present-day values.”). *See also* Kloenne U., Nauels A., Pearson P., DeConto R. M., Findlay H. S., Hugelius G., Robinson A., Rogelj J., Schuur E. A. G., Stroeve J., & Schleussner C.-F. (2023) *Only halving emissions by 2030 can minimize risks of crossing cryosphere thresholds*, NAT. CLIM. CHANG. 13(1): 9–11, 10 (“The IPCC assesses that … [f]or Antarctica, there is large uncertainty around potential instabilities, which could trigger significant losses. The threshold for instability of the West Antarctic Ice Sheet (WAIS) might be between 1.5-2°C. Only parts would be lost below 2°C, with complete or near-complete loss at 2-3°C peak warming. Above 3°C the WAIS will be completely and the East Antarctic Wilkes Subglacial Basin substantially or completely lost over multiple millennia. Large losses from East Antarctica could occur above 5°C.”).

[33] Rantanen M., Karpechko A. Y., Lipponen A., Nordling K., Hyvärinen O., Ruosteenoja K., Vihma T. & Laaksonen A. (2022) *The Arctic has warmed nearly four times faster than the globe since 1979*, COMMUN. EARTH ENVIRON. 3(168): 1–10, 3 (“During 1979–2021, major portions of the Arctic Ocean were warming at least four times as fast as the global average (Fig. 1c). The most extreme AA values occur in the sea areas near Novaya Zemlya, which were locally warming up to seven times as fast as the global average. These high warming rates are consistent with recent research[44], and evidently, the primary reason for such a high amplification ratio is the reduction of cold-season ice cover, which has been most pronounced in the Barents Sea[44,45]. Furthermore, it has been found that changes in atmospheric circulation have amplified the warming in this area[46,47]. In general, there are no regions within the Arctic Circle where AA[43] is smaller than two, apart from the northern North Atlantic.”); *discussed in* Budryk Z. (11 August 2022) *Arctic warming up to four times as fast as global average: study*, THE HILL; *and* Fountain H. (11 August 2022) *Arctic Warming Is Happening Faster Than Described, Analysis Shows*, THE NEW YORK TIMES. *See also* Jacobs P., Lenssen N. J. L., Schmidt G. A., & Rohde R. A. (2021) *The Arctic Is Now Warming Four Times As Fast As the Rest of the Globe*, Presentation at the American Geophysical Union Fall Meeting, A13E-02 (“We demonstrate the Arctic is likely warming over 4 times faster than the rest of the world, some 3-4 times the global average, with higher rates found both for more recent intervals as well as more accurate latitudinal boundaries. These results stand in contrast to the widely-held conventional wisdom — prevalent across scientific and lay publications alike — that the Arctic is "only" warming around twice as fast as the global mean.”); *discussed in* Voosen P. (14 December 2021) *The Arctic is warming four times faster than the rest of the world*, SCIENCE; *and* Chylek P., Folland C., Klett J. D., Wang M., Hengartner N., Lesins G., & Dubey M. K. (2022) *Annual Mean Arctic Amplification 1970–2020: Observed and Simulated by CMIP6 Climate Models*, GEOPHYS. RES. LETT. 49(13): 1–8, 1 (“While the annual mean Arctic Amplification (AA) index varied between two and three during the 1970–2000 period, it reached values exceeding four during the first two decades of the 21st century. The AA did not change in a continuous fashion but rather in two sharp increases around 1986 and 1999. During those steps the mean global surface air temperature trend remained almost constant, while the Arctic trend increased. Although the “best” CMIP6 models reproduce the increasing trend of the AA in 1980s they do not capture the sharply increasing trend of the AA after 1999 including its rapid step-like increase. We propose that the first sharp AA increase around 1986 is due to external forcing, while the second step close to 1999 is due to internal climate variability, which models cannot reproduce in the observed time…. Annual mean Arctic Amplification (AA) within the period 1970–2020 changed in steep steps around 1986 and 1999. It reached values over 4.0…”); *discussed in* Los Alamos National Laboratory (5 July 2022) *Arctic temperatures are increasing four times faster than global warming*, PHYS.ORG.

[34] Kim Y.-H., Min S.-K., Gillett N. P., Notz D., & Malinina E. (2023) *Observationally-constrained projections of an ice-free Arctic even under a low emission scenario*, NAT. COMMUN. 14: 3139, 5 (“Based on the GHG+ scaling factors, we produce observationally-constrained future changes in Arctic SIA under four SSP scenarios. Results indicate that the first sea ice-free September will occur as early as the 2030s–2050s irrespective of emission scenarios. Extended occurrences of an ice-free Arctic in the early summer months are projected later in the century under higher emissions scenarios.”). *See also* Bonan D. B., Schneider T., Eisenman I., & Wills R. C. J. (2021) *Constraining the Date of a Seasonally Ice-Free Arctic Using a Simple Model*, GEOPHYS. RES. LETT. 48(18): 1–12, 1 (“Under a high-emissions scenario, an ice-free Arctic will likely (>66% probability) occur between 2036 and 2056 in September and between 2050 and 2068 from July to October. Under a medium-emissions scenario, the “likely” date occurs between 2040 and 2062 in September and much later in the 21st century from July to October.”); Docquier D. & Koenigk T. (2021)

Observation-based selection of climate models projects Arctic ice-free summers around 2035, COMMUN. EARTH ENVIRON. 2(144): 1–8, 4, 6 ("In the high-emission scenario, five out of six selection criteria that include ocean heat transport provide a first ice-free Arctic in September before 2040 (range of multi-model means: 2032–2039), more than 20 years before the date of ice-free Arctic for the multi-model mean without model selection (i.e. 2061)"; "This model selection reveals that sea-ice area and volume reach lower values at the end of this century compared to the multi-model mean without selection. This arises both from a more rapid reduction in these quantities through this century and from a lower present-day sea-ice area. Using such a model selection, the timing of an almost ice-free Arctic in summer is advanced by up to 29 years in the high-emission scenario, i.e. it could occur as early as around 2035."); Peng G., Matthews J. L., Wang M., Vose R., & Sun L. (2020) *What Do Global Climate Models Tell Us about Future Arctic Sea Ice Coverage Changes?*, CLIMATE 8(15): 1–24, 17 ("Excluding the values later than 2100, the averaged projected [first ice-free Arctic summer year (FIASY)] value for RCP4.5 was 2054 with a spread of 74 years; for RCP8.5, the averaged FIASY was 2042 with a spread of 42 years. ...which put the mean FIASY at 2037. The RCP8.5 projections tended to push FIASY earlier, except for those of the MICRO-ESM and MICRO-ESM-CHEM models. Those two models also tended to project earlier Arctic ice-free dates and longer durations."); *and* Overland J. E. & Wang M. (2013) *When will the summer Arctic be nearly sea ice free?*, GEOPHYS. RES. LETT. 40(10): 2097–2101, 2097 ("Three recent approaches to predictions in the scientific literature are as follows: (1) extrapolation of sea ice volume data, (2) assuming several more rapid loss events such as 2007 and 2012, and (3) climate model projections. Time horizons for a nearly sea ice-free summer for these three approaches are roughly 2020 or earlier, 2030 ± 10 years, and 2040 or later. Loss estimates from models are based on a subset of the most rapid ensemble members. … Observations and citations support the conclusion that most global climate model results in the CMIP5 archive are too conservative in their sea ice projections. Recent data and expert opinion should be considered in addition to model results to advance the very likely timing for future sea ice loss to the first half of the 21st century, with a possibility of major loss within a decade or two."). However, findings of ice-free September Arctic sea ice may be too early by a decade if models are not properly accounting for larger changes in atmospheric circulation, *according to* Topál D. & Ding Q. (2023) *Atmospheric circulation-constrained model sensitivity recalibrates Arctic climate projections*, NAT. CLIM. CHANG. 1–9, 5 ("To showcase our point, we use the abovementioned method to constrain the timing of the first sea-ice-free September in the SMILEs and CMIP6 models. The cumulative probability density functions (CDFs) corresponding to the time of emergence of the first seasonally sea-ice-free Arctic[52,5]3 (below 1 million km^2 in September) in the raw and the calibrated SIE time series in the model ensembles show prospects of a 9–11-year delay of the 'likely' (in IPCC[54] terms) probability ($P > 0.66$) of a September ice-free Arctic, such that an ice-free summer before 2050 is 'as likely as not' (in IPCC terms $0.33 < P < 0.66$) (Fig. 5c; Methods). This result is in contrast to estimates from previous studies that project ice-free September as early as mid-century[33]. Our results are also at odds with a recent study, where the authors used Arctic temperatures as an emergent constraint on ice-free projections in CMIP6 (ref. 40).").

[35] Bonan D. B., Schneider T., Eisenman I., & Wills R. C. J. (2021) *Constraining the Date of a Seasonally Ice-Free Arctic Using a Simple Model*, GEOPHYS. RES. LETT. 48(18): 1–12, 1 ("Under a high-emissions scenario, an ice-free Arctic will likely (>66% probability) occur between 2036 and 2056 in September and between 2050 and 2068 from July to October. Under a medium-emissions scenario, the "likely" date occurs between 2040 and 2062 in September and much later in the 21st century from July to October."). However, findings of ice-free September Arctic sea ice may be too early by a decade if models are not properly accounting for larger changes in atmospheric circulation, *according to* Topál D. & Ding Q. (2023) *Atmospheric circulation-constrained model sensitivity recalibrates Arctic climate projections*, NAT. CLIM. CHANG. 1–9, 5 ("To showcase our point, we use the abovementioned method to constrain the timing of the first sea-ice-free September in the SMILEs and CMIP6 models. The cumulative probability density functions (CDFs) corresponding to the time of emergence of the first seasonally sea-ice-free Arctic[52,5]3 (below 1 million km^2 in September) in the raw and the calibrated SIE time series in the model ensembles show prospects of a 9–11-year delay of the 'likely' (in IPCC[54] terms) probability ($P > 0.66$) of a September ice-free Arctic, such that an ice-free summer before 2050 is 'as likely as not' (in IPCC terms $0.33 < P < 0.66$) (Fig. 5c; Methods). This result is in contrast to estimates from previous studies that project ice-free September as early as mid-century[33]. Our results are also at odds with a recent study, where the authors used Arctic temperatures as an emergent constraint on ice-free projections in CMIP6 (ref. 40).").

[36] Pistone K., Eisenman I., & Ramanathan V. (2019) *Radiative Heating of an Ice-Free Arctic Ocean*, GEOPHYS. RES. LETT. 46(13): 7474–7480, 7477 ("This heating of 0.71 W/m^2 is approximately equivalent to the direct radiative effect of emitting one trillion tons of CO_2 into the atmosphere (see calculation in Appendix A). As of 2016, an estimated 2.4 trillion tons of CO_2 have been emitted since the preindustrial period due to both fossil fuel combustion (1.54 trillion tons) and land use changes (0.82 trillion tons), with an additional 40 billion tons of CO_2 per year emitted from these sources during 2007–2016 (Le Quéré et al., 2018). Thus, the additional warming due to the complete loss of Arctic sea ice would be equivalent to 25 years of global CO_2 emissions at the current rate."). *See also* Institute for Governance & Sustainable Development (2019) *Plain Language Summary of Pistone K., et al*.

[37] Wadhams P. (2017) A FAREWELL TO ICE: A REPORT FROM THE ARCTIC, Oxford University Press, 107–108 ("Warm air over an ice-free Arctic also causes the snowline to retreat. … This of the same magnitude as the sea ice negative anomaly during the same period, and the change in albedo is roughly the same between snow-covered land and snow-free tundra as it is between sea ice and open water. Nobody has yet published the calculations for tundra as Pistone and her colleagues did for sea ice, but the similarity of the magnitudes means that snowline retreat and sea ice retreat are each adding about the same amount to global warming.").

[38] National Snow & Ice Data Center, *The Sun sets on the Arctic melt season* (*last visited* 21 November 2023) ("On September 10, 2023, Antarctic extent reached an annual maximum of 16.96 million square kilometers (6.55 million square miles). This year's maximum was 1.03 million square kilometers (398,000 square miles) below the previous record low set in 1986. There is growing evidence that the Antarctic sea ice system has entered a new regime, featuring a much stronger influence of warm ocean waters limiting ice growth (Figure 5b)."). *See also* Hobbs W., Spence P., Meyer A., Schroeter S., Fraser A. D., Reid P., Tian T. R., Wang Z., Liniger G., Doddridge E. W., & Boyd P. W. (2024) *Observational Evidence for a Regime Shift in Summer Antarctic Sea Ice*, J. CLIM. 37(7): 2263–2275, 2272 ("In the last 15 years, summer Antarctic sea ice variability has been significantly greater than the earlier satellite record. This increased variance is tied to a marked increase in month-to-month sea ice autocorrelation. These changes, along with changes in the spatial variance of Antarctic sea ice shown by Schroeter et al. (2023), are all consistent with theoretical precursors of a transition to a new sea ice state."); *and* Gilbert E. (29 January 2024) *Why 2023 was such an exceptional year for Antarctic sea ice*, CARBON BRIEF ("Although current sea ice extent is no longer the lowest on record, conditions are still well below the 1981-2010 average, and this situation may well persist into the 2024 melt season. So, while it is too early to say conclusively that the recent sea-ice lows are the beginning of a regime shift in Antarctic sea ice, it seems inevitable that it will eventually decline in response to human-caused climate change.").

[39] National Snow & Ice Data Center (4 March 2024) *Leaping toward spring* ("Antarctic sea ice extent appears to have reached its seasonal minimum, ending up as tied with 2022 for second lowest in the satellite data record, just above 2023. Thus, the last three years are the three lowest in the 46-year record and the first three years that reached an extent below 2.0 million square kilometers (772,000 square miles). Having three such years in a row is unusual.").

[40] Gatti L. V., *et al.* (2021) *Amazonia as a carbon source linked to deforestation and climate change*, NATURE 595(7867): 388–393, 388 ("Southeastern Amazonia, in particular, acts as a net carbon source (total carbon flux minus fire emissions) to the atmosphere. Over the past 40 years, eastern Amazonia has been subjected to more deforestation, warming and moisture stress than the western part, especially during the dry season… the intensification of the dry season and an increase in deforestation seem to promote ecosystem stress, increase in fire occurrence, and higher carbon emissions in the eastern Amazon. This is in line with recent studies that indicate an increase in tree mortality and a reduction in photosynthesis as a result of climatic changes across Amazonia."). *See also* Brienen R. J. W., *et al.* (2015) *Long-term decline of the Amazon carbon sink*, NATURE 519(7543): 344–348, 344 ("While this analysis confirms that Amazon forests have acted as a long-term net biomass sink, we find a long-term decreasing trend of carbon accumulation. Rates of net increase in above-ground biomass declined by one-third during the past decade compared to the 1990s. This is a consequence of growth rate increases levelling off recently, while biomass mortality persistently increased throughout, leading to a shortening of carbon residence times.").

[41] Lovejoy T. E. & Nobre C. (2018) *Amazon's Tipping Point*, SCI. ADV. 4(2): eaat2340, 1 ("We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to nonforest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation."). *See also*

Hoegh-Guldberg O., *et al.* (2018) *Chapter 3: Impacts of 1.5 ºC of Global Warming on Natural and Human Systems*, *in* GLOBAL WARMING OF 1.5 °C, *Special Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 3-263 ("Global warming of 3°C is projected to reduce the extent of tropical rainforest in Central America, with biomass being reduced by about 40%, which can lead to a large replacement of rainforest by savanna and grassland (Lyra et al., 2017). Overall, modelling studies (Huntingford et al., 2013; Nobre et al., 2016) and observational constraints (Cox et al., 2013) suggest that pronounced rainforest dieback may only be triggered at 3°C–4°C (*medium confidence*), although pronounced biomass losses may occur at 1.5°C– 2°C of global warming."); *and* Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE 575: 592–595, 593 ("Estimates of where an Amazon tipping point could lie range from 40% deforestation to just 30% forest-cover loss. About 17% has been lost since 1970. The rate of deforestation varies with changes in policy. Finding the tipping point requires models that include deforestation and climate change as interacting drivers, and that incorporate fire and climate feedbacks as interacting tipping mechanisms across scales.").

[42] Scientists Elena Shevliakova and Stephen Pacala presented their preliminary analysis at a Princeton conference on safeguarding the Amazon: *see* Makhijani P. (23 October 2019) *A world without the Amazon? Safeguarding the Earth's largest rainforest is focus of Princeton conference*, PRINCETON UNIVERSITY ("Building on the earlier work of Brazilian climate scientists such as Carlos Nobre, who spoke at the conference, Shevliakova and Pacala modeled the climate impacts by 2050 of deforesting the whole of the Amazon and replacing it with pasture. If the Amazon disappears altogether, even in the scenario in which the world is able to slash its carbon emissions, average temperatures worldwide would rise 0.25°C beyond the expected increase, the scientists noted. "We will be less likely to reach Paris Agreement goals, including climate change stabilization under 1.5°C," Shevliakova said. In the Amazonian region, the model indicated that by completely eliminating the forest, the region would get up to 4.5°C hotter, making it practically uninhabitable. The effect on rainfall would be equally catastrophic: on average, it would rain 25% less in Brazil. As Shevliakova stated, "It's a bad story any way you look at it.""). *See also* Cuadros A. (4 January 2023) *Has the Amazon Reached Its 'Tipping Point'?*, THE NEW YORK TIMES ("For all the slashing and burning of recent years, the ecosystem still stores about 120 billion tons of carbon in its trunks, branches, vines and soil — the equivalent of about ten years of human emissions. If all of that carbon is released, it could warm the planet by as much as 0.3 degrees Celsius. According to the Princeton ecologist Stephen Pacala, this alone would probably make the Paris Agreement — the international accord to limit warming since preindustrial times to 2 degrees — "impossible to achieve." Which, in turn, may mean that other climate tipping points are breached around the world. As the British scientist Tim Lenton put it to me, "The Amazon feeds back to everything."); *and* Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 41 ("An Amazon tipping point would have global impacts from possibly large losses of carbon to the atmosphere. The best estimates suggest that a large-scale collapse of 40 per cent of the forest before the end of this century could lead to emissions of ~30 GtC and an additional global warming of ~0.1°C (Armstrong McKay et al., 2022).").

[43] Forster P. M., *et al.* (2023) *Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence*, EARTH SYST. SCI. DATA 15(6): 2295–2327, 2313, 2312–2313 (Table 7 gives remaining carbon budget for a 50% likelihood to limit global warming to 1.5°C of 250 $GtCO_2$ (values rounded to closes 50 $GtCO_2$); "The GCB updates have previously started from the AR6 WGI estimate and subtracted the latest estimates of historical CO_2 emissions. The RCB estimates presented here consider the same updates in historical CO_2 emissions from the GCB as well as the latest available quantification of human-induced warming to date and a reassessment of non-CO_2 warming contributions. … RCB estimates consider projected reductions in non-CO_2 emissions that are aligned with a global transition to net zero CO_2 emissions. These estimates assume median reductions in non-CO_2 emissions between 2020–2050 of CH_4 (50 %), N_2O (25 %) and SO_2 (77 %). If these non-CO_2 greenhouse gas emission reductions are not achieved, the RCB will be smaller (see Supplement, Sect. S8). Note that the 50 % RCB is expected to be exhausted a few years before the 1.5 °C global warming level is reached due to the way it factors future warming from non-CO_2 emissions into its estimate."). *Compare with* Friedlingstein P., *et al.* (2022) *Global Carbon Budget 2022*, EARTH SYST. SCI. DATA 14(11): 4811–4900, 4814 ("The remaining carbon budget for a 50 % likelihood to limit global warming to 1.5, 1.7, and 2 ◦C has, respectively, reduced to 105 GtC (380 $GtCO_2$), 200 GtC (730 $GtCO_2$), and 335 GtC (1230 $GtCO_2$) from the beginning of 2023, equivalent to 9, 18, and 30 years, assuming 2022 emissions levels.").

[44] Forster P. M., *et al.* (2023) *Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence*, EARTH SYST. SCI. DATA 15(6): 2295–2327, 2312 ("The RCB is estimated by application of the WGI AR6 method described in Rogelj et al. (2019), which involves the combination of the assessment of five factors: (i) the most recent decade of human-induced warming, (ii) the transient climate response to cumulative emissions of CO_2 (TCRE), (iii) the zero emissions commitment (ZEC), (iv) the temperature contribution of non-CO_2 emissions and (v) an adjustment term for Earth system feedbacks that are otherwise not captured through the other factors. AR6 WGI reassessed all five terms (Canadell et al., 2021). The incorporation of factor (v) was further considered by Lamboll and Rogelj (2022).").

[45] Canadell J. G., *et al.* (2021) *Chapter 5: Global Carbon and other Biogeochemical Cycles and Feedbacks*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 5-739 ("The applicability of the linear feedback framework (Section 5.4.5.5) suggests that large-scale biogeochemical feedbacks are approximately linear in the forcing from changes in CO_2 and climate. Nevertheless, regionally the biosphere is known to be capable of producing abrupt changes or even 'tipping points' (Higgins and Scheiter, 2012; Lasslop et al., 2016).").

[46] Canadell J. G., *et al.* (2021) *Chapter 5: Global Carbon and other Biogeochemical Cycles and Feedbacks*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 5-67 ("There is *low confidence* in the estimate of the non-CO_2 biogeochemical feedbacks, due to the large range in the estimates of α for some individual feedbacks (Figure 5.29c), which can be attributed to the diversity in how models account for these feedbacks, limited process-level understanding, and the existence of known feedbacks for which there is not sufficient evidence to assess the feedback strength."). *See also* Chen D., Rojas M., Samset B. H., Cobb K., Diongue Niang A., Edwards P., Emori S., Faria S. H., Hawkins E., Hope P., Huybrechts P., Meinshausen M., Mustafa S. K., Plattner G.-K., & Tréguier A.-M. (2021) *Chapter 1: Framing, Context and Methods*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 202 ("Such paleoclimate evidence has even fuelled concerns that anthropogenic GHGs could tip the global climate into a permanent hot state (Steffen et al., 2018). However, there is no evidence of such non-linear responses at the global scale in climate projections for the next century, which indicate a near-linear dependence of global temperature on cumulative GHG emissions (Section 1.3.5, Chapter 5, Section 5.5 and Chapter 7, Section 7.4.3.1). At the regional scale, abrupt changes and tipping points, such as Amazon forest dieback and permafrost collapse, have occurred in projections with Earth System Models (Drijfhout et al., 2015; Bathiany et al., 2020; Chapter 4, Section 4.7.3). In such simulations, tipping points occur in narrow regions of parameter space (e.g., CO_2 concentration or temperature increase), and for specific climate background states. This makes them difficult to predict using ESMs relying on parmeterizations of known processes. In some cases, it is possible to detect forthcoming tipping points through time-series analysis that identifies increased sensitivity to perturbations as the tipping point is approached (e.g., 'critical slowing-down', Scheffer et al., 2012)."); Bathiany S., Hidding J., & Scheffer M. (2020) *Edge Detection Reveals Abrupt and Extreme Climate Events*, J. CLIM. 33(15): 6399–6421, 6416 ("Despite their societal relevance, our knowledge about the risks of future abrupt climate shifts is far from robust. Several important aspects are highly uncertain: future greenhouse gas emissions (scenario uncertainty), the current climate state (initial condition uncertainty), the question whether and how to model specific processes (structural uncertainty), and what values one should choose for parameters appearing in the equations (parametric uncertainty). Such uncertainties can be explored using ensemble simulations. For example, by running many simulations with different combinations of parameter values a perturbed-physics ensemble can address how parameter uncertainty affects the occurrence of extreme events (Clark et al. 2006). This strategy can be particularly beneficial for studying abrupt events as well since abrupt shifts are associated with region-specific processes, whereas models are usually calibrated to produce a realistic global mean climate at the expense of regional realism (Mauritsen et al. 2012; McNeall et al. 2016). The currently available model configurations are therefore neither reliable nor sufficient to assess the risk of abrupt shifts (Drijfhout et al. 2015). It is hence very plausible that yet-undiscovered tipping points can occur in climate models."); McIntyre M. E. (2023) *Climate tipping points: A personal view*, PHYSICS TODAY 76(3), 44–49, 45–46 ("Nearly all the climate system's real complexity is outside the scope of any model, whether it's

a global climate model that aims to represent the climate system as a whole or a model that only simulates the carbon cycle, ice flow, or another subsystem…. Changes taking only a few years are almost instantaneous from a climate-system perspective. They're a warning to take seriously the possibility of tipping points in the dynamics of the real climate system.[9] The warning is needed because some modelers have argued that tipping points are less probable for the real climate system than for the simplified, low-order climate models studied by dynamic-systems researchers.[3] Other researchers, however, have suggested that such a tipping point may be reached sometime in the next few decades or even sooner.[6,7] Some of its mechanisms resemble those of the Dansgaard–Oeschger warmings and would suddenly accelerate the rate of disappearance of Arctic sea ice. As far as I am aware, no such tipping points have shown up in the behavior of the biggest and most sophisticated climate models. The suggested tipping-point behavior depends on fine details that are not well resolved in the models, including details of the sea ice and the layering of the upper ocean. Also of concern are increases in the frequency and intensity of destructive weather extremes. Such increases have already been observed in recent years. Climate scientists are asking how much further the increases will go and precisely how they will develop. That question is, of course, bound up with the question of tipping points. A failure to simulate many of the extremes themselves, especially extremes of surface storminess, must count as another limitation of the climate models. The reasons are related to the resolution constraints of climate models."); Spratt D. (19 April 2023) *Faster than forecast, climate impacts trigger tipping points in the Earth system*, BULLETIN OF THE ATOMIC SCIENTISTS ("While observed warming has been close to climate model projections, the impacts have in many instances been faster and even more extreme than the models forecasted. William Ripple and his co-researchers show that many positive feedbacks are not fully accounted for in climate models…. In September 2022, Stockholm University's David Armstrong McKay and his colleagues concluded that even global warming of 1-degree Celsius risks triggering some tipping points, just one data point in an alarming mountain of research on tipping points presented in the last year and a half.... Speaking in 2018, Steffen said that the dominant linear, deterministic framework for assessing climate change is flawed, especially at higher levels of temperature rise. Model projections that don't include these feedback and cascading processes "become less useful at higher temperature levels… or, as my co-author John Schellnhuber says, we are making a big mistake when we think we can 'park' the Earth System at any given temperature rise – say 2°C – and expect it to stay there."); *and* Spratt D. & Dunlop I. (2017) *What lies beneath? The scientific understatement of climate risks*, 21 ("As discussed above, climate models are not yet good at dealing with tipping points. This is partly due to the nature of tipping points, where a particular and complex confluence of factors abruptly change a climate system characteristic and drive it to a different state. To model this, all the contributing factors and their forces have to be well identified, as well as their particular interactions, plus the interactions between tipping points. Researchers say that "complex, nonlinear systems typically shift between alternative states in an abrupt, rather than a smooth manner, which is a challenge that climate models have not yet been able to adequately meet.").

[47] Forster P., Rosen D., Lamboll R., & Rogelj J. (11 November 2022) *Guest post: What the tiny remaining 1.5C carbon budget means for climate policy*, CARBON BRIEF ("The latest estimates from the Global Carbon Project (GCP) show that total worldwide CO2 emissions in 2022 have reached near-record levels. The GCP's estimates put the remaining carbon budget for 1.5C – specifically, the amount of CO2 that can still be emitted for a 50% chance of staying below 1.5C of warming – at 380bn tonnes of CO2 (GtCO2). At the current rate of emissions, this budget would be blown in just nine years. While that is a disconcertingly short amount of time, the budget for 1.5C may actually be even tighter. Combining the latest insights from the Intergovernmental Panel on Climate Change (IPCC) with the GCP's data, we estimate that the remaining 1.5C carbon budget could be just 260GtCO2 – around 120GtCO2 smaller. If emissions continued at current levels, this budget would run out in around six and half years.").

[48] Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS [West Antarctic Ice Sheet] and GrIS [Greenland Ice Sheet] tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF [low-latitude coral reefs], and North Atlantic subpolar gyre / Labrador-Irminger Sea convection abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST [Global Mean Surface Temperature] returns below 1.5°C within an uncertain overshoot time (likely decades) (94). … The chance of

triggering CTPs [Climate tipping points] is already non-negligible and will grow even with stringent climate mitigation (SSP1-1.9 in Fig. 2, B and C). Nevertheless, achieving the Paris Agreement's aim to pursue efforts to limit warming to 1.5°C would clearly be safer than keeping global warming below 2°C (90) (Fig. 2). Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC [North Atlantic subpolar gyre / Labrador-Irminger Sea convection] collapse is crossed. The likelihood of triggering AMOC [Atlantic Meridional Overturning Circulation] collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C. A cluster of abrupt shifts occur in ESM [Earth System Models] at 1.5 to 2°C (19). Although not tipping elements, ASSI [Arctic Summer Sea Ice] loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C.").

[49] Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE 575(7784): 592–595, 592 ("Models suggest that the Greenland ice sheet could be doomed at 1.5 °C of warming3, which could happen as soon as 2030. …The world's remaining emissions budget for a 50:50 chance of staying within 1.5 °C of warming is only about 500 gigatonnes (Gt) of CO_2. Permafrost emissions could take an estimated 20% (100 Gt CO_2) off this budget, and that's without including methane from deep permafrost or undersea hydrates. If forests are close to tipping points, Amazon dieback could release another 90 Gt CO_2 and boreal forests a further 110 Gt CO_2. With global total CO_2 emissions still at more than 40 Gt per year, the remaining budget could be all but erased already. …We argue that the intervention time left to prevent tipping could already have shrunk towards zero, whereas the reaction time to achieve net zero emissions is 30 years at best. Hence we might already have lost control of whether tipping happens. A saving grace is that the rate at which damage accumulates from tipping — and hence the risk posed — could still be under our control to some extent."). *See also* Ripple W. J., Wolf C., Newsome T. M., Gregg J. W., Lenton T. M., Palomo I., Eikelboom J. A. J., Law B. E., Huq S., Duffy P. B., & Rockström J. (2021) *World Scientists' Warning of a Climate Emergency 2021*, BIOSCIENCE: biab079, 1–5, 1 ("There is also mounting evidence that we are nearing or have already crossed tipping points associated with critical parts of the Earth system, including the West Antarctic and Greenland ice sheets, warm-water coral reefs, and the Amazon rainforest.").

[50] Steffen W., *et al.* (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33): 8252–8259, 8253, 8256 ("Earth System dynamics can be described, studied, and understood in terms of trajectories between alternate states separated by thresholds that are controlled by nonlinear processes, interactions, and feedbacks. Based on this framework, we argue that social and technological trends and decisions occurring over the next decade or two could significantly influence the trajectory of the Earth System for tens to hundreds of thousands of years and potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be inhospitable to current human societies and to many other contemporary species.… Hothouse Earth is likely to be uncontrollable and dangerous to many, particularly if we transition into it in only a century or two, and it poses severe risks for health, economies, political stability (**12**, **39**, **49**, **50**) (especially for the most climate vulnerable), and ultimately, the habitability of the planet for humans.").

[51] Rockström J., *et al.* (2021) *Identifying a Safe and Just Corridor for People and the Planet*, EARTH'S FUTURE 9(4): 1–7, 2 ("Critical to achieving a full integration of 'safe' and 'just' is to scientifically assess a safe and just corridor for human development on Earth (Figure 1), which we define as follows: Safe Earth system targets are those where biophysical stability of the Earth system is maintained and enhanced over time, thereby safeguarding its functions and ability to support humans and all other living organisms. Just Earth system targets are those where nature's benefits, risks, and related responsibilities are eq-uitably shared among all human beings in the world. A safe and just corridor for people and the planet is where safe and just Earth system target ranges overlap. This corridor bounds pathways of future human development that are both safe and just over time. This safe and just corridor will provide high-level "outcome" goals and the context for companies, cities, governments, and other actors who want to take action by operationalizing scientifically guided sustainability in their ventures (Andersen et al., 2020). Safe and just also implies that the Earth's natural resources, such as budgets for carbon, nutrients, water, and land, are finite (defined by safety) and have to be shared between people and with nature."). *See also* Möller T., Högner A., Schleussner C.-F., Bien S., Kitzmann N., Lamboll R., Rogelj J., Donges J., Rockström J., & Wunderling N. (2023) *Achieving net zero greenhouse gas emissions critical to limit climate tipping risks*, NATURE PORTFOLIO (*preprint*), 1–29, 12 ("Our study reveals that

under a pathway following current climate policies, tipping risks until 2300 are high (median 45 %) and increase even further in the long-term (median 76 %). Pledged NDCs under the UNFCCC in 2020 fail to adhere to the Paris Agreement LTTG, and are insufficient to constrain tipping risks (median 30 % until 2300). Overshoots with peak temperatures above 1.8 °C lead to very steep tipping risk gradients of more than 5 % per 0.1 °C time-averaged temperature increase during the overshoot above 1.5 °C. This confirms the importance of reaching at least NZGHG emissions in the second half of the 21st century and returning GMT to below 1.5 °C by 2100.").

[52] Earth Commission (31 May 2023) *A just world on a safe planet: First study quantifying Earth System Boundaries live* ("Safe: 1.5°C to avoid high likelihood of multiple climate tipping points. NOT YET BREACHED; Just: 1°C to avoid high exposure to significant harm from climate change. BREACHED AT 1.2°C; **Safe and Just:** 1°C "); *discussing* Rockström J., *et al.* (2023) *Safe and just Earth system boundaries*, NATURE 619: 102–111.

[53] Arias P. A., *et al.* (2021) *Technical Summary*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), TS-9 ("Timing of crossing 1.5°C global warming: Slightly different approaches are used in SR1.5 and in this Report. SR1.5 assessed a likely range of 2030 to 2052 for reaching a global warming level of 1.5°C (for a 30-year period), assuming a continued, constant rate of warming. In AR6, combining the larger estimate of global warming to date and the assessed climate response to all considered scenarios, the central estimate of crossing 1.5°C of global warming (for a 20-year period) occurs in the early 2030s, ten years earlier than the midpoint of the likely range assessed in the SR1.5, assuming no major volcanic eruption. (TS.1.3, Cross-Section Box TS.1)").

[54] Xu Y., Ramanathan V., & Victor D. G. (2018) *Global warming will happen faster than we think*, NATURE 564(7734): 30–32, 31 ("In 2017, industrial carbon dioxide emissions are estimated to have reached about 37 gigatonnes[2]. This puts them on track with the highest emissions trajectory the IPCC has modelled so far. This dark news means that the next 25 years are poised to warm at a rate of 0.25–0.32 °C per decade[3]. That is faster than the 0.2 °C per decade that we have experienced since the 2000s, and which the IPCC used in its special report."). *See also* Hansen J. E., Sato M., Simons L., Nazarenko L. S., Sangha I., Kharecha P., Zachos J. C., von Schuckmann K., Loeb N. G., Osman M. B., Jin Q., Tselioudis G., Jeong E., Lacis A., Ruedy R., Russell G., Cao J., & Li J. (2023*) Global warming in the pipeline*, OXF. OPEN CLIM. CHANGE 3(1): 1–33, 21 ("With current policies, we expect climate forcing for a few decades post-2010 to increase 0.5–0.6 W/m^2 per decade and produce global warming of at least +0.27°C per decade. In that case, global warming will reach 1.5°C in the 2020s and 2°C before 2050 (Fig. 24). Such acceleration is dangerous in a climate system that is already far out of equilibrium and dominated by multiple amplifying feedbacks." … Figure 25 caption reads "Edges of the predicted post-2010 accelerated warming rate (see text) are 0.36 and 0.27°C per decade."); *and* Ritchie P. D. L., Alkhayuon H., Cox P. M., & Wieczorek S. (2023) *Rate-induced tipping in natural and human systems*, EARTH SYST. DYNAM. 14(3): 669–683, 669–670 ("Large and abrupt changes in the state of an open system may occur when the external forcing exceeds some critical level (Scheffer, 2010; Lenton, 2011; Kuehn, 2011). The points in time, or in the level of forcing, at which such changes occur are commonly referred to as bifurcationinduced tipping points (Ashwin et al., 2012). They have been identified in many domains, including ecosystems (Scheffer et al., 1993, 2001, 2009; Siteur et al., 2014; Dakos et al., 2019; Pierini and Ghil, 2021) and the human brain (Rinzel and Ermentrout, 1998; Moehlis, 2008; Screen and Simmonds, 2010; Mitry et al., 2013; Maturana et al., 2020), and are of particular concern under anthropogenic climate change (Lenton et al., 2008; Ashwin and von der Heydt, 2020; Arias et al., 2021; Ritchie et al., 2021; Boers and Rypdal, 2021; Boulton et al., 2022). Furthermore, it has recently been recognised that critical levels can be exceeded temporarily without causing tipping (van der Bolt et al., 2018; Ritchie et al., 2019; Alkhayuon et al., 2019; O'Keeffe and Wieczorek, 2020). This occurs when the time of exceedance is short compared to the inherent timescale of the system (O'Keeffe and Wieczorek, 2020; Ritchie et al., 2021; Alkhayuon et al., 2023). However, there is another, less obvious potential consequence of changes in external forcing. When an external forcing changes faster than some critical rate rather than necessarily by a large amount, this can lead to rate-induced tipping points (Stocker and Schmittner, 1997; Luke and Cox, 2011; Wieczorek et al., 2011; Ashwin et al., 2012; Ritchie and Sieber, 2016; Siteur et al., 2016; Suchithra et al., 2020; Arumugam et al., 2020; Pierini and Ghil, 2021; Wieczorek et al., 2023; Longo et al., 2021; Kuehn and Longo, 2022; Kaur and Sharathi Dutta, 2022; Hill et al., 2022; Arnscheidt and Rothman, 2022). In contrast to bifurcationinduced tipping, rate-induced tipping occurs due to fastenough changes in external forcing and usually does not exceed any critical levels as a result of external forcing. Such tipping points are much less widely known and yet are arguably even more relevant

to contemporary issues such as climate change (Lohmann and Ditlevsen, 2021; Clarke et al., 2021; O'Sullivan et al., 2022), ecosystem collapse (Scheffer et al., 2008; Vanselow et al., 2019; van der Bolt and van Nes, 2021; Neijnens et al., 2021; Vanselow et al., 2022), and the resilience of human systems (Witthaut et al., 2021).").

[55] Hansen J. E., Sato M., Simons L., Nazarenko L. S., Sangha I., Kharecha P., Zachos J. C., von Schuckmann K., Loeb N. G., Osman M. B., Jin Q., Tselioudis G., Jeong E., Lacis A., Ruedy R., Russell G., Cao J., & Li J. (2023*)* *Global warming in the pipeline*, OXF. OPEN CLIM. CHANGE 3(1): 1–33, 21 ("With current policies, we expect climate forcing for a few decades post-2010 to increase 0.5–0.6 W/m^2 per decade and produce global warming of at least +0.27°C per decade. In that case, global warming will reach 1.5°C in the 2020s and 2°C before 2050 (Fig. 24). Such acceleration is dangerous in a climate system that is already far out of equilibrium and dominated by multiple amplifying feedbacks." … Figure 25 caption reads "Edges of the predicted post-2010 accelerated warming rate (see text) are 0.36 and 0.27°C per decade.").

[56] Xu Y., Ramanathan V., & Victor D. G. (2018) *Global warming will happen faster than we think*, Comment, NATURE 564(7734): 30–32, 30–31 ("But the latest IPCC special report underplays another alarming fact: global warming is accelerating. Three trends—rising emissions, declining air pollution and natural climate cycles—will combine over the next 20 years to make climate change faster and more furious than anticipated. In our view, there's a good chance that we could breach the 1.5 °C level by 2030, not by 2040 as projected in the special report (see 'Accelerated warming'). The climate-modelling community has not grappled enough with the rapid changes that policymakers care most about, preferring to focus on longer-term trends and equilibria."). Since Xu, Ramanathan, and Victor Comment was published, the IPCC has updated its estimate for when 1.5 °C will be exceeded: ***see*** Arias P. A., ***et al.*** (2021) *Technical Summary*, ***in*** CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), TS-9 ("Timing of crossing 1.5°C global warming: Slightly different approaches are used in SR1.5 and in this Report. SR1.5 assessed a likely range of 2030 to 2052 for reaching a global warming level of 1.5°C (for a 30-year period), assuming a continued, constant rate of warming. In AR6, combining the larger estimate of global warming to date and the assessed climate response to all considered scenarios, the central estimate of crossing 1.5°C of global warming (for a 20-year period) occurs in the early 2030s, ten years earlier than the midpoint of the likely range assessed in the SR1.5, assuming no major volcanic eruption. (TS.1.3, Cross-Section Box TS.1)").

[57] These six tipping points, shown in **Figure** Error! Main Document Only.**,** are the Greenland ice sheet, West Antarctic ice sheet, low-latitude (warm water) coral reefs, abrupt permafrost thaw, abrupt loss of Barents Sea winter ice, and collapse of the subpolar gyre (SPG) overturning circulation in the Labrador Sea. *See* Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC collapse is crossed. The likelihood of triggering AMOC collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C.A cluster of abrupt shifts occur in ESMs at 1.5 to 2°C (19). Although not tipping elements, ASSI loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C.").

[58] Here we distinguish between abrupt shifts, as in Drijfhout *et al*. (2015), and the more restrictive definition of "core climate tipping points" defined by Armstrong McKay *et al.* (2022) as "when change in part of the climate system becomes (i) selfperpetuating beyond (ii) a warming threshold as a result of asymmetry in the relevant feedbacks, leading to (iii) substantial and widespread Earth system impacts." For description of the eleven abrupt shifts, *see* Drijfhout S., Bathiany S., Beaulieu C., Brovkin V., Claussen M., Huntingford C., Scheffer M., Sgubin G., & Swingedouw D. (2015) *Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models*, PROC. NAT'L. ACAD. SCI. 112(43): E5777–E5786, E5777, E5784 ("Abrupt transitions of regional climate in response to the gradual rise in atmospheric greenhouse gas concentrations are notoriously difficult to foresee. However, such events could be particularly challenging in view of the capacity required for society and ecosystems to adapt to them. We present, to our knowledge, the first systematic screening of the massive climate model ensemble informing the recent Intergovernmental Panel on Climate Change report, and reveal evidence of 37 forced regional abrupt changes

in the ocean, sea ice, snow cover, permafrost, and terrestrial biosphere that arise after a certain global temperature increase. Eighteen out of 37 events occur for global warming levels of less than 2°, a threshold sometimes presented as a safe limit."; 11 abrupt shifts are shown between 1.0–1.5°C in "Fig. 4. Abrupt shifts as a function of global temperature increase. Shown are the number of abrupt climate changes occurring in the CMIP5 database for different intervals of warming relative to the preindustrial climate."). *See also* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, Rev. Geophys. 61(e2021RG000757): 1–81, 48 ("Earth system elements that this review indicates are at higher risk of crossing critical thresholds or undergoing substantial changes in response to warming this century under moderate (RCP4.5) emissions scenarios include loss of Arctic summer sea ice, loss of portions of the GIS, loss of portions of the West Antarctic Ice-sheet, Amazon rainforest dieback, boreal forest ecosystem shifts, some permafrost carbon release, and coral reef loss (Figure 14). In contrast, methane release from marine methane hydrates and strato-cumulus cloud deck evaporation will likely require longer timescales and higher emissions forcing in order to occur at large scales, while disruptions of tropical monsoons may be contingent on large shifts in other Earth system components and are unlikely to occur as a direct response to changes in aerosol forcing or land cover (see Section 2.6). Critical thresholds for weakening of the AMOC remain unclear and a transition of this system to a different state may not occur this century (see Section 2.1). While the GIS and WAIS may transgress critical thresholds this century (see Section 2.3), timescales of ice loss may require many centuries to millennia to run to completion (Bakker et al., 2016; Clark et al., 2016; Golledge et al., 2015; Huybrechts & De Wolde, 1999)."); Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, Nature 575(7784): 592–595, 593 ("A further key impetus to limit warming to 1.5 °C is that other tipping points could be triggered at low levels of global warming. The latest IPCC models projected a cluster of abrupt shifts between 1.5 °C and 2 °C, several of which involve sea ice. This ice is already shrinking rapidly in the Arctic...."); Arias P. A., *et al.* (2021) *Technical Summary*, *in* Climate Change 2021: The Physical Science Basis, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), TS-71–TS-72 ("It is *likely* that under stabilization of global warming at 1.5°C, 2.0°C, or 3.0°C relative to 1850–1900, the AMOC will continue to weaken for several decades by about 15%, 20% and 30% of its strength and then recover to pre-decline values over several centuries (*medium confidence*). At sustained warming levels between 2°C and 3°C, there is limited evidence that the Greenland and West Antarctic Ice Sheets will be lost almost completely and irreversibly over multiple millennia; both the probability of their complete loss and the rate of mass loss increases with higher surface temperatures (*high confidence*). At sustained warming levels between 3°C and 5°C, near-complete loss of the Greenland Ice Sheet and complete loss of the West Antarctic Ice Sheet is projected to occur irreversibly over multiple millennia (*medium confidence*); with substantial parts or all of Wilkes Subglacial Basin in East Antarctica lost over multiple millennia (*low confidence*). Early-warning signals of accelerated sea-level-rise from Antarctica, could possibly be observed within the next few decades. For other hazards (e.g., ice sheet behaviour, glacier mass loss and global mean sea level change, coastal floods, coastal erosion, air pollution, and ocean acidification) the time and/or scenario dimensions remain critical, and a simple and robust relationship with global warming level cannot be established (*high confidence*)... The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with climate change (*high confidence*). It is *very unlikely* that gas clathrates (mostly methane) in deeper terrestrial permafrost and subsea clathrates will lead to a detectable departure from the emissions trajectory during this century. Possible abrupt changes and tipping points in biogeochemical cycles lead to additional uncertainty in 21st century atmospheric GHG concentrations, but future anthropogenic emissions remain the dominant uncertainty (*high confidence*). There is potential for abrupt water cycle changes in some high-emission scenarios, but there is no overall consistency regarding the magnitude and timing of such changes. Positive land surface feedbacks, including vegetation, dust, and snow, can contribute to abrupt changes in aridity, but there is only *low confidence* that such changes will occur during the 21st century. Continued Amazon deforestation, combined with a warming climate, raises the probability that this ecosystem will cross a tipping point into a dry state during the 21st century (*low confidence*)."); *and* Lee J.-Y., Marotzke J., Bala G., Cao L., Corti S., Dunne J. P., Engelbrecht F., Fischer E., Fyfe J. C., Jones C., Maycock A., Mutemi J., Ndiaye O., Panickal S., & T. Zhou (2021) *Chapter 4: Future Global Climate: Scenario-Based Projections and Near-Term Information*, *in* Climate Change 2021: The Physical Science Basis, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 4-96 (Table 4.10 lists 15 components of the Earth system susceptible to tipping points).

[59] Lenton T. M., *et al.* (eds.) (2023) *Summary Report*, in GLOBAL TIPPING POINTS REPORT 2023, 13 ("Already, at today's 1.2°C global warming, tipping of warm-water coral reefs is likely and we cannot rule out that four other systems may pass tipping points: the ice sheets of Greenland and West Antarctica, the North Atlantics Subpolar Gyre circulation, and parts of the permafrost subject to abrupt thaw."). *See also* Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): 1–10, 7 ("Current warming is ~1.1°C above preindustrial and even with rapid emission cuts warming will reach ~1.5°C by the 2030s (23). We cannot rule out that WAIS [West Antarctic ice sheet] and GrIS [Greenland ice sheet] tipping points have already been passed (see above) and several other tipping elements have minimum threshold values within the 1.1 to 1.5°C range. Our best estimate thresholds for GrIS, WAIS, REEF, and abrupt permafrost thaw (PFAT) are ~1.5°C although WAIS and GrIS collapse may still be avoidable if GMST [global mean surface temperature] returns below 1.5°C within an uncertain overshoot time (likely decades) (94). Setting aside achievability (and recognizing internal climate variability of ~±0.1°C), this suggests that ~1°C is a level of global warming that minimizes the likelihood of crossing CTPs [climate tipping points].").

[60] Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 36 ("At 2°C of global warming, overall risk levels associated with the unequal distribution of impacts (RFC3), global aggregate impacts (RFC4) and large-scale singular events (RFC5) would be transitioning to high (*medium confidence*), those associated with extreme weather events (RFC2) would be transitioning to very high (*medium confidence*), and those associated with unique and threatened systems (RFC1) would be very high (*high confidence*) (Figure 3.3, panel a). With about 2°C warming, climate-related changes in food availability and diet quality are estimated to increase nutrition-related diseases and the number of undernourished people, affecting tens (under low vulnerability and low warming) to hundreds of millions of people (under high vulnerability and high warming), particularly among low-income households in low- and middle-income countries in sub-Saharan Africa, South Asia and Central America (*high confidence*). For example, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20% (*medium confidence*). Climate change risks to cities, settlements and key infrastructure will rise sharply in the mid- and long-term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high confidence*)."; "RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet instability or thermohaline circulation slowing.").

[61] Drijfhout S., Bathiany S., Beaulieu C., Brovkin V., Claussen M., Huntingford C., Scheffer M., Sgubin G., & Swingedouw D. (2015) *Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models*, PROC. NAT'L. ACAD. SCI. 112(43): E5777–E5786, E5784 ("Permafrost carbon release (51) and methane hydrates release (52) were not expected in CMIP5 simulations, because of missing biogeochemical components in those models capable of simulating such changes."). *See also* Bathiany S., Hidding J., & Scheffer M. (2020) *Edge Detection Reveals Abrupt and Extreme Climate Events*, J. CLIM. 33(15): 6399–6421, 6416 ("Despite their societal relevance, our knowledge about the risks of future abrupt climate shifts is far from robust. Several important aspects are highly uncertain: future greenhouse gas emissions (scenario uncertainty), the current climate state (initial condition uncertainty), the question whether and how to model specific processes (structural uncertainty), and what values one should choose for parameters appearing in the equations (parametric uncertainty). Such uncertainties can be explored using ensemble simulations. For example, by running many simulations with different combinations of parameter values a perturbed-physics ensemble can address how parameter uncertainty affects the occurrence of extreme events (Clark et al. 2006). This strategy can be particularly beneficial for studying abrupt events as well since abrupt shifts are associated with region-specific processes, whereas models are usually calibrated to produce a realistic global mean climate at the expense of regional realism (Mauritsen et al. 2012; McNeall et al. 2016). The currently available model configurations are therefore neither reliable nor sufficient to assess the risk of abrupt shifts (Drijfhout et al. 2015). It

is hence very plausible that yet-undiscovered tipping points can occur in climate models."); Canadell J. G., *et al.* (2021) *Chapter 5: Global Carbon and other Biogeochemical Cycles and Feedbacks*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 5-78 ("There is *low confidence* in the estimate of the non-CO_2 biogeochemical feedbacks, due to the large range in the estimates of α for some individual feedbacks (Figure 5.29c), which can be attributed to the diversity in how models account for these feedbacks, limited process-level understanding, and the existence of known feedbacks for which there is not sufficient evidence to assess the feedback strength."); *and* Permafrost Pathways, *Course of Action: Mitigation Policy*, Woodwell Climate Research Center (*last visited* 14 February 2023) ("Depending on how hot we let it get, carbon emissions from Arctic permafrost thaw are expected to be in the range of 30 to more than 150 billion tons of carbon (110 to more than 550 Gt CO_2) this century, with upper estimates on par with the cumulative emissions from the entire United States at its current rate. To put it another way, permafrost thaw emissions could use up between 25 and 40 percent of the remaining carbon budget that would be necessary to cap warming at the internationally agreed-upon 2 degrees Celsius global temperature threshold established in the Paris Agreement.... Despite the enormity of this problem, gaps in permafrost carbon monitoring and modeling are resulting in permafrost being left out of global climate policies, rendering our emissions targets fundamentally inaccurate. World leaders are in a race against time to reduce emissions and prevent Earth's temperature from reaching dangerous levels. The problem is, without including current and projected emissions from permafrost, this race will be impossible to finish.... 82% [o]f IPCC models do not include carbon emissions from permafrost thaw.").

[62] Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE 575(7784): 592–595, 594 ("In our view, the clearest emergency would be if we were approaching a global cascade of tipping points that led to a new, less habitable, 'hothouse' climate state[11]. Interactions could happen through ocean and atmospheric circulation or through feedbacks that increase greenhouse-gas levels and global temperature."). *See also* Wunderling N., Donges J. F., Kurths J., & Winkelmann R. (2021) *Interacting tipping elements increase risk of climate domino effects under global warming*, EARTH SYST. DYN. 12(2): 601–619, 614 ("In this study, we show that this risk increases significantly when considering interactions between these climate tipping elements and that these interactions tend to have an overall destabilising effect. Altogether, with the exception of the Greenland Ice Sheet, interactions effectively push the critical threshold temperatures to lower warming levels, thereby reducing the overall stability of the climate system. The domino-like interactions also foster cascading, non-linear responses. Under these circumstances, our model indicates that cascades are predominantly initiated by the polar ice sheets and mediated by the AMOC. Therefore, our results also imply that the negative feedback loop connecting the Greenland Ice Sheet and the AMOC might not be able to stabilise the climate system as a whole."); Klose A. K., Wunderling N., Winkelmann R., & Donges J. F. (2021) *What do we mean, `tipping cascade'?*, ENVIRON. RES. LETT. 16(12): 125011, 1–12, 1 ("Here we illustrate how different patterns of multiple tipping dynamics emerge from a very simple coupling of two previously studied idealized tipping elements. In particular, we distinguish between a two phase cascade, a domino cascade and a joint cascade. A mitigation of an unfolding two phase cascade may be possible and common early warning indicators are sensitive to upcoming critical transitions to a certain degree. In contrast, a domino cascade may hardly be stopped once initiated and critical slowing down-based indicators fail to indicate tipping of the following element. These different potentials for intervention and anticipation across the distinct patterns of multiple tipping dynamics should be seen as a call to be more precise in future analyses of cascading dynamics arising from tipping element interactions in the Earth system."); Rocha J. C., Peterson G., Bodin Ö., & Levin S. (2018) *Cascading regime shifts within and across scales*, SCIENCE 362(6421): 1379–1383, 1383 ("A key lesson from our study is that regime shifts can be interconnected. Regime shifts should not be studied in isolation under the assumption that they are independent systems. Methods and data collection need to be further developed to account for the possibility of cascading effects. Our finding that ~45% of regime shift couplings can have structural dependence suggests that current approaches to environmental management and governance underestimate the likelihood of cascading effects."); *and* Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 16 ("Human influence has likely increased the chance of compound extreme events since the 1950s. Concurrent and repeated climate hazards have occurred in all regions, increasing impacts and risks to health,

ecosystems, infrastructure, livelihoods and food (*high confidence*). Compound extreme events include increases in the frequency of concurrent heatwaves and droughts (*high confidence*); fire weather in some regions (*medium confidence*); and compound flooding in some locations (*medium confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Compound climate hazards can overwhelm adaptive capacity and substantially increase damage (*high confidence*).").

[63] Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 101 ("Direct interactions between Greenland and West Antarctic ice sheets via sea level[:] It is known that an increase in sea level has an overall destabilizing influence on marine-based sectors of ice sheets, possibly triggering or enhancing the retreat of their grounding line (Schoof, 2007; Weertman, 1974). In the case of ice sheet collapse, the induced sea level rise would vary locally depending on gravitational effects (with sea level falling near the former ice sheet as less water is attracted towards it), rotational effects, and mantle deformation (Kopp et al., 2010; Mitrovica et al., 2009). Overall, sea level rise is expected to negatively impact both the GrIS and WAIS, but more strongly the latter, where most of the bedrock lies well below sea level (Gomez et al., 2020).").

[64] Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 100 ("The AMOC, Greenland Ice Sheet (GrIS), and West Antarctic Ice Sheet (WAIS) are key tipping systems and are threatened by increasing CO_2 emissions and temperatures (Armstrong McKay et al., 2022; Pörtner et al., 2019). Moreover, GrIS, AMOC, and WAIS interact on very different timescales, ranging from decades to multiple centuries. While some of those links might be stabilising, others are destabilizing and would allow for the possibility of large-scale cascading events."). *See also* Rosser J., Winkelmann R., & Wunderling N. (2024) *Cryosphere tipping elements decisive for tipping risks and cascading effects in the Earth system*, NATURE PORTFOLIO (*preprint*), 1–35, 14 ("We initially focus on the GIS as it is consistently one of the most important elements in both the Sobol variance analysis (see Figs. 1 and 2) and the leave one out analysis (see Fig. 3), giving the biggest decrease in mean number of elements tipped when removed from the 1.5℃ scenario. At 1.5℃, the impact of totally removing the GIS is a reduction of 56% in the mean number of elements tipped in the system, but it also has significant impacts in the qualitative behaviour of the system. As the GIS has a low tipping point (between 0.8–3.0℃) and strong links to other tipping elements (AMOC, WAIS), it is a key initiator of cascades at low global warming levels. So, when it is removed, the amount of tipping events and cascading effects that we record in the other elements is greatly reduced. Although these are the only elements with direct links to the GIS, there are cascading impacts through these links onto the entire system, so the outcome of removing the GIS is a significant reduction in tipping for every investigated element. … AMOC behaves very differently to the GIS in the model, acting as a mediator of cascades and also as a stabiliser on the GIS in the cases where the AMOC tips due to its strong stabilising link to the GIS. This makes its impact much more nuanced than the GIS as seen in Figure 4. When the AMOC is removed entirely at 1.5℃, the mean number of elements tipped is reduced by 22%, much less than the 56% when the GIS term was removed. This is because the total removal of the AMOC tipping (and the subsequent loss of Amazon and ENSO tipping, which are only disintegrating at this temperature due to AMOC forcing) is mostly compensated by increases in the tipping of the GIS and WAIS, as the GIS is no longer stabilised by the AMOC and is more likely to tip and influence the WAIS. Therefore, removing an element can have both a quantitative impact on the amount of tipping in a system but also a large qualitative impact on the locations of tipping and the behaviour of different elements. This suggests that if elements are missing from an analysis or a climate model, even the broad behaviour of climate elements may be incorrectly modelled, and the relative importance of elements and regions of the climate system may be misjudged."); *and* Klose A. K., Donges J. F., Feudel U., & Winkelmann R. (2023) *Rate-induced tipping cascades arising from interactions between the Greenland Ice Sheet and the Atlantic Meridional Overturning Circulation*, EARTH SYS. DYNAM. (*preprint*): 1–25, 13, 15 ("Decreasing the surface mass balance emulating a warming climate beyond its effective threshold $a^{(2)}_{0dgc}$ (corresponding to a strong surface mass balance decrease) does not allow for a GIS stabilization (Fig. 4(a) and (b)). Instead, for an AMOC residing sufficiently close to its hosing threshold, a GIS deglaciation and tipping of the AMOC to the 'off'-state is observed."; "A limited decrease of the surface mass balance may allow for a GIS stabilization by the negative temperature feedback. … Accordingly, the occurrence of qualitatively distinct tipping dynamics and outcomes vary with the ice sheet melting time scales. This implies that safe pathways for the evolution of tipping element drivers preventing cascading tipping and their boundary to dangerous

pathways involving cascades are controlled by rates of changes of the responsible control parameters in addition to their magnitude.”).

[65] Golledge N. R., Keller E. D., Gomez N., Naughten K. A., Bernales J., Trusel L. D., & Edwards T. L. (2019) *Global environmental consequences of twenty-first-century ice-sheet melt*, NATURE 566(7742): 65–72, 66 (“We introduce annual transient freshwater fluxes from our simulated ice sheets into the climate simulations from 2000-2100 CE under RCP 4.5 and 8.5 conditions. Time-evolving fluxes are calculated by assuming all mass changes in the ice sheet result in a net flux of freshwater to the proximal ocean, which by 2100 CE reach maxima of approximately 0.042 and 0.015 Sv for Antarctica and Greenland respectively for RCP 4.5, and 0.160 and 0.018 Sv for Antarctica and Greenland respectively under RCP 8.5.”); 68–69 (“In our experiments a gradual slowing in the first half of the century steepens after 2050, leading to a reduction in AMOC strength of 3 to 4 Sv (approximately 15%) over 50 years. This occurs purely as a consequence of the imposed meltwater fluxes and so would presumably add to any weakening from future climate forcing. The lower (counter-clockwise) cell of the AMOC is weaker and responds more slowly, with changes in this instance being forced primarily by Antarctic meltwater (Figure 5b). Since current climate models are thought to overestimate the stability of the AMOC, it is possible that future ice-sheet meltwater fluxes may play an even more important role than we predict here.”). *See also* Li Q., England M. H., Hogg A. M., Rintoul S. R., & Morrison A. K. (2023) *Abyssal ocean overturning slowdown and warming driven by Antarctic meltwater*, NATURE 615(7954): 841–847, 845, 847 (“The strength of the AABW overturning cell and the AMOC is projected to decrease by 42% (10.0 Sv) and 19% (2.8 Sv) by 2050, respectively. Meltwater forcing drives virtually all of the reduction in overturning in the AABW cell (Fig. 3d,e), with seawater ageing along the pathway of AABW outflow (Extended Data Fig. 11). The projected decline of AMOC results in reduced northward ocean heat transport, leading to a cooling trend in the abyssal Atlantic Ocean (Fig. 2). In contrast, the projected decline of AABW drives a warming trend across the abyssal Southern Ocean (Fig. 2), reminiscent in structure to recently observed bottom water trend.”; “We have shown that projected increases in Antarctic ice melt are set to drive a substantial slowdown of the lower cell of the global overturning circulation over the coming decades, resulting in large and widespread warming of deep waters and reduced ventilation of the abyssal ocean. In particular, a net slowdown of the abyssal ocean overturning circulation of just over 40% is projected to occur by 2050. These changes in the lower cell would profoundly alter the ocean overturning of heat, fresh water, oxygen, carbon and nutrients, with impacts felt throughout the global ocean for centuries to come.”).

[66] Smeed D. A., Josey S. A., Beaulieu C., Johns W. E., Moat B. I., Frajka-Williams E., Rayner D., Meinen C. S., Baringer M. O., Bryden H. L., & McCarthy G. D. (2018) *The North Atlantic Ocean Is in a State of Reduced Overturning*, GEOPHYS. RES. LETT. 45(3): 1527–1533, 1527 (“Using data from an array of instruments that span the Atlantic at 26°N, we show that the AMOC has been in a state of reduced overturning since 2008 as compared to 2004–2008. This change of AMOC state is concurrent with other changes in the North Atlantic such as a northward shift and broadening of the Gulf Stream and altered patterns of heat content and sea surface temperature. These changes resemble the response to a declining AMOC predicted by coupled climate models.”). *See also* Caesar L., Rahmstorf S., Robinson A., Feulner G., & Saba V. (2018) *Observed fingerprint of a weakening Atlantic Ocean overturning circulation*, NATURE 556(7700): 191–196, 195 (“We calibrated the observed AMOC decline to be 3 ± 1 Sv (around 15%) since the mid-twentieth century, and reconstructed the evolution of the AMOC for the period 1870–2016. For recent decades, our reconstruction of the AMOC evolution agrees with the results of several earlier studies using different methods, suggesting that our AMOC index can also reproduce interdecadal variations. Our findings show that in recent years the AMOC appears to have reached a new record low, consistent with the record-low annual SST in the subpolar Atlantic (since observations began in 1880) reported by the National Oceanic and Atmospheric Administration for 2015.”); *and* Fox-Kemper B., *et al.* (2021) *Chapter 9: Ocean, Cryosphere and Sea Level Change*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 1239 (“Projected AMOC decline by 2100 ranges from 24 [4 to 46] % in SSP1-2.6 to 39 [17–55] % in SSP5-8.5 (medium confidence) (Section 4.3.2.3). Note that these ranges are based on ensemble means of individual models, largely smoothing out internal variability. If single realizations are considered, the ranges become wider, especially by lowering the low end of the range (Section 4.3.2.3). In summary, it is very likely that AMOC will decline in the 21st century, but there is low confidence in the model’s projected timing and magnitude.”).

[67] van Westen R. M., Kliphuis M., & Dijkstra H. A. (2024) *Physics-based early warning signal shows that AMOC is on tipping course*, SCI. ADV. 10(6): 1–11, 1–2 ("This result differs substantially from earlier model simulations with GCMs that have used extremely large freshwater forcing [e.g., 1 Sv per year over 50°N to 70°N (20)] or large initial salinity perturbations (21). The AMOC collapse in these simulations is a direct response to the very strong forcing, whereas in our model simulations, which are more akin to the simulations in Earth System Models of Intermediate Complexity (17, 18), the collapse is primarily a response due to internal feedbacks. … Also, on the basis of the change in the AMOC per forcing change (here about 8-Sv AMOC change due to a forcing change of 0.03 Sv), it is clear that we found an AMOC tipping event (6) in the CESM simulation, which is the first one found in a complex GCM."). *See also* PROC. NAT'L. ACAD. SCI. 118(9): 1–6, 1, 4 ("Here we show that rate-induced transitions are indeed a concern for the climate system, by demonstrating explicitly the existence of a rate-induced collapse of the AMOC in a three-dimensional model of the global thermohaline circulation with time-dependent freshwater forcing…. From Fig. 3A it is clear that there is no well-defined critical rate separating tipping from tracking realizations. For T > 150 y all realizations track. For 50 y < T < 150 y there is a mixed pattern with some realizations tipping, some tracking, and others visiting the edge state. While for T < 50 y most realizations tip, this is still not guaranteed, since we find a realization for T = 10 y that evolves toward the edge state. Nevertheless, the probability of tipping increases with the rate, comparable to systems with added noise (28).").

[68] National Oceanic and Atmospheric Administration, National Ocean Service (20 January 2023) *What is the Atlantic Meridional Overturning Circulation (AMOC)?* ("The ocean's water is constantly circulated by currents. Tidal currents occur close to shore and are influenced by the sun and moon. Surface currents are influenced by the wind. However, other, much slower currents that occur from the surface to the seafloor are driven by changes in the saltiness and ocean temperature, a process called thermohaline circulation. These currents are carried in a large "global conveyor belt," which includes the AMOC. AMOC stands for Atlantic Meridional Overturning Circulation. The AMOC circulates water from north to south and back in a long cycle within the Atlantic Ocean. This circulation brings warmth to various parts of the globe and also carries nutrients necessary to sustain ocean life.").

[69] Orihuela-Pinto B., England M. H., & Taschetto A. S. (2022) *Interbasin and interhemispheric impacts of a collapsed Atlantic Overturning Circulation*, NAT. CLIM. CHANG. 12(6): 558–565, 558 ("We find that an AMOC collapse drives a complex rearrangement of the global atmospheric circulation that affects all latitudes, from the tropics to the polar circulation of both hemispheres. We find that changes in the tropical Pacific involve a robust intensification of the Walker circulation, a weakening of the subtropical highs in the Southern Hemisphere and an intensification of the Amundsen Sea Low over west Antarctica."). *See also* Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 43 ("The Atlantic Meridional Overturning Circulation is very likely to weaken over the 21st century for all considered scenarios (*high confidence*), however an abrupt collapse is not expected before 2100 (*medium confidence*). If such a low probability event were to occur, it would very likely cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, and large impacts on ecosystems and human activities."); *and* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, REV. GEOPHYS. 61: 1–81, 5, 32–33 ("A slowdown or shutdown of the AMOC system would significantly affect regional and global climate patterns (L. C. Jackson et al., 2015; W. Liu et al., 2020). Paleoclimate evidence and numerical simulations have identified AMOC transitions and/or latitudi-nal shift of deep-water formation sites as potential drivers of multiple large, rapid shifts in past climate, including fast or abrupt changes occurring on timescales as short as a few decades (Alley et al., 2001; Bozbiyik et al., 2011; Brovkin et al., 2021; Clark et al., 2001; Ganopolski & Rahmstorf, 2001; Rahmstorf, 2002). The impacts of past AMOC shifts affected climate globally, significantly altering tropical rainfall patterns and causing heat redis-tribution between the northern and southern hemispheres (S. Li & Liu, 2022; Masson-Delmotte et al., 2013). Changes to the overturning circulation could also affect the ocean's strength as a heat and carbon sink (X. Chen & Tung, 2018; Fontela et al., 2016; Nielsen et al., 2019; Romanou et al., 2017) and heat redistribution (S. Li & Liu, 2022; W. Liu & Fedorov, 2019; X. Ma et al., 2020). … In Heinrich events, for example, large discharges of fresh ice from the Laurentide ice sheet into the North Atlantic are hypothesized to have been

associated with slowing of the AMOC and cooling of the entire north-ern hemisphere, resulting in a shift of tropical precipitation maxima southward to dry and weaken the West African and South Asian summer monsoons while enhancing South American monsoon precipitation (Chiang & Bitz, 2005; Deplazes et al., 2013; Schneider et al., 2014; X. Wang et al., 2004). In these sorts of scenarios, monsoons may be responding predictably and even linearly to the abrupt forcing of extratropical climate; synchronous changes in insolation may "pace" or "trigger" these changes (Cheng et al., 2016), but the nonlinear response may originate in midlatitude ocean-atmosphere dynamics. Such scenarios bear important lessons for the possible response of monsoons to abrupt changes in the Greenland or Antarctic ice sheets or the Atlantic Meridional Overturning Circulation.").

[70] Milkoreit M. (ed.) (2023) *Section 3: Governance of Earth system tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 33 (Table 3.3.1 shows "Impacts of ESTPs [Earth system tipping points]." For AMOC, these are: "Regional sea level changes (fall in convection region & North European Shelf seas, rise further south). Shift in jet stream and storm tracks affecting weather patterns in Europe, potential increase in extreme weather events, e.g. cold winters in Europe, south-ward hurricanes shift. Partial & temporary counteraction of global warming. Southward shift in ITCZ leading to drying in the Sahel and Southern Asia; Some models project drying in parts of the Amazon. Summer monsoon weakening and shifts in Africa and Asia. Up to 10°C cooling in North Atlantic and 3°C cooling in Northern Europe / Eastern Canada, warming amplification in Southern Hemisphere. Drastic shifts in many ecosystems on land and in the sea around the world, e.g. Amazon drying. Affects dust aerosols via monsoon disruption in those regions; ocean circulation changes can affect pollutant pathways. Shifted temperatures/precipitation &weather patterns/extremes no longer matching infrastructure tolerance ranges. Threat to food security because of impacts on marine life (reduction of plankton), changes in precipitation severely impacting agriculture (particularly wheat and maize) & food security (particularly in Europe). Warming amplification in Southern Hemisphere accelerating Antarctic Ice Sheet melt and coral bleaching, Amazon drying; monsoon (African and Asian) shifts accelerated. Conflicts over food and water, displacement from uninhabitable areas, anomie, financial crises, etc."). *See also* van Westen R. M., Kliphuis M., & Dijkstra H. A. (2024) *Physics-based early warning signal shows that AMOC is on tipping course*, SCI. ADV. 10(6): 1–11, 3 ("The Amazon rainforest also shows a drastic change in their precipitation patterns due to ITCZ shifts, and the dry season becomes the wet season and vice versa. These AMOC-induced precipitation changes could severely disrupt the ecosystem of the Amazon rainforest (7, 24, 25) and potentially lead to cascading tipping (26–28). … The European climate is greatly affected (Fig. 3A) under the AMOC collapse. Note that the corresponding changes occur within a relatively short period (model years 1750 to 1850) and under a very small change in surface freshwater forcing. The yearly averaged atmospheric surface temperature trend exceeds 1°C per decade over a broad region in northwestern Europe, and for several European cities, temperatures are found to drop by 5° to 15°C (Fig. 3C). The trends are even more notable when considering particular months (Fig. 3B). As an example, February temperatures for Bergen (Norway) will drop by about 3.5°C per decade (Fig. 3D).").

[71] Kemp L., Xu C., Depledge J., Ebi K. L., Gibbins G., Kohler T. A., Rockström J., Scheffer M., Schellnhuber H. J., Steffen W., & Lenton T. M. (2022) *Climate Endgame: Exploring catastrophic climate change scenarios*, PROC. NAT'L. ACAD. SCI. 119(34): 1–9, 3 ("Third, climate change could exacerbate vulnerabilities and cause multiple, indirect stresses (such as economic damage, loss of land, and water and food insecurity) that coalesce into system-wide synchronous failures. This is the path of systemic risk. Global crises tend to occur through such reinforcing "synchronous failures" that spread across countries and systems, as with the 2007–2008 global financial crisis (44). It is plausible that a sudden shift in climate could trigger systems failures that unravel societies across the globe. The potential of systemic climate risk is marked: The most vulnerable states and communities will continue to be the hardest hit in a warming world, exacerbating inequities. Fig. 1 shows how projected population density intersects with extreme >29 °C mean annual temperature (MAT) (such temperatures are currently restricted to only 0.8% of Earth's land surface area). Using the medium-high scenario of emissions and population growth (SSP3-7.0 emissions, and SSP3 population growth), by 2070, around 2 billion people are expected to live in these extremely hot areas. Currently, only 30 million people live in hot places, primarily in the Sahara Desert and Gulf Coast (43). Extreme temperatures combined with high humidity can negatively affect outdoor worker productivity and yields of major cereal crops. These deadly heat conditions could significantly affect populated areas in South and southwest Asia(47). Fig. 2 takes a political lens on extreme heat, overlapping SSP3-7.0 or SSP5-8.5 projections of >29 °C MAT circa 2070, with the Fragile States Index (a measurement of the instability of states). There is a striking overlap between currently vulnerable states and future areas of extreme warming. If current political fragility does not improve significantly in

the coming decades, then a belt of instability with potentially serious ramifications could occur."). *See also* Stern N., Stiglitz J., & Taylor C. (2022) *The economics of immense risk, urgent action and radical change: towards new approaches to the economics of climate change*, J. ECON. METHODOL. 29(3): 181–216, 181 ("Moreover, at the core of the standard IAM methodology is an analysis of intertemporal trade-offs; how much the current generation should sacrifice in order for future generations to be spared the devastation of climate change. Rising to the climate challenges does indeed involve deep normative questions, including how different generations' welfare is to be compared and the rights of future generations. But the world has been much more focused than the IAMs on a different set of issues, the risks of catastrophic consequences. These potentially catastrophic risks are in large measure *assumed* away in the IAMs.").

[72] Molina M., Zaelke D., Sarma K. M., Andersen S. O., Ramanathan V., & Kaniaru D. (2009) *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*, PROC. NAT'L. ACAD. SCI. 106(49): 20616–20621, 20616 ("Current emissions of anthropogenic greenhouse gases (GHGs) have already committed the planet to an increase in average surface temperature by the end of the century that may be above the critical threshold for tipping elements of the climate system into abrupt change with potentially irreversible and unmanageable consequences. This would mean that the climate system is close to entering if not already within the zone of "dangerous anthropogenic interference" (DAI). Scientific and policy literature refers to the need for "early," "urgent," "rapid," and "fast-action" mitigation to help avoid DAI and abrupt climate changes. We define "fast-action" to include regulatory measures that can begin within 2–3 years, be substantially implemented in 5–10 years, and produce a climate response within decades. We discuss strategies for short-lived non-CO_2 GHGs and particles, where existing agreements can be used to accomplish mitigation objectives. Policy makers can amend the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs) with high global warming potential. Other fast-action strategies can reduce emissions of black carbon particles and precursor gases that lead to ozone formation in the lower atmosphere, and increase biosequestration, including through biochar. These and other fast-action strategies may reduce the risk of abrupt climate change in the next few decades by complementing cuts in CO_2 emissions."). *See also* Molina M., Ramanathan V. & Zaelke D. (2020) *Best path to net zero: Cut short-lived climate pollutants*, BULLETIN OF THE ATOMIC SCIENTISTS ("And let us be clear: By "speed," we mean measures—including regulatory ones—that can begin within two-to-three years, be substantially implemented in five-to-10 years, and produce a climate response within the next decade or two.").

[73] Armstrong McKay D. I., Staal A., Abrams J. F., Winkelmann R., Sakschewski B., Loriani S., Fetzer I., Cornell S. E., Rockström J., & Lenton T. M. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611): eabn7950, 1–10, 7 ("The chance of triggering CTPs is already non-negligible and will grow even with stringent climate mitigation (SSP1-1.9 in Fig. 2, B and C). Nevertheless, achieving the Paris Agreement's aim to pursue efforts to limit warming to 1.5°C would clearly be safer than keeping global warming below 2°C (90) (Fig. 2). Going from 1.5 to 2°C increases the likelihood of committing to WAIS and GrIS collapse near complete warm-water coral die-off, and abrupt permafrost thaw; further, the best estimate threshold for LABC collapse is crossed. The likelihood of triggering AMOC collapse, Boreal forest shifts, and extra-polar glacier loss becomes non-negligible at >1.5°C and glacier loss becomes likely by ~2°C. A cluster of abrupt shifts occur in ESMs at 1.5 to 2°C (19). Although not tipping elements, ASSI loss could become regular by 2°C, gradual permafrost thaw would likely become widespread beyond 1.5°C, and land carbon sink weakening would become significant by 2°C."). *See also* Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE 575(7784): 592–595, 594 ("In our view, the clearest emergency would be if we were approaching a global cascade of tipping points that led to a new, less habitable, 'hothouse' climate state[11]. Interactions could happen through ocean and atmospheric circulation or through feedbacks that increase greenhouse-gas levels and global temperature. Alternatively, strong cloud feedbacks could cause a global tipping point[12,13].We argue that cascading effects might be common. Research last year[14] analysed 30 types of regime shift spanning physical climate and ecological systems, from collapse of the West Antarctic ice sheet to a switch from rainforest to savanna. This indicated that exceeding tipping points in one system can increase the risk of crossing them in others. Such links were found for 45% of possible interactions[14]. In our view, examples are starting to be observed. … If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us. We need to change our approach to the climate problem. … In our view, the evidence from tipping points alone suggests that we

are in a state of planetary emergency: both the risk and urgency of the situation are acute….”); Steffen W., *et al*. (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33): 8252–8259, 8254 (“This analysis implies that, even if the Paris Accord target of a 1.5 °C to 2.0 °C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly onto a “Hothouse Earth” pathway. The challenge that humanity faces is to create a “Stabilized Earth” pathway that steers the Earth System away from its current trajectory toward the threshold beyond which is Hothouse Earth (Fig. 2). The human-created Stabilized Earth pathway leads to a basin of attraction that is not likely to exist in the Earth System's stability landscape without human stewardship to create and maintain it. Creating such a pathway and basin of attraction requires a fundamental change in the role of humans on the planet. This stewardship role requires deliberate and sustained action to become an integral, adaptive part of Earth System dynamics, creating feedbacks that keep the system on a Stabilized Earth pathway (Alternative Stabilized Earth Pathway).”); *and* Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 36, 42 (“In terrestrial ecosystems, 3–14% of the tens of thousands of species assessed will likely face a very high risk of extinction at a GWL of 1.5°C. Coral reefs are projected to decline by a further 70–90% at 1.5°C of global warming (high confidence). At this GWL, many low-elevation and small glaciers around the world would lose most of their mass or disappear within decades to centuries (high confidence). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island development states and Least Developed Countries (high confidence).”; “The likelihood of abrupt and irreversible changes and their impacts increase with higher global warming levels (*high confidence*). As warming levels increase, so do the risks of species extinction or irreversible loss of biodiversity in ecosystems such as forests (*medium confidence*), coral reefs (*very high confidence*) and in Arctic regions (*high confidence*). Risks associated with large-scale singular events or tipping points, such as ice sheet instability or ecosystem loss from tropical forests, transition to high risk between 1.5°C–2.5°C (*medium confidence*) and to very high risk between 2.5°C–4°C (*low confidence*). The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with further warming (*high confidence*).”).

[74] Xu Y. & Ramanathan V. (2017) *Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes*, PROC. NAT'L. ACAD. SCI. 114(39): 10319–10323, 10320 (“Box 2. Risk Categorization of Climate Change to Society. … [A] 2 °C warming would double the land area subject to deadly heat and expose 48% of the population. A 4 °C warming by 2100 would subject 47% of the land area and almost 74% of the world population to deadly heat, which could pose existential risks to humans and mammals alike unless massive adaptation measures are implemented, such as providing air conditioning to the entire population or a massive relocation of most of the population to safer climates. … This bottom 3 billion population comprises mostly subsistent farmers, whose livelihood will be severely impacted, if not destroyed, with a one- to five-year megadrought, heat waves, or heavy floods; for those among the bottom 3 billion of the world's population who are living in coastal areas, a 1- to 2-m rise in sea level (likely with a warming in excess of 3 °C) poses existential threat if they do not relocate or migrate. It has been estimated that several hundred million people would be subject to famine with warming in excess of 4 °C (54). However, there has essentially been no discussion on warming beyond 5 °C. Climate change-induced species extinction is one major concern with warming of such large magnitudes (>5 °C). The current rate of loss of species is ~1,000-fold the historical rate, due largely to habitat destruction. At this rate, about 25% of species are in danger of extinction in the coming decades (56). Global warming of 6 °C or more (accompanied by increase in ocean acidity due to increased CO_2) can act as a major force multiplier and expose as much as 90% of species to the dangers of extinction (57). The bodily harms combined with climate change-forced species destruction, biodiversity loss, and threats to water and food security, as summarized recently (58), motivated us to categorize warming beyond 5 °C as unknown??, implying the possibility of existential threats.”). *See also* Xu C., Kohler T. A., Lenton T. M., Svenning J.-C., & Scheffer M. (2020) *Future of the human climate niche*, PROC. NAT'L. ACAD. SCI. 117(21): 11350–11355, 11350 (“Here, we demonstrate that for millennia, human populations have resided in the same narrow part of the climatic envelope available on the globe, characterized by a major mode around ~11 °C to 15 °C mean annual temperature (MAT). …We show that in a business-as-usual climate change scenario, the geographical position of this temperature niche is projected to shift more over the coming 50 y than it has moved since 6000 BP. … Specifically, 3.5 billion people will be exposed to MAT ≥29.0 °C, a situation found in the present climate only in 0.8% of the global

land surface, mostly concentrated in the Sahara, but in 2070 projected to cover 19% of the global land (Fig. 3). … For instance, accounting for population growth projected in the SSP3 scenario, each degree of temperature rise above the current baseline roughly corresponds to one billion humans left outside the temperature niche, absent migration (*SI Appendix,* Fig. S14).”); Watts N., *et al.* (2021) *The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises*, THE LANCET 397(10269): 129–170, 129 (“Vulnerable populations were exposed to an additional 475 million heatwave events globally in 2019, which was, in turn, reflected in excess morbidity and mortality (indicator 1.1.2). During the past 20 years, there has been a 53.7% increase in heat-related mortality in people older than 65 years, reaching a total of 296 000 deaths in 2018 (indicator 1.1.3). The high cost in terms of human lives and suffering is associated with effects on economic output, with 302 billion h of potential labour capacity lost in 2019 (indicator 1.1.4). India and Indonesia were among the worst affected countries, seeing losses of potential labour capacity equivalent to 4–6% of their annual gross domestic product (indicator 4.1.3).”); Atwoli L., *et al.* (2021) *Call for emergency action to limit global temperature increases, restore biodiversity, and protect health*, THE LANCET 398(10304): 939–941, 939 (“Harms disproportionately affect the most vulnerable, including children, older populations, ethnic minorities, poorer communities, and those with underlying health problems.”); Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Arias P., Bustamante M., Elgizouli I., Flato G., Howden M., Méndez C., Pereira J., Pichs-Madruga R., Rose S. K., Saheb Y., Sánchez R., Ürge-Vorsatz D., Xiao C., & Yassaa N. (eds.), 36 (“In terrestrial ecosystems, 3–14% of the tens of thousands of species assessed will likely face a very high risk of extinction at a GWL of 1.5°C. Coral reefs are projected to decline by a further 70–90% at 1.5°C of global warming (high confidence). At this GWL, many low-elevation and small glaciers around the world would lose most of their mass or disappear within decades to centuries (high confidence). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island development states and Least Developed Countries (high confidence).”); *and* Berwyn B. (14 February 2023) *Sea Level Rise Could Drive 1 in 10 People from Their Homes, with Dangerous Implications for International Peace, UN Secretary General Warns*, INSIDE CLIMATE NEWS.

[75] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-19 (“With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts in some regions (*high confidence*). Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5°C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5°C of global warming. Projected percentage changes in frequency are higher for rarer events (*high confidence*).”). *See also* Fischer E. M., Sippel S., & Knutti R. (2021) *Increasing probability of record-shattering climate extremes*, NAT. CLIM. CHANGE 11: 689–695, 689 (“Here, we show models project not only more intense extremes but also events that break previous records by much larger margins. These record-shattering extremes, nearly impossible in the absence of warming, are likely to occur in the coming decades. We demonstrate that their probability of occurrence depends on warming rate, rather than global warming level, and is thus pathway-dependent. In high-emission scenarios, week-long heat extremes that break records by three or more standard deviations are two to seven times more probable in 2021–2050 and three to 21 times more probable in 2051–2080, compared to the last three decades.”).

[76] Archer D., Eby M., Brovkin V., Ridgwell A., Cao L., Mikolajewicz U., Caldeira K., Matsumoto K., Munhoven G., Montenegro A., & Tokos K. (2009) *Atmospheric Lifetime of Fossil Fuel Carbon Dioxide*, ANNU. REV. EARTH PLANET. SCI. 37(1): 1–25, 19–20 (“The models presented here present a broadly coherent picture of the fate of fossil fuel CO_2 released to the atmosphere. Equilibration with the ocean will absorb most of it on a time scale of 2-20 centuries. Even if this equilibration were allowed to run to completion, a substantial fraction of the CO_2, 20-40%, would remain in the atmosphere awaiting slower chemical reactions with $CaCO_3$ and igneous rocks. The remaining CO_2 is abundant enough to continue to have a substantial impact of climate for thousands of years. The changes in climate amplify

themselves somewhat by driving CO_2 out of the warmer ocean…. Nowhere in these model results or in the published literature is there any reason to conclude that the effects of CO_2 release will be substantially confined to just a few centuries. In contrast, generally accepted modern understanding of the global carbon cycle indicates that climate effects of CO_2 releases to the atmosphere will persist for tens, if not hundreds, of thousands of years into the future.").

[77] Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., Skea J., Slade R., Al Khourdajie A., van Diemen R., McCollum D., Pathak M., Some S., Vyas P., Fradera R., Belkacemi M., Hasija A., Lisboa G., Luz S., & Malley J. (eds.), SPM-31 ("In modelled global low emission pathways, the projected reduction of cooling and warming aerosol emissions over time leads to net warming in the near- to mid-term. In these mitigation pathways, the projected reductions of cooling aerosols are mostly due to reduced fossil fuel combustion that was not equipped with effective air pollution controls."). *See also* Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived climate forcers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 6-8 ("Additional CH_4 and BC mitigation would contribute to offsetting the additional warming associated with SO_2 reductions that would accompany decarbonization (*high confidence*).").

[78] Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., Skea J., Slade R., Al Khourdajie A., van Diemen R., McCollum D., Pathak M., Some S., Vyas P., Fradera R., Belkacemi M., Hasija A., Lisboa G., Luz S., & Malley J. (eds.), SPM-31 ("In modelled global low emission pathways, the projected reduction of cooling and warming aerosol emissions over time leads to net warming in the near- to mid-term. In these mitigation pathways, the projected reductions of cooling aerosols are mostly due to reduced fossil fuel combustion that was not equipped with effective air pollution controls."). *See also* Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived climate forcers*, in CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 6-8 ("Additional CH_4 and BC mitigation would contribute to offsetting the additional warming associated with SO_2 reductions that would accompany decarbonization (*high confidence*)."); Ramanathan V. & Feng Y. (2008) *On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead*, PROC. NAT'L. ACAD. SCI. 105(38): 14245–14250, 14248 ("Switching from coal to ''cleaner'' natural gas will reduce CO_2 emission and thus would be effective in minimizing future increases in the committed warming. However, because it also reduces air pollution and thus the ABC [Atmospheric Brown Cloud] masking effect, it may speed up the approach to the committed warming of 2.4°C (1.4–4.3°C)."); United Nations Environment Programme & World Meteorological Organization (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 254 ("Evaluating global mean temperature change, it was found that the targeted measures to reduce emissions of methane and BC could greatly reduce warming rates over the next few decades (Figure 6.1; Box 6.1). When all measures are fully implemented, warming during the 2030s relative to the present would be only half as much as in the reference scenario. In contrast, even a fairly aggressive strategy to reduce CO_2 emissions, as for the CO_2-measures scenario, does little to mitigate warming until after the next 20-30 years (Box 6.2). In fact, sulfur dioxide (SO_2) is co-emitted with CO_2 in some of the most highly emitting activities, coal burning in large-scale combustion such as in power plants, for example, that are obvious targets for reduced usage under a CO_2-emissions mitigation strategy. Hence such strategies can lead to additional near-term warming (Figure 6.1), in a well-known temporary effect (e.g. Raes and Seinfeld, 2009), although most of the nearterm warming is driven by CO_2 emissions in the past. The CO_2-measures scenario clearly leads to long-term benefits however, with a dramatically lower warming rate at 2070 under that scenario than under the scenario with only CH_4 and BC measures (see Figure 6.1 and timescales in Box 6.2). Hence the near-term measures clearly cannot be substituted for measures to reduce emissions of long-lived GHGs. The near-term measures largely target different source sectors for emissions than the CO_2 measures, so that the emissions reductions of the short-lived pollutants are almost identical regardless of whether the CO_2 measures are implemented or not, as shown in Chapter 5. The near-term measures and the CO_2 measures also impact climate change over different timescales

owing to the different lifetimes of these substances. In essence, the near-term CH_4 and BC measures are effectively uncoupled from CO_2 measures examined here."); *and* Wanser K., Wong A., Karspeck A., & Esguerra N. (2023) NEAR-TERM CLIMATE RISK AND INTERVENTION: *A ROADMAP FOR RESEARCH, U.S. RESEARCH INVESTMENT, AND INTERNATIONAL SCIENTIFIC COOPERATION*, SilverLining, 12 ("Particles (i.e., aerosols) in the atmosphere generally increase the total amount of sunlight reflected to space by scattering incoming sunlight. Anthropogenic activities produce both GHGs and other particulate matter; while GHGs warm climate, aerosols have a cooling effect both by directly scattering sunlight (i.e., the aerosol direct effect) and indirectly as the aerosols interact with clouds, increasing their brightness and/or their duration (i.e., the cloud–aerosol effect) … The potential global cooling effect of all anthropogenic aerosols is estimated at 0.5–1.1°C (see Figure 6). Thus, these effects are potentially very large while also serving as a large source of uncertainty, making reducing these uncertainties among the highest priorities for climate research, particularly in the context of assessing near-term climate risk. Particles from emissions produced by human activities are also associated with significant adverse health and environmental effects. Actions are ongoing around the world to substantially reduce them, including recent regulation to substantially reduce sulfate emissions from ships. As the world reduces these particulate emissions, the loss of this cooling "shield" could lead to rapid substantial warming.").

[79] Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., Skea J., Slade R., Al Khourdajie A., van Diemen R., McCollum D., Pathak M., Some S., Vyas P., Fradera R., Belkacemi M., Hasija A., Lisboa G., Luz S., & Malley J. (eds.), SPM-30–SPM-31 ("Deep GHG emissions reductions by 2030 and 2040, particularly reductions of methane emissions, lower peak warming, reduce the likelihood of overshooting warming limits and lead to less reliance on net negative CO_2 emissions that reverse warming in the latter half of the century… Future non-CO_2 warming depends on reductions in non-CO_2 GHG, aerosol and their precursor, and ozone precursor emissions. In modelled global low emission pathways, the projected reduction of cooling and warming aerosol emissions over time leads to net warming in the near- to mid-term. In these mitigation pathways, the projected reductions of cooling aerosols are mostly due to reduced fossil fuel combustion that was not equipped with effective air pollution controls. Non-CO_2 GHG emissions at the time of net zero CO_2 are projected to be of similar magnitude in modelled pathways that limit warming to 2°C (>67%) or lower. These non-CO_2 GHG emissions are about 8 [5–11] $GtCO_2$-eq per year, with the largest fraction from CH_4 (60% [55–80%]), followed by N_2O (30% [20–35%]) and F-gases (3% [2–20%]). [FOOTNOTE 52] Due to the short lifetime of CH_4 in the atmosphere, projected deep reduction of CH_4 emissions up until the time of net zero CO_2 in modelled mitigation pathways effectively reduces peak global warming. (*high confidence*) {3.3, AR6 WG I SPM D1.7}").

[80] Dreyfus G. B., Xu Y., Shindell D. T., Zaelke D., & Ramanathan V. (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22): 1–8, 5 ("Aggressive decarbonization to achieve net-zero CO_2 emissions in the 2050s (as in the decarb-only scenario) results in weakly accelerated net warming compared to the reference case, with a positive warming up to 0.03 °C in the mid-2030s, and no net avoided warming until the mid-2040s due to the reduction in co-emitted cooling aerosols (Figure 3a). By 2050, decarbonization measures result in very limited net avoided warming (0.07°C), consistent with Shindell and Smith, but rise to a likely detectable 0.25°C by 2060 and a major benefit of 1.4°C by 2100 (Table S5). In contrast, pairing decarbonization with mitigation measures targeting CH_4, BC, HFC, and N_2O (not an SLCP due to its longer lifetime) independent from decarbonization are essential to slowing the rate of warming by the 2030s to under 0.3°C per decade (Table 1, Figure 3b), similar to the 0.2°C to 0.25°C per decade warming prior to 2020. Recent studies suggest that rate of warming rather than level of warming controls likelihood of record-shattering extreme weather events. By 2050, the net avoided warming from the targeted non-CO_2 measures is 0.26°C, almost 4 times larger than the net benefit of decarbonization alone (0.07°C) (Table S5).").

[81] Xu Y. & Ramanathan V. (2017) *Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes*, PROC. NAT'L. ACAD. SCI. 114(39): 10315–10323, 10321 ("The SP [super pollutant] lever targets SLCPs. Reducing SLCP emissions thins the SP blanket within few decades, given the shorter lifetimes of SLCPs (weeks for BC to about 15 years for HFCs). The mitigation potential of the SP lever with a maximum deployment of current technologies … is about 0.6 °C by 2050 and 1.2 °C by 2100 (SI Appendix, Fig. S5B and Table S1)."). *See also* Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr

A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived climate forcers*, in CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 821 ("Across the SSPs, the collective reduction of CH_4, ozone precursors and HFCs can make a difference of global mean surface air temperature of 0.2 with a very likely range of [0.1–0.4] °C in 2040 and 0.8 with a very likely range of [0.5–1.3] °C at the end of the 21st century (comparing SSP3-7.0 and SSP1-1.9), which is substantial in the context of the Paris Agreement. Sustained methane mitigation, wherever it occurs, stands out as an option that combines near- and long-term gains on surface temperature (*high confidence*) and leads to air quality benefits by reducing surface ozone levels globally (*high confidence*).").

[82] Shindell D., *et al.* (2012) *Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security*, SCIENCE 335(6065): 183–189, 183–185 ("The global mean response to the CH_4 plus BC measures was –0.54 ± 0.05ºC in the climate model. …Roughly half the forcing is relatively evenly distributed (from the CH_4 measures). The other half is highly inhomogeneous, especially the strong BC forcing, which is greatest over bright desert and snow or ice surfaces. Those areas often exhibit the largest warming mitigation, making the regional temperature response to aerosols and ozone quite distinct from the more homogeneous response to well-mixed greenhouse gases.… BC albedo and direct forcings are large in the Himalayas, where there is an especially pronounced response in the Karakoram, and in the Arctic, where the measures reduce projected warming over the next three decades by approximately two thirds and where regional temperature response patterns correspond fairly closely to albedo forcing (for example, they are larger over the Canadian archipelago than the interior and larger over Russia than Scandinavia or the North Atlantic)."). *See also* United Nations Environment Programme & World Meteorological Organization (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 254, 262 ("Evaluating global mean temperature change, it was found that the targeted measures to reduce emissions of methane and BC could greatly reduce warming rates over the next few decades (Figure 6.1; Box 6.1). When all measures are fully implemented, warming during the 2030s relative to the present would be only half as much as in the reference scenario. In contrast, even a fairly aggressive strategy to reduce CO_2 emissions, as for the CO_2-measures scenario, does little to mitigate warming until after the next 20-30 years (Box 6.2)."; "Large impacts of the measures examined here were also seen for the Arctic despite the minimal amount of emissions currently taking place there. This occurs due to the high sensitivity of the Arctic both to pollutants that are transported there from remote sources and to radiative forcing that takes place in areas of the northern hemisphere outside the Arctic. The 16 measures examined here, including the measures on pellet stoves and coal briquettes, reduce warming in the Arctic by 0.7 ºC (range 0.2 to 1.3 ºC) at 2040. This is a large portion of the 1.1 ºC (range 0.7 to 1.7 ºC) warming projected under the reference scenario for the Arctic, and hence implementation of the measures would be virtually certain to substantially slow, but not halt, the pace of Arctic climate change.").

[83] Potential for mitigation from landfills (29-36 million metric tons CH4 in 2030) and energy sector (circa 29-57 million metric tons CH4 in 2030 from oil and gas; 12-25 MtCH4 from coal). *See* United Nations Environment Programme & Climate & Clean Air Coalition (2021) *Summary for Policymakers*, *in* GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 6, 10. ("Oil, gas and coal: the fossil fuel sector has the greatest potential for targeted mitigation by 2030. Readily available targeted measures could reduce emissions from the oil and gas sector by 29–57 Mt/yr and from the coal sector by 12–25 Mt/yr. Up to 80 per cent of oil and gas measures and up to 98 per cent of coal measures could be implemented at negative or low cost; "Waste: existing targeted measures could reduce methane emissions from the waste sector by 29–36 Mt/yr by 2030"). Cutting black carbon and tropospheric ozone (which methane is a precursor of) can reduce air pollution levels and save up to 2.4 million lives every year and increase annual crop production by more than 50 million tons. *See* United Nations Environment Programme & World Meteorological Organization (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 193, 201 ("Implementing all measures could avoid 2.4 million premature deaths (within a range of 0.7–4.6 million) associated with reductions in $PM_{2.5}$, associated with 5.3–37.4 million years of life lost (YLL), based on the 2030 population."; "Total global production gains of all crops ranges between 30 and 140 million tonnes (model mean: 52 million tonnes). The annual economic gains for all four crops in all regions ranges between US$4billion and US$33 billion, of which US$2–28 billion in Asia.").

[84] Shindell D. (14 June 2023) *Wildfire smoke and dirty air are also climate change problems: Solutions for a world on fire*, MODERN SCIENCES ("Black carbon – the tiny particles in the air from wildfires and also from vehicles – along with methane, hydrofluorocarbons and tropospheric ozone, are known as short-lived climate pollutants. They account for around half of today's global warming, contributing to rising sea levels and more frequent and extreme climatic events, including the devastating wildfires we're increasingly seeing across the world. In addition, these pollutants have disastrous impacts on human health, food supplies and biodiversity.").

[85] Dreyfus G. B., Xu Y., Shindell D. T., Zaelke D., & Ramanathan V. (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22): e2123536119, 1–8, 1 ("We find that mitigation measures that target only decarbonization are essential for strong long-term cooling but can result in weak near-term warming (due to unmasking the cooling effect of co-emitted aerosols) and lead to temperatures exceeding 2°C before 2050. In contrast, pairing decarbonization with additional mitigation measures targeting short-lived climate pollutants (SLCPs) and N_2O, slows the rate of warming a decade or two earlier than decarbonization alone and avoids the 2°C threshold altogether. These non-CO_2 targeted measures when combined with decarbonization can provide net cooling by 2030, reduce the rate of warming from 2030 to 2050 by about 50%, roughly half of which comes from methane, significantly larger than decarbonization alone over this timeframe.")

[86] Goldstein A., Noon M. L., Ledezma J. C., Roehrdanz P. R., Raghav S., McGreevey M., Stone C., Shrestha S., Golden Kroner R., Hole D., & Turner W. (2021) IRRECOVERABLE CARBON: *THE PLACES WE MUST PROTECT TO AVERT CLIMATE CATASTROPHE*, Conservation International, 7 ("'Irrecoverable carbon' refers to the vast stores of carbon in nature that are vulnerable to release from human activity and, if lost, could not be restored by 2050 — when the world must reach net-zero emissions to avoid the worst impacts of climate change... There are high concentrations of irrecoverable carbon in the Amazon (31.5 Gt), the Congo Basin (8.1 Gt), and New Guinea (7.3 Gt). Other important irrecoverable carbon reserves are located in the Pacific Northwest of North America, the Valdivian forests of Chile, the mangroves and swamp forests of Guyana, the peatlands of Northern Scotland, Niger Delta's mangroves, Cambodia's Tonle Sap Lake, the Scandinavian and Siberian boreal forests, and the eucalyptus forest of Southeast Australia, among others."). *See also* Griscom B. W., *et al.* (2017) *Natural climate solutions*, PROC. NAT'L. ACAD. SCI. 114(44): 11645–11650, 11645 ("Better stewardship of land is needed to achieve the Paris Climate Agreement goal of holding warming to below 2 °C; however, confusion persists about the specific set of land stewardship options available and their mitigation potential. To address this, we identify and quantify "natural climate solutions" (NCS): 20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands. We find that the maximum potential of NCS—when constrained by food security, fiber security, and biodiversity conservation—is 23.8 petagrams of CO_2 equivalent ($PgCO_2e$) y^{-1} (95% CI 20.3–37.4). This is ≥30% higher than prior estimates, which did not include the full range of options and safeguards considered here. About half of this maximum (11.3 $PgCO_2e$ y^{-1}) represents cost-effective climate mitigation, assuming the social cost of CO_2 pollution is ≥100 USD $MgCO_2e^{-1}$ by 2030. Natural climate solutions can provide 37% of cost-effective CO_2 mitigation needed through 2030 for a >66% chance of holding warming to below 2 °C. One-third of this cost-effective NCS mitigation can be delivered at or below 10 USD $MgCO_2^{-1}$. Most NCS actions—if effectively implemented—also offer water filtration, flood buffering, soil health, biodiversity habitat, and enhanced climate resilience. Work remains to better constrain uncertainty of NCS mitigation estimates. Nevertheless, existing knowledge reported here provides a robust basis for immediate global action to improve ecosystem stewardship as a major solution to climate change."); Goldstein A., *et al.* (2020) *Protecting irrecoverable carbon in Earth's ecosystems*, NAT. CLIM. CHANGE 10(4): 287–295; *and* Noon M. L., Goldstein A., Ledezma J. C., Roehrdanz P. R., Cook-Patton S. C., Spawn-Lee S. A., Wright T. M., Gonzalez-Roglich M., Hole D. G., Rockström J., & Turner W. R. (2021) *Mapping the irrecoverable carbon in Earth's ecosystems*, NAT. SUSTAIN. 5: 37–46.

[87] Griscom B. W., *et al.* (2017) *Natural climate solutions*, PROC. NAT'L. ACAD. SCI. 114(44): 11645–11650, 11645 ("Better stewardship of land is needed to achieve the Paris Climate Agreement goal of holding warming to below 2 °C; however, confusion persists about the specific set of land stewardship options available and their mitigation potential. To address this, we identify and quantify "natural climate solutions" (NCS): 20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across

global forests, wetlands, grasslands, and agricultural lands. We find that the maximum potential of NCS—when constrained by food security, fiber security, and biodiversity conservation—is 23.8 petagrams of CO_2 equivalent ($PgCO_2e$) y^{-1} (95% CI 20.3–37.4). This is ≥30% higher than prior estimates, which did not include the full range of options and safeguards considered here. About half of this maximum (11.3 $PgCO_2e$ y^{-1}) represents cost-effective climate mitigation, assuming the social cost of CO_2 pollution is ≥100 USD $MgCO_2e^{-1}$ by 2030. Natural climate solutions can provide 37% of cost-effective CO_2 mitigation needed through 2030 for a >66% chance of holding warming to below 2 °C. One-third of this cost-effective NCS mitigation can be delivered at or below 10 USD $MgCO_2^{-1}$. Most NCS actions—if effectively implemented—also offer water filtration, flood buffering, soil health, biodiversity habitat, and enhanced climate resilience. Work remains to better constrain uncertainty of NCS mitigation estimates. Nevertheless, existing knowledge reported here provides a robust basis for immediate global action to improve ecosystem stewardship as a major solution to climate change."). *See also* Moomaw W. R., Masino S. A., & Faison E. K. (2019) *Intact Forests in the Unites States: Proforestation Mitigates Climate Change and Serves the Greatest Good*, Perspective, FRONT. FOR. GLOB. CHANGE 2(27): 1–10, 1 ("Climate change and loss of biodiversity are widely recognized as the foremost environmental challenges of our time. Forests annually sequester large quantities of atmospheric carbon dioxide (CO_2), and store carbon above and below ground for long periods of time. Intact forests—largely free from human intervention except primarily for trails and hazard removals—are the most carbon-dense and biodiverse terrestrial ecosystems, with additional benefits to society and the economy. … The recent *1.5 Degree Warming Report* by the Intergovernmental Panel on Climate Change identifies *reforestation* and *afforestation* as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land, and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential—termed *proforestation*—is a more effective, immediate, and low-cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation, and scenic beauty."); *and* World Wildlife Fund (2020) LIVING PLANET REPORT 2020 – BENDING THE CURVE OF BIODIVERSITY LOSS, Almond R. E. A., Grooten M., & Petersen T. (eds.), 6 ("The global Living Planet Index continues to decline. It shows an average 68% decrease in population sizes of mammals, birds, amphibians, reptiles and fish between 1970 and 2016. … It matters because biodiversity is fundamental to human life on Earth, and the evidence is unequivocal – it is being destroyed by us at a rate unprecedented in history. Since the industrial revolution, human activities have increasingly destroyed and degraded forests, grasslands, wetlands and other important ecosystems, threatening human well-being. Seventy-five per cent of the Earth's ice-free land surface has already been significantly altered, most of the oceans are polluted, and more than 85% of the area of wetlands has been lost.").

[88] World Meteorological Organization (2024) STATE OF THE GLOBAL CLIMATE 2023, 3 ("The ten-year average 2014–2023 global temperature is 1.20±0.12°C above the 1850–1900 average, the warmest 10-year period on record.").

[89] Forster P. M., et al. (2023) *Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence*, EARTH SYST. SCI. DATA 15(6): 2295–2327, 2296 ("The indicators show that human-induced warming reached 1.14 [0.9 to 1.4] ◦C averaged over the 2013–2022 decade and 1.26 [1.0 to 1.6] ◦C in 2022. Over the 2013–2022 period, human-induced warming has been increasing at an unprecedented rate of over 0.2 ◦C per decade."). *See also* Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, in CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-5 ("The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 [11] is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is likely that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to 0.1°C, and internal variability changed it by –0.2°C to 0.2°C. It is very likely that well-mixed GHGs were the main driver[12] of tropospheric warming since 1979, and extremely likely that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s."… Footnote 11: "The period distinction with A.1.2 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010– 2019 is 1.06 [0.88 to 1.21] °C." Footnote 12: "Throughout this SPM, 'main driver' means responsible for more than 50% of the change.").

[90] Dhakal S., Minx J. C., Toth F. L., Abdel-Aziz A., Figueroa Meza M. J., Hubacek K., Jonckheere I. G. C., Kim Y.-G., Nemet G. F., Pachauri S., Tan X. C., & Wiedmann T. (2022) *Chapter 2: Emissions Trends and Drivers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., Skea J., Slade R., Al Khourdajie A., van Diemen R., McCollum D., Pathak M., Some S., Vyas P., Fradera R., Belkacemi M., Hasija A., Lisboa G., Luz S., & Malley J. (eds.), 228 ("Global GHG emissions continued to rise since AR5, but the rate of emissions growth slowed (high confidence). GHG emissions reached 59 ± 6.6 $GtCO_2$-eq in 2019 (Table 2.1 and Figure 2.5). In 2019, CO_2 emissions from the FFI were 38 (±3.0) Gt, CO_2 from LULUCF 6.6 ± 4.6 Gt, CH_4 11 ± 3.2 $GtCO_2$-eq, N_2O 2.7 ± 1.6 $GtCO_2$-eq and F-gases 1.4 ± 0.41 $GtCO_2$-eq. There is high confidence that average annual GHG emissions for the last decade (2010–2019) were the highest on record in terms of aggregate CO_2-eq emissions…")

[91] In 2023, the global average atmospheric concentrations reached new highs, with CO_2 at 419.3 parts per million (ppm), CH_4 at 1922.6 parts per billion (ppb) and N_2O at 336.7 ppb. Over the past two decades, CO_2 concentrations have increased at a rate 100 times faster than at any point since the last ice age (11,000–17,000 years ago). Rates of increase for methane for the 2020–2022 (16.3 ppb/yr) period nearly doubled from the 2007–2019 average (7.3 ppb/year), but were not as high for 2023 (+10.9 pbb). *See* National Oceanic and Atmospheric Administration (5 April 2024) *No sign of greenhouse gases increases slowing in 2023* ("The global surface concentration of CO_2, averaged across all 12 months of 2023, was 419.3 parts per million (ppm), an increase of 2.8 ppm during the year. This was the 12th consecutive year CO_2 increased by more than 2 ppm, extending the highest sustained rate of CO_2 increases during the 65-year monitoring record. … Atmospheric methane, less abundant than CO2 but more potent at trapping heat in the atmosphere, rose to an average of 1922.6 parts per billion (ppb). The 2023 methane increase over 2022 was 10.9 ppb, lower than the record growth rates seen in 2020 (15.2 ppb), 2021(18 ppb) and 2022 (13.2 ppb), but still the 5th highest since renewed methane growth started in 2007. … In 2023, levels of nitrous oxide, the third-most significant human-caused greenhouse gas, climbed by 1 ppb to 336.7 ppb. The two years of highest growth since 2000 occurred in 2020 (1.3 ppb) and 2021 (1.3 ppb)."); *and* National Oceanic and Atmospheric Administration Global Monitoring Laboratory (22 March 2019) *Global carbon dioxide growth in 2018 reached 4th highest on record*, News & Features ("In the last two decades, the rate of increase has been roughly 100 times faster than previous natural increases, such as those that occurred at the end of the last ice age 11,000-17,000 years ago.").

[92] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: *BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS*, 28 ("Fossil fuels: release during oil and gas extraction, pumping and transport of fossil fuels accounts for roughly 23 per cent of all anthropogenic emissions, with emissions from coal mining contributing 12 per cent.").

[93] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: *BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS*, 28 ("Agriculture: emissions from enteric fermentation and manure management represent roughly 32 per cent of global anthropogenic emissions. Rice cultivation adds another 8 per cent to anthropogenic emissions. Agricultural waste burning contributes about 1 per cent or less.").

[94] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: *BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS*, 28 ("Waste: landfills and waste management represents the next largest component making up about 20 per cent of global anthropogenic emissions.").

[95] Saunois M., *et al.* (2020) *The Global Methane Budget* 2000-2017, EARTH SYST. SCI. DATA 12(3): 1561–1623, 1561 ("For the 2008–2017 decade, global methane emissions are estimated by atmospheric inversions (a top-down approach) to be 576 Tg CH_4 yr^{-1} (range 550–594, corresponding to the minimum and maximum estimates of the model ensemble). Of this total, 359 Tg CH_4 yr^{-1} or ~ 60 % is attributed to anthropogenic sources, that is emissions caused by direct human activity (i.e. anthropogenic emissions; range 336–376 Tg CH_4 yr^{-1} or 50 %–65 %).").

[96] World Meteorological Organization (2022) SCIENTIFIC ASSESSMENT OF OZONE DEPLETION 2022: *EXECUTIVE SUMMARY*, GAW Report No, 278, 14 ("Global atmospheric abundances and emissions of most HFCs are increasing. CO_2-equivalent emissions of HFCs derived from observations increased by 18% from 2016 to 2020.").

[97] World Meteorological Organization (2022) SCIENTIFIC ASSESSMENT OF OZONE DEPLETION: 2022, GAW Report No. 278 (Figure 2-15).

[98] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: A scientific assessment*, J. GEOPHYS. RES. ATMOS. 118(11): 5380–5552, 5420 ("Major sources of BC are also major sources of $PM_{2.5}$, but the converse is not always true; major sources of $PM_{2.5}$ may produce little BC if their emissions are primarily inorganic. Sources that are BC and OC emitters are shown in the table. Resuspended dust, secondary pollutants like sulfate and nitrate, or sea salt, could also be contributors to PM2.5 at some locations but are not included in Table 11."); major sources in Table 11 include (in order of decreasing importance): transport (vehicle exhaust including gasoline and diesel); IN = industry including coal and oil and biomass burning; coal burning power plants; RE = residential energy; OB= open burning of biomass and refuse; SA = secondary aerosols; O= Others.

[99] Climate & Clean Air Coalition, *Black carbon* (*last visited* 18 July 2023).

[100] Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived Climate Forcers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 848 ("Knowledge of carbonaceous aerosol atmospheric abundance continues to rely on global models due to a lack of global-scale observations. For BC, models agree within a factor of two with measured surface mass concentrations in Europe and North America, but underestimate concentrations at the Arctic surface by one to two orders of magnitude, especially in winter and spring (Lee et al., 2013; Lund et al., 2018a).").

[101] Szopa S., Naik V., Adhikary B., Artaxo P., Berntsen T., Collins W. D., Fuzzi S., Gallardo L., Kiendler-Scharr A., Klimont Z., Liao H., Unger N., & Zanis P. (2021) *Chapter 6: Short-lived Climate Forcers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 837–838 ("Based on limited isotopic evidence, Chapter 2 assesses that the global tropospheric ozone increased by less than 40% between 1850 and 2005 (low confidence) (Section 2.2.5.3). The CMIP6 models are in line with this increase of tropospheric ozone with an ensemble-mean value of 109 ± 25 Tg (model range) from 1850–1859 to 2005–2014 (Figure 6.4). This increase is higher than the AR5 value of 100 ± 25 Tg from 1850–2010 due to higher ozone precursor emissions in CMIP6. However, the AR5 and CMIP6 values are close when considering the reported uncertainties. The uncertainties are equivalent in CMIP6 and AR5 despite enhanced inclusion of coupled processes in the CMIP6 ESMs (e.g., biogenic NMVOC emissions or interactive stratospheric ozone chemistry).").

[102] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 51–57 ("Long-term exposure to ozone can cause inflammation and allergic responses leading to respiratory mortality, as well as the development of a systemic oxidative, proinflammatory environment that can increase the risk of cardiovascular diseases. … It should be noted that the larger impact of ozone on health has been reported in several previous studies. Malley et al. (2017) used the new health exposure relationships (Turner et al. 2016) along with modelled ozone distributions, and found a 125 per cent increase in respiratory deaths attributable to ozone exposure in 2010 compared to previous estimates – 1.04–1.23 million deaths compared to 0.40–0.55 million. … Further to this, a bias-adjusted model recently reported total worldwide ozone-related premature deaths of 1.0 ± 0.3 million (Shindell et al. 2018). The value for respiratory-related premature deaths due to ozone was 0.6 ± 0.2 million for 2010, and 1.0 ± 0.3 million without bias adjustment, the latter being consistent with the value reported by Malley et al. (2017).").

[103] Feng Z., Xu Y., Kobayashi K., Dai L., Zhang T., Agathokleous E., Calatayud V., Paoletti E., Mukherjee A., Agrawal M., Park R. J., Oak Y. J., & Yue X. (2022) *Ozone pollution threatens the production of major staple crops in East Asia*, NAT. FOOD 3: 47–56, 47 ("East Asia is a hotspot of surface ozone (O_3) pollution, which hinders crop growth and reduces yields. Here, we assess the relative yield loss in rice, wheat and maize due to O_3 by combining O_3 elevation experiments across Asia and air monitoring at about 3,000 locations in China, Japan and Korea. China shows

the highest relative yield loss at 33%, 23% and 9% for wheat, rice and maize, respectively. The relative yield loss is much greater in hybrid than inbred rice, being close to that for wheat. Total O_3-induced annual loss of crop production is estimated at US$63 billion."). *See also* United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 68 ("Methane also plays a significant role in reducing crop yields and the quality of vegetation. Ozone exposure is estimated to result in yield losses in wheat, 7.1 per cent; soybean,12.4 per cent; maize, 6.1 per cent; and rice, 4.4 per cent for near present-day global totals (Mills et al. 2018; Shindell et al. 2016; Avnery et al. 2011a)"); *and* Shindell D., Faluvegi G., Kasibhatla P., & Van Dingenen R. (2019) *Spatial Patterns of Crop Yield Change by Emitted Pollutant*, EARTH'S FUTURE 7(2): 101–112, 101 ("Our statistical modeling indicates that for the global mean, climate and composition changes have decreased wheat and maize yields substantially whereas rice yields have increased. Well-mixed greenhouse gasses drive most of the impacts, though aerosol-induced cooling can be important, particularly for more polluted area including India and China. Maize yield losses are most strongly attributable to methane emissions (via both temperature and ozone).").

[104] Mar K. A., Unger C., Walderdorff L., & Butler T. (2022) *Beyond CO_2 equivalence: The impacts of methane on climate, ecosystems, and health*, ENV. SCI. POL. 134: 127–136, 129 ("Methane is an important contributor to the formation of tropospheric O_3. In addition to acting as a greenhouse gas and being directly harmful to human health (see Section 3.3), it also harms plants by causing cellular damage within the leaves, adversely affecting plant production, reducing the rate of photosynthesis, and requiring increased resource allocation to detoxify and repair leaves (Ashmore, 2005, Sitch et al., 2007). This results in an estimated $11-$18 billion worth of global crop losses annually (Avnery et al., 2011). Beyond this, however, O_3 damage to plants may significantly reduce the ability of terrestrial ecosystems to absorb carbon, negating some of the enhanced carbon uptake due to CO_2 fertilization that is expected to partially offset rising atmospheric CO_2 concentrations (Sitch et al., 2007, Ciais et al., 2013, Arneth et al., 2010, Ainsworth et al., 2012).").

[105] Dhakal S., Minx J. C., Toth F. L., Abdel-Aziz A., Figueroa Meza M. J., Hubacek K., Jonckheere I. G. C., Kim Y.-G., Nemet G. F., Pachauri S., Tan X. C., & Wiedmann T. (2022) *Chapter 2: Emissions Trends and Drivers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla P. R., Skea J., Slade R., Al Khourdajie A., van Diemen R., McCollum D., Pathak M., Some S., Vyas P., Fradera R., Belkacemi M., Hasija A., Lisboa G., Luz S., & Malley J. (eds.), 233 ("Latin America and the Caribbean contributed 11% of GHG emissions growth since 1990 (2.2 $GtCO_2$-eq), and 5% (0.3 $GtCO_2$-eq) since 2010.").

[106] Organisation for Economic Co-operation and Development, *et al.* (2022) LATIN AMERICAN ECONOMIC OUTLOOK 2022: *TOWARDS A GREEN AND JUST TRANSITION*, 30 ("LAC's share in total GHG emissions (8.1%) (Figure 4) is proportional to its share in total world population (8.4%), slightly higher than its share in global GDP (6.4%) but lower than the per-capita emissions of other regions with similar development levels.").

[107] International Monetary Fund (2021) REGIONAL ECONOMIC OUTLOOK: *WESTERN HEMISPHERE*, 35 ("LAC, with the exception of the Caribbean, makes limited use of fossil fuels in electricity generation (renewable share of 60 percent) thanks to enabling policies and governments' catalytic role in financing green technologies. The energy sector amounts to only 43 percent of total GHG emissions in LAC, well below the world average of 74 percent. LAC, however, stands out for its large share of emissions from agriculture, livestock, forestry, and change in land use (45 percent in LAC versus the world average of 14 percent).").

[108] World Bank Group (2022) A ROADMAP FOR CLIMATE ACTION IN LATIN AMERICA AND THE CARIBBEAN 2021-2025, 11 ("The livestock sector and associated land-use changes alone account for one-third of regional GHG emissions. Over the last decade, land-use changes have driven the largest share of growth in regional emissions, contributing two-thirds of the net increase. Emissions from deforestation have been increasing since 2016, with the largest annual increase since 2010 occurring in 2020, largely due to accelerating deforestation in Brazil following a decline in the 2000s.").

[109] World Bank Group (2022) A ROADMAP FOR CLIMATE ACTION IN LATIN AMERICA AND THE CARIBBEAN 2021-2025, 12 ("Transitioning toward cleaner technologies that emit fewer greenhouse gases in the cement, glass, chemical, and pulp and paper sectors will be important to help decarbonize the manufacturing sector in LAC. Targeting larger manufacturing hubs with significant GHG emission profiles, such as heavy industries in Brazil and Mexico, the cement sector in Colombia and Peru, and agro-processing in Argentina or Central America, would contribute towards a material reduction in manufacturing's carbon footprint across the region.").

[110] Evans S. (5 October 2021) *Analysis: Which countries are historically responsible for climate change?*, CARBON BRIEF ("By the end of 2021, the US will have emitted more than 509GtCO2 since 1850. At 20.3% of the global total, this is by far the largest share and is associated with some 0.2C of warming to date.").

[111] Rivera A., Movalia S., Pitt H., & Larsen K. (2022) *Global Greenhouse Gas Emissions: 1990-2020 and Preliminary 2021 Estimates*, Rhodium Group, 3 (Figure 3).

[112] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[113] Evans S. (5 October 2021) *Analysis: Which countries are historically responsible for climate change?*, CARBON BRIEF ("Japan on 2.7% and Canada, with 2.6%, close out the top 10 largest contributors to historical emissions.").

[114] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[115] Evans S. (5 October 2021) *Analysis: Which countries are historically responsible for climate change?*, CARBON BRIEF ("By the end of 2021, the US will have emitted more than 509GtCO2 since 1850. At 20.3% of the global total, this is by far the largest share and is associated with some 0.2C of warming to date…. Russia is third, with some 6.9% of global cumulative CO2 emissions, followed by Brazil (4.5%) and Indonesia (4.1%). Notably, the chart above shows how the latter pair are in the top 10 largely as a result of their emissions from deforestation, despite relatively low totals from the use of fossil fuels…. Japan on 2.7% and Canada, with 2.6%, close out the top 10 largest contributors to historical emissions.").

[116] Evans S. (5 October 2021) *Analysis: Which countries are historically responsible for climate change?*, CARBON BRIEF ("Russia is third, with some 6.9% of global cumulative CO2 emissions, followed by Brazil (4.5%) and Indonesia (4.1%). Notably, the chart above shows how the latter pair are in the top 10 largely as a result of their emissions from deforestation, despite relatively low totals from the use of fossil fuels…. The rainforest nations of Brazil and Indonesia were also being deforested in the late 19th and early 20th centuries by settlers growing rubber, tobacco and other cash crops. But deforestation began "in earnest" from around 1950, including for cattle ranching, logging and palm-oil plantations.").

[117] ClimateWatch, *Historical GHG Emissions* (*last visited* 18 July 2023).

[118] International Energy Agency (2023) *Methane Tracker Database*.

[119] International Energy Agency (2023) *Methane Tracker Database*.

[120] International Energy Agency (2023) *Methane Tracker Database*.

[121] ClimateWatch, *Historical GHG Emissions* (*last visited* 18 July 2023).

[122] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 3 ("Agriculture, transport, domestic and commercial refrigeration are the sectors that product the largest emissions of methane, particulate matter, black carbon, and HFCs.").

[123] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 3 ("The results indicate a maximum potential reduction in warming of up to 0.9º C by 2050, if implementing SLCP measures across the LAC region.").

[124] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 3 ("A number of SLCP measures has been identified that, by 2050, has the potential to reduce warming in LAC by up to 0.9 degrees Celsius, premature mortality from PM2.5 by at least 26 per cent annually, and avoid the loss of 3–4 million tonnes of four staple crops each year.").

[125] ClimateWatch, *Historical GHG Emissions* (*last visited* 15 June 2023).

[126] Project on Organization, Development, Education and Research (2022) *The Gas Industry in Latin America and the Caribbean*, 26, Graphic 11 ("Natural gas production in Latin America amounted to 182.94 billion cubic meters (bcm) in 2020, representing 4.75% of total world production.[62]").

[127] Shen L., Zavala-Araiza D., Gautam R., Omara M., Scarpelli T., Sheng J., Sulprizio M. P., Zhuang J., Zhang Y., Qu Z., Lu X., Hamburg S. P., Jacob D. (2021) *Unravelling a large methane emission discrepancy in Mexico using satellite observations*, REM. SENS. ENVIRON. 260: 1–9, 1 ("Our results show that Mexico's oil and gas sector has the largest discrepancy, with oil and gas emissions (1.3 ±0.2 Tg a1) higher by a factor of two relative to bottom-up estimates—accounting for a quarter of total anthropogenic emissions. Our satellite-based inverse modeling estimates show that more than half of the oil/gas emissions in eastern Mexico are from the southern onshore basin (0.79 ±0.13 Tg a1), pointing at high emission sources which are not represented in current bottom-up inventories (e.g., venting of associated gas, high-emitting gathering/processing facilities related to the transport of associated gas from offshore).

[128] International Energy Agency (2022) *Methane Emissions from Oil and Gas Operations* ("Taking average natural gas prices from 2017 to 2021 – before the recent price surge – the annual investment required is less than the total value of the captured methane that could be sold, meaning that related methane emissions from oil and gas could be reduced by almost 75% at an overall saving to the global oil and gas industry.").

[129] International Energy Agency (2023) *Global Methane Tracker 2023: Strategies to reduce emissions from oil and gas operations* ("Even if there was no value to the captured gas, almost all available abatement measures would be cost effective in the presence of an emissions price of only about 15 USD/tCO_2-eq.").

[130] International Energy Agency (2023) *Global Methane Tracker 2023: Strategies to reduce emissions from oil and gas operations* ("The technologies and measures to prevent methane emissions from oil and gas operations are well known and have been deployed in multiple locations around the world. Key examples include leak detection and repair campaigns, installing emissions control devices, and replacing components that emit methane in their normal operations.").

[131] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[132] Alvarez. R. A., *et al.* (2018) *Assessment of methane emissions from the U.S. oil and gas supply chain*, SCIENCE 361(6398): 186–188, 186 ("Methane emissions from the U.S. oil and natural gas supply chain were estimated by using ground-based, facility-scale measurements and validated with aircraft observations in areas accounting for ~30% of U.S. gas production. When scaled up nationally, our facility-based estimate of 2015 supply chain emissions is 13 ± 2 teragrams per year, equivalent to 2.3% of gross U.S. gas production. This value is ~60% higher than the U.S. Environmental Protection Agency inventory estimate, likely because existing inventory methods miss emissions released during abnormal operating conditions. Methane emissions of this magnitude, per unit of natural gas consumed, produce radiative forcing over a 20-year time horizon comparable to the CO_2 from natural gas combustion. Substantial emission reductions are feasible through rapid detection of the root causes of high emissions and deployment of less failure-prone systems.")

[133] Alvarez. R. A., *et al.* (2018) *Assessment of methane emissions from the U.S. oil and gas supply chain*, SCIENCE 361(6398): 186–188, 186 ("Component-based inventory estimates like the GHGI have been shown to underestimate facility-level emissions probably because of the technical difficulty and safety and liability risks associated with measuring large emissions from, for example, venting tanks such as those observed in aerial survey").

[134] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[135] Blanco-Donado E. P., Schneider I. L., Artaxo P., Lozano-Osorio J., Artaxo P., Portz L., & Oliveira M. L. S. (2022) *Source identification and global implications of black carbon*, GEOSCI. FRONT. 13(101149): 1–13, 1 ("In Latin America and the Caribbean, the main sources of BC emission are vehicular traffic in urban areas and biomass burning from deforestation, cooking, and heating (Artaxoetal., 2013; Britoetal., 2013).").

[136] Rivas M. E., Suarez-Aleman A., & Serebesky T. (2019) STYLIZED URBAN TRANSPORTATION FACTS IN LATIN AMERICA AND THE CARIBBEAN, Technical Note No. IDB-TN-1640, Inter-American Development Bank, 5, 7, 10 ("Over the past 10 years, most of countries in LAC have increased their motorization rate, with the average annual growth rate in the region equaling 4.7 percent. In 2015, the average motorization for LAC reached 201 vehicles per 1000 inhabitants."; "Some cities have witnessed a reduction in their public transportation shares by one-half. This passenger leakage to private transportation modes has an impact on public transportation performance, which in turn increases the leakage, generating a vicious circle between private and public transportation."; "The productivity of urban transport has decrease in the region, which is exacerbated by a low cost recovery. The evidence shows that productivity of the public transport sector in LAC, expressed by different partial indicators, has stagnated or even decreased. This has resulted in rising costs in the public transport sector, as is also observed in other labor-intensive sectors. These rising costs can be attributed in part to difficulties associated with replacing labor with capital as well as a slowdown in technological advances. Public transportation faces two additional aggravating factors: vehicular congestion and the negative impact of a positive income elasticity with respect to the demand for private transportation).").

[137] Rehermann F. & Pablo-Romero M. (2018) *Economic growth and transport energy consumption in the Latin American and Caribbean countries*, ENERGY POL'Y 122: 518–527, 519 ("Therefore, the economic growth in the Latin American and Caribbean (LAC) countries may have a noticeable impact on the energy consumption in the transport sector. In this sense, in 2015, the transport sector accounted for 36.8% of total energy consumption (higher than the world percentage shown before), followed by the industrial and residential sectors, with 31.6% and 15.7%, respectively (IEA,2018). It should also be noted that this transport sector energy consumption continues to be based mainly on oil, accounting for 88.4% of total energy consumed, followed by biofuels, natural gas and electricity, with 7.8%, 3.5%, and 0.3%, respectively (IEA, 2018).").

[138] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, Figure 1.6.

[139] Brewer T. L. (2019) *Black carbon emissions and regulatory policies in transportation*, ENERGY POLICY 129: 1047–1055, 1047 ("Globally, transportation accounts for approximately 19 percent of BC emissions, and diesel engines contribute 90 percent of transportation's share (US EPA, 2017). The transportation sector in the United States is estimated to account for about 52 percent of US black carbon emissions, and diesel engines contribute about 90 percent of the transportation BC emissions").

[140] Environment and Climate Change Canada (2021) *Black Carbon Inventory 2013-2021*, 13 ("Transportation and Mobile Equipment is by far the largest source of black carbon in Canada, accounting for 15 kt (56%) of total emissions in 2021. Of the various sources in this category, off-road diesel engines account for 8.9 kt (34%) of total emissions in 2021. The other large source in this category is diesel engines used for on-road transport, which account for 2.4 kt (9.1%) of total emissions.")

[141] ClimateWatch, *Historical GHG Emissions* (*last visited* 15 June 2023).

[142] International Center for Tropical Agriculture (14 May 2020) *Latin America's Latin America's livestock sector needs emissions reduction to meet 2030 targets*, PHYS.ORG ("Livestock is a pivotal source of income for Latin American countries but the sector is one of the largest sources of greenhouse gas emissions (GHG) in the region. Agriculture in Latin America produces 20 percent of the region's emissions, 70 percent of which comes from livestock, according to research by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)."); Arango J., Ruden A., Martinez-Baron D., Loboguerrero A.M., Berndt A., Chacon M., Torres, C.F., Oyhantcabal W., Gomez C.A., Ricci P., Ku-Vera J., Burkart S., Moorby J.M., Chirinda N. (2020) *Ambition Meets Reality: Achieving GHG Emission Reduction Targets in the Livestock Sector in Latin America*, FRONT. SUST. FOOD SYST. 4(65): 1–9, 1–2 ("Despite its economic importance, the cattle sector is also a major source of GHG emissions, particularly as enteric methane emissions (Table 1). … Previous studies have shown that emission reduction ambitions submitted under the Paris Agreement would lead to global GHG emission reductions of 52–58 GtCO2 eq yr−1 by 2030. Unfortunately, this level of emission reductions will not limit global warming to 1.5◦ C (IPCC, 2018).").

[143] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[144] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[145] Silva-Martinez R. D., Sanches-Pereira A., Ortiz W., Galindo M. F. G., & Coelho S. T. (2020) *The state-of-the-art of organic waste to energy in Latin America and the Caribbean*, REN. ENERGY 156: 509–525, 516–517 ("In the Caribbean Islands, biomass from agricultural and forest residues is utilized to produce electricity through combustion techniques. In countries like the Dominican Republic [12] or Cuba, combustion is practiced to employ the energy content of residues such as sugarcane straw and bagasse, rice husk, coffee husk, and firewood [13]. In the British Virgin Islands most wastes are incinerated, despite the high costs involved [7]. Conversely, in Puerto Rico for example, there is no incineration of waste or residues, where all waste are landfilled or recycled [7]. In the case of Central America, currently sugarcane bagasse and straw are the only agricultural residues to produce energy at large scale [8]. … In the case of South America, particularly in Brazil, bagasse from sugarcane is the main source of agro electricity with an operating power potential of more than 9 GW [17], considering that burning bagasse is still by far the least cost option in comparison with other thermochemical routes [18].").

[146] Engelhardt V., Perez T., Donoso L., Muller T., & Wiedensohler A. (2022) *Black carbon and particulate matter mass concentrations in the Metropolitan District of Caracas, Venezuela: An assessment of temporal variation and contributing sources*, ELEM. SCI ANTH. 10: 1–22, 1 ("The annual median for eBC and PM2.5 was1.6 and 9.2 mgm–3, respectively, in the urban site, while PM2.5 in the forest site was 6.6mgm–3. To our knowledge, these are the first measurements of this type in the northernmost area of South America. eBC and PM2.5 sources identification during wet and dry seasons was obtained by percentiles of the conditional bivariate probability function(CBPF). CBPF showed seasonal variations of eBC and PM2.5 sources and that their contributions are higher during the dry season. Biomass burning events are a relevant contributing source of aerosols for both sites of measurements inferred by fire pixels from satellite data, the national fire department's statistics data, and backward trajectories.Our results indicate that biomass burning might affect the atmosphere on a regional scale, contribute to regional warming, and have implications for local and regional air quality and, therefore, human health").

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[147] Goncalves Jr. S. J., Magalhaes N., Charello R. C., Evangelista H., & Godoi R. H. M. (2022) *Relative contributions of fossil fuel and biomass burning sources to black carbon aerosol on the Southern Atlantic Ocean Coast and King George Island (Antarctic Peninsula)*, AN. ACAD. BRAS. CIENC. 94(e20210805): 1–20, 16 ("It is plausible to assume that the most significant contribution of BC to the study, in general, is from fossil fuel combustion since in the summer for the Southern Hemisphere, there are slight burning spots from the surrounding continents. A thorough understanding of fire events and an accurate prediction of air masses and continual measurements for the determination of BC in the Antarctica atmosphere are deemed essential, especially in the period of the dry season in the regions of South America, which appears the most biomass burning events arise (around August to November).").

[148] Booth M. S. (2018) *Not Carbon Neutral: Assessing the Net Emissions Impact of Residues Burned for Bioenergy*, ENVIRON. RES. LETT. 13: 1–10, 8 ("For bioenergy to offer genuine climate mitigation, it is essential to move beyond the assumption of instantaneous carbon neutrality. The [net emissions impact (NEI)] approach provides a simple

means to estimate net bioenergy emissions over time, albeit one that tends to underestimate actual impacts. The model finds that for plants burning locally sourced wood residues, from 41% (extremely rapid decomposition) to 95% (very slow decomposition) of cumulative direct emissions should be counted as contributing to atmospheric carbon loading by year 10. Even by year 50 and beyond, the model shows that net emissions are a significant proportion of direct emissions for many fuels."). *See also* Sterman J. D., *et al.* (2018) *Does Replacing Coal with Wood Lower CO_2 Emissions? Dynamic Lifecycle Analysis of Wood Bioenergy*, ENVIRON. RES. LETT. 13: 1–10, 8 ("Scenario 2 shows the realistic case with the combustion efficiency and supply chain emissions estimated for wood pellets (supplementary table S5), again assuming 25% of the biomass is harvested by thinning. Because production and combustion of wood generate more CO2 than coal, the first impact of bioenergy use is an increase in atmospheric CO2. Regrowth gradually transfers C from the atmosphere to biomass and soil C stocks, leading to a carbon debt payback time of 52 years; after 100 years CO2 remains 62% above the zero C case.").

[149] *See* Intergovernmental Panel on Climate Change (2019) *Summary for Policymakers*, *in* CLIMATE CHANGE AND LAND: *AN IPCC SPECIAL REPORT ON CLIMATE CHANGE, DESERTIFICATION, LAND DEGRADATION, SUSTAINABLE LAND MANAGEMENT, FOOD SECURITY, AND GREENHOUSE GAS FLUXES IN TERRESTRIAL ECOSYSTEMS*, Shukla P. R., *et al.* (eds.), 27 ("Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts, assuming carbon dioxide removal by BECCS at a scale of 11.3 GtCO2 yr-1 in 2050, and noting that bioenergy without CCS can also achieve emissions reductions of up to several GtCO2 yr-1 when it is a low carbon energy source {2.6.1; 6.3.1}. Studies linking bioenergy to food security estimate an increase in the population at risk of hunger to up to 150 million people at this level of implementation {6.3.5}. The red hatched cells for desertification and land degradation indicate that while up to 15 million km2 of additional land is required in 2100 in 2°C scenarios which will increase pressure for desertification and land degradation, the actual area affected by this additional pressure is not easily quantified {6.3.3; 6.3.4}."); Swift M. J. & Anderson J. M. (1994) *Biodiversity and Ecosystem Function in Agricultural Systems*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 99, Schulze E. D. & Mooney H. A. (eds.), 15–41 ("The conversion of natural systems to intensive, arable monocropping reduces biodiversity in the plant, herbivore and decomposer subsystems. The isolation of biodiversity as a factor determining changes in ecosystem functioning is complicated, however, because each of these subsystems affects the others (Fig. 2.2) and also influences the physicochemical factors regulating soil processes. The response of the soil organism community to cultivations practices is varied (Figs. 2.6, 2.7), but in general agricultural soils are characterised by a lower species richness, including the disappearance of key functional groups."); *and* Bauhus J., Kouki J., Paillet Y., Asbeck T., & Marchetti M. (2017) *How does the forest-based bioeconomy impact forest diversity?*, *in* TOWARD A SUSTAINABLE EUROPEAN FOREST-BASED BIOECONOMY, Winkel G. (ed.), European Forest Institute, 67–76, 69 ("Around 25% of forest-dwelling species depend on dead wood and senescent trees for at least a part of their lifecycle. . . . Large amounts of dead wood and senescent trees, as well as tree cavities, are typical of mature and over-mature stages of forest development and are typically found in higher quantities and qualities in unmanaged forests. Conversely, forest management tends to truncate successional forest development cycles and to eliminate such elements. Shorter rotation lengths are likely to have the same – amplified – impact on forest biodiversity.").

[150] *See* Sierra Club (2017) *The Conventional Biomass Industry in California* ("[L]ike coal generation, solid fuel biomass generation releases criteria pollutants (including oxides of nitrogen (NOx), sulfur oxides (SOx), and fine particulate matter) that cause negative human health impacts, including asthma, heart disease, and premature death. In fact, biomass combustion is dirtier than coal generation with regards to particulate matter and NOx. Biomass generation proponents state that solid fuel facilities reduce pollution as these plants filter out 99 percent of PM 2.5 pollution and 95 percent of black carbon emissions. However, this claim refers to the most technologically advanced plants. The majority of the existing solid fuel, conventional biomass incineration facilities in California were built in the late 1980s and are not based on the most advanced technology. Furthermore, as many as 75 percent of conventional biomass facilities across the United States have been found not to be compliant with public health laws."); Arvesen A., *et al.* (2018) *Cooling aerosols and changes in albedo counteract warming from CO 2 and black carbon from forest bioenergy in Norway*, SCI. REP. 8(3299): 1–12, 8 ("For combustion plant sizes > 1 MW, assumed emission factor values for dust, CO, NO_x and SO_2 are in compliance with current air pollution regulations in Norway (combustion plant sizes < 1 MW are not subject to regulatory emission limits)[12]. The fractions of PM_{10} that are black carbon and organic carbon are assumed to be 4.3% and 17%, respectively, for all combustion plant size classes[13]. For biogenic CO_2, we employ a generic emission factor of 1.8 kg CO_2 dry kg^{-1}."); Cai H. & Wang M. Q. (2014) *Estimation of*

Emission Factors of Particulate Black Carbon and Organic Carbon from Stationary, Mobile, and Non-point Sources in the United States for Incorporation into GREET, Argonne National Laboratory, Technical Report ANL/ESD-14/6, 13, 31 (Table 15: Listing mean black carbon emissions from biomass-fired boilers as emitting 0.273 g/kWh compared with 0.009 g/kWh from coal-fired boilers; "For biomass-fired boilers, we relied on a source profile (ID 4704) with the highest quality rating in SPECIATE that was based on a study on source sampling of fine PM emissions from wood-fired industrial boilers by the National Risk Management Research Laboratory of the EPA (EPA 2014a)."); Pozzer A., Dominici F., Haines A., Witt C., Münzel T., & Lelieveld J. (2020) *Regional and global contributions of air pollution to risk of death from COVID-19*, CARDIOVASC. RES. 116(14): 2247–2253, 2251 ("Our results suggest that air pollution is an important cofactor increasing the risk of mortality from COVID-19. This provides extra motivation for combining ambitious policies to reduce air pollution with measures to control the transmission of COVID-19."); *and* Li H., Xu X.-L., Dai D.-W., Huang Z.-Y., Ma Z., & Guan Y.-J. (2020) *Air pollution and temperature are associated with increased COVID-19 incidence: A time series study*, INT. J. INFECT. DIS. 97: 278–282, 278 ("First, a significant correlation was found between COVID-19 incidence and AQI in both Wuhan ($R^2 = 0.13$, $p < 0.05$) and XiaoGan ($R^2 = 0.223$, $p < 0.01$). Specifically, among four pollutants, COVID-19 incidence was prominently correlated with $PM_{2.5}$ and NO_2 in both cities. In Wuhan, the tightest correlation was observed between NO_2 and COVID-19 incidence ($R^2 = 0.329$, $p < 0.01$). In XiaoGan, in addition to the $PM_{2.5}$ ($R^2 = 0.117$, $p < 0.01$) and NO_2 ($R^2 = 0.015$, $p < 0.05$), a notable correlation was also observed between the PM_{10} and COVID-19 incidence ($R^2 = 0.105$, $p < 0.05$). Moreover, temperature is the only meteorological parameter that constantly correlated well with COVID-19 incidence in both Wuhan and XiaoGan, but in an inverse correlation ($p < 0.05$).").

[151] Globally, large-scale deployment of BECCS would decrease food and water security and could intensify social conflicts, especially in low- and middle-income countries. *See* Canadell J. G., *et al.* (2021) *Chapter 5: Global Carbon and other Biogeochemical Cycles and Feedbacks*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 5-108 ("Deployment of BECCS at the scales envisioned by many 1.5–2.0°C mitigation scenarios could threaten biodiversity and require large land areas, competing with afforestation, reforestation and food security (Smith et al. 2018; Anderson and Peters 2016)"); Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019) GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES, Brondizio E. S., Settele J., Díaz S., & Ngo H. T. (eds.), XXII ("[The] largescale deployment of intensive bioenergy plantations, including monocultures, replacing natural forests and subsistence farmlands, will likely have negative impacts on biodiversity and can threaten food and water security as well as local livelihoods, including by intensifying social conflict."); *and* Hasegawa T., Sands R. D., Brunelle T., Cui Y., Frank S., Fujimori S., & Popp A. (2020) *Food security under high bioenergy demand toward long-term climate goals*, CLIM. CHANGE 163: 1587–1601, 1598 ("Land-based mitigation options play an important role in the assessment of stringent climate mitigation policies (Popp et al. 2014b, 2017). Bioenergy should be in high demand because carbon is absorbed directly from the atmosphere (negative emission) when combined with carbon capture and storage. However, potential competition for land between food and bioenergy crop production is of concern. The large-scale use of bioenergy, to support stringent temperature ceilings of 2 or 1.5 °C by the end of this century, would change land dynamics, put pressure on land resources (Popp et al. 2014b), compete with food production, and increase the risk of hunger in middle- and low-income regions (Frank et al. 2017; Hasegawa et al. 2015a, 2018). The use of bioenergy to replace fossil fuels is addressed in other studies (e.g., Hasegawa et al. 2018; Bauer et al. 2018) but not in the context of food security. This study provides an in-depth analysis of the relationship between bioenergy and use of land for meeting food demand."). High implementation of BECCS could increase the population at risk of hunger by up to 150 million people. *See* Intergovernmental Panel on Climate Change (2019) *Summary for Policymakers*, *in* CLIMATE CHANGE AND LAND: *AN IPCC SPECIAL REPORT ON CLIMATE CHANGE, DESERTIFICATION, LAND DEGRADATION, SUSTAINABLE LAND MANAGEMENT, FOOD SECURITY, AND GREENHOUSE GAS FLUXES IN TERRESTRIAL ECOSYSTEMS*, Shukla P. R., *et al.* (eds.), 27 ("Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts, assuming carbon dioxide removal by BECCS at a scale of 11.3 GtCO2 yr-1 in 2050, and noting that bioenergy without CCS can also achieve emissions reductions of up to several GtCO2 yr-1 when it is a low carbon energy source {2.6.1; 6.3.1}. Studies linking bioenergy to food security estimate an increase in the population at risk of hunger to up to 150 million people at this level of implementation {6.3.5}. The red hatched cells for desertification and land degradation indicate that while up to 15 million km2 of additional land is required in 2100 in 2°C scenarios which will increase

pressure for desertification and land degradation, the actual area affected by this additional pressure is not easily quantified {6.3.3; 6.3.4}.").

[152] Bioenergy facilities have been linked with environmental injustice, specifically the wood pellet industry in the U.S. *See* Purifoy D. (5 October 2020) *How Europe's Wood Pellet Appetite Worsens Environmental Racism in the South*, SOUTHERLY ("From Northampton County to Alabama's Black Belt, residents and activists say companies such as Enviva exploit mostly communities of color with promises to build up busted local economies with a "green energy" industry. Instead, communities hosting wood pellet facilities are not only further burdened by pollution and other local dangers, they are also entangled in yet another climate damaging trend — the destruction of biodiverse hardwood forests and the rise of monoculture tree plantations to produce energy that appears to pose climate threats similar to coal."); Popkin G. (21 April 2021) *There's a Booming Business in America's Forests. Some Aren't Happy About It.*, THE NEW YORK TIMES ("Richie Harding, a pastor in Northampton County, took a dimmer view. He said he was incensed that Enviva had plopped its mill amid established neighborhoods. "Northampton County has a lot of land," he said. "Why would you put it in the backyard of these people?" Pellet mills, which can emit volatile organic compounds and other hazardous air pollutants, are 50 percent more likely to be located near "environmental justice-designated" communities, defined as counties with above-average poverty levels and a population that's at least 25 percent nonwhite, according to an analysis by the Dogwood Alliance, an environmental nonprofit based in Asheville. In November, the Mississippi Department of Environmental Quality fined Drax, the power company, $2.5 million for air-quality violations at mills it operates there."); Koester S. & Davis S. (2018) *Siting of Wood Pellet Production in Environmental Justice Communities in the Southeastern United States*, ENVIRON. JUSTICE 11(2): 64–70, 70 ("By defining EJ communities as communities with high levels of poverty and large nonwhite populations, we showed that they are roughly 50% more likely than non-EJ communities to have a biomass pellet facility located in their community. In addition, North and South Carolina had wood pellet production facilities located exclusively in EJ communities. A contemporary instance of a biomass wood pellet production facility being placed in an EJ community is illustrated by our example of Richmond County, North Carolina, showing that residents' right to EJ is being denied. This research details the continued pattern of energy projects and development being sited in areas where communities are economically, politically, and socially marginalized."); Grunald M. (26 March 2021) *The 'Green Energy' That Might Be Ruining the Planet*, POLITICO MAGAZINE ("U.S. pellet mills have often been located in predominantly minority communities, which has added an environmental justice angle to the politics of biomass. A local activist named Belinda Joyner, who is Black, once confronted a Black state regulator about Enviva's expansion of the Northampton mill. Joyner told the regulator his agency was ignoring a minority community's complaints about truck traffic and dust and a debarker that rattled at night as if someone had left a quarter in the dryer. The regulator said he was sympathetic, but as long as Enviva complied with air quality laws, he had no choice but to issue the permit."); *and* Anderson P. & Powell K. (2018) *Dirty Deception: How the Wood Biomass Industry Skirts the Clean Air Act*, Environmental Integrity Project, 4–5 ("[Environmental Integrity Project's] survey reveals that these facilities emit dangerous amounts of air pollution, and further finds that state agencies consistently fall well short of their duty to ensure that these facilities control their pollution to the levels required by law, frequently due to misleading information supplied by the industry. As a result, many large pellet mills have been allowed to emit air pollution, especially volatile organic compounds (VOCs) and hazardous air pollutants at levels well above legal limits for years at a time.").

[153] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[154] Piamonte C., Correal M., & Rihm A. (21 November 2022) *If we talk about climate change, we MUST talk about waste*, Inter-American Development Bank ("In Latin America and the Caribbean (LAC), waste production continues to grow. Projections indicate that the region will produce 296 million tons of municipal solid waste by 2030, of which 52% is expected to be organic. Currently, LAC countries dispose of 56% of their waste in sanitary landfills – most of them without biogas capture systems – and 40% in inadequate disposal sites, while less than 4% of waste is valorized. This context not only increases the challenges for waste management in the region, but also poses a threat to methane mitigation."),

[155] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[156] Climate Watch, *US Greenhouse Gas Emissions* (*last visited* 27 June 2023).

[157] United States Environmental Protection Agency (21 April 2023) *Basic Information about Landfill Gas*, Landfill Methane Outreach Program ("Municipal solid waste (MSW) landfills are the third-largest source of human-related methane emissions in the United States, accounting for approximately 14.3 percent of these emissions in 2021. The methane emissions from MSW landfills in 2021 were approximately equivalent to the greenhouse gas (GHG) emissions from nearly 23.1 million gasoline-powered passenger vehicles driven for one year or the CO_2 emissions from nearly 13.1 million homes' energy use for one year. At the same time, methane emissions from MSW landfills represent a lost opportunity to capture and use a significant energy resource.").

[158] Flerlage H., Velders G. J. M., & de Boer J. (2021) *A review of bottom-up and top-down emission estimates of hydrofluorocarbons (HFCs) in different parts of the world*, CHEMOS. 283(131208): 1–16, 1 ("Hydrofluorocarbons (HFCs) are widespread alternatives for the ozone-depleting substances (ODSs) chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). They are used today in a variety of applications, mainly as refrigerants for cooling and air conditioning or as foam-blowing agents (Montzka et al., 2018).").

[159] Flerlage H., Velders G. J. M., & de Boer J. (2021) *A review of bottom-up and top-down emission estimates of hydrofluorocarbons (HFCs) in different parts of the world*, CHEMOS. 283(131208): 1–16, 2 ("HFCs do not deplete the ozone layer like chlorine- or bromine- containing analogues do (Ravishankara et al., 1994). Recent findings show an indirect depletion potential due to radiative forcing increasing tropospheric and stratospheric temperatures, which alters atmospheric circulation and accelerates the catalytic ozone destruction cycle (Hurwitz et al., 2015). While this effect has limited impact, HFCs being halocarbons, are potent greenhouse gases (Ramanathan, 1975). Global warming potentials (GWPs) express the effect of a substance on global warming relative to CO2, based on the mass of the substance emitted. HFCs have GWPs of up to several thousands and thus significantly contribute to global radiative forcing (Montzka et al., 2015).").

[160] Flerlage H., Velders G. J. M., & de Boer J. (2021) *A review of bottom-up and top-down emission estimates of hydrofluorocarbons (HFCs) in different parts of the world*, CHEMOS. 283(131208): 1–16, 12 ("In Latin America and the Caribbean, 80% of HFC emissions are emitted by Argentina, Brazil and Mexico (CCAP and UNEP, 2016).").

[161] Flerlage H., Velders G. J. M., & de Boer J. (2021) *A review of bottom-up and top-down emission estimates of hydrofluorocarbons (HFCs) in different parts of the world*, CHEMOS. 283(131208): 1–16, 12 ("Emissions of HFC-134a according to government reports to the UNFCCC reached 3.9 Gg yr1 in 2015, while HFC-152a were reported to be 0 Gg yr1 in 2007–2015 (Minist´erio Da Ciˆencia, Tecnologia E Inovaç˜ao, 2017).").

[162] Sustainable Energy for All (2021) *Chilling Prospects: Tracking Sustainable Cooling for All*, 19 ("In Latin America and the Caribbean, the number of those at highest risk in six countries high-impact countries for access to sustainable cooling grew slightly from 47.6 million people in 2020, to 48.8 million people in 2021. ").

[163] Sustainable Energy for All (2021) *Chilling Prospects: Tracking Sustainable Cooling for All*, 19 ("Of those at highest risk, the vast majority are the urban poor, which increased by 500,000 people compared to the previous year. Within the region, the most significant growth in the urban poor category was observed in Brazil (299,000 people) and Bolivia (55,000 people).").

[164] Bayer E. (18 February 2021) *Consumers can transform Latin America's power systems: Here's how*, INTERNATIONAL ENERGY AGENCY ("By 2050, two-thirds of the world's households could have an AC unit. This means that AC stocks in Latin America and the Caribbean could increase more than sixfold, putting a strain on transmission and local distribution grids. However, more energy efficient ACs could reduce the additional electricity system load, and the remaining load could be cycled to help avoid grid strain during peak hours.").

[165] International Energy Agency (2018) THE FUTURE OF COOLING: *OPPORTUNITIES FOR ENERGY EFFICIENT AIR CONDITIONING*; *discussed in* Bayer, E. (18 February 2021) *Consumers can transform Latin America's power systems: Here's how*, INTERNATIONAL ENERGY AGENCY ("By 2050, two-thirds of the world's households could have an AC

unit. This means that AC stocks in Latin America and the Caribbean could increase more than sixfold, putting a strain on transmission and local distribution grids.”).

[166] Yepez A. & Urteaga J.A. (20 April 2023) *Latin America and the Caribbean can mitigate climate change by tapping into its energy efficiency potential*, Inter-American Development Bank (“The region’s energy intensity, which means the amount of energy consumed per unit of gross domestic product, decreased at an average annual rate of 0.8% from 2010 to 2018. Worldwide, energy intensity decreased at a rate of 2.1% per year, making Latin America and the Caribbean the region with the least improvement in this indicator.”).

[167] Porras F., Walter A., Soriano G., & Ramirez A.D. (2023) *On the adoption of stricter energy efficiency standards for residential air conditioners: Case study Guayaquil, Ecuador*, HELIYON 9(3): e13893, 1–17, 3 (“The average MEPS (continuous line) for LATAM countries shown in Table 1 is approximately 30% below the average MEPS in the main manufacturing regions. The UNEP Model Regulations are voluntary guidelines for governments in developing countries considering a regulatory framework that requires new room air conditioners to be clean and efficient, following a sustainable pathway [12]. Fig. 1 also shows the current gap between LATAM MEPS and the UNEP Model Regulations (dashed line). The comparison indicates that LATAM MEPS should be increased by 67% to meet UNEP guidelines.”).

[168] Yepez A. & Urteaga J.A. (20 April 2023) *Latin America and the Caribbean can mitigate climate change by tapping into its energy efficiency potential*, Inter-American Development Bank (“According to Inter-American Development Bank estimates, the region has the potential to save at least 20% of its energy consumption just by using more efficient lighting, refrigeration and air conditioning equipment, and motors and compressors. These steps would mitigate approximately 470 MtCO_2e, based on an estimated emission factor for the region of 0.34 TCO2/MWh.”).

[169] Flerlage H., Velders G. J. M., & de Boer J. (2021) *A review of bottom-up and top-down emission estimates of hydrofluorocarbons (HFCs) in different parts of the world*, CHEMOS. 283(131208): 1–16, 10 (“The global distribution of HFC emissions is quite inhomogeneous. Canada, Japan, Australia, and Russia account for about 20% of HFC emissions reported from Annex I countries, while the majority (about 80%) stem from the US and the EU”).

[170] United States Environmental Protection Agency (30 May 2023) *Phaseout of Ozone-Depleting Substances (ODS)* ("In the United States, ozone-depleting substances (ODS) are regulated as class I or class II controlled substances. Class I substances, such as chlorofluorocarbons (CFCs) and halons, have a higher ozone depletion potential and have been phased out in the U.S.; with a few exceptions, this means no one can produce or import class I substances. Class II substances are all hydrochlorofluorocarbons (HCFCs, which are transitional substitutes for many class I substances. New production and import of most HCFCs were phased out as of 2020. The most common HCFC in use today is HCFC-22 or R-22, a refrigerant still used in existing air conditioners and refrigeration equipment.").

[171] Baccini A., Walker W., Carvalho L., Farina M., Sulla-Menashe D., & Houghton R. A. (2017) *Tropical forests are a net carbon source based on aboveground measurements of gain and loss*, SCIENCE 358(6360): 230–234, 2–3 (“Our analysis reveals that degradation and disturbance account for 70, 81, and 46% of carbon losses, respectively, across tropical America, Africa, and Asia. For the tropics as a whole, D/D accounts for ~69% of total carbon losses. Although this percentage is higher than previous estimates (22, 23), D/D are scale-dependent phenomena that can only be measured and interpreted relative to the resolution of the sample grid (i.e., 21.4 ha in this study; fig. S7).”).

[172] Lovejoy T. E. & Nobre C. (2018) *Amazon’s Tipping Point*, SCI. ADV. 4(2): eaat2340, 1 (“We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to nonforest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation.”). *See also* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, REV. GEOPHYS. 61(e2021RG000757): 1–81, 28 (“Ultimately, current research cannot eliminate the possibility that changes across the boreal zone due to a warming climate could act as a net positive climate feedback, thanks to the potential for permafrost thaw and wildfires to liberate the soil carbon that makes up the majority of stored carbon across this ecosystem.

Consequently, boreal forest dieback and shifts represent one of the more potentially immediate and significant climate system tipping elements (Table 7).").

[173] Lovejoy T. E. & Nobre C. (2018) *Amazon's Tipping Point*, SCI. ADV. 4(2): eaat2340, 1 ("We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to nonforest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation."). *See also* Wang S., Foster A., Lenz E. A., Kessler J. D., Stroeve J. C., Anderson L. O., Turetsky M., Betts R., Zou S., Liu W., Boos W. R., & Hausfather Z. (2023) *Mechanisms and Impacts of Earth System Tipping Elements*, REV. GEOPHYS. 61(e2021RG000757): 1–81, 28 ("Ultimately, current research cannot eliminate the possibility that changes across the boreal zone due to a warming climate could act as a net positive climate feedback, thanks to the potential for permafrost thaw and wildfires to liberate the soil carbon that makes up the majority of stored carbon across this ecosystem. Consequently, boreal forest dieback and shifts represent one of the more potentially immediate and significant climate system tipping elements (Table 7).").

[174] Griscom B. W., *et al*. (2017) *Natural climate solutions*, PROC. NAT'L. ACAD. SCI. 114(44): 11645–11650, 11645 ("Better stewardship of land is needed to achieve the Paris Climate Agreement goal of holding warming to below 2 °C; however, confusion persists about the specific set of land stewardship options available and their mitigation potential. To address this, we identify and quantify "natural climate solutions" (NCS): 20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands. We find that the maximum potential of NCS—when constrained by food security, fiber security, and biodiversity conservation—is 23.8 petagrams of CO_2 equivalent ($PgCO_2e$) y^{-1} (95% CI 20.3–37.4). This is ≥30% higher than prior estimates, which did not include the full range of options and safeguards considered here. About half of this maximum (11.3 $PgCO_2e$ y^{-1}) represents cost-effective climate mitigation, assuming the social cost of CO_2 pollution is ≥100 USD $MgCO_2e^{-1}$ by 2030. Natural climate solutions can provide 37% of cost-effective CO_2 mitigation needed through 2030 for a >66% chance of holding warming to below 2 °C. One-third of this cost-effective NCS mitigation can be delivered at or below 10 USD $MgCO_2^{-1}$. Most NCS actions—if effectively implemented—also offer water filtration, flood buffering, soil health, biodiversity habitat, and enhanced climate resilience. Work remains to better constrain uncertainty of NCS mitigation estimates. Nevertheless, existing knowledge reported here provides a robust basis for immediate global action to improve ecosystem stewardship as a major solution to climate change."). *See also* Moomaw W. R., Masino S. A., & Faison E. K. (2019) *Intact Forests in the Unites States: Proforestation Mitigates Climate Change and Serves the Greatest Good*, Perspective, FRONT. FOR. GLOB. CHANGE 2(27): 1–10, 1 ("Climate change and loss of biodiversity are widely recognized as the foremost environmental challenges of our time. Forests annually sequester large quantities of atmospheric carbon dioxide (CO_2), and store carbon above and below ground for long periods of time. Intact forests—largely free from human intervention except primarily for trails and hazard removals—are the most carbon-dense and biodiverse terrestrial ecosystems, with additional benefits to society and the economy. … The recent *1.5 Degree Warming Report* by the Intergovernmental Panel on Climate Change identifies *reforestation* and *afforestation* as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land, and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential—termed *proforestation*—is a more effective, immediate, and low-cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation, and scenic beauty."); *and* World Wildlife Fund (2020) LIVING PLANET REPORT 2020 – BENDING THE CURVE OF BIODIVERSITY LOSS, Almond R. E. A., Grooten M., & Petersen T. (eds.), 6 ("The global Living Planet Index continues to decline. It shows an average 68% decrease in population sizes of mammals, birds, amphibians, reptiles and fish between 1970 and 2016. … It matters because biodiversity is fundamental to human life on Earth, and the evidence is unequivocal – it is being destroyed by us at a rate unprecedented in history. Since the industrial revolution, human activities have increasingly destroyed and degraded forests, grasslands, wetlands and other important ecosystems, threatening human well-being. Seventy-five per cent of the Earth's ice-free land surface has already been significantly altered, most of the oceans are polluted, and more than 85% of the area of wetlands has been lost.").

[175] Rockström J., Beringer T., Hole D., Griscom B., Mascia M. B., Folke C., & Creutzig F. (2021) *We Need Biosphere Stewardship That Protects Carbon Sinks and Builds Resilience*, PROC. NAT'L. ACAD. SCI. 118(38): e2115218115, 1–8, 2 ("Using the reduced complexity climate model MAGICC6 ("Model for the Assessment of Greenhouse Gas Induced Climate Change Version 6"), we examined changes in global mean temperature up till now and in the future under the RCP2.6 emission scenario—the only emission pathway that aligns with the Paris agreement—but assumed that ecosystems on land had stopped absorbing CO_2 from 1900 onwards. In such a world, global temperatures would have risen much faster (Fig. 1C, red line). In fact, we would have already crossed the 1.5 °C threshold, demonstrating that terrestrial ecosystems have reduced warming by at least 0.4 °C since 1900.").

[176] Duffy K. A., Schwalm C. R., Arcus V. L., Koch G. W., Liang L. L., & Schipper L. A. (2021) *How close are we to the temperature tipping point of the terrestrial biosphere?*, SCI. ADV. 7(3): eaay1052, 1–8, 1 ("The temperature dependence of global photosynthesis and respiration determine land carbon sink strength. While the land sink currently mitigates ~30% of anthropogenic carbon emissions, it is unclear whether this ecosystem service will persist and, more specifically, what hard temperature limits, if any, regulate carbon uptake. Here, we use the largest continuous carbon flux monitoring network to construct the first observationally derived temperature response curves for global land carbon uptake. We show that the mean temperature of the warmest quarter (3-month period) passed the thermal maximum for photosynthesis during the past decade. At higher temperatures, respiration rates continue to rise in contrast to sharply declining rates of photosynthesis. Under business-as-usual emissions, this divergence elicits a near halving of the land sink strength by as early as 2040."). *See also* Hubau W., *et al.* (2020) *Asynchronous carbon sink saturation in African and Amazonian tropical forests*, NATURE 579: 80–87, 85 ("In summary, our results indicate that although intact tropical forests remain major stores of carbon and are key centres of biodiversity11, their ability to sequester additional carbon in trees is waning. In the 1990s intact tropical forests removed 17% of anthropogenic CO_2 emissions. This declined to an estimated 6% in the 2010s, because the pan-tropical weighted average per unit area sink strength declined by 33%, forest area decreased by 19% and anthropogenic CO_2 emissions increased by 46%. Although tropical forests are more immediately threatened by deforestation46 and degradation47, and the future carbon balance will also depend on secondary forest dynamics48 and forest restoration plans49, our analyses show that they are also affected by atmospheric chemistry and climatic changes. Given that the intact tropical forest carbon sink is set to end sooner than even the most pessimistic climate driven vegetation models predict4,5, our analyses suggest that climate change impacts in the tropics may become more severe than predicted. Furthermore, the carbon balance of intact tropical forests will only stabilize once CO_2 concentrations and the climate stabilizes."); *and* Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-26 ("Based on model projections, under the intermediate scenario that stabilizes atmospheric CO_2 concentrations this century (SSP2-4.5), the rates of CO_2 taken up by the land and oceans are projected to decrease in the second half of the 21st century (*high confidence*). Under the very low and low GHG emissions scenarios (SSP1-1.9, SSP1-2.6), where CO_2 concentrations peak and decline during the 21st century, land and oceans begin to take up less carbon in response to declining atmospheric CO_2 concentrations (*high confidence*) and turn into a weak net source by 2100 under SSP1-1.9 (*medium confidence*). It is very unlikely that the combined global land and ocean sink will turn into a source by 2100 under scenarios without net negative emissions32 (SSP2-4.5, SSP3-7.0, SSP5-8.5)… Additional ecosystem responses to warming not yet fully included in climate models, such as CO_2 and CH_4 fluxes from wetlands, permafrost thaw and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*).").

[177] Goldstein A., Noon M. L., Ledezma J. C., Roehrdanz P. R., Raghav S., McGreevey M., Stone C., Shrestha S., Golden Kroner R., Hole D., & Turner W. (2021) IRRECOVERABLE CARBON: THE PLACES WE MUST PROTECT TO AVERT CLIMATE CATASTROPHE, Conservation International, 7 ("'Irrecoverable carbon' refers to the vast stores of carbon in nature that are vulnerable to release from human activity and, if lost, could not be restored by 2050 — when the world must reach net-zero emissions to avoid the worst impacts of climate change. … There are high concentrations of irrecoverable carbon in the Amazon (31.5 Gt), the Congo Basin (8.1 Gt), and New Guinea (7.3 Gt). Other important irrecoverable carbon reserves are located in the Pacific Northwest of North America, the Valdivian forests of Chile, the mangroves and swamp forests of Guyana, the peatlands of Northern Scotland, Niger Delta's mangroves, Cambodia's Tonle Sap Lake, the Scandinavian and Siberian boreal forests, and the eucalyptus forest of Southeast Australia, among others."). *See also* Goldstein A., *et al.* (2020) *Protecting irrecoverable carbon in Earth's ecosystems*,

NAT. CLIM. CHANGE 10(4): 287–295; *and* Noon M. L., Goldstein A., Ledezma J. C., Roehrdanz P. R., Cook-Patton S. C., Spawn-Lee S. A., Wright T. M., Gonzalez-Roglich M., Hole D. G., Rockström J., & Turner W. R. (2021) *Mapping the irrecoverable carbon in Earth's ecosystems*, NAT. SUSTAIN. 5: 37–46.

[178] Goldstein A., Noon M. L., Ledezma J. C., Roehrdanz P. R., Raghav S., McGreevey M., Stone C., Shrestha S., Golden Kroner R., Hole D., & Turner W. (2021) IRRECOVERABLE CARBON: THE PLACES WE MUST PROTECT TO AVERT CLIMATE CATASTROPHE, Conservation International, 7 ("'Irrecoverable carbon' refers to the vast stores of carbon in nature that are vulnerable to release from human activity and, if lost, could not be restored by 2050 — when the world must reach net-zero emissions to avoid the worst impacts of climate change... There are high concentrations of irrecoverable carbon in the Amazon (31.5 Gt), the Congo Basin (8.1 Gt), and New Guinea (7.3 Gt). Other important irrecoverable carbon reserves are located in the Pacific Northwest of North America, the Valdivian forests of Chile, the mangroves and swamp forests of Guyana, the peatlands of Northern Scotland, Niger Delta's mangroves, Cambodia's Tonle Sap Lake, the Scandinavian and Siberian boreal forests, and the eucalyptus forest of Southeast Australia, among others."). *See also* Goldstein A., *et al.* (2020) *Protecting irrecoverable carbon in Earth's ecosystems*, NAT. CLIM. CHANGE 10(4): 287–295; *and* Noon M. L., Goldstein A., Ledezma J. C., Roehrdanz P. R., Cook-Patton S. C., Spawn-Lee S. A., Wright T. M., Gonzalez-Roglich M., Hole D. G., Rockström J., & Turner W. R. (2021) *Mapping the irrecoverable carbon in Earth's ecosystems*, NAT. SUSTAIN. 5: 37–46.

[179] Griscom B. W., *et al.* (2017) *Natural climate solutions*, PROC. NAT'L. ACAD. SCI. 114(44): 11645–11650, 11645 ("Better stewardship of land is needed to achieve the Paris Climate Agreement goal of holding warming to below 2 °C; however, confusion persists about the specific set of land stewardship options available and their mitigation potential. To address this, we identify and quantify "natural climate solutions" (NCS): 20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands. We find that the maximum potential of NCS—when constrained by food security, fiber security, and biodiversity conservation—is 23.8 petagrams of CO_2 equivalent ($PgCO_2e$) y^{-1} (95% CI 20.3–37.4). This is ≥30% higher than prior estimates, which did not include the full range of options and safeguards considered here. About half of this maximum (11.3 $PgCO_2e$ y^{-1}) represents cost-effective climate mitigation, assuming the social cost of CO_2 pollution is ≥100 USD $MgCO_2e^{-1}$ by 2030. Natural climate solutions can provide 37% of cost-effective CO_2 mitigation needed through 2030 for a >66% chance of holding warming to below 2 °C. One-third of this cost-effective NCS mitigation can be delivered at or below 10 USD $MgCO_2^{-1}$. Most NCS actions—if effectively implemented—also offer water filtration, flood buffering, soil health, biodiversity habitat, and enhanced climate resilience. Work remains to better constrain uncertainty of NCS mitigation estimates. Nevertheless, existing knowledge reported here provides a robust basis for immediate global action to improve ecosystem stewardship as a major solution to climate change."). *See also* Moomaw W. R., Masino S. A., & Faison E. K. (2019) *Intact Forests in the Unites States: Proforestation Mitigates Climate Change and Serves the Greatest Good*, Perspective, FRONT. FOR. GLOB. CHANGE 2(27): 1–10, 1 ("Climate change and loss of biodiversity are widely recognized as the foremost environmental challenges of our time. Forests annually sequester large quantities of atmospheric carbon dioxide (CO_2), and store carbon above and below ground for long periods of time. Intact forests—largely free from human intervention except primarily for trails and hazard removals—are the most carbon-dense and biodiverse terrestrial ecosystems, with additional benefits to society and the economy. … The recent *1.5 Degree Warming Report* by the Intergovernmental Panel on Climate Change identifies *reforestation* and *afforestation* as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land, and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential—termed *proforestation*—is a more effective, immediate, and low-cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation, and scenic beauty."); *and* World Wildlife Fund (2020) *Living Planet Report 2020 – Bending the curve of biodiversity loss*, Almond R. E. A., Grooten M., & Petersen T. (eds.), 5 ("The global Living Planet Index continues to decline. It shows an average 68% decrease in population sizes of mammals, birds, amphibians, reptiles and fish between 1970 and 2016. … It matters because biodiversity is fundamental to human life on Earth, and the evidence is unequivocal – it is being destroyed by us at a rate unprecedented in history. Since the industrial revolution, human activities have increasingly destroyed and

degraded forests, grasslands, wetlands and other important ecosystems, threatening human well-being. Seventy-five per cent of the Earth's ice-free land surface has already been significantly altered, most of the oceans are polluted, and more than 85% of the area of wetlands has been lost.").

[180] Cuadros A. (4 January 2023) *Has the Amazon Reached Its 'Tipping Point'?*, THE NEW YORK TIMES ("For all the slashing and burning of recent years, the ecosystem still stores about 120 billion tons of carbon in its trunks, branches, vines and soil — the equivalent of about ten years of human emissions. If all of that carbon is released, it could warm the planet by as much as 0.3 degrees Celsius. According to the Princeton ecologist Stephen Pacala, this alone would probably make the Paris Agreement — the international accord to limit warming since preindustrial times to 2 degrees — "impossible to achieve." Which, in turn, may mean that other climate tipping points are breached around the world. As the British scientist Tim Lenton put it to me, "The Amazon feeds back to everything.").

[181] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1693 ("**The positive feedback between climate change and land use change, particularly deforestation, is projected to increase the threat to the Amazon forest, resulting in the increase of fire occurrence, forest degradation (*high confidence*) and long-term loss of forest structure (*medium confidence*).** The combined effect of both impacts will lead to a long-term decrease in carbon stocks in forest biomass, compromising Amazonia's role as a carbon sink, largely conditioned on the forest's responses to elevated atmospheric CO_2 (*medium confidence*). The southern portion of the Amazon has become a net carbon source to the atmosphere in the past decade (*high confidence*)."). *See also* Gatti L. V., *et al.* (2021) *Amazonia as a carbon source linked to deforestation and climate change*, NATURE 595: 388–393, 389, 390 ("Vertically averaged ΔVP values, which are proportional to surface flux, suggest that ALF-SE [southeastern Amazon] has the largest CO_2 emission to the atmosphere, followed by SAN-NE [northeastern Amazon]. By contrast, ΔVP values for the western sites RBA-SWC [southwestern-central Amazon] and TAB_TEF-NWC [northwestern-central Amazonia] indicate near-neutral C balance or C sinks."; "Over the nine years studied (2010–2018), the FC_{NBE} value for ALF-SE [southeastern Amazon] indicates that it is a steadily increasing source [of carbon], at a rate of 0.036 ± 0.015 g C m^{-2} d^{-1} yr^{-1} (Pearson's correlation, $r = 0.68$, $P = 0.045$) (Extended Data Fig. 5a).").

[182] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 7 ("The 2022 mean temperature in LAC was between the 12th and 21st highest on record, depending on the data set used, close to the 1991–2020 average (-0.06 °C to 0.10 °C) and 0.55 °C [0.46 °C to 0.70 °C] above the 1961–1990 average (Table 1). The annual mean temperature anomalies relative to 1991–2020 across the LAC region are shown in Figure 3 and Table 1 (see details regarding the data sets in the Data sets and methods section). Warming was less pronounced in the region in 2022 compared to 2021, and especially when compared to 2020 (which was one of the three warmest years on record). The 1991–2022 period shows the highest warmest trend (about 0.2 °C or higher per decade) since 1900 in the LAC region (compared with the previous 30-year periods of 1900–1930, 1931–1960, 1961–1990).").

[183] Lovejoy T. E. & Nobre C. (2018) *Amazon's Tipping Point*, SCI. ADV. 4(2): eaat2340, 1 ("We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to nonforest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation."). *See also* Hoegh-Guldberg O., *et al.* (2018) *Chapter 3: Impacts of 1.5 ºC of Global Warming on Natural and Human Systems*, *in* GLOBAL WARMING OF 1.5 °C, *Special Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 3-263 ("Global warming of 3°C is projected to reduce the extent of tropical rainforest in Central America, with biomass being reduced by about 40%, which can lead to a large replacement of rainforest by savanna and grassland (Lyra et al., 2017). Overall, modelling studies (Huntingford et al., 2013; Nobre et al., 2016) and observational constraints (Cox et al., 2013) suggest that pronounced rainforest dieback may only be triggered at 3°C–4°C (medium confidence), although pronounced biomass losses may occur at 1.5°C– 2°C of global warming.").

[184] Taylor L. (5 September 2022) *The Amazon rainforest has already reached a crucial tipping point,* NEW SCIENTIST ("Marlene Quintanilla at the Amazon Geo-Referenced Socio-Environmental Information Network (RAISG) and her colleagues, working in partnership with various groups, including the Coordinator of Indigenous Organizations of the Amazon River Basin, used forest coverage data to map how much of the Amazon was lost between 1985 and 2020 and also looked at forest density, rainfall patterns and carbon storage. …The report finds that 33 per cent of the Amazon remains pristine and 41 per cent of areas have low degradation and could restore themselves. But 26 per cent of areas have been found to have gone too far to restore themselves: 20 per cent is lost entirely and 6 per cent is highly degraded and would need human support to be restored."). *See also* Lenton T. M., Rockstrom J., Gaffney O., Rahmstorf S., Richardson K., Steffen W., & Schellnhuber H. J. (2019) *Climate tipping points—too risky to bet against*, Comment, NATURE, 575: 592–595, 593 ("Estimates of where an Amazon tipping point could lie range from 40% deforestation to just 30% forest-cover loss. About 17% has been lost since 1970. The rate of deforestation varies with changes in policy. Finding the tipping point requires models that include deforestation and climate change as interacting drivers, and that incorporate fire and climate feedbacks as interacting tipping mechanisms across scales.").

[185] Douville H., *et al*. (2021) *Chapter 8: Water Cycle Changes*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 8-112 ("Both deforestation and drying are projected to increase by 2100, resulting in a worst-case scenario of up to a 50% loss in forest cover by 2050 (Soares-Filho et al., 2006; Boisier et al., 2015; Steege et 50 al., 2015; Gomes et al., 2019).").

[186] Wang-Erlandsson L., *et al.* (2022) *A planetary boundary for green water*, NAT. REV. EARTH ENVIRON. 3: 380–392, 380 ("Green water — terrestrial precipitation, evaporation and soil moisture — is fundamental to Earth system dynamics and is now extensively perturbed by human pressures at continental to planetary scales. However, green water lacks explicit consideration in the existing planetary boundaries framework that demarcates a global safe operating space for humanity. In this Perspective, we propose a green water planetary boundary and estimate its current status. The green water planetary boundary can be represented by the percentage of ice-free land area on which root-zone soil moisture deviates from Holocene variability for any month of the year. Provisional estimates of departures from Holocene-like conditions, alongside evidence of widespread deterioration in Earth system functioning, indicate that the green water planetary boundary is already transgressed. Moving forward, research needs to address and account for the role of root-zone soil moisture for Earth system resilience in view of ecohydrological, hydroclimatic and sociohydrological interactions."); *discussed in* Stockhom Resilience Center (26 April 2022) *Freshwater boundary exceeds safe limits* ("Now researchers have explored the water boundary in more detail. The authors argue that previous assessments did not sufficiently capture the role of green water and particularly soil moisture for ensuring the resilience of the biosphere, for securing land carbon sinks, and for regulating atmospheric circulation. "The Amazon rainforest depends on soil moisture for its survival. But there is evidence that parts of the Amazon are drying out. The forest is losing soil moisture as a result of climate change and deforestation," says Arne Tobian, second author and PhD candidate at the Stockholm Resilience Centre and Potsdam Institute for Climate Impact Research. "These changes are potentially pushing the Amazon closer to a tipping point where large parts could switch from rainforest to savannah-like states," he adds.").

[187] Boulton C. A., Lenton T. M., & Boers N. (2022) *Pronounced loss of Amazon rainforest resilience since the early 2000s*, NAT. CLIM. CHANG. 12(3): 271–78, 277 ("Other factors, including rising atmospheric temperatures in response to anthropogenic greenhouse gas emissions, may additionally have negative effects on Amazon resilience (and are contributing to the warming of northern tropical Atlantic SSTs; Fig. 6a). Furthermore, the rapid change in climate is triggering ecological changes but ecosystems are having difficulties in keeping pace. In particular, the replacement of drought-sensitive tree species by drought-resistant ones is happening slower than changes in (hydro)meteorological conditions50, potentially reducing forest resilience further. In summary, we have revealed empirical evidence that the Amazon rainforest has been losing resilience since the early 2000s, risking dieback with profound implications for biodiversity, carbon storage and climate change at a global scale. We further provided empirical evidence suggesting that overall drier conditions, culminating in three severe drought events, combined with pronounced increases in human land-use activity in the Amazon, probably played a crucial role in the observed resilience loss. The amplified loss of Amazon resilience in areas closer to human land use suggests that reducing deforestation will not just protect

the parts of the forest that are directly threatened but also benefit Amazon rainforest resilience over much larger spatial scales.").

[188] Lenton T. M., Held H., Kriegler E., Hall J. W., Lucht W., Rahmstorf S., & Schellnhuber H. J. (2008) *Tipping elements in the Earth's climate system*, PROC. NAT'L. ACAD. SCI. 105(6): 1786–1793, 1790 ("A large fraction of precipitation in the Amazon basin is recycled, and, therefore, simulations of Amazon deforestation typically generate 20–30% reductions in precipitation (78), lengthening of the dry season, and increases in summer temperatures (79) that would make it difficult for the forest to reestablish, and suggest the system may exhibit bistability."). *See also* Staal A., Fetzer I., Wang-Erlandsson L., Bosmans J. H. C., Dekker S. C., van Nes E. H., Rockström J., & Tuinenburg O. A. (2020) *Hystersis of tropical forests in the 21st century*, NAT. COMMUN. 11(4978): 1–8, 5 ("Whether the Amazon in particular is an important global 'tipping element' in the Earth system is a question of great scientific and societal interest[36,37]. Despite our incomplete understanding of Amazon tipping, it is generally considered to be true that the forest's role in the hydrological cycle is so large that deforestation and/or climate change may trigger a tipping point [2,36–38]. More recently, the possibility of fire-induced tipping has also been suggested [5,6]. Although fire occurs at a local scale, a considerable portion of the Amazon would be susceptible to this kind of tipping; by accounting for the feed-backs at both local and regional scales, it becomes more likely that the Amazon is a tipping element. Although under the current climate a majority of the Amazon forest still appears resilient to disturbance (also see ref. 39), we show that this resilience may deteriorate as a result of redistributions of rainfall due to global climate change.").

[189] Gatti L. V., *et al.* (2021) *Amazonia as a carbon source linked to deforestation and climate change*, NATURE 595(7867): 388–393, 388 ("Southeastern Amazonia, in particular, acts as a net carbon source (total carbon flux minus fire emissions) to the atmosphere. Over the past 40 years, eastern Amazonia has been subjected to more deforestation, warming and moisture stress than the western part, especially during the dry season… the intensification of the dry season and an increase in deforestation seem to promote ecosystem stress, increase in fire occurrence, and higher carbon emissions in the eastern Amazon. This is in line with recent studies that indicate an increase in tree mortality and a reduction in photosynthesis as a result of climatic changes across Amazonia."). *See also* Brienen R. J. W., *et al.* (2015) *Long-term decline of the Amazon carbon sink*, NATURE 519(7543): 344–348, 344 ("While this analysis confirms that Amazon forests have acted as a long-term net biomass sink, we find a long-term decreasing trend of carbon accumulation. Rates of net increase in above-ground biomass declined by one-third during the past decade compared to the 1990s. This is a consequence of growth rate increases levelling off recently, while biomass mortality persistently increased throughout, leading to a shortening of carbon residence times.").

[190] Clarke B., Barnes C., Rodrigues R., Zachariah M., Stewart S., Raju E., Baumgart N., Heinrich D., Libonati R., Santos D., Albuquerque R., Muniz Alves L., & Otto F. (2024) *Climate change, not El Niño, main driver of exceptional drought in highly vulnerable Amazon River Basin*, World Weather Attribution, 3–4 ("Since June 2023, the Amazon River Basin (ARB) has received significantly below average rainfall. Initially, the northern half of the basin was most affected by this, but from September the entire basin has experienced a significant moisture deficit. … As of January 2024, large parts of the ARB are in a state of exceptional meteorological, agricultural and ecological drought (WMO, 2016). … The drought has caused the lowest water levels in 120 years, when measurements began, in many of the tributaries in the Amazon River (nature, 2023)."); 4–5 ("The ARB is extremely large, making up more than a third of the South American continent by land area, stretching from the high Andes in Peru and Colombia down to low-lying coastal regions of eastern Brazil, and is largely a tropical climate. Rainforest covers approximately 83% of the basin, and spatial variability of rainfall over the region is partly determined by feedbacks between the land surface and atmosphere (Paredes-Trejo et al., 2021)."); 34 ("The 2023 Amazon drought is frequently cited as the most extreme on the historical record.").

[191] Clarke B., Barnes C., Rodrigues R., Zachariah M., Stewart S., Raju E., Baumgart N., Heinrich D., Libonati R., Santos D., Albuquerque R., Muniz Alves L., & Otto F. (2024) *Climate change, not El Niño, main driver of exceptional drought in highly vulnerable Amazon River Basin*, World Weather Attribution, 4–5 ("Finally, while the rate of deforestation has decreased in the past year, multiple years of heightened deforestation previously have resulted in a less resilient and drier land surface (Rodrigues, 2023). Moreover, droughts in the northwestern Amazon such as this can be especially devastating to the forest and potentially accelerate a tipping point because the forest there is less resilient to rainfall variability than that in the eastern Amazon, which experiences more variability (Ciemer et al.,

2019; Hirota et al., 2021)."). *See also* Armstrong McKay D. I. & Loriani S. (eds.) (2023) *Section 1: Earth systems tipping points*, in GLOBAL TIPPING POINTS REPORT 2023, Lenton T. M., et al. (eds.), 41 ("Recent CMIP6 models indicate that localised shifts in peripheral parts of the Amazon forest system are more likely than a large-scale tipping event (IPCC AR6 WG1 Ch5, 2021; Parry et al., 2022). However, the latter cannot be ruled out (Hirota et al., 2021) because several compounding and possibly synergistic disturbances (e.g. combining an extreme hot drought with forest fires) may play a role in reducing forest resilience, with greater resilience loss closer to human activities (Boulton et al., 2022). Such synergies are generally not considered in Earth system models (Willcock et al., 2023)."); 113 ("For example, if the system is perturbed by something like an extreme weather event (e.g. a drought in the Amazon rainforest) such that it causes tipping by pushing the system past the ability for restoring feedbacks to return the system back to the previous state, CSD will not occur.").

[192] United States Congressional Research Service (2023) *U.S. Forest Carbon Data: In Brief*, 2 ("Carbon flux is the net annual change in carbon stocks. The flux estimate for any given year (e.g., 2020) is the change between stock estimates for that year (2020) and the following year (2021). Negative flux values indicate more carbon was removed from the atmosphere and sequestered than was released in that year (e.g., net carbon sink); net negative flux is typically called *net sequestration* (or sometimes just *sequestration*). Positive flux values indicate more carbon was released than was sequestered in that year (e.g., *net carbon source*). According to the *Inventory*, U.S. forests were a net carbon sink in 2021, having sequestered 794 MMT CO_2 equivalents (or 216 MMT of carbon) that year (see **Figure 3** for net sequestration by MMT CO_2 equivalents, **Table 2** for flux data by MMT CO_2 equivalents, and **Table 3** for flux data by MMT of carbon). This total represents an offset of approximately 13% of the gross greenhouse gas emissions from the United States in 2021.")

[193] Zhuang Y., Fu R., Santer B. D., Dickinson R. E., & Hall A. (2021) *Quantifying contributions of natural variability and anthropogenic forcings on increased fire weather risk over the western United States*, EARTH ATMOS. PLANET. SCI. 118(45): e2111875118, 1–9, 7 ("Overall, we find that over the period 1979 to 2020, anthropogenic warming has contributed at least twice as much as natural variability to the rapid increase of fire weather risk. Our observational analogue-based attribution approach complements the estimates we obtain from global climate model simulations (10, 16, 28). Both methods constrain the range of the true contribution of anthropogenic forcing to the observed increase of VPD over the WUS. We estimate this range to be 0.33 to 0.42 hPa/decade or 68 to 88% of the observed trend. We have shown here that VPD is a robust, physically meaningful proxy for fire risk. During two specific extreme events—the August Complex fire and the California Creek fire in 2020—VPD values exceeded the highest values observed previously for similar atmospheric circulation patterns. For the August Complex "Gigafire" in the WUS, anthropogenic warming likely explains 50% of the unprecedented high VPD anomalies in the month of the fire's occurrence (August 2020). On the August 16, 2020 start date of the August Complex fire and the September 4, 2020 start date of the California Creek fire, anthropogenic forcing likely contributed 32 and 52%, respectively, to the unprecedented high VPD′ at the beginning of these two extreme fire events").

[194] Natural Resources Canada (2022) THE STATE OF CANADA'S FORESTS: *ANNUAL REPORT 2022*, 27 ("With almost 362 million hectares (ha), Canada ranks as the country with the third- largest forest area in the world. Much of this forest grows in the boreal zone. There, over 280 million hectares of forest are interspersed with lakes, wetlands and other ecosystem types. According to Canada's National Deforestation Monitoring System, the forest area of Canada is stable, with less than half of 1% deforested since 1990.").

[195] Fletcher R. (12 February 2019) *Canada's forests actually emit more carbon than they absorb — despite what you've heard on Facebook*, CBC NEWS ("That's because our trees, in particular, have actually hurt our bottom line. For the past 15 years, they've been "more of a source than a sink," said Dominique Blain, a director in the science and technology branch of Environment and Climate Change Canada. Canada's managed forests were a net contributor of roughly 78 megatonnes of emissions in 2016, the most recent year on record.").

[196] Wieting J. (2019) *Hidden, ignored and growing: B.C.'s forest carbon emissions*, Sierra Club British Columbia, 1 ("These massive and growing forest emissions are a result of destructive logging, pine beetle outbreaks and wildfires. B.C.'s forests stopped absorbing more carbon than they release in the early 2000s. Uncounted forest emissions are now often greater than the total amount of emissions that are actually counted.").

[197] Caesar L., Rahmstorf S., Robinson A., Feulner G., & Saba V. (2018) *Observed fingerprint of a weakening Atlantic Ocean overturning circulation*, NATURE 556: 191–196, 195 ("We have also defined an improved SST-based AMOC index, which is optimized in its regional and seasonal coverage to reconstruct AMOC changes. Analysis of an ensemble of CMIP5 model simulations confirms that this index can very well reconstruct the long-term trend of the AMOC. We calibrated the observed AMOC decline to be 3±1 Sv (around 15%) since the mid-twentieth century, and reconstructed the evolution of the AMOC for the period 1870–2016. For recent decades, our reconstruction of the AMOC evolution agrees with the results of several earlier studies using different methods, suggesting that our AMOC index can also reproduce interdecadal variations. Our findings show that in recent years the AMOC appears to have reached a new record low, consistent with the record-low annual SST in the subpolar Atlantic (since observations began in 1880) reported by the National Oceanic and Atmospheric Administration for 2015. Surface temperature proxy data for the subpolar Atlantic suggest that "the AMOC weakness after 1975 is an unprecedented event in the past millennium"7 . This is consistent with the coral nitrogen-15 data that led Sherwood et al.28 to conclude that "the persistence of the warm, nutrient-rich regime since the early 1970s is largely unique in the context of the last approximately 1,800yr". Although long-term natural variations cannot be ruled out entirely29,30, the AMOC decline since the 1950s is very likely to be largely anthropogenic, given that it is a feature predicted by climate models in response to rising CO2 levels. This declining trend is superimposed by shorter-term (interdecadal) natural variability").

[198] Whitmarsh F., Zika J., & Czaja A. (2015) *Ocean heat uptake and the global surface temperature record*, Briefing paper No. 14, Grantham Institute, 2 ("It is likely that changes in the ocean have contributed significantly to the pause. Due to its large mass and high heat capacity, the ocean absorbs a substantial amount of heat. It is estimated that the earth gained 274 ZJi of heat energy between 1971 and 2010, of which around 90% was taken up by the ocean (figure 3)28,ii. According to one estimate, the top 2000 m of the ocean took up 240 ZJ of heat energy between 1955 and 2010, but only increased in temperature by about 0.09°C due to its high heat capacity14. If the lower 10 km of the atmosphere were able to absorb this same quantity of heat it would warm by 36°C.").

[199] United Nations (2022) THE SUSTAINABLE DEVELOPMENT GOALS REPORT 2022, 53 ("Sea levels have already risen faster than in any preceding century. Projections show that sea level could rise 30 to 60 centimetres by 2100, even if greenhouse gas emissions are sharply reduced and global warming is limited to well below 2 °C. A rising sea level would lead to more frequent and severe coastal flooding and erosion. Ocean warming will also continue with increasingly intense and frequent marine heatwaves, ocean acidification and reduced oxygen. About 70 to 90 per cent of warm-water coral reefs will disappear even if the 1.5 °C threshold is reached; they would die off completely at the 2 °C level. These impacts are expected to occur at least throughout the rest of this century, threatening marine ecosystems and the more than 3 billion people who rely on the ocean for their livelihoods.").

[200] Subramaniam A., Yager P. L., Carpenter E. J., Mahaffey C., Bjorkman K., Cooley S., Kustka A. B., Montoya J. P. Sanudo-Wilhelmy S. A., Shipe R., & Capone D. G. (2008) *Amazon River enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean*, PROC. NAT'L. ACAD. SCI. 105(30): 10460–10465, 10460 ("The fresh water discharged by large rivers such as the Amazon is transported hundreds to thousands of kilometers away from the coast by surface plumes. The nutrients delivered by these river plumes contribute to enhanced primary production in the ocean, and the sinking flux of this new production results in carbon sequestration. Here, we report that the Amazon River plume supports N2 fixation far from the mouth and provides important pathways for sequestration of atmospheric CO2 in the western tropical North Atlantic (WTNA). We calculate that the sinking of carbon fixed by diazotrophs in the plume sequesters 1.7 Tmol of C annually, in addition to the sequestration of 0.6 Tmol of C yr1 of the new production supported by NO3 delivered by the river.").

[201] Subramaniam A., Yager P. L., Carpenter E. J., Mahaffey C., Bjorkman K., Cooley S., Kustka A. B., Montoya J. P. Sanudo-Wilhelmy S. A., Shipe R., & Capone D. G. (2008) *Amazon River enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean*, PROC. NAT'L. ACAD. SCI. 105(30): 10460–10465, 10460 ("More importantly, our simulations caution against extreme exploitation of rivers for its far-reaching consequences on climate.").

[202] Brodeur J., Cannizzo Z., Cross J., Davis J., DeAngelo B., Harris J., Kinkade C., Peth J., Samek K., Schub A., Stedman S.-M., Theuerkauf S., Vaughan L., & Wenzel L. (2022) *NOAA Blue Carbon White Paper*, National Oceanic and Atmospheric Administration, 1 ("While coastal blue carbon habitats have been shown to sequester up to ten times as much carbon per equivalent area as tropical forests (4), making them some of the most efficient natural carbon sinks in the world, they cover only a relatively small portion (<1%) of the Earth's surface. In the United States, it is estimated that coastal blue carbon habitats sequester a net quantity of 4.8 million metric tons (MMT) of carbon dioxide annually…").

[203] United States White House (2021) *Executive Order on Tackling the Climate Crisis at Home and Abroad*, Briefing Room ("Sec. 216. Conserving Our Nation's Lands and Waters. (a) The Secretary of the Interior, in consultation with the Secretary of Agriculture, the Secretary of Commerce, the Chair of the Council on Environmental Quality, and the heads of other relevant agencies, shall submit a report to the Task Force within 90 days of the date of this order recommending steps that the United States should take, working with State, local, Tribal, and territorial governments, agricultural and forest landowners, fishermen, and other key stakeholders, to achieve the goal of conserving at least 30 percent of our lands and waters by 2030.").

[204] United States Environmental Protection Agency (2019) INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS, 1990-2017.

[205] Blue Carbon Canada, *Evaluating the Current and Future Capacity for Natural Climate Solutions in Canada's Oceans* (*last visited* 7 July 2023).

[206] Issifu I., Alava J. J., Lam V. W. Y., & Sumaila U. R. (2022) *Impact of Ocean Warming, Overfishing and Mercury on European Fisheries: A Risk Assessment and Policy Solution Framework*, FRONT. MAR. SCI. 8: 1–13, 2 ("A combination of climate-related stresses and widespread over-exploitation of fisheries reduces the scope for adaptation and increases risks of stock collapse (Allison et al., 2009). Overfishing makes marine fisheries production more vulnerable to ocean warming by compromising the resilience of many marine species to climate change, and continued warming will hinder efforts to rebuild overfished populations (Free et al., 2019). It can also exacerbate the mercury levels in some fish species.").

[207] National Oceanic and Atmospheric Administration Fisheries (2023) STATUS OF STOCKS 2022: ANNUAL REPORT TO CONGRESS ON THE STATUS OF U.S. FISHERIES, 10 ("Incorporating environmental data into stock assessments also provides essential data for fisheries managers. Researchers studying Pacific cod in Alaska recently found that bottom temperatures of 3-6 degrees Celsius are ideal for young fish to survive to adulthood. Incorporating bottom temperature data into stock assessments has allowed better predictions of Pacific cod spawning and improved planning for fishing seasons. Studies on the East Coast yielded similar findings. By incorporating bottom temperatures into stock assessments, scientists recently discovered that "cold pools" were essential to the survival of young yellowtail flounder off southern New England and the Mid-Atlantic. These findings show that integrating environmental data into stock assessments provides more accurate estimates of current and future stock size, giving fishery managers better tools to set appropriate catch limits.").

[208] National Oceanic and Atmospheric Administration Fisheries (2023) STATUS OF STOCKS 2022: ANNUAL REPORT TO CONGRESS ON THE STATUS OF U.S. FISHERIES, 3 ("NMFS manages 492 stocks or stock complexes in 45 fishery management plans. At the end of 2022, the overfishing list included 24 stocks, the overfished list included 48 stocks, and two stocks were rebuilt. One of those stocks is considered rebuilt based on changes to its reference points. Since 2000, 49 stocks have been rebuilt.").

[209] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-10 ("It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past

decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006.").

[210] Cissé G., McLeman R., Adams H., Aldunce P., Bowen K., Campbell-Lendrum D., Clayton S., Ebi K. L., Hess J., Huang C., Liu Q., McGregor G., Semenza J., & Tirado M. C. (2022) *Chapter 7: Health, Wellbeing, and the Changing Structure of Communities*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1060 ("The global magnitude of climate-sensitive diseases was estimated in 2019 to be 39,503,684 deaths (69.9% of total annual deaths) and 1,530,630,442 DALYs (Vos et al., 2020). Of these, cardiovascular diseases (CVDs) comprised the largest proportion of climate-sensitive diseases (32.8% of deaths and 15.5% DALYs). The next largest category consists of respiratory diseases – with chronic respiratory disease contributing to 7% of deaths and 4.1% of DALYs and respiratory infection and tuberculosis contributing to 6.5% of deaths and 6% of DALYs.").

[211] V20 Finance Mininsters (12 November 2022) *New Health Data Shows Unabated Climate Change Will Cause 3.4 Million Deaths Per Year by Century End*, Press Release ("Unabated climate change will cause 3.4 million deaths per year by the end of the Century, new data presented to COP27 today shows. Health-related deaths of the over-65s will increase by 1,540%, and in India alone there will be 1 million additional heat-related deaths by 2090, if no action to limit warming is taken, the data shows.").

[212] Yglesias-González M., Palmeiro-Silva Y., Sergeeva M., Cortés S., Hurtado-Epstein A., Buss D. F., Hartinger S. M., & Red de Clima y Salud de América Latina y el Caribe (2022) *Code Red for Health response in Latin America and the Caribbean: Enhancing peoples' health through climate action*, LANCET REG. HEALTH AM. 11(100248): 1–8, 3 ("Dengue cases have almost tripled from 2000-2009 (6.78 million) to 2010-2019 (16.52 million) and the largest record of cases occurred in 2019."); *citing* Pan American Health Organization & World Health Organization, Dengue, PLISA Health Information for the Americas (*last visited* 24 May 2023)

[213] Colón-González F. J., Harris I., Osborn T. J., São Bernardo C. S., Peres C. A., Hunter P. R., Warren R., van Vuurene D., & Lake I. R. (2018) *Limiting global-mean temperature increase to 1.5–2 °C could reduce the incidence and spatial spread of dengue fever in Latin America*, PROC. NAT'L. ACAD. SCI. 115(24): 6243–6248, 6244 ("The number of dengue cases for the 2050s period was, on average, 260% larger than the 961–1990 baseline scenario with about 6.9 million extra cases per year").

[214] Rosenberg R., Lindsey N., Fischer M., Gregory C. J., Hinckley A. F., Mead P. S., Paz-Bailey G., Waterman S. H., Drexler N. A., Kersh G. J., Hooks H., Partridge S. K., Visser S. N., Beard C. B., & Petersen L. R. (2018) *Vital Signs: Trends in Reported Vectorborne Disease Cases — United States and Territories, 2004–2016*, MORB. MORTAL WKLY. REP. 67(17): 496–501, 496 ("A total 642,602 cases were reported. The number of annual reports of tickborne bacterial and protozoan diseases more than doubled during this period, from >22,000 in 2004 to >48,000 in 2016. Lyme disease accounted for 82% of all tickborne disease reports during 2004–2016. The occurrence of mosquito borne diseases was marked by virus epidemics. Transmission in Puerto Rico, the U.S. Virgin Islands, and American Samoa accounted for most reports of dengue, chikungunya, and Zika virus diseases; West Nile virus was endemic, and periodically epidemic, in the continental United States.").

[215] Canadian Institute for Climate Choices (2021) THE HEALTH COST OF CLIMATE CHANGE: *HOW CANADA CAN ADAPT, PREPARE, AND SAVE LIVES*, III ("Warming temperatures from climate change are creating ideal conditions for the spread of the ticks that carry Lyme disease into many parts of Canada where they have never been seen. We project that, under a low-emissions future, additional cases of Lyme disease due to demographic change and climate change will rise to about 8,500 annually by mid-century and 9,900 by the end of the century, up from an average of about 600 cases per year.").

[216] Zhao Q., *et al.* (2021) *Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study*, LANCET PLAN. HEALTH 5(7): E415–E425, E416 ("We found that 5 083 173 deaths were associated with non- optimal temperatures per year, accounting for 9·43% of all deaths and equating to 74 excess deaths per 100 000 residents.").

[217] Takashasi K., Honda Y., & Emori S. (2007) *Assessing Mortality Risk from Heat Stress due to Global Warming*, J. RISK RES. 10(3): 339–354, 353 ("Assuming that no adaptation or acclimation takes place, when the rates of change of excess mortality due to heat stress are examined by country, the results of our calculations show increases of approximately 100% to 1000%.

[218] Zhao Q., *et al.* (2021) *Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study*, LANCET PLAN. HEALTH 5(7): E415–E425, E418 (Table 1).

[219] Huang C., Barnett A. G., Wang X., Vaneckova P., FitzGerald G., & Tong S. (2011) *Projecting Future Heat-Related Mortality under Climate Change Scenarios: A Systematic Review*, ENVIRON. HEALTH PERSPECT. 119(12): 1681–1690, 1683 ("In three cities in Canada, Doyon et al. (2008) projected a significant increase in temperature-related mortality in summer that was not offset by a significant but smaller estimated decrease in fall and winter mortality. Cheng et al. (2009b) projected that heat-related mortality in four Canadian cities would more than double by the 2050s and triple by the 2080s, and that cold-related mortality could decrease by 45–60% by the 2050s and by 60–70% by the 2080s.").

[220] Shindell D., Zhang Y., Scott M., Ru M., Stark K., & Ebi K. L. (2020) *The Effects of Heat Exposure on Human Mortality Throughout the United States*, GEOHEALTH 4(4): 1–11, 8 ("Finally, the World Health Organization projected increases in heat-related deaths in North America under a fairly high-warming scenario, with totals of 7,300 additional deaths in the 2030s and 16,000 in the 2050s relative to 1961–1990 without adaptation (World Health Organization, 2014). These increases are qualitatively similar to results obtained here, but difficult to compare quantitatively owing to methodological differences. In particular, the World Health Organization study included only persons aged 65 and older, used the same ERF everywhere, and analyzed impacts in different years and over a larger area.").

[221] Tuholske C., Caylor K., Funk C., Verdin A., Sweeney S., Grace K., Peterson P., & Evans T. (2021) *Global urban population exposure to extreme heat*, PROC. NAT'L. ACAD. SCI. 118(41): 1–9, 2 ("Global exposure increased 199% in 34 y, from 40 billion persondays in 1983 to 119 billion person-days in 2016, growing by 2.1 billion person-days/yr−1 (Fig. 1A). Population growth (Fig. 1B) and total urban warming (Fig. 1C) contributed 66% (1.5 billion person-days/yr−1) and 34% (0.7 billion person-days/yr−1) to the annual rate of increase in exposure, respectively. That is, total urban warming elevated the global annual rate of increase in exposure by 52% compared to urban population growth alone.").

[222] Li D., Yuan J., & Kopp R. E. (2020) *Escalating global exposure to compound heat-humidity extremes with warming*, ENVIRON. RES. LETT. 15(6): 1–11, 1 ("Maintaining the current population distribution, this exposure is projected to increase to 508 million with 1.5 ◦C of warming, 789 million with 2.0 ◦C of warming, and 1.22 billion with 3.0 ◦C of warming (similar to late-century warming projected based on current mitigation policies.").

[223] Tuholske C., Caylor K., Funk C., Verdin A., Sweeney S., Grace K., Peterson P., & Evans T. (2021) *Global urban population exposure to extreme heat*, PROC. NAT'L. ACAD. SCI. 118(41): 1–9, *Appendix* (Table S2).

[224] Feron S., Cordero R. R., Damiani A., Llanillo P. J., Jorquera J., Sepulveda E., Asencio V., Laroze D., Labbe F., Carrasco J., & Torres G. (2018) *Observations and Projections of Heat Waves in South America*, SCI. REP. 9(8173): 1–15, 12 ("Under the RCP4.5 scenario, by mid-century, the number of HWs per season (HWN) is expected to at least double in southern SA, while they may increase 5–10 times or more in the Atacama Desert and along the coastline of northern SA. Indeed, by mid-century HWN estimates are expected to range from less that 2 in southern SA to more than 3 in northern SA and the Atacama Desert.").

[225] Tuholske C., Caylor K., Funk C., Verdin A., Sweeney S., Grace K., Peterson P., & Evans T. (2021) *Global urban population exposure to extreme heat*, PROC. NAT'L. ACAD. SCI. 118(41): 1–9, *Appendix* (Table S2).

[226] First Street Foundation (2022) THE SIXTH NATIONAL RISK ASSESSMENT: *HAZARDOUS HEAT*, 4 ("The results indicate that the incidence of extreme heat is growing across the country, both in absolute and relative terms. In absolute terms, the incidence of heat that exceeds the threshold of the National Weather Service's (NWS) highest category for heat, called "Extreme Danger" (Heat Index above 125°F) is expected to impact about 8 million people this year, increasing to about 107 million people in 2053, an increase of 13 times over 30 years. This increase in "Extreme Danger Days" is concentrated in the middle of the country, in areas where there are no coastal influences to mitigate extreme temperatures.").

[227] Parsons L. A., Jung J., Masuda Y. J., Vargas Zeppetello L. R., Wolff N. H., Kroeger T., Battisti D. S., & Spector J. T. (2021) *Tropical deforestation accelerates local warming and loss of safe outdoor working hours*, ONE EARTH 4(12): 1730–1740, 1734 ("Our results indicate that recent tropical deforestation is associated with losses of >0.5 h per day of safe work time for $2.8 million outdoor workers. To contextualize our findings, we compare these results with the findings from the 2019 Lancet Countdown on Health and Climate Change,24 which reports that humid heat exposure in 2018 led to 133.6 billion potential global lost work hours (an increase of $45 billion global lost work hours since 2000).

[228] Parsons L. A., Jung J., Masuda Y. J., Vargas Zeppetello L. R., Wolff N. H., Kroeger T., Battisti D. S., & Spector J. T. (2021) *Tropical deforestation accelerates local warming and loss of safe outdoor working hours*, ONE EARTH 4(12): 1730–1740, Supplemental Information, Figure 6.

[229] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 24 ("In 2021, average potential income loss from heat-related labour capacity reduction represented 1.60% of national GDPs in SA, with Venezuela having the highest total potential loss as a proportion of GDP (10.6%) and Chile the lowest (0.02%) (Fig. 8). Total potential income losses that year amounted to US$22 billion (0.68% of the regional GDP). The highest potential income losses are estimated to occur in the construction and agriculture sectors, where the work demands more physical power, and where workers are the most exposed to the elements and have limited capacity to shelter. In 2021, the countries with the highest total losses were Brazil and Venezuela with US$11.2 and US$4.8 billion, respectively.").

[230] Environmental Protection Agency (2015) CLIMATE CHANGE AND LABOR, 28 ("In 2100, over 1.8 billion labor hours across the workforce are projected to be lost due to unsuitable working conditions (95% confidence interval of 1.2-2.4 billion). These lost hours would be very costly, totalling over $170 billion in lost wages in 2100 (95% confidence interval of $110-$220 billion").

[231] Rentschler J. & Leonova N. (2022) AIR POLLUTION AND POVERTY: PM2.5 EXPOSURE IN 211 COUNTRIES AND TERRITORIES, Policy Research Working Paper 10005, World Bank, 1 ("This study contributes (i) updated global exposure estimates for the World Health Organizations's 2021 revised fine particulate matter (PM2.5) thresholds, and (ii) estimates of the number of poor people exposed to unsafe PM2.5 concentrations. It shows that 7.28 billion people, or 94 percent of the world population, are directly exposed to unsafe average annual PM2.5 concentrations. Low- and middle-income countries account for 80 percent of people exposed to unsafe PM2.5 levels").

[232] Silva R. A., *et al.* (2018) *Future Global Mortality from Changes in Air Pollution Attributable to Climate Change*, NAT. CLIM. CHANG. 7(9): 647–651, 650 ("We estimate 3,340 (−30,300 to 47,100) ozone-related deaths in 2030, relative to 2000 climate, and 43,600 (−195,000 to 237,000) in 2100 (14% of the increase in global ozone-related mortality). For PM2.5, we estimate 55,600 (−34,300 to 164,000) deaths in 2030 and 215,000 (−76,100 to 595,000) in 2100 (countering by 16% the global decrease in PM2.5-related mortality.").

[233] van der Wall E. E. (2015) *Air pollution: 6.6 million premature deaths in 2050!*, NETH. HEART J. 23(12): 557–558, 557 ("Model projections based on a business-as-usual emission scenario indicate that the contribution of outdoor air

pollution to premature mortality could double by 2050. The authors of the Nature paper foresee therefore that, if no further interventions are undertaken, the annual toll from polluted air may lead to 6.6 million premature deaths by 2050, with the biggest increase in Asia.”).

[234] Glavinskas V. (4 May 2023) *A game-changing partnership takes on air pollution in Latin America and the Caribbean*, ENVIRONMENTAL DEFENSE FUND (“Around 80% of people in Latin America live in cities. And because pollution in those cities is high, it means about 500 million people are breathing air that exceeds the World Health Organization's guidelines for pollutants like nitrogen dioxide, soot and ground-level ozone”).

[235] American Lung Association Ozone Pollution Trends (*last visited* 7 August 2023) (“Exposure to unhealthy levels of ozone air pollution makes breathing difficult for more Americans all across the country than any other single pollutant. In the years 2019, 2020 and 2021, some 103 million people lived in the 124 counties that earned an F for ozone. More than 30% of the nation’s population, including 23.6 million children, 15.4 million people age 65 or older, and millions in other groups at high risk of health harm, are exposed to high levels of ozone on enough days to earn the air they breathe a failing grade.”).

[236] Internal Displacement Monitoring Centre (2023) 2022 GLOBAL REPORT ON INTERNAL DISPLACEMENT, 11 (*see* Global figures at a glance, showing internal displacements in 2021: 38 million internal displacements (14.4m by conflict and violence, 23.7m by disasters)).

[237] Institute for Economics & Peace (2020) ECOLOGICAL THREAT REGISTER 2020: *UNDERSTANDING ECOLOGICAL THREATS, RESILIENCE AND PEACE*, 7 (“One hundred and forty-one countries are exposed to at least one ecological threat, with 19 countries facing four or more threats. 6.4 billion people live in countries which are exposed to medium to high ecological threats. An estimated 1.2 billion people are at risk of displacement by 2050.”).

[238] Internal Displacement Monitoring Centre (2023) 2022 GLOBAL REPORT ON INTERNAL DISPLACEMENT, 11 (*see* Global figures at a glance, showing internal displacements in 2021: The Americas (381,000 by conflict and violence, 1,659,000 by disasters)).

[239] World Bank (2018) *Internal Climate Migration in Latin America*, Groundswell Policy Note #3, 2 (“Latin America could see up to 10.6 million climate migrants by 2050.”).

[240] Wing I. S., De Cian E., & Mistry M. N. (2021) *Global vulnerability of crop yields to climate change*, J. ENVIRON. ECON. MANAG. 109(102462): 1–18, 17 (“Projecting climatically-driven changes in crop yields, by combining our estimated responses over the period 1981–2011 with temperature and precipitation fields from an ensemble of climate model simulations, we find substantial agreement among ESMs on crop yield declines of <10% by mid-century and <25% by century’s end especially for soybeans, maize, and winter wheat.”).

[241] Banerjee O., Cicowiez M., Rios A. R., & De Lima C. Z. (2021) *Climate change impacts on agriculture in Latin America and the Caribbean: An application of the integrated economic-environmental modeling (IEEM) platform*, IDB Working Paper Series No. IDB-WP-01289, Inter-American Development Bank, 17 (“The yield impacts derived from Prager et al. (2020) are as follows: by 2050, the simple average across all countries is -19.0 percent for bean, -17.2 percent for maize, -1.8 percent for rice, +14.2 percent for soybean, and -4.8 percent for wheat. These yield impacts are implemented as productivity shocks in IEEM and introduced linearly between 2021 and 2050 (see Figure 3.1). Together, these five crops represent between 0.7 (Barbados) and 89.5 (Paraguay) percent of the total cultivated area in the LAC countries modeled (see Figure 3.2).”).

[242] Bárcena A., Samaniego J., Peres W., & Alatorre J. E. (2020) THE CLIMATE EMERGENCY IN LATIN AMERICA AND THE CARIBBEAN: *THE PATH AHEAD – RESIGNATION OR ACTION?*, Economic Commission for Latin American and the Caribbean Books No. 160, 122 (“The Caribbean relies heavily on economic activities such as tourism and agriculture, which are particularly sensitive to climatic conditions (ECLAC, 2010). Agriculture generates a large number of jobs, and the rural population continues to constitute a substantial percentage of the total population (ECLAC/MINURVI/UN-HABITAT, 2016). It is therefore relevant that, in different climate scenarios, yields of

cassava, banana, sweet potato and tomato plantations are predicted to fall by between 1% and 30% by 2050, with rice crop yields ranging from a 3% decrease to a 2% increase. Lower yields would have negative consequences in a number of areas, such as growth in output and investment in agriculture, the external sector, poverty reduction and food security (Clarke and others, 2013; ECLAC, 2015a).").

[243] Lesk C., Coffel E., Winter J., Ray D., Zscheischler J., Seneviratne S. I., & Horton R. (2021) *Stronger temperature–moisture couplings exacerbate the impact of climate warming on global crop yields*, NAT. FOOD 2: 683–691, 686 ("We project that such heightened crop heat sensitivities due to changing temperature–moisture couplings will worsen the impacts of warming on maize and soy yields across most of the globe (Fig. 5a and Supplementary Fig. 2). In the multimodel median, these additional yield impacts (ΔΔY) amount to regional maize (soy) losses of 7% (9%) in the United States …"). *See also* Climate Matters (20 September 2021) *Climate Change and Crops* ("Climate models show that in many areas, drought and heat will align more often in the future, worsening crop damages as the climate warms. The researchers estimate that U.S. yields may decline from current averages by 7% for corn and 9% for soybean after 2050.").

[244] Vergara W., Rios A. R., Paliza L. M. G., Gutman P., Isbell P., Suding P. H., & Samaniego J. (2013) *The climate and development challenge for Latin America and the Caribbean: options for climate-resilient, low-carbon development*, Inter-American Development Bank, 13 ("Based on recent analysis and new estimates, the projected yearly economic damages in LAC caused by some of the major physical impacts associated with this likely rise of 2 ° C over preindustrial levels are estimated to gradually increase and reach approximately $ 100 billion annually by 2050—or approximately 2.2 percent of 2010 gross domestic product (GDP, $4.6 trillion)").

[245] Smith A. B. (10 January 2023) *2022 U.S. billion-dollar weather and climate disasters in historical context*, National Oceanic and Atmospheric Administration ("In broader context, the total cost of U.S. billion-dollar disasters over the last 5 years (2018-2022) is $595.5 billion, with a 5-year annual cost average of $119.1 billion, the latter of which is nearly triple the 43-year inflation adjusted annual average cost. The U.S. billion-dollar disaster damage costs over the last 10-years (2013-2022) were also historically large: at least $1.1 trillion from 152 separate billion-dollar events.").

[246] Canadian Institute for Climate Choices (2023) *Tip of the Iceberg: Executive Summary*, i ("Over the past five decades, the costs of weather-related disasters like floods, storms, and wildfires in Canada have risen from tens of millions of dollars to billions of dollars annually. Between 2010 and 2019, insured losses for catastrophic weather events totaled over $18 billion, and the number of catastrophic events was over three times higher than in the 1980s.").

[247] Deloitte (2022) TURNING POINT: *A NEW ECONOMIC CLIMATE IN THE UNITED STATES*, 15 ("Climate damage to the US economy could cost $14.5 trillion over the next 50 years").

[248] Kőműves Z. (24 August 2021) *IPCC report: the macroeconomic impacts of climate action and inaction*, Cambridge Econometrics ("These numbers mean alarmingly high damages even in a couple of decades, but due to the exponential shape of the damage function, losses can grow by up to 65% and 30% of GDP by 2100 in the two scenarios, respectively.").

[249] World Bank (2022) CONSOLIDATING THE RECOVERY: *SEIZING GREEN GROWTH OPPORTUNITIES*, Semiannual Report for Latin America and the Caribbean, x ("Climate change poses important challenges to the region's economies. On average, 1.7 percent of annual GDP has been lost in Latin American countries due to climate related disasters over the last two decades (CELAC, SRE, and Global Center on Adaptation 2021). An analysis of the impact of extreme weather events in the past two decades shows that eight Caribbean nations figure among the top twenty globally in losses as a percentage of GDP, and five in terms of deaths per capita.1").

[250] (6 March 2023) *Climate change could cost Latin America 16% of GDP this century, says Moody's*, REUTERS ("If no new policy action is taken, Moody's foresees a steady deterioration in GDP, losing 10% by 2075 and ending the century down 16% as the region loses production capacity starting this year and losses mount at increasing rates."); *discussing* Coutino A. (2023) LATIN AMERICA UNDER THE RISK OF CLIMATE CHANGE, Moodys.

[251] Canada Office of the Parliamentary Budget Officer (2022) *Global greenhouse gas emissions and Canadian GDP*, 4 ("We estimate that the 0.9-degree Celsius average increase in Canada's surface temperature and 2.5 per cent average increase in precipitation (relative to the 1961-1990 reference levels) have lowered the level of Canadian real GDP in 2021 by 0.8 per cent").

[252] Office of Management and Budget (2022) *Chapter 3. Long-Term Budget Outlook*, *in* ANALYTICAL PERSPECTIVES: BUDGET OF THE U.S. GOVERNMENT FISCAL YEAR 2024, 33 ("In analysis by the Network for Greening the Financial System (NGFS) suggests that U.S. GDP will be nearly 2.5 percent lower by the middle of the century under current policies relative to a no-further-warming counterfactual, with losses accelerating in the second half of the century.").

[253] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1698, 1700 ("The main climate impact drivers like extreme heat, drought, relative SLR [sea level rise], coastal flooding, erosion, marine heatwaves, ocean aridity (*high confidence*) and aridity, drought and wildfires will increase by midcentury (*medium confidence*) (Figure 12.6, WGI AR6 Table 12.6, Ranasinghe et al., 2021)."; "Warming and drier conditions are projected through the reduction of total annual precipitation, extreme precipitation and consecutive wet days and an increase in consecutive dry days (Chou et al., 2014). Heatwaves will increase in frequency and severity in places close to the equator like Colombia (Guo et al., 2018; Feron et al., 2019), with a decrease but strong wetting in coastal areas, pluvial and river flood and mean wind increase (Mora et al., 2014). Models project a *very likely* 2°C GWL [global warming level] increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes. Nevertheless, models project inconsistent changes in the region for extreme precipitation (*low confidence*) (Figure 12.6; WGI AR6 Table 12.14) (Ranasinghe et al., 2021). The main climate impact drivers in the region, like extreme heat, mean precipitation and coastal and oceanic drivers, will increase and snow, ice and permafrost will decrease with *high confidence* (WGI AR6 Table 12.6) (Ranasinghe et al., 2021).").

[254] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1692–1693 ("Extreme precipitation events, which result in floods, landslides and droughts, are projected to intensify in magnitude and frequency due to climate change (*medium confidence*). Floods and landslides pose a risk to life and infrastructure; a 1.5°C increase would result in an increase of 100–200% in the population affected by floods in Colombia, Brazil and Argentina, 300% in Ecuador and 400% in Peru (*medium confidence*).").

[255] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2050, 2052 ("Compared to larger landmasses, many climate change-driven impacts and risks are amplified for small islands. This is due largely to their boundedness (surrounded by ocean), their comparatively small land areas, and often their remoteness from more populated parts of the world, which restricts the global connectivity of islands. This is true on all types of islands (Figure 15.2). 15.3.1 Synthesis of Observed and Projected Changes in the Physical Basis There is increased evidence of warming in the small islands, particularly in the latter half of the 20th century (high confidence). The diversity of metrics and timescales used across studies makes it impossible to provide explicit comparisons; however, Table 15.1 provides a summary of observed changes. Some phenomena have no demonstrable trends in a region because of limited observed data, these include TC frequency in the northeastern Pacific and Indian oceans (Walsh et al., 2016); other phenomena are too variable to detect an overarching trend, including rainfall in regions where inter-annual and decadal variabilities such as the El

Niño-Southern Oscillation, North Atlantic Oscillation, Pacific Decadal Variability, Atlantic Multidecadal Variability are dominant (Jones et al., 2015; McGree et al., 2019). There are also marked regional variations in the rates of SLR (Merrifield and Maltrud, 2011; Palanisamy et al., 2012; Esteban et al., 2019) and relative SLR (RSLR; that is, incorporating land movement). Various factors, including interannual and decadal sea level variations associated with low-frequency modulation of ENSO and the Pacific Decadal Oscillation (PDO) and vertical land motion contribute to both relative sea level variations and related uncertainties. Increased distantsource swell height from extra-tropical cyclones (ETCs) also contributes to ESLs (Mentaschi et al., 2017; Vitousek et al., 2017). Together, these stressors increase ESLs and their impacts, including coastal erosion and marine flooding and their impacts on both ecosystems and ecosystem services and human activities (Section 15.3.3.1 and Table 15.3). Like observed impacts, projected impacts include some high confidence assessments, which are distributed across a diversity of models, timescales and metrics. Generalised trends, and specific projections when available, are provided in Table 15.2. However, actual values and spatial distribution of precipitation changes remain uncertain as they are strongly model dependent (Paeth et al., 2017). Furthermore, the current capabilities of climate models, to adequately represent variability in climate drivers including ENSO, and the topography of small islands limit confidence in these future changes (Cai et al., 2015a; Harter et al., 2015; Guilyardi et al., 2016).”; Table 15.1).

[256] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2045 (“A sense of urgency is prevalent among small islands in the combating of climate change and in adherence to the Paris Agreement to limit global warming to 1.5°C above pre-industrial levels. Small islands are increasingly affected by increases in temperature, the growing impacts of tropical cyclones (TCs), storm surges, droughts, changing precipitation patterns, sea level rise (SLR), coral bleaching and invasive species, all of which are already detectable across both natural and human systems (very high confidence1)”).

[257] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2050, 2052 (“Most of the research that has been conducted on exposure and vulnerability from climate change demonstrates that factors including those that are geopolitical and political, environmental, socioeconomic and cultural together conspire to increase exposure and vulnerability of small islands (Box 15.1; Betzold, 2015; McCubbin et al., 2015; Duvat et al., 2017b; Otto et al., 2017; Weir et al., 2017; Taupo et al., 2018; Barclay et al., 2019; Hay et al., 2019a; Ratter et al., 2019; Salmon et al., 2019; Bordner et al., 2020; Douglass and Cooper, 2020; Duvat et al., 2020a). Additional pressures on coastal and marine environments, including overexploitation of natural resources, may further exacerbate possible impacts in the future (Bell et al., 2013; Pinnegar et al., 2019; Siegel et al., 2019). … Furthermore, these factors exacerbate climate change-induced problems such as coastal flooding and erosion faced by small islands. These impacts continue to worsen, putting small islands at increasingly higher risk to the impacts of climate change (Box 15.1). There are multiple stressors that affect the vulnerability of small islands to climate change (McNamara et al., 2019).”).

[258] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2099 (“Agriculture and fisheries are heavily influenced by climate, which means a change in occurrence of TCs, air temperature, ocean temperature and/or rainfall can have considerable impacts on the production and availability of crops and seafood and therefore the health and welfare of island inhabitants. Projected impacts of climate change on agriculture and fisheries in some cases will enhance productivity, but in many cases could undermine food production, greatly exacerbating food insecurity challenges for human populations in small islands. Small islands mostly depend on rain-fed agriculture, which is likely to be affected in

various ways by climate change, including loss of agricultural land through floods and droughts, and contamination of freshwater and soil through salt-water intrusion, warming temperatures leading to stresses of crops, and extreme events such as cyclones. In some islands, crops that have been traditionally part of people's diet can no longer be cultivated due to such changes. For example, severe rainfall during planting seasons can damage seedlings, reduce growth and provide conditions that promote plant pests and diseases. Changes in the frequency and severity of TCs or droughts will pose challenges for many islands. For example, more pronounced dry seasons, warmer temperatures and greater evaporation could cause plant stress reducing productivity and harvests. The impacts of drought may hinder insects and animals from pollinating crops, trees and other vegetative food sources on tropical islands. For instance, many agroforestry crops are completely dependent on insect pollination, and it is, therefore, important to monitor and recognise how climate change is affecting the number and productivity of these insects. Coastal agroforest systems in small islands are important to national food security but rely on biodiversity (e.g., insects for pollination services). Biodiversity loss from traditional agroecosystems has been identified as one of the most serious threats to food and livelihood security in islands. Ecosystem-based adaptation practices and diversification of crop varieties are possible solutions.").

[259] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2046 ("Reef island and coastal area habitability in small islands is expected to decrease because of increased temperature, extreme sea levels and degradation of buffering ecosystems, which will increase human exposure to sea-related hazards (high confidence). Climate and non-climate drivers of reduced habitability are context specific. On small islands, coastal land loss attributable to higher sea level, increased extreme precipitation and wave impacts and increased aridity have contributed to food and water insecurities that are likely to become more acute in many places (high confidence). In the Caribbean, additional warming by 0.2°–1.0°C, could lead to a predominantly drier region (5–15% less rain than present day), a greater occurrence of droughts along with associated impacts on agricultural production and yield in the region. Crop suitability modelling on several commercially important crops grown in Jamaica found that even an increase of less than +1.5°C could result in a reduction in the range of crops that farmers may grow. Most Pacific Island Countries could experience ≥ 50% declines in maximum fish catch potential by 2100 relative to 1980–2000 under both an RCP2.6 and RCP8.5 scenario {15.3.4.3, 15.3.4.4}.").

[260] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1691 ("**Central and South America (CSA) are highly exposed, vulnerable and strongly impacted by climate change, a situation amplified by inequality, poverty, population growth and high population density, land use change particularly deforestation with the consequent biodiversity loss, soil degradation, and high dependence of national and local economies on natural resources for the production of commodities (*high confidence*[1]).** Profound economic, ethnic and social inequalities are exacerbated by climate change. High levels of widespread poverty, weak water governance, unequal access to safe water and sanitation services and lack of infrastructure and financing reduce adaptation capacity, increasing and creating new population vulnerabilities (*high confidence*).… **The scientific evidence since the IPCC's Fifth Assessment Report (AR5) increased the confidence in the synergy among fire, land use change, particularly deforestation, and climate change, directly impacting human health, ecosystem functioning, forest structure, food security and the livelihoods of resource-dependent communities (*medium confidence*).** Regional increases in temperature, aridity and drought increased the frequency and intensity of fire. On average, people in the region were more exposed to high fire danger between 1 and 26 additional days depending on the sub-region for the years 2017–2020 compared to 2001–2004 (*high confidence*).").

[261] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1722–1723 (Table 12.6).

[262] United Nations Office for the Coordination of Humanitarian Affairs (2020) NATURAL DISASTERS IN LATIN AMERICA AND THE CARIBBEAN, 2000-2019, 2 ("Latin America and the Caribbean (LAC) is the second most disaster-prone region in the world 152 million affected by 1,205 disasters (2000-2019)*").

[263] Herring S., Hoell A., Christidis N., & Stott P. (2023) EXPLAINING EXTREME EVENTS FROM A CLIMATE PERSPECTIVE, American Meteorological Society.

[264] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-10 ("It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006."). *See also* Kotz M., Wenz L., & Levermann A. (2021) *Footprint of greenhouse forcing in daily temperature variability*, PROC. NAT'L. ACAD. SCI. 118(32): e2103294118, 1–8, 1 ("Assessing historical changes to daily temperature variability in comparison with those from state-of-the-art climate models, we show that variability has changed with distinct global patterns over the past 65 years, changes which are attributable to rising concentrations of greenhouse gases. If these rises continue, temperature variability is projected to increase by up to 100% at low latitudes and decrease by 40% at northern high latitudes by the end of the century.").

[265] Fischer E. M., Sippel S., & Knutti R. (2021) *Increasing probability of record-shattering climate extremes*, NAT. CLIM. CHANGE 11: 689–685, 689 ("Here, we show models project not only more intense extremes but also events that break previous records by much larger margins. These record-shattering extremes, nearly impossible in the absence of warming, are likely to occur in the coming decades. We demonstrate that their probability of occurrence depends on warming rate, rather than global warming level, and is thus pathway-dependent. In high-emission scenarios, week-long heat extremes that break records by three or more standard deviations are two to seven times more probable in 2021–2050 and three to 21 times more probable in 2051–2080, compared to the last three decades. In 2051–2080, such events are estimated to occur about every 6–37 years somewhere in the northern midlatitudes.").

[266] Balch J. K., Abatzoglou J. T., Joseph M. B., Koontz M. J., Mahood A. L., McGlinchy J., Cattau M. E., & Williams A. P. (2022) *Warming weakens the night-time barrier to global fire*, NATURE 602: 442–448, 442 ("Night-time provides a critical window for slowing or extinguishing fires owing to the lower temperature and the lower vapour pressure deficit (VPD). However, fire danger is most often assessed based on daytime conditions[1,2], capturing what promotes fire spread rather than what impedes fire. Although it is well appreciated that changing daytime weather conditions are exacerbating fire, potential changes in night-time conditions—and their associated role as fire reducers—are less understood. Here we show that night-time fire intensity has increased, which is linked to hotter and drier nights. Our findings are based on global satellite observations of daytime and night-time fire detections and corresponding hourly climate data, from which we determine landcover-specific thresholds of VPD (VPD_t), below which fire detections are very rare (less than 95 per cent modelled chance). Globally, daily minimum VPD increased by 25 per cent from 1979 to 2020. Across burnable lands, the annual number of flammable night-time hours—when VPD exceeds VPD_t—increased by 110 hours, allowing five additional nights when flammability never ceases. Across nearly one-fifth of burnable lands, flammable nights increased by at least one week across this period. Globally, night fires have become 7.2 per cent more intense from 2003 to 2020, measured via a satellite record. These results reinforce the lack of night-time relief that wildfire suppression teams have experienced in recent years. We expect that continued night-time

warming owing to anthropogenic climate change will promote more intense, longer-lasting and larger fires."); *discussed in* Dickie G. (19 July 2022) *Steamy nights in European heatwave worsen health and fire risks – experts*, REUTERS.

[267] Hicke J. A., Lucatello S., Mortsch L. D., Dawson J., Domínguez Aguilar M., Enquist C. A. F., Gilmore E. A., Gutzler D. S., Harper S., Holsman K., Jewett E. B., Kohler T. A., & Miller K. (2022) *Chapter 14: North America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1931 (" Without limiting warming to 1.5°C, key risks to North America are expected to intensify rapidly by mid-century (high confidence). These risks will result in irreversible changes to ecosystems, mounting damages to infrastructure and housing, stress on economic sectors, disruption of livelihoods, and issues with mental and physical health, leisure and safety. Immediate, widespread and coordinated implementation of adaptation measures aimed at reducing risks and focused on equity have the greatest potential to maintain and improve the quality of life for North Americans, ensure sustainable livelihoods and protect the long-term biodiversity, and ecological and economic productivity, in North America (high confidence). Enhanced sharing of resources and tools for adaptation across economic, social, cultural and national entities enables more effective short- and long-term responses to climate change. {14.2, 14.4, 14.5, 14.6, 14.7").

[268] George Washington University (2018) ASCERTAINMENT OF THE ESTIMATED EXCESS MORTALITY FROM HURRICANE MARÍA IN PUERTO RICO, Milken Institute School of Public Health, 9 ("Results from the preferred statistical model, shown below, estimate that excess mortality due to Hurricane María using the displacement scenario is estimated at 1,271 excess deaths in September and October (95% CI: 1,154-1,383), 2,098 excess deaths from September to December (95% CI: 1,872-2,315), and, 2,975 (95% CI: 2,658-3,290) excess deaths for the total study period of September 2017 through February 2018.").

[269] Deloitte (2022) TURNING POINT: *A NEW ECONOMIC CLIMATE IN THE UNITED STATES*, 6 ("If global average warming reaches around 3°C by century's end, Deloitte's analysis indicates that economic damages would grow and compound, affecting every industry and region in the country. Failing to take sufficient action could result in economic losses to the US economy of $14.5 trillion (in present-value terms11) over the next 50 years. In this climate-damaged future, the economy would lose nearly 4% of GDP12–$1.5 trillion in 2070 alone.").

[270] National Oceanic and Atmospheric Administration Fisheries (19 August 2021) *Social Indicators for Coastal Communities* (Table: Environmental Justice in Commercial Fishing Communities).

[271] *See* Jina A. (2021) *Climate Change and the U.S. Economic Future*, U.S. Energy & Climate Roadmap: Policy Insight, Energy Policy Institute of Chicago, 17 ("The aggregate picture masks substantial local differences in these impacts. Figure 6 shows damages at the county level as a proportion of that county's income level in 2080-2099 under a high emissions scenario. As expected, the colder, more northerly parts of the United States have much lower damages than the rest of the country. In southern, coastal states, meanwhile, there is an overall high negative impact, as they experience higher temperatures and exposure to enhanced coastal damages from storms and sea level rise. … The pattern of damages in Figure 6 also reveals another potential impact of climate change: an increase in inequality across the country. Figure 7 ranks counties by income level, and then plots damages in groups that gather together income deciles from poorest to wealthiest. The pattern of damages is strongly correlated with income levels, and the poorest counties su"er the largest damages. Indeed, the poorest third of counties are projected to experience damages of between 2 and 20 percent of county income under a high emissions scenario. This aspect of climate impacts in the United States has the potential to substantially widen the income gap between rich and poor parts of the country, saddling those areas that may already have fewer resources to adapt with larger damages."); *and* Sawyer D., Ness R., Lee C., & Miller S. (2022) DAMAGE CONTROL: *REDUCING THE COSTS OF CLIMATE IMPACTS IN CANADA*, Canadian Climate Institute, 60–61 ("Low-income households will see the largest reductions in real household income. While high-income households lose more income in absolute terms, the share of real income lost by low-income households is higher. By mid-century, the lowest-income households are projected to face income losses, relative to the refence case, of 5.8 per cent under high-emissions and 4.8 per cent under the low-emissions scenario (Figure 11). This

compares to losses of 4 per cent and 3.2 per cent for the highest-income households in the same period. By the end of the century, the impacts on real household income cut deep into affordability. Low-income households face real income cuts on average of 23 per cent in the high-emissions scenario, and 12 per cent under low-emissions. Even the median group faces significant income losses of 9 to 19 per cent under low- and high-emissions scenarios, respectively.9 The disproportionate losses for low-income households are driven by lower baseline levels of income, resulting in the same dollar amount of lost income comprising a higher share of total income lost compared to high-income households. As well, there is a higher share of income coming from low-income employment in the service sector that is impacted heavily by damages to infrastructure and supply chain disruptions. Finally, the lower-income groups tend to spend more of their income on transportation services and housing, both of which are highly climate-sensitive. Other equity-deserving groups, such as Indigenous people, racialized people, recent immigrants, and women, are disproportionately represented in low-income groups (Statistics Canada 2021; Statistics Canada 2022).10 Therefore, climate change impacts risk exacerbating inequality across multiple dimensions.").

[272] Hicke J. A., Lucatello S., Mortsch L. D., Dawson J., Domínguez Aguilar M., Enquist C. A. F., Gilmore E. A., Gutzler D. S., Harper S., Holsman K., Jewett E. B., Kohler T. A., & Miller K. (2022) *Chapter 14: North America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1932 ("**Climate hazards are projected to intensify further across North America (very high confidence).** Heatwaves over land and in the ocean, as well as wildfire activity, will intensify; subarctic snowpack, glacial mass and sea ice will decline (virtually certain); and sea level rise will increase at geographically differential rates (virtually certain). Humidity-enhanced heat stress, aridification and extreme precipitation events that lead to severe flooding, erosion, debris flows and ultimately loss of ecosystem function, life and property are projected to intensify (high confidence). {14.2}").

[273] United States Office of Management and Budget (2022) FEDERAL BUDGET EXPOSURE TO CLIMATE RISKS, 277 ("The Office of Management and Budget (OMB) assessments found that the Federal Government could spend between an additional $25 billion to $128 billion annually due to just six climate-related financial risks included in this report—disaster relief, flood insurance, crop insurance, healthcare expenditures, wildland fire suppression spending, and flood risk at Federal facilities – and considering only a limited scope of total potential damages to those programs. Table 21-1 summarizes quantified annual estimated expenditures of these assessed programs (in 2020$) in projected ranges to mid- and late-century. Many other risks to the Federal budget are apparent but have not yet been quantified, such as the risks to national security, changes to ecosystems, and infrastructure expenditures which can each have wide-ranging and diffuse effects to the budget").

[274] International Monetary Fund (2022) WORLD ECONOMIC OUTLOOK: *COUNTERING THE COST-OF-LIVING CRISIS*, 71 ("Decades of procrastination have transformed what could have been a smooth transition to a more carbon-neutral society into what will likely be a more challenging one. By the end of the decade, the global economy needs to emit 25 percent less greenhouse gases than in 2022 to have a fighting chance to reach the goals set in Paris in 2015 and avert catastrophic climate disruptions. Because the energy transition needed to accomplish this has to be rapid, it is bound to involve some costs in the next few years. While there is little consensus on the expected near-term macroeconomic consequences of climate change policies, this chapter's central message is that if the right measures are implemented immediately and phased in gradually over the next eight years, the costs will remain manageable and are dwarfed by the innumerable long-term costs of inaction. Different assumptions regarding the speed at which electricity generation can transition toward low-carbon technologies put these costs somewhere between 0.15 and 0.25 percentage point of GDP growth and an additional 0.1 to 0.4 percentage point of inflation a year with respect to the baseline, if budget-neutral policies are assumed. To avoid amplifying these costs, it is important that both climate and monetary policies be credible. Stop-and-go policies and further procrastinating on the grounds that "now is not the time" will only exacerbate the toll.").

[275] Trust S., Joshi S., Lenton T., & Oliver J. (2023) THE EMPEROR'S NEW CLIMATE SCENARIOS: *LIMITATIONS AND ASSUMPTIONS OF COMMONLY USED CLIMATE-CHANGE SCENARIOS IN FINANCIAL SERVICES*, Institute and Faculty of Actuaries & University of Exeter, 3 ("Dr Sarah Ivory University of Edinburgh There is a problem with the current

climate-scenario modelling which means it does not accurately depict the future we know is coming, or the financial implications of this. Climate scenario users in financial services have two pathways forward. To spend all of your time understanding why existing models are wrong and tweaking them is equivalent to rearranging deck chairs on the Titanic. To build new models which get political buy-in on climate action is equivalent to launching the life boats. It still won't save all of us, but it's the best option we have.").

[276] Trust S., Joshi S., Lenton T., & Oliver J. (2023) THE EMPEROR'S NEW CLIMATE SCENARIOS: *LIMITATIONS AND ASSUMPTIONS OF COMMONLY USED CLIMATE-CHANGE SCENARIOS IN FINANCIAL SERVICES*, Institute and Faculty of Actuaries & University of Exeter, 6 ("There is a disconnect between climate science and the economic models that underpin financial services climate-scenario modelling, where model parsimony has cost us real-world efficacy. Real-world impacts of climate change, such as the impact of tipping points (both positive and negative, transition and physical-risk related), sea-level rise and involuntary mass migration, are largely excluded from the damage functions of public reference climate-change economic models. Some models implausibly show the hot-house world to be economically positive, whereas others estimate a 65% GDP loss or a 50–60% downside to existing financial assets if climate change is not mitigated, stating these are likely to be conservative estimates.").

[277] Morrison A. (3 July 2023) *Climate scenario models in financial services significantly underestimate climate risk*, UNIVERSITY OF EXETER ("This severely limits the usefulness of the models to business leaders and policy makers, who may reasonably believe these models effectively capture risk levels, unaware that many of the most severe climate impacts have not been considered."); *discussing* Trust S., Joshi S., Lenton T., & Oliver J. (2023) THE EMPEROR'S NEW CLIMATE SCENARIOS: *LIMITATIONS AND ASSUMPTIONS OF COMMONLY USED CLIMATE-CHANGE SCENARIOS IN FINANCIAL SERVICES*, Institute and Faculty of Actuaries & University of Exeter.

[278] Kőműves Z. (24 August 2021) *IPCC report: the macroeconomic impacts of climate action and inaction*, CAMBRIDGE ECONOMETRICS ("These large damage estimates are still likely to understate the true losses, since our method is based on the observed relationship between temperature and economic output, and we focus only on the impacts of gradual warming on productivity. They do not account for tipping points or other unprecedented changes in the climate system. Given the high uncertainty around increasing climate sensitivity in the future and carbon-cycle feedbacks it is near impossible to get accurate estimates. Natural factors are not the only uncertainty to account for. Escalating climate impacts could bring disruption of value chains, trade, and geopolitical crises as well.").

[279] World Meteorological Organization (22 May 2023) *Economic costs of weather-related disasters soars but early warnings save lives*, Press Release 22052023 ("Over sixty percent of economic losses due to weather-, climate- and water-related disasters were reported for developed economies. However, the economic losses were equivalent to less than 0.1% of the gross domestic product (GDP) in respective economies in more than four fifths of these disasters. No disasters were reported with economic losses greater than 3.5% of the respective GDPs. In Least Developed Countries, 7% of disasters for which economic losses were reported had an impact equivalent to more than 5% of the respective GDPs, with several disasters causing economic losses up to nearly 30%. In Small Island Developing States, 20% of disasters with reported economic losses led to an impact equivalent to more than 5% of the respective GDPs, with some disasters causing economic losses above 100%."); *discussing* World Meteorological Organization (2023) ATLAS OF MORTALITY AND ECONOMIC LOSSES FROM WEATHER, CLIMATE AND WATER-RELATED HAZARDS.

[280] World Bank Group (2022) *A Roadmap for Climate Action in Latin America and the Caribbean 2021 - 2025*, 1 ("In rankings of the impacts of extreme weather events from 2000 to 2019, five Caribbean nations figure among the top 20 globally in terms of fatalities per capita, while in terms of economic losses as a share of GDP eight of the top 20 countries are in the Caribbean").

[281] World Meteorological Organization (22 May 2023) *Economic costs of weather-related disasters soars but early warnings save lives*, Press Release 22052023 ("North America, Central America and Caribbean: A reported 2 107 weather-, climate- and water-related resulted in 77 454 deaths and US$ 2.0 trillion in economic losses."); *discussing* World Meteorological Organization (2023) ATLAS OF MORTALITY AND ECONOMIC LOSSES FROM WEATHER, CLIMATE AND WATER-RELATED HAZARDS.

[282] Vergara W., Rios A. R., Paliza L. M. G., Gutman P., Isbell P., Suding P. H., & Samaniego J. (2013) *The climate and development challenge for Latin America and the Caribbean: options for climate-resilient, low-carbon development*, Inter-American Development Bank, 14 ("Based on recent analysis and new estimates, the projected yearly economic damages in LAC caused by some of the major physical impacts associated with this likely rise of 2° C over pre industrial levels are estimated to gradually increase and reach approximately $100 billion annually by 2050 or approximately 2.2 percent of 2010 gross domestic product (GDP, $4.6 trillion)").

[283] World Bank Group (2022) A ROADMAP FOR CLIMATE ACTION IN LATIN AMERICA AND THE CARIBBEAN 2021-2025, 1 ("In Latin America and the Caribbean (LAC) the rapidly changing climate is increasing the frequency and intensity of extreme weather-related events. The year 2020 saw the most catastrophic fire season over the Pantanal region and a record number of storms during the Atlantic cyclone season. Eta and Iota, two category 4 hurricanes, affected more than 8 million people in Central America, causing tens of billions of dollars in damage. In Honduras, annual average losses due to climate-related shocks are estimated at 2.3 percent of gross domestic product (GDP). In rankings of the impacts of extreme weather events from 2000 to 2019, five Caribbean nations figure among the top 20 globally in terms of fatalities per capita, while in terms of economic losses as a share of GDP eight of the top 20 countries are in the Caribbean.1 Extreme precipitation events, which result in floods and landslides, are projected to intensify in magnitude and frequency due to climate change, with a 1.5o C increase in mean global temperature projected to result in an increase of up to 200 percent in the population affected by floods in Colombia, Brazil, and Argentina; 300 percent in Ecuador; and 400 percent in Peru.2 Climate shocks reduce the income of the poorest 40 percent by more than double the average of the LAC population and could push an estimated 2.4–5.8 million people in the region into extreme poverty by 2030.3").

[284] Barcena A., Samaniego J., Wilson P., & Alatorre J. E. (2020) THE CLIMATE EMERGENCY IN LATIN AMERICA AND THE CARIBBEAN: *THE PATH AHEAD – RESIGNATION OR ACTION?*, Economic Commission for Latin American and the Caribbean, 122 ("The Caribbean relies heavily on economic activities such as tourism and agriculture, which are particularly sensitive to climatic conditions (ECLAC, 2010). Agriculture generates a large number of jobs, and the rural population continues to constitute a substantial percentage of the total population (ECLAC/MINURVI/UN-HABITAT, 2016). It is therefore relevant that, in different climate scenarios, yields of cassava, banana, sweet potato and tomato plantations are predicted to fall by between 1% and 30% by 2050, with rice crop yields ranging from a 3% decrease to a 2% increase. Lower yields would have negative consequences in a number of areas, such as growth in output and investment in agriculture, the external sector, poverty reduction and food security (Clarke and others, 2013; ECLAC, 2015a).").

[285] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1732 ("In several regions of CSA, water scarcity is a serious challenge to local livelihoods and economic activities. Regions that are (seasonally) dry, partly with large populations and increasing water demand, exhibit particularly significant water stress. These include the Dry Corridor in CA, coastal areas of Peru (SWS) and northern Chile (SWS), the Bolivian-Peruvian Altiplano (NWS, SAM), the Dry Andes of Central Chile (SWS), Western Argentina and Chaco in northwestern Paraguay (SES) and Sertão in northeastern Brazil (NES) (high confidence) (Kummu et al., 2016; Mekonnen and Hoekstra, 2016; Schoolmeester et al., 2018). In NWS and SWS, downstream areas are increasingly affected by decreasing and unreliable river runoff due to rapid glacier shrinkage (high confidence) (Table SM12.6; Carey et al., 2014; Drenkhan et al., 2015; Buytaert et al., 2017). Many regions in CSA rely heavily on hydroelectric energy, and as a result of rising energy demand, hydropower capacity is constantly being extended (Schoolmeester et al., 2018). Worldwide, SA features the second-fastest growth rate, with about 5.2 GW additional annual capacity installed in 2019 (IHA, 2020). This development requires additional water storage options, which entail the construction of large dams and reservoirs with important social-ecological implications. River fragmentation and corresponding loss of habitat connectivity due to dam constructions have been described for, for example, the NSA, SAM, NES and SES (high confidence) (Grill et al., 2015; Anderson et al., 2018a), with important implications for freshwater biota, such as fish migration (medium confidence) (Pelicice et al., 2015; Herrera-

R et al., 2020). Furthermore, examples in, for instance, NWS (Carey et al., 2012; Duarte-Abadía et al., 2015; Hommes and Boelens, 2018) and SWS (Muñoz et al., 2019b) showcase unresolved water-related conflicts between local villagers, peasant communities, hydropower operators and governmental institutions in a context of distrust and lack of water governance (high confidence)").

[286] Deloitte (2022) TURNING POINT: *A NEW ECONOMIC CLIMATE IN THE UNITED STATES*, 17 ("The losses to the US would rapidly increase and compound as temperatures continue to rise. The US economy would be smaller and less productive, and there would be fewer job opportunities. Over the next 50 years, nearly 900,000 job opportunities would disappear on average, every year, due to climate damages. In 2070 alone, insufficient climate action would result in more than 2 million fewer jobs across the US.").

[287] Sawyer D., Ness R., Lee C., & Miller S. (2022) DAMAGE CONTROL: *REDUCING THE COSTS OF CLIMATE IMPACTS IN CANADA*, Canadian Climate Institute, 60 ("Low-income households will see the largest reductions in real household income. While high-income households lose more income in absolute terms, the share of real income lost by low-income households is higher. By mid-century, the lowest-income households are projected to face income losses, relative to the refence case, of 5.8 per cent under high-emissions and 4.8 per cent under the low-emissions scenario (Figure 11). This compares to losses of 4 per cent and 3.2 per cent for the highest-income in the same period. By the end of the century, the impacts on real household income cut deep into affordability. Low-income households face real income cuts on average of 23 per cent in the high-emissions scenario, and 12 per cent under low-emissions. Even the median group faces significant income losses of 9 to 19 percent").

[288] *See generally* Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, Pan American Health Organization, United Nations International Children's Emergency Fund, & World Food Programme (2023) REGIONAL OVERVIEW OF FOOD SECURITY AND NUTRITION – LATIN AMERICA AND THE CARIBBEAN 2022: *TOWARDS IMPROVING AFFORDABILITY OF HEALTHY DIETS*.

[289] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 6 ("The region hosts most of the LAC population (66%) and of roughly 6% of the global population.").

[290] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("Of particular concern in SA, where 168.7 million people are affected by moderate or severe food insecurity, climate change will put additional pressure on food systems. The changing environmental conditions, including more intense and lengthy droughts, extreme weather events, higher temperatures, and increased atmospheric CO_2 concentrations, affect the growth, yield, and nutritional content of several crops, including four staple crops (wheat, rice, maize, and soybean). In 2021, the duration of the growth season of these four crops followed a downward trend, exposing potential threats to crop yields. The average duration of the growing season for spring wheat, winter wheat, maize, soybean, and rice had decreased by 2.5%, 2.2%, 1.6%, 1.3% and 0.4%, respectively, compared to a 1981–2010 baseline (indicator 1.4). These impacts threaten the livelihoods of people depending on the agricultural sector and, ultimately, pose an acute menace to food security in the region.").

[291] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("Of particular concern in SA, where 168.7 million people are affected by moderate or severe food insecurity, climate change will put additional pressure on food systems. The changing environmental conditions, including more intense and lengthy droughts, extreme weather events, higher temperatures, and increased atmospheric CO_2 concentrations, affect the growth, yield, and nutritional content of several crops, including four staple crops (wheat, rice, maize, and soybean). In 2021, the duration of the growth season of these four crops followed a downward trend, exposing potential threats to crop yields. The average duration of the growing season for spring wheat, winter wheat, maize, soybean, and rice had decreased by 2.5%, 2.2%, 1.6%, 1.3% and 0.4%, respectively, compared to a 1981–2010 baseline (indicator 1.4). These impacts threaten the livelihoods of people depending on the agricultural sector and, ultimately, pose an acute menace to food security in the region.").

[292] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2058–2060 ("SLR undermines the long-term persistence of freshwater-dependent ecosystems on islands (Goodman et al., 2012) and is one of the greatest threats to the goods and services these environments provide (Box 16.1; Mitsch and Hernandez, 2013). Hoegh-Guldberg et al. (2019) posit that as sea level rises, managing the risk of salinisation of freshwater resources will become increasingly important. On Roi-Namur, Marshall Islands, Storlazzi et al. (2018) found that the availability of freshwater is impacted by the compounding effect of SLR and coastal flooding. In other Pacific atolls, Terry and Chui (2012) showed that freshwater resources could be significantly affected by a 0.40-m SLR. Similar impacts are anticipated for some Caribbean countries (Stennett-Brown et al., 2017). Such changes in SLR could increase salinity in estuarine and aquifer water, affecting ground and surface water resources for drinking and irrigation water (Mycoo, 2018a) across the region (high confidence). SLR also affects groundwater quality (Bailey et al., 2016), salinity (Gingerich et al., 2017) and water-table height (Masterson et al., 2014).").

[293] Mycoo M., Wairiu M., Campbell D., Duvat V., Golbuu Y., Maharaj S., Nalau J., Nunn P., Pinnegar J., & Warrick O. (2022) *Chapter 15: Small Islands*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 2065 ("Climate change impacts on freshwater systems frequently exacerbate existing pressure, especially in locations already experiencing water scarcity (Section 15.3.3.2 and Cross-Chapter Box INTERREG in Chapter 16; Schewe et al., 2014; Holding et al., 2016; Karnauskas et al., 2016), making water security a key risk (KR4 in Figure 15.5) in small islands. Small islands are usually environments where demand for resources related to socioeconomic factors such as population growth, urbanisation and tourism already place increasing pressure on limited freshwater resources. In many small islands, water demand already exceeds supply. For example, in the Caribbean, Barbados is utilising close to 100% of its available water resources and St. Lucia has a water supply deficit of approximately 35% (Cashman, 2014)…. The Caribbean and Pacific regions have historically been affected by severe droughts (Peters, 2015; FAO, 2016; Barkey and Bailey, 2017; Paeniu et al., 2017; Trotman et al., 2017; Anshuka et al., 2018) with significant physical impacts and negative socioeconomic outcomes. Water quality is affected by drought as well as water availability. The El Niño related 2015–1016 drought in Vanuatu led to reliance on small amounts of contaminated water left at the bottom of household tanks (Iese et al., 2021a). The highest land disturbance percentages have coincided with major droughts in Cuba (de Beurs et al., 2019). Drought has been shown to have an impact on rainwater harvesting in the Pacific (Quigley et al., 2016) and Caribbean (Aladenola et al., 2016), especially in rural areas where connections to centralised public water supply have been difficult. Increasing trends in drought are apparent in the Caribbean (Herrera and Ault, 2017) although trends in the western Pacific are not statistically significant (McGree et al., 2016).").

[294] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1712 ("Despite the observed increase in rainfall in the region, between 2014 and 2016 Brazil endured a water crisis that affected the population and economy of major capital cities in the SES region (Blunden and Arndt, 2014; Nobre et al., 2016a). Extremely long dry spells have become more frequent in southeastern Brazil, affecting 40 million people and the economies in cities such as Rio de Janeiro, São Paulo and Belo Horizonte, which are the industrial centres of the country (medium confidence: medium evidence, medium agreement) (PBMC, 2014; Nobre et al., 2016a; Cunningham et al., 2017; Marengo et al., 2017, 2020b; Lima and Magaña Rueda, 2018)."). *See also* Nobre C. A., *et al.* (2016) *Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015*, J. WATER RES. PROTECT. 8(2): 562–262, 259 ("Mean discharge in the summer (Nov-Mar) of 2014 was 17.9 m^3/s and in 2015 it was 24.0 m^3/s, far below the average summer discharge, 59.8 m^3/s (70.0%

and 60%, respectively), for the period 1930-2013. The 1953/54 rainfall deficit prompted construction of the Cantareira Reservoir system [19] . After this, longer-term planning by regional governments has fallen short, and many residents are already enduring sporadic water cutoffs, some lasting for many days. The Cantareira reservoir system reached critical conditions in early 2015. Storage levels were only 5% of its 1.3 billion m^3 capacity in January 2015 and 15% at the end of the rainy season in March 2015.").

[295] Vicedo-Cabrera A. M., *et al.* (2021) *The burden of heat-related mortality attributable to recent human-induced climate change*, NAT. CLIM. CHANG. 11: 492–500, Supplementary Materials (Supplementary Table 4).

[296] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("The changing environmental conditions are also affecting the geographical distribution of infectious diseases. The region is endemic for dengue, which is responsible for a high burden of disease and frequent epidemic cycles across the region. The climate suitability for dengue transmission reached its highest level in recent years, with an increase of 35.3% in 2012–2021 compared to the 1951–1960 baseline (indicator 1.3). Estimated fitness for dengue transmission between 1951 and 2021 increased over time in all countries where the mosquito is found (except Argentina and Suriname). Adding to climate-related pressures, urbanisation, and mobility in countries such as Brazil and Peru have increased dengue spread to higher latitudes and less populated areas. Climate change can also lead to viral sharing among previously geographically isolated wildlife species, leading to cross-species transmission and disease emergence. Compounding the increase in dengue risk posed by climate changes, temperate Southern Cone countries are highly vulnerable to severe dengue outcomes, mainly driven by rapid urbanisation. Argentina and Uruguay experienced increased vulnerability between 1990 and 2019 (indicator 2.3).").

[297] Yglesias-González M., Palmeiro-Silva Y., Sergeeva M., Cortés S., Hurtado-Epstein A., Buss D. F., Hartinger S. M., & Red de Clima y Salud de América Latina y el Caribe (2022) *Code Red for Health response in Latin America and the Caribbean: Enhancing peoples' health through climate action*, LANCET REG. HEALTH AM. 11(100248): 1–8, 3 ("Dengue cases have almost tripled from 2000-2009 (6.78 million) to 2010-2019 (16.52 million) and the largest record of cases occurred in 2019."); *citing* Pan American Health Organization & World Health Organization, *Dengue*, PLISA Health Information for the Americas (*last visited* 24 May 2023).

[298] Kephart J. L., Avila-Palencia I., Bilal U., Gouveia N., Caiaffa W. T., & Diez Roux A. V. (2021) *COVID-19, Ambient Air Pollution, and Environmental Health Inequities in Latin American Cities*, J. URBAN HEALTH. 98(3): 428–432, 428 ("High levels of air pollution in many Latin American cities in the past may have primed many residents for more severe infection and mortality from COVID-19 by contributing to the development of chronic diseases. Many of the chronic diseases associated with long-term, cumulative exposure to air pollution appear to be correlated with a higher vulnerability to severe COVID-19 outcomes, including hospitalization, need for critical care, and death [1, 2]. A recent study in the USA reported that a long-term increase of only 1 $\mu g/m^3$ $PM_{2.5}$ was associated with an 8% increase in COVID-19 death rate [3]. In addition to cumulative exposures, it is plausible that short-term air pollution exposures interact with SARS-CoV-2 infection itself [4], possibly via their effects on inflammation-related processes. However, the effect of immediate changes in air pollution on COVID-19-related mortality is yet to be tested.").

[299] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1722 (Table 12.6).

[300] World Bank (2015) INDIGENOUS LATIN AMERICA IN THE TWENTY-FIRST CENTURY: *THE FIRST DECADE*, 9 ("The number of indigenous persons living in poverty has fallen, but the gap separating them from other Latin Americans has either remained stagnant or widened. Poverty, in fact, afflicts 43 percent of the indigenous population in the region—more than twice the proportion of non-indigenous people—while 24 percent of all indigenous people live in extreme poverty, 2.7 times more than the proportion of non-indigenous people.").

[301] United Nations Department of Economic and Social Affairs – Indigenous Peoples, *Climate Change* (*last visited* 11 July 2023) ("Indigenous peoples are among the first to face the direct consequences of climate change, due to their dependence upon, and close relationship, with the environment and its resources. Climate change exacerbates the difficulties already faced by indigenous communities including political and economic marginalization, loss of land and resources, human rights violations, discrimination and unemployment. … Climate change poses threats and dangers to the survival of indigenous communities worldwide, even though indigenous peoples contribute the least to greenhouse emissions. In fact, indigenous peoples are vital to, and active in, the many ecosystems that inhabit their lands and territories and may therefore help enhance the resilience of these ecosystems. In addition, indigenous peoples interpret and react to the impacts of climate change in creative ways, drawing on traditional knowledge and other technologies to find solutions which may help society at large to cope with impending changes."). *See also* Human Rights Council (30 April 2012) *Expert Mechanism on the Rights of Indigenous Peoples: Study on the role of languages and culture in the promotion and protection of the rights and identity of indigenous peoples*, United Nations General Assembly, Fifth session, A/HRC/EMRIP/2012/3, 16 ("As the Independent Expert in the field of cultural rights has noted, protecting cultures can be challenging "especially in societies where people feel that their cultural heritage is under threat, due in particular to the dynamism or dominance of other cultures, globalization and development processes and/or the dominant position of corporate actors in the field of culture and leisure."63 Moreover, loss of lands, territories and resources can limit the ability of indigenous cultures to adapt organically. Because of these changes and obstacles, there must be a conscious effort to maintain traditional values and instil cultural strength, pride and dignity.").

[302] *See* Riehl A. (26 November 2018) *The impact of climate change on language loss*, THE CONVERSATION ("While approximately 7,000 languages are spoken in the world today, only about half are expected to survive this century. A number of factors contribute to this loss: increasing globalization, which pushes countries and individuals to shift to national or international languages for economic reasons; lack of support for regional languages in educational systems and mass media; persecution of minority linguistic groups by governments and disruption of communities during war and emigration. … One stressor that may be the tipping point for some communities is climate change. Many small linguistic communities are located on islands and coastlines vulnerable to hurricanes and a rise in sea levels. Other communities are settled on lands where increases in temperature and fluctuations in precipitation can threaten traditional farming and fishing practices. These changes will force communities to relocate, creating climate change refugees. The resultant dispersal of people will lead to the splintering of linguistic communities and increased contact with other languages. These changes will place additional pressures on languages that are already struggling to survive."); *and* Sustainability for All (15 May 2023) *The Silent Death Of The World's Languages, Another Consequence Of Climate Change*, ACCIONA ("The reasons why indigenous languages are disappearing do not strictly obey linguistic processes such as the (non) transmission between generations, political conflicts or lack of legal recognition. The **climate crisis** is also a determining factor. Many small **linguistic communities are located on islands or coasts** which are vulnerable to hurricanes or **rising sea levels**. Other communities are settled in lands where rising temperatures and rainfall fluctuations can threaten traditional farming and fishing practices. These changes oblige the communities to relocate, creating **climate change refugees**. The catastrophes caused 23.7 million internal displacements in 2021, most of which were due to meteorological phenomena. The resulting migration of people causes linguistic communities to fragment and greater contact with other languages. These changes have repercussions on minority languages, which were already struggling to survive.").

[303] *See generally* Economic Commission for Latin America and the Caribbean (2014) GUARANTEEING INDIGENOUS PEOPLE'S RIGHTS IN LATIN AMERICA: *PROGRESS IN THE LAST DECADE AND REMAINING CHALLENGES*, United Nations.

[304] International Labour Office (2017) INDIGENOUS PEOPLES AND CLIMATE CHANGE: *FROM VICTIMS TO CHANGE AGENTS THROUGH DECENT WORK*, 7 ("It is important to highlight that the risks that climate change poses for indigenous peoples differ from the risks that it poses for other groups in society, including the poor (in their entirety). This is because indigenous peoples share six characteristics that, in combination, are not present in any other group. Thus they are especially vulnerable to the direct impacts of climate change; to the impacts of environmental destruction that leads to climate change; and to mitigation and adaptation measures. First, indigenous peoples are among the poorest of the poor, the stratum most vulnerable to climate change. Second, they depend on renewable natural resources most at risk

to climate variability and extremes for their economic activities and livelihoods. Third, they live in geographical regions and ecosystems that are most exposed to the impacts of climate change, while also sharing a complex cultural relationship with such ecosystems. Fourth, high levels of exposure and vulnerability to climate change force indigenous peoples to migrate, which in most cases is not a solution and can instead exacerbate social and economic vulnerabilities. Fifth, gender inequality, a key factor in the deprivation suffered by indigenous women, is magnified by climate change. Sixth, and lastly, many indigenous communities continue to face exclusion from decision-making processes, often lacking recognition and institutional support. This limits their access to remedies, increases their vulnerability to climate change, undermines their ability to mitigate and adapt to climate change, and consequently poses a threat to the advances made in securing their rights.").

[305] Hagen I., Huggel C., Ramajo L., Chacón N., Ometto J. P., Postigo J. C., & Castellanos E. J. (2022) *Climate change-related risks and adaptation potential in Central and South America during the 21st century*, ENV. RES. LETT. 17(3): 1–26, 4 ("Indigenous communities often lack access to infrastructure and public service systems, as well as territorial autonomy and self-determination, and are often forced to occupy climate risk prone areas such as low-lying coastlines, steep slopes and floodplains (González 2015, World Bank Group 2015).").

[306] Sobrevila C. (2008) THE ROLE OF INDIGENOUS PEOPLES IN BIODIVERSITY CONSERVATION: *THE NATURAL BUT OFTEN FORGOTTEN PARTNERS*, World Bank, xi–xii, 3 ("Many or most of the world's major centers of biodiversity coincide with areas occupied or controlled by Indigenous Peoples. Traditional Indigenous Territories encompass up to 22 percent of the world's land surface and they coincide with areas that hold 80 percent of the planet's biodiversity. Also, the greatest diversity of indigenous groups coincides with the world's largest tropical forest wilderness areas in the Americas (including Amazon), Africa, and Asia, and 11 percent of world forest lands are legally owned by Indigenous Peoples and communities. This convergence of biodiversity-significant areas and indigenous territories presents an enormous opportunity to expand efforts to conserve biodiversity beyond parks, which tend to benefit from most of the funding for biodiversity conservation."). *See also* Oswald-Spring Ú. (2022) *The Impact of Climate Change on the Gender Security of Indigenous Women in Latin America*, *in* ENVIRONMENT, CLIMATE, AND SOCIAL JUSTICE, Madhanagopal D., Beer C. T., Nikku B. R., & Pelser A. J. (eds.), 117 ("with a global representation of only 5%, indigenous people protect 80% of the biodiversity on the planet. Women are especially active in environmental care and ecosystem restoration. However, the dominant mindset in the North American political scenario has prioritized military security over environmental conflicts. Their reference object was the state. The values at risk are sovereignty and territorial integrity, reducing interest in people and nature. Gender security focuses on women, indigenous and vulnerable groups, analysing gender relations, equity, and empowerment to overcome the patriarchal worldview and institutions represented by transnational corporations, churches, and authoritarian governments. Latin America, especially Central America and Mexico (Mesoamerica), are highly affected by climate change. Indigenous women are also the poorest in the whole region. They have a limited capacity for adaptation and little governmental support. They often live in abrupt mountain regions or have migrated into unsafe slums of megacities."; "The global indigenous population of approximately 300 million people is composed of about 5,000 distinct indigenous cultures worldwide, living in every climate from the Arctic Circle to the tropical rain forests. Although Indigenous Peoples make up only 4 percent of the world's population, they represent 95 percent of the world's cultural diversity.").

[307] *See* Ramos E. P., & Dias K. M. (2021) *Gender, Migration, Climate Change and Disasters in Latin America and the Caribbean*, UN Women; *and* Revelo L. A. (2022) *Women's Autonomy and Gender Equality at the Centre of Climate Action in Latin America and the Caribbean*, UN Women.

[308] *See* Ramos E. P., & Dias K. M. (2021) *Gender, Migration, Climate Change and Disasters in Latin America and the Caribbean*, UN Women; *and* Revelo L. A. (2022) *Women's Autonomy and Gender Equality at the Centre of Climate Action in Latin America and the Caribbean*, UN Women.

[309] Boyer A. E., Meijer S. S., & Gilligan M. (2020) ADVANCING GENDER IN THE ENVIRONMENT: *EXPLORING THE TRIPLE NEXUS OF GENDER INEQUALITY, STATE FRAGILITY, AND CLIMATE VULNERABILITY*, International Union for Conservation of Nature & United States Agency for International Development, 21 ("Research highlights another devastating gender-related issue in the aftermath of disasters, particularly those that lead to displacement and economic loss, and increased instances of domestic and sexual violence.[98] Social stress due to loss of resources, unemployment, and livelihoods in

a post-disaster context can strain household power dynamics and increase instances of intimate partner violence (IPV).[99] Women and girls, members of the LGBT community, and people who do not conform with societal gender norms report increased instances of sexual violence and GBV in post-disaster contexts in emergency shelters that are overcrowded, unsafe, unfamiliar, and lack privacy.[100, 101] Additionally, when aid workers who are not sensitized to gender issues, or where emergency shelters do not provide adequate resources, there is a risk of exacerbating gender inequalities, as evidenced by instances where LGBT people were turned away or arrested for trying to access emergency shelters in disaster situations.[102]"). *See also* Ramos E. P., & Dias K. M. (2021) *Gender, Migration, Climate Change and Disasters in Latin America and the Caribbean*, UN Women; Revelo L. A. (2022) *Women's Autonomy and Gender Equality at the Centre of Climate Action in Latin America and the Caribbean*, UN Women; *and* Felisi E. (27 June 2021) *Gender and Sexual Minorities: The Invisible Victims of Climate Change*, REPORTOUT.

[310] Renshaw N., Adoo-Kissi-Debrah R., Kumar A., Massawudu Musah L., & Burson J. (2022) *A healthy future for children and adolescents*, THE LANCET 400(10358): 1100–1101, 1100 ("Today, over 90% of children breathe dangerously polluted air, and in low-income and middle-income countries this figure is 98%."); *citing* World Health Organization (2021) WHO GLOBAL AIR QUALITY GUIDELINES: *PARTICULATE MATTER (PM2.5 AND PM10), OZONE, NITROGEN DIOXIDE, SULFUR DIOXIDE AND CARBON MONOXIDE*.

[311] World Health Organization (2018) AIR POLLUTION AND CHILD HEALTH: PRESCRIBING CLEAN AIR, 5, 12–13 ("• Some 543 000 deaths in children under 5 years and 52 000 deaths in children aged 5–15 years were attributed to the joint effects of ambient and household air pollution in 2016. • Together, household air pollution from cooking and ambient air pollution cause more than 50% of acute lower respiratory tract infection (ALRI) in children under 5 years in LMICs. • Of the total number of deaths attributable to the joint effects of household and ambient air pollution worldwide in 2016, 9% were in children."; "There is strong evidence that exposure to ambient air pollution can negatively affect children's mental and motor development…. There is robust evidence that exposure to air pollution damages children's lung function and impedes their lung function growth, even at lower levels of exposure. Studies have found compelling evidence that prenatal exposure to air pollution is associated with impairment of lung development and lung function in childhood. Conversely, there is evidence that children experience better lung function growth in areas in which ambient air quality has improved…. There is substantial evidence that exposure to ambient air pollution increases the risk of children for developing asthma and that breathing pollutants exacerbates childhood asthma as well.").

[312] United Nations International Children's Emergency Fund (2 December 2022) *9 Out Of 10 Children in Latin America and The Caribbean are Exposed to at Least Two Climate and Environmental Shocks* ("The Children's Climate Risk Index (CCRI) reveals that in Latin America and the Caribbean: 55 million children are exposed to water scarcity; 60 million children are exposed to cyclones;85 million children are exposed to Zika; 115 million children are exposed to Dengue; 45 million children are exposed to heatwaves; 105 million children are exposed to air pollution. While nearly every child around the world is at risk from at least one of these climate and environmental hazards, the data reveal the worst affected countries face multiple and often overlapping shocks that threaten to erode development progress and deepen child deprivations.

[313] United Nations International Children's Emergency Fund (2022) THE COLDEST YEAR OF THE REST OF THEIR LIVES: *PROTECTING CHILDREN FROM THE ESCALATING IMPACTS OF HEATWAVES*, 24 ("There are deep and terrible effects of failing to limit global heating to 1.7 degrees. Although exposure to high heatwave duration is expected to increase in both emission scenarios, the difference in projections between low and very high emission scenarios means that by 2050, over 370 million more children will be exposed to high heatwave duration under the very high emission scenario.").

[314] Cissé G., McLeman R., Adams H., Aldunce P., Bowen K., Campbell-Lendrum D., Clayton S., Ebi K. L., Hess J., Huang C., Liu Q., McGregor G., Semenza J., & Tirado M. C. (2022) *Chapter 7: Health, Wellbeing, and the Changing Structure of Communities*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller

V., Okem A., & Rama B. (eds.), 1053 ("Older adults (generally defined as persons aged 65 and older) are disproportionately vulnerable to the health impacts associated with climate change and weather extremes.").

[315] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("In the last ten years, the more frequent and intense heatwaves have increasingly put the health and survival of children under one year old and adults above 65 years at risk. On average, children <1 year were exposed to 2.35 million more person-days of heatwaves each year, and adults above 65 years exposed to 12.3 million more person-days, as compared to a 1996–2005 baseline (indicator 1.1.1).").

[316] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("In the last ten years, the more frequent and intense heatwaves have increasingly put the health and survival of children under one year old and adults above 65 years at risk. On average, children <1 year were exposed to 2.35 million more person-days of heatwaves each year, and adults above 65 years exposed to 12.3 million more person-days, as compared to a 1996–2005 baseline (indicator 1.1.1).").

[317] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 2 ("Since the year 2000, the estimated number of heat-related deaths has increased continuously among people over 65 in almost all countries.").

[318] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 8 ("Indicator 1.1.2: heat-related mortality—headline finding: the estimated number of heat-related deaths has increased, on average, by 160% in the 2017–2021 period compared to the 2000–2004 period.").

[319] Bryant N., Stone R., Connelly C., & Boerner K. (2022) *The Impact of Climate Change: Why Older Adults are Vulnerable*, LeadingAge LTSS Center, University of Massachusetts Boston, 4 ("Researchers have examined how several aspects of climate change—including extreme heat or cold, poor air quality, and extreme weather disasters—affect the health of older Americans. For example, heat waves, hurricanes, and flooding are all associated with higher risk of hospitalization and higher mortality rates for people 65 and older, compared to people under the age of 65. In addition, older adults may be at increased risk for: ¬ The psychological health effects of weather events. ¬ Negative physical and mental health outcomes resulting from air pollution, wildfires, and droughts. ¬ Disruption of services due to forced evacuations. These interruptions can worsen preexisting conditions for people with chronic illness.").

[320] World Bank (2022) CONSOLIDATING THE RECOVERY: *SEIZING GREEN GROWTH OPPORTUNITIES*, Latin America and the Caribbean Semiannual Report, 29 ("All in all, the combined effects of climate change in LAC are projected to push between 2.4 million and 5.8 million people into extreme poverty by 2030 (Jafino et al. 2020), mostly due to health-related effects—the increasing prevalence of child stunting, vector-borne diseases, and diarrhea—resulting from lack of access to safe water and sanitation, excessive heat, and more frequent droughts and floods (figure 2.5).").

[321] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1746 ("In IPCC's Third Assessment Report (TAR), AR4 and AR5, WGII recognised higher risks associated with poor living conditions, substandard housing, inadequate services, location of hazardous sites stemming from a lack of alternatives and the need to work more seriously on strengthening governance structures involving residents and community organisations, among others (Wilbanks et al., 2007; Revi et al., 2014). The AR5 CSA chapter stated that poverty levels remained high (45% for CA and 30% for SA in 2010) despite years of sustained economic growth. Poor and vulnerable groups are disproportionately affected in negative ways by climate change

(Section 8.2.1.4; Section 8.2.2.3; SR15 Section 5.2 and Section 5.2.1, Roy et al., 2018) due to physical exposure derived from their place of residence or work, illiteracy, low income and skills, political and institutional marginalisation tied to a lack of recognition of informal settlements and employment, poor access to good-quality services and infrastructure, resources and information and other factors (very high confidence) (UN-Habitat, 2018; SR15 Sections 5.2.1, 5.6.2, 5.6.3, 5.6.4, Roy et al., 2018).").

[322] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1765.

[323] Kumari Rigaud K., de Sherbinin A., Jones B., Bergmann J., Clement V., Ober K., Schewe J., Adamo S., McCusker B., Heuser S., & Midgley A. (2018) GROUNDSWELL: *PREPARING FOR INTERNAL CLIMATE MIGRATION*, The World Bank, xxi ("Under all three scenarios in this report, there is an upward trend of internal climate migration in SubSaharan Africa, South Asia, and Latin America by 2050. In the worst-case or "pessimistic" scenario, the number of internal climate migrants could reach more than 143 million (around 86 million in Sub-Saharan Africa, 40 million in South Asia, and 17 million in Latin America) by 2050 (Figure 1). The poorest people and the poorest countries are the hardest hit…. Across all scenarios, climate change is a growing driver of internal migration. Climate change impacts (crop failure, water stress, sea level rise) increase the probability of migration under distress, creating growing challenges for human development and planning. Vulnerable people have the fewest opportunities to adapt locally or to move away from risk and, when moving, often do so as a last resort. Others, even more vulnerable, will be unable to move, trapped in increasingly unviable areas. Internal climate migration will intensify over the next several decades and could accelerate after 2050 under the pessimistic scenario due to stronger climate impacts combined with steep population growth in many regions.").

[324] World Bank (2018) *Internal Climate Migration in Latin America*, Groundswell Policy Note #3, 4 (Table 1).

[325] World Bank (2018) *Internal Climate Migration in Latin America*, Groundswell Policy Note #3, 6 ("Lower global emissions reduce climate pressure on ecosystems and livelihoods and broaden the opportunities for people to stay in place or move under better circumstances. In Latin America, under the more climate-friendly scenario, there would be up to 87 percent less climate migrants—with numbers reduced from a high of 17.1 million under the pessimistic reference scenario to 2.2–9.4 million under this scenario.").

[326] Center for Puerto Rican Studies (2018) *New Estimates: 135,000+ Post-Maria Puerto Ricans Relocated to Stateside*, Centro DS2018-01, 1 ("Based on school enrollment data, we estimate that more than 135,000 Puerto Ricans relocated to the United States six months after Hurricane Maria landed in Puerto Rico. Prior estimates of the magnitude of this exodus are based on movement of passenger or projections based on recent migration trends from Puerto Rico to the United States.").

[327] Cantor D. J. (2018) CROSS-BORDER DISPLACEMENT, CLIMATE CHANGE, AND DISASTERS: *LATIN AMERICA AND THE CARIBBEAN*, United Nations High Commissioner for Refugees, 22 ("At the regional level, including in the Americas, there are several regional integration processes that have developed agreements that either allow for free movement based on supranational forms of 'citizenship' of the pertinent entity (i.e. erasing national boundaries between member States) or allow for favourable migration treatment between member States. They may offer a legal basis for international movement by persons affected by a disaster. Nonetheless, given their close ties to national laws and policies in the pertinent blocs, they will be addressed further in relation to each of the regions in turn.96").

[328] *See for example* Campa A. (21 May 2022) *Climate Migrants Lack a Clear Path to Asylum in the US*, INSIDE CLIMATE NEWS; *and* Limoges B. (24 April 2021) *'I'm trapped here': Haitian asylum seekers languish in Mexico*, AL JAZEERA.

[329] Gemenne F., Zickgraf C., Hut E., & Castillo Betancourt T. (2021) *Forced displacement related to the impacts of climate change and disasters*, Reference Paper for the 70th Anniversary of the 1951 Refugee Convention, *Prepared for the United Nations High Commissioner for Refugees*, 5 ("Throughout the 1990s, public debates were dominated by an alarmist narrative claiming that the world should prepare for millions of 'climate refugees' in the coming decade. This narrative geared policy debates in two directions. First, the regular use of the expression 'climate refugees' led many experts or organisations to point out that the term was a misnomer because the 1951 Geneva Convention made no mention of environmental phenomena as a basis for international protection needs. This absence of an explicit reference to environmental factors in existing legal instruments3 prompted many initiatives to create an international legal status for 'climate refugees': resolutions were voted in parliaments, expert groups were set up, and lawyers debated whether this new status should be created through a new convention or an amendment to the Geneva Convention (Gemenne 2015). For many activists, politicians and civil society organisations, this lack of international status was the key reason why policies were blind to the environmental drivers of human mobility, and therefore the first priority. It soon appeared that such a status in international law was not just a political no-go area, but also a response that would not meet the needs of the displaced, as most were internally displaced and therefore ineligible to an international status (McAdam 2011). In spite of this, an international status for 'climate refugees' continues to be a key demand of many prominent activists, parliamentarians and civil society organisations, such as the Parliamentary Assembly of the Council of Europe, who insist this would be the most appropriate way to protect the displaced. Others, however, argue that persons who are suddenly displaced due to climate or disasters qualify for international protection and that there is no need for a new category (UNHCR 2018)").

[330] United Nations High Commissioner for Refugees (2022) *Climate Change, Displacement and Human Rights*, 1 ("The climate crisis is already amplifying vulnerability and driving displacement, which impacts a broad array of human rights, including the rights to education, adequate standard of living and health of those displaced. Highly climate vulnerable countries host 40% of refugees and are home to 70% of people internally displaced by conflict or violence. While these populations are often highly exposed and vulnerable to climate-related shocks, they have fewer resources and support to adapt to an increasingly hostile environment. This raises concerns about the right to equality and non-discrimination. At the same time, human mobility can protect people and their human rights. This may be through well-prepared and timely emergency evacuations, assisting communities to plan for relocation to safer settlement areas as a measure of last resort, or facilitating safe, orderly and regular migration through regular pathways to prevent displacement from occurring. The freedom and capacity to move is part of upholding human rights and can contribute to climate change adaptation. Extreme weather, which is becoming more frequent and intense with climate change, greatly impacts displaced persons. Recent floods in Sudan were some of the worst observed in decades. Alganaa refugee camp in Sudan's White Nile State was submerged by flood waters in November 2021, leaving 35,000 South Sudanese refugees in need of urgent assistance."). *See also* United States White House (2021) REPORT ON THE IMPACT OF CLIMATE CHANGE ON MIGRATION, 7 ("Extreme weather events9 and conflict are the top two drivers of forced displacement globally, together responsible for the annual movement of nearly 30 million people from their homes.10 There is a strong correlation between countries and regions most vulnerable to climate change and those that are fragile and/or experiencing conflict or violence. Climate-related impacts may further stress vulnerable communities, increasing the risk of conflict and displacement in the absence of effective prevention efforts, and vice versa. Climate-related impacts also pose an increased risk to marginalized communities displaced by conflict related to the impacts of climate change. This risk is more acute in regions with weak governance and dispute resolution infrastructure, and in growing peri-urban areas where many migrants are heading. Climate change can cause or exacerbate resource scarcity, which may drive conflict directly as well as induce migration of populations in vulnerable situations attempting to secure safety or livelihoods elsewhere.11 Moreover, changes to biodiversity have strong intersections with climate change that also can affect migration, and threaten food and economic security.12 The subsequent movement of large numbers of people, by force or by choice, brings new groups into contact with one another, potentially shifting power balances, causing further resource scarcity, or igniting tensions between previously separated groups. 13 Where climate-related migrations occur within or near population centers, or in locations important for political or economic stability, such as within many nations' coastal zones, the destabilizing forces associated with climate change may result in outsized affects overall.").

[331] Alvarez J. A., Arena M., Brousseau A., Faruqee H., Corugedo E. W. F., Guajardo J., Peraza G., & Yepez J. (2022) *Regional Spillovers from the Venezuelan Crisis: Migration Flows and Their Impact on Latin America and the*

Caribbean, International Monetary Fund Departmental Papers, 4 ("The destination and composition of Venezuela's migrant flows changed as the crisis intensified. Most migrants have settled in other Latin American countries, while some have migrated to other regions, mainly to the United States and Spain. Colombia has received the largest number of migrants, totaling 2.5 million or about 5 percent of the Colombian population in August 2022.14 Chile, Ecuador, and Peru have also received sizable flows, with the combined number of migrants exceeding 2 million (more than 3 percent of the local population on average).").

[332] *See* International Crisis Group (2022) HARD TIMES IN A SAFE HAVEN: PROTECTING VENEZUELAN MIGRANTS IN COLOMBIA, Latin America Report No. 94.

[333] Global Witness (2022) DECADE OF DEFIANCE: TEN YEARS OF REPORTING LAND AND ENVIRONMENTAL ACTIVISM WORLDWIDE, 16 ("Global Witness started reporting on the killings of Land and Environmental Defenders in 2012.31 Since then, 1733 defenders have been killed trying to protect their land and resources: that's an average of one defender killed approximately every two days over ten years.").

[334] Global Witness (2022) DECADE OF DEFIANCE: TEN YEARS OF REPORTING LAND AND ENVIRONMENTAL ACTIVISM WORLDWIDE, 23–26 ("In Brazil, where 342 defenders have been killed over the last decade, the Gini index (the most widely used indicator of inequality) of land ownership distribution is 0.73, placing Brazil among the countries with the greatest land inequality in the world. Research has shown that inequality is greater in the states with highest agricultural commodity production, such as in Mato Grosso, Mato Grosso do Sul, Bahia and in the MATOPIBA region (which comprises the Cerrado biome areas of the states of Maranhão, Tocantins, Piauí and Bahia). Attacks against defenders are also high in these states according to Global Witness data. For example, in Mato Grosso, nine farm workers were tortured and killed in 2017 by hired assassins in an area of illegal deforestation.59 The same study also points out that 10% of the largest properties occupy 73% of the agricultural area of Brazil. In all Brazilian states, the 10% of the largest properties own more than 50% of the area. In six states and MATOPIBA, the 10% of the largest properties own more than 70% of the area.60 44 of the 342 defenders killed in Brazil over the last decade were protesting against agribusiness. Colombia has the highest concentration of landholdings in Latin America, with the largest 1% of landholdings concentrated over 81% of land, leaving only 19% of land distributed among the remaining 99% of farms.61").

[335] Glazebrook T. & Opoku E. (2018) *Defending the Defenders: Environmental Protectors, Climate Change and Human Rights*, ETHICS ENVIRON. 23(2): 83–109.

[336] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1693 ("**The most widely reported obstacle to adaptation in terrestrial, freshwater, ocean and coastal ecosystems is financing (*high confidence*).** There is also a significant gap in identifying limits to adaptation and weak institutional capacity for implementation. This hinders the development of comprehensive adaptation programmes, even under adequate funding.").

[337] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN.

[338] Clean Air Task Force, *Oil and Gas Mitigation Program* (*last visited* 13 June 2023) ("Venting is even more harmful than flaring, since methane warms the climate so powerfully, and VOC and toxic pollutants are released unabated. Venting of this gas should be prohibited in all cases as an absolutely unnecessary source of harmful air pollution. There are numerous lowcost (and usually profitable) ways to utilize natural gas from oil wells. Flaring should be a last resort: only in the most extreme cases should oil producers be allowed to flare gas, and it should be strictly a temporary measure. Rules prohibiting venting of natural gas can easily reduce emissions by 95%.").

[339] These include precision framing using variable rate technology and nitrogen inhibitors to suppress microbial activity that produces N_2O: Balafoutis A., Beck B., Fountas S., Vangeyte J., van der Wal T., Soto I., Gómez-Barbero M., Barnes A., & Eory V. (2017) *Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics*, SUSTAINABILITY 9(8): 1339, 1–28, 9 ("Tekin (2010) estimated that VRNA can increase wheat production between 1% and 10% offering savings in nitrogen fertilisation between 4% and 37%.").

[340] Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe—results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21, 16–17 ("An additional almost 10 percent of baseline emissions in 2050 could be removed at a marginal cost below 20 €/t CO2eq by implementing proper waste and wastewater handling in China, India and the rest of South-East Asia. This would likely come with considerable co-benefits in the form of reduced air and water pollution.").

[341] United States Climate Alliance (2018) FROM SLCP CHALLENGE TO ACTION: A ROADMAP FOR REDUCING SHORT-LIVED CLIMATE POLLUTANTS TO MEET THE GOALS OF THE PARIS AGREEMENT, 15 ("Significant opportunities for reducing methane emissions from landfills and capturing value can be seized by reducing food loss and waste, diverting organic waste to beneficial uses, and improving landfill management. These and other actions collectively could reduce methane emissions from waste by an estimated 40-50 percent by 2030 (Appendix A). Such efforts could add value in our states by reducing emissions of volatile organic compounds and toxic air contaminants from landfills, recovering healthy food for human consumption in food insecure communities, supporting healthy soils and agriculture, generating clean energy and displacing fossil fuel consumption, and providing economic opportunities across these diverse sectors. Many of these benefits will accrue in low-income and disadvantaged communities."). See also Geyik Ö., Hadjikakou M., & Bryan B. A. (2022) Climate-friendly and nutrition-sensitive interventions can close the global dietary nutrient gap while reducing GHG emissions, Nat. Food. 4: 61–73, 61 ("Here, we estimate the non-CO2 greenhouse gas emissions resulting from closing the world's dietary nutrient gap—that between country-level nutrient supply and population requirements—for energy, protein, iron, zinc, vitamin A, vitamin B12 and folate under five climate-friendly intervention scenarios in 2030. We show that improving crop and livestock productivity and halving food loss and waste can close the nutrient gap with up to 42% lower emissions (3.03 Gt CO2eq yr−1) compared with business-as-usual supply patterns with a persistent nutrient gap (5.48 Gt CO2eq yr−1).").

[342] In the U.S. alone, natural gas stoves emit 28.1 Gg of methane a year, among other climate pollutants that are hazardous to the environment and human health: *see* Lebel E. D., Finnegan C. J., Ouyang Z., & Jackson R. B. (2022) *Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes*, ENVIRON. SCI. TECHNOL. 56(4): 2529–2539, 2529 ("Natural gas stoves in >40 million U.S. residences release methane (CH_4)─a potent greenhouse gas─through post-meter leaks and incomplete combustion. We quantified methane released in 53 homes during all phases of stove use: steady-state-off (appliance not in use), steady-state-on (during combustion), and transitory periods of ignition and extinguishment. We estimated that natural gas stoves emit 0.8–1.3% of the gas they use as unburned methane and that total U.S. stove emissions are 28.1 [95% confidence interval: 18.5, 41.2] Gg CH_4 year^{-1}. More than three-quarters of methane emissions we measured originated during steady-state-off. Using a 20-year timeframe for methane, annual methane emissions from all gas stoves in U.S. homes have a climate impact comparable to the annual carbon dioxide emissions of 500 000 cars. In addition to methane emissions, co-emitted health-damaging air pollutants such as nitrogen oxides (NO_x) are released into home air and can trigger respiratory diseases. In 32 homes, we measured NO_x (NO and NO_2) emissions and found them to be linearly related to the amount of natural gas burned ($r^2 = 0.76$; $p \ll 0.01$). Emissions averaged 21.7 [20.5, 22.9] ng NO_x J^{-1}, comprised of 7.8 [7.1, 8.4] ng NO_2 J^{-1} and 14.0 [12.8, 15.1] ng NO J^{-1}. Our data suggest that families who don't use their range hoods or who have poor ventilation can surpass the 1-h national standard of NO_2 (100 ppb) within a few minutes of stove usage, particularly in smaller kitchens.").

[343] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 111 (Table 3.2).

[344] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 111 (Table 3.2).

[345] Climate & Clean Air Coalition & United Nations Environment Programme (2018) INTEGRATED ASSESSMENT OF SHORT-LIVED CLIMATE POLLUTANTS IN LATIN AMERICA AND THE CARIBBEAN, 111 (Table 3.2).

[346] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "New regulations that limit methane emissions from fugitive sources—like the drilling, extraction, and transportation process—will be applied in the near term to the oil and gas sector.). *See also* Clune R., Corb L., Glazener W., Henderson K., Pinner D., Walter D. (May 2022), NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, 3 ("To reach net zero, our analysis shows that at least 60 percent of the natural gas that's now being used would need to be replaced by zero-carbon energy sources, primarily in the power, manufacturing, chemicals, and buildings sectors. And methane emissions from venting and from fugitive leaks in oil and gas production would need to be curbed by nearly 80 percent by 2030.").

[347] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "Just 7 percent of our energy is supplied by non-hydro renewables. Diversifying supply chains for materials vital to renewable infrastructure could increase the usage of renewables. Biogenic, low-carbon fuel innovations could be used in transport sectors where electricity isn't viable"; "Model for a net-zero future in Canada" Figure); ("Small modular reactors are promising for powering remote communities and off-grid industrial projects. At scale, however, modular reactors are currently unproven. Deploying them could involve lower initial capital costs compared with their large-reactor counterparts.").

[348] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 6 (Exhibit 4).

[349] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "As an alternative fuel, hydrogen is plentiful, non-toxic, efficient, and safe. Clean hydrogen could boost the resilience of Canada's energy sector through various applications in the industrial sector, transportation, and buildings. New technologies can be scaled to create fresh market demand for low-carbon hydrogen, and to decarbonize those sectors that cannot yet be fully electrified. Support for hydrogen end-use technologies could provide resource-based provinces the opportunity to lead the transition to a low-carbon future.").

[350] Environment and Climate Change Canada (2017) STRATEGY ON SHORT-LIVED CLIMATE POLLUTANTS – 2017, 7–9 (Figure 1; "Regulatory measures to address wood-burning appliances are limited at both federal and provincial/territorial levels. Some provinces regulate the sale of new wood-burning appliances, while some municipalities have by-laws relating to residential wood combustion, including emission standards, bans on certain types of appliances, or restrictions on the use of wood-burning appliances during smog days. Measures to address emissions from existing sources are limited to wood stove change-out programs or rebates for certain new appliances in some provinces and territories.").

[351] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 3 ("To reach net zero, our analysis shows that at least 60 percent of the natural gas that's now being used would need to be replaced by zero-carbon energy sources, primarily in the power, manufacturing, chemicals, and buildings sectors. And methane emissions from venting and from fugitive leaks in oil and gas production would need to be curbed by nearly 80 percent by 2030.").

[352] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 6–7 (Renewable power. In a net-zero scenario, the country's energy system would be reconfigured. Indeed, the United States has set a target to create a "carbon-pollution-free power sector by 2035."5 Energy consumption would shift away from fossil fuels, which provide 90 percent of primary energy today, and toward renewables, which would produce just over 75 percent of primary energy in 2050. This shift would result in more than 35 percent of the emissions reduction that is needed in 2025 and more

than onequarter of the reduction in 2030. To expand the use of renewable power, the United States would install 40 gigawatts per year of renewable capacity in 2025. By 2030, the installation rate for renewables would reach 100 gigawatts per year, three times what it is now, as utilities tap the best solar resources from Texas to California and wind resources in the Midwest. Utilities would also build out power grids and modernize them with flexibility resources including storage and dispatchable low-carbon power (for example, gas power plants with carbon capture, utilization, and storage) to prevent interruptions in electricity supply. Makers of renewable-electricity and storage equipment would expand production capacity to meet this demand, supporting $300 billion of capital investment per year by 2025."). *See also* Tai H., Samandari H., Pacthod D., Polymeneas E., Bolano A., Prat M. P., & Lodesani F. (2022) THE ENERGY TRANSITION: A REGION-BY-REGION AGENDA FOR NEAR-TERM ACTION, 48 ("However, the current trajectory is not at the pace and scale the global pathway requires to limit warming to 1.5°C. There are six high-priority measures that could be taken to help the United States embark on a more orderly energy transition. . . Securing access to adequate land with high load factors for the deployment of renewables.").

[353] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "Loss of carbon contained in soils and terrestrial systems—primarily due to land-use change— perpetuates the accumulation of carbon in the atmosphere at the same time as it limits the inherent ability of ecosystems to withdraw that same carbon when necessary. Decisive action in the short term can restore lost and degraded habitats, as well as protect the longevity of ecological functions and ecosystem services. With a commitment to long-term funding, protected areas can be properly stewarded. Indigenous knowledge and practices in sustainable land and resource management can also be applied to achieve a net-zero future. There is much to be learnt from Indigenous practices in sustainable resource management; from traditions that dictate taking from the land only what's needed, and only what nature can replace."). *See also* Robertson G. P., Hamilton S. K., Paustian K., & Smith P. (2022) *Land-based Climate Solutions for the United States*, GLOB. CHANGE BIOL. 28: 4912–4919, 4913 ("Efforts to curb emissions of CO2 and other greenhouse gases (GHGs) have fallen well short of those needed to meet the international goal of limiting warming to 1.5 or even 2°C by the end of the century (IPCC, 2018). Consequently, we now face an urgent need for negative emissions technologies (NETs) capable of removing GHGs from the atmosphere. NETs fall into three broad categories (Field & Mach, 2017): improved ecosystem stewardship or nature-based solutions, whereby more carbon is stored in ecosystems via practices like reforestation and afforestation, conservation agriculture, and wetland restoration; biological carbon capture with geologic storage as in bioenergy with carbon capture and storage (BECCS) and ocean fertilization; and non-biological technologies such as enhanced rock weathering and direct air capture. Several NETs, including conservation agriculture and bioenergy, can also contribute to GHG avoidance by substituting renewable inputs for fossil fuel use."); *and* Fargione J. E., *et al.* (2018) *Natural Climate Solutions for the United States*, SCI. ADV. 4(11): 1–14, 1 ("Natural climate solutions (NCS), a portfolio of discrete land stewardship options, are the most mature approaches available for carbon conservation and uptake compared to nascent carbon capture technologies and could complement increases in zero-carbon energy production and energy efficiency to achieve needed climate change mitigation.").

[354] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "CCUS is the process of capturing carbon dioxide emissions at sources like power plants, cement-production facilities, manufacturing operations, and oil sands, and either reusing or storing it so it will not enter the atmosphere. With five large-scale commercial projects now in operation, Canada has the second-largest CCUS capacity in the world. Most CCUS technologies, however, are still in the early stages of development. They would benefit from scaled demonstration and continued innovation to refine the technology and manage costs.").

[355] Robertson G. P., Hamilton S. K., Paustian K., & Smith P. (2022) *Land-based Climate Solutions for the United States*, GLOB. CHANGE BIOL. 28: 4912–4919, 4913 ("Efforts to curb emissions of CO2 and other greenhouse gases (GHGs) have fallen well short of those needed to meet the international goal of limiting warming to 1.5 or even 2°C by the end of the century (IPCC, 2018). Consequently, we now face an urgent need for negative emissions technologies (NETs) capable of removing GHGs from the atmosphere. NETs fall into three broad categories (Field & Mach, 2017): improved ecosystem stewardship or nature-based solutions, whereby more carbon is stored in ecosystems via practices like reforestation and afforestation, conservation agriculture, and wetland restoration; biological carbon capture with geologic storage as in bioenergy with carbon capture and storage (BECCS) and ocean fertilization; and non-biological

technologies such as enhanced rock weathering and direct air capture. Several NETs, including conservation agriculture and bioenergy, can also contribute to GHG avoidance by substituting renewable inputs for fossil fuel use.”).

[356] Robertson G. P., Hamilton S. K., Paustian K., & Smith P. (2022) *Land-based Climate Solutions for the United States*, GLOB. CHANGE BIOL. 28: 4912–4919, 4913 (“Efforts to curb emissions of CO2 and other greenhouse gases (GHGs) have fallen well short of those needed to meet the international goal of limiting warming to 1.5 or even 2°C by the end of the century (IPCC, 2018). Consequently, we now face an urgent need for negative emissions technologies (NETs) capable of removing GHGs from the atmosphere. NETs fall into three broad categories (Field & Mach, 2017): improved ecosystem stewardship or nature-based solutions, whereby more carbon is stored in ecosystems via practices like reforestation and afforestation, conservation agriculture, and wetland restoration; biological carbon capture with geologic storage as in bioenergy with carbon capture and storage (BECCS) and ocean fertilization; and non-biological technologies such as enhanced rock weathering and direct air capture. Several NETs, including conservation agriculture and bioenergy, can also contribute to GHG avoidance by substituting renewable inputs for fossil fuel use.”). *See also* Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) (“Model for a net-zero future in Canada”; (“An area in which Canada is an emerging world leader, clean DAC is contingent on the scale and progress of advancements in this technology. Since DAC consumes energy, its economic and environmental viability depends its proximity to renewable energy sources.”).

[357] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA’S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 6 (Exhibit 4).

[358] Nisbet-Jones P. B. R., Fernandez J. M., Fisher R. E., France J. L., Lowry D., Waltham D. A., Woolley Maisch C. A., & Nisbet E. G. (2021) *Is the destruction or removal of atmospheric methane a worthwhile option?*, PHILOS. TRANS. R. SOC. A 380(2215): 1–12, 5 (“Methane is relatively difficult to oxidize compared to other hydrocarbons. The major destruction options include (i) thermal-catalytic oxidation, which is typically with metal catalysts; (ii) photocatalytic oxidation; (iii) biological uptake by aerobic methanotrophic bacteria or their bio-engineered methane-oxidising enzymes and (iv) removal by uptake on zeolites or porous polymers, with the added benefit of not emitting CO2 waste.”). *See also* Ming T., Li W., Yuan Q., Davies P., de Richter R., Peng C., Deng Q., Yuan Y., Caillol S., & Zhou N. (2022) *Perspectives on removal of atmospheric methane*, ADV. APPL. ENER. 5(100086): 1–9, 1 (“This article reviews proposed methods for atmospheric methane removal at a climatically significant scale. These methods include enhancement of natural hydroxyl and chlorine sinks, photocatalysis in solar updraft towers, zeolite catalyst in direct air capture devices, and methanotrophic bacteria.”).

[359] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) (“Model for a net-zero future in Canada”; “Canada must invest more in technologies that improve energy efficiencies for transportation, buildings, industrial, and agricultural and forestry operations. Near-term investment in sustainable retrofits for buildings and homes will be needed to improve that resilience to climate events. Policies to incentivize both residential and commercial retrofits can be accelerated and expanded to encourage the widespread adoption of technology that improves energy efficiencies in buildings.”; “Canada must invest more in technologies that improve energy efficiencies for transportation, buildings, industrial, and agricultural and forestry operations. Policies to incentivize both eco-friendly retrofits can be expanded to accelerate the adoption of technology that improves energy efficiencies in buildings.”). *See also* Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA’S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 2 (“Reducing emissions from existing facilities and infrastructure is a major part of the decarbonization agenda. Much of the necessary reduction can come from retrofitting emissions-intensive assets, such as chemical, manufacturing, and power plants, through electrification, the use of low-emissions energy sources (such as hydrogen and biofuels), and carbon capture.”).

[360] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA’S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 2 (“Reducing emissions from existing facilities and infrastructure is a major part of the decarbonization agenda. Much of the necessary reduction can come from retrofitting emissions-intensive assets, such as chemical, manufacturing, and power plants, through electrification, the use of low-emissions energy sources (such as hydrogen and biofuels), and carbon capture.”).

[361] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 10 ("As mentioned earlier, hundreds of US-based companies have set net-zero targets for themselves. Many of these targets apply to the emissions from not only their own operations but also their suppliers and the use of their products. Similarly, the White House issued an executive order in December 2021, calling for the federal government to buy zeroemissions goods and services in categories ranging from electricity to vehicles to building materials. Commitments such as these could put pressure on businesses to decarbonize, even if they themselves have not yet set emissions targets (Exhibit 7).").

[362] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "Turning electricity into a major source of power will require more infrastructure support and investment, like expanding and modernizing electricity grids to make widespread electric vehicle use affordable. Increased investments in electric buses and rail could encourage cleaner-energy transit systems.").

[363] Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 5–6, 12 ("Some changes will be possible only if other entities also make changes; for example, mass uptake of electric vehicles depends significantly on the utility sector expanding grid capacity to support charging networks. In these cases, companies may find it helpful to join other organizations in addressing shared needs, such as the need for industrial-scale networks in hydrogen production and distribution.").

[364] Environment and Climate Change Canada (2017) STRATEGY ON SHORT-LIVED CLIMATE POLLUTANTS – 2017, 8 ("Based on an assessment of current measures related to black carbon emissions, key mitigation gaps for black carbon include existing on- and off-road mobile diesel sources, stationary diesel engines and wood-burning appliances. In the case of on- and off- road mobile diesel sources, current federal regulatory measures focus on fuels as well as new vehicles and engines. These have and will continue to result in black carbon emission reductions as fleets turn over. However, due to the long lifetimes of diesel vehicles, turnover of the in-use fleet is slow, and fleets are still dominated by engines pre-dating the most recent emissions standards. Although some provinces and territories have implemented measures focusing on existing vehicles, on- and off- road diesel vehicles and engines continue to be Canada's largest source of black carbon emissions.").

[365] Balafoutis A., Beck B., Fountas S., Vangeyte J., van der Wal T., Soto I., Gómez-Barbero M., Barnes A., & Eory V. (2017) *Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics*, SUSTAINABILITY 9(8): 1339, 1–28, 9 ("Tekin (2010) estimated that VRNA can increase wheat production between 1% and 10% offering savings in nitrogen fertilisation between 4% and 37%."). *See also* Butler A. H., Daniel J. S., Portmann R. W., Ravishankara A. R., Young P. J., Fahey D. W., & Rosenlof K. H. (2016) *Diverse policy implications for future ozone and surface UV in a changing climate*, ENV. RES. LETT. 11(6): 064017, 1–7, 4 ("A key point is that if the world were to achieve reductions of CO2 and CH4 concentrations to RCP 2.6 levels, N2O mitigation would become important to avoid exacerbation of both climate change and ozone layer depletion.").

[366] Deloitte, *How Canada can decarbonize by 2050* (*last visited* 28 June 2023) ("Model for a net-zero future in Canada"; "Canada must invest more in technologies that improve energy efficiencies for transportation, buildings, industrial, and agricultural and forestry operations."). *See also* Clune R., Corb L., Glazener W., Henderson K., Pinner D., & Walter D. (2022) NAVIGATING AMERICA'S NET-ZERO FRONTIER: A GUIDE FOR BUSINESS LEADERS, McKinsey Sustainability, 6 (Exhibit 4).

[367] Pérez-Domínguez I., del Prado A., Mittenzwei K., Hristov J., Frank S., Tabeau A., Witzke P., Havlik P., van Meijl H., Lynch J., Stehfest E., Pardo G., Barreiro-Hurle J., Koopman J. F. L., & Sanz-Sánchez M. J. (2021) *Short- and Long-term Warming Effects of Methane May Affect the Cost-effectiveness of Mitigation Policies and Benefits of Low-meat Diets*, NAT. FOOD 2: 970–980, 970 ("Methane's short atmospheric life has important implications for the design of global climate change mitigation policies in agriculture. Three different agricultural economic models are used to explore how short- and long-term warming effects of methane can affect the cost-effectiveness of mitigation policies and dietary transitions. Results show that the choice of a particular metric for methane's warming potential is key to

determine optimal mitigation options, with metrics based on shorter-term impacts leading to greater overall emission reduction. Also, the promotion of low-meat diets is more effective at reducing greenhouse gas emissions compared to carbon pricing when mitigation policies are based on metrics that reflect methane's long-term behaviour. A combination of stringent mitigation measures and dietary changes could achieve substantial emission reduction levels, helping reverse the contribution of agriculture to global warming.").

[368] Environment and Climate Change Canada (2017) STRATEGY ON SHORT-LIVED CLIMATE POLLUTANTS – 2017, 10 ("Forthcoming federal, provincial and territorial measures under development to address oil and gas sources will address the largest mitigation gap for this SLCP. The key remaining mitigation gaps for methane are for municipal solid waste landfills and agriculture sources (enteric fermentation in particular).").

[369] Lin J., Khanna N., Liu X., Wang W., Gordon J., & Dai F. (2022) *Opportunities to Tackle Short-lived Climate Pollutants and Other Greenhouse Gases for China*, SCI. TOTAL ENVIRON. 842(156842): 1–17, 11 ("Outside of the energy sector, the United States has also seen some federal and state action in reducing methane emissions from landfills. In 2010, the California Air Resources Board adopted a rule requiring methane controls on all landfills with >450 tons of waste in place, restricting flares, and requiring ongoing monitoring and reporting mandates for all landfills (California Air Resources Board, 2021a). California's 2015 SLCP Bill (SB-1383) also included quantitative goals for diverting organic waste from landfills to reduce methane emissions (California Senate, 2016b).").

[370] Environment and Climate Change Canada (2017) STRATEGY ON SHORT-LIVED CLIMATE POLLUTANTS – 2017, 10 ("Forthcoming federal, provincial and territorial measures under development to address oil and gas sources will address the largest mitigation gap for this SLCP. The key remaining mitigation gaps for methane are for municipal solid waste landfills and agriculture sources (enteric fermentation in particular).").

[371] Lin J., Khanna N., Liu X., Wang W., Gordon J., & Dai F. (2022) *Opportunities to Tackle Short-lived Climate Pollutants and Other Greenhouse Gases for China*, SCI. TOTAL ENVIRON. 842 (156842): 1–17, 11 ("Outside of the energy sector, the United States has also seen some federal and state action in reducing methane emissions from landfills. In 2010, the California Air Resources Board adopted a rule requiring methane controls on all landfills with >450 tons of waste in place, restricting flares, and requiring ongoing monitoring and reporting mandates for all landfills (California Air Resources Board, 2021a).").

[372] Moomaw W. R., Masino S. A., & Faison E. K. (2019) *Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good*, FRONT. FOR. GLOB. CHANGE 2(27): 1–10, 1 ("The recent 1.5 Degree Warming Report by the Intergovernmental Panel on Climate Change identifies reforestation and afforestation as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land, and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential—termed proforestation—is a more effective, immediate, and low-cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation, and scenic beauty.").

[373] Penniman L. (2021) *Black Gold*, *in* ALL WE CAN SAVE: TRUTH, COURAGE, AND SOLUTIONS FOR THE CLIMATE CRISIS, Johnson A. E. & Wilkinson K. K. (eds.), One World, 305 ("Our ancestral practices are bolstered by Western science and listed among the most substantive solutions to global warming, per Project Drawdown's analysis….").

[374] Sobrevilla C. (2008) THE ROLE OF INDIGENOUS PEOPLE IN BIODIVERSITY CONSERVATION: *THE NATURAL BUT OFTEN FORGOTTEN PARTNERS*, World Bank, xii ("Traditional Indigenous Territories encompass up to 22 percent of the world's land surface and they coincide with areas that hold 80 percent of the planet's biodiversity. Also, the greatest diversity of indigenous groups coincides with the world's largest tropical forest wilderness areas in the Americas (including Amazon), Africa, and Asia, and 11 percent of world forest lands are legally owned by Indigenous Peoples and communities. This convergence of biodiversity-significant areas and indigenous territories presents an enormous opportunity to expand efforts to conserve biodiversity beyond parks, which tend to benefit from most of the funding

for biodiversity conservation”). *See also* United Nations Department of Economic and Social Affairs (2021) STATE OF THE WORLD’S INDIGENOUS PEOPLES: *RIGHTS TO LANDS, TERRITORIES AND RESOURCES*, ST/ESA/375, 163 (“According to a World Bank report, traditional indigenous territories constitute up to 22 per cent of the world’s land surface.540 A recent report maintains that indigenous peoples and local communities customarily claim and manage more than 50 per cent of the world’s land but legally own just 10 per cent, which means that at least 40 per cent of the world’s land — around 5 billion hectares — remains unprotected and vulnerable to commercial pressures, including land-grabbing by powerful entities such as Governments and corporations, as well as environmental destruction.”).

[375] Veit P., Gibbs D., & Reytar K. (6 January 2023) *Indigenous Forests Are Some of the Amazon’s Last Carbon Sinks*, WORLD RESOURCES INSTITUTE (“Our analysis of carbon emissions and removals finds that Indigenous forests in all nine Amazonian countries were net carbon sinks between 2001 and 2021, collectively emitting an average of 120 million tonnes of CO_2e per year and removing 460 million tonnes CO_2/year, making them a net sink of 340 million tonnes of CO_2e/year.[4] However, the relative magnitudes of emissions and removals — known as carbon fluxes — varied greatly between countries.”).

[376] Stevens C., Winterbottom R., Springer J., & Raytar K. (2014) SECURING RIGHTS, COMBATING CLIMATE CHANGE, World Resources Institute & Rights and Resources Initiative, 10 (“There is strong evidence that strengthening community forest rights is associated with healthy forests. For example, a recent study measured carbon in 30 community forests over three to four years, covering Guinea Bissau, India, Mali, Nepal, Papua New Guinea, Senegal, and Tanzania. The 30 community forests showed an overall average increase in forest carbon storage of 4.9 tonnes per hectare per year.16 In three forests, total carbon stock decreased due to illegal clear-cutting for cropland by non-community members.17 A separate analysis of 80 forests in 10 countries across Latin America, East Africa, and South Asia found that community forest management is associated with high levels of carbon storage.18”). *See also* Rights and Resources Initiative (2015) WHO OWNS THE WORLD’S LAND? A GLOBAL BASELINE OF FORMALLY RECOGNIZED INDIGENOUS AND COMMUNITY LAND RIGHTS, 22 (“The success of policies to mitigate climate change and promote forest restoration also hinge on secure community tenure. Comparative global research has found that legal forest rights for Indigenous Peoples and local communities and government protection of those rights tend to lower deforestation and carbon emissions, whereas deforestation rates tend to be higher where communities’ land rights are not secure.192”); *and* United Nations Department of Economic and Social Affairs (2021) STATE OF THE WORLD’S INDIGENOUS PEOPLES: *RIGHTS TO LANDS, TERRITORIES AND RESOURCES*, ST/ESA/375, 27 (“Recognizing indigenous rights to lands, territories and resources can contribute to political stability, economic growth and sustainable development at the broader global level. Acknowledgement of such rights carries environmental benefits. It has been noted that recognizing the rights of indigenous peoples to lands, territories and resources promotes the protection of ecosystems, waterways, biological diversity, and the general maintenance of natural resources.92 Respect for such rights can actually contribute to the reduction of carbon emissions from deforestation. Studies point to lower deforestation in forests that are inhabited by indigenous peoples and in which their relevant rights are recognized.93 Evidence of the relationship between indigenous peoples and their lands, territories and resources suggests that acknowledgement of and respect for indigenous rights in this regard would likely be conducive to promoting the Sustainable Development Goals.94”).

[377] Stevens C., Winterbottom R., Springer J., & Raytar K. (2014) SECURING RIGHTS, COMBATING CLIMATE CHANGE, World Resources Institute & Rights and Resources Initiative, 27 (“These findings are supported by a WRI deforestation analysis for the Brazilian Amazon. From 2000 to 2012, forest loss was only 0.6 percent inside Indigenous Lands compared with 7.0 percent outside. (See Figure 4.) Figure 5 shows a section of the Brazilian Amazon under intense deforestation pressure. Forest loss between 2000 and 2012 is clustered close to, but rarely inside, the borders of Indigenous Lands.”).

[378] Stevens C., Winterbottom R., Springer J., & Raytar K. (2014) SECURING RIGHTS, COMBATING CLIMATE CHANGE, World Resources Institute & Rights and Resources Initiative, 29 (“The Brazilian government generally protects Indigenous Peoples’ forest rights, but Indigenous Peoples often forcefully defend their own forest by expelling loggers, ranchers, and other intruders.67 Indigenous Lands are the only areas of the Amazon with roads cutting across them that have not succumbed to deforestation.68 The roads do not always go around Indigenous Lands, but the deforestation does. As a result, community forests in the Brazilian Amazon tend to be relatively carbon-rich,

containing 36 percent more carbon per hectare than areas of the Brazilian Amazon outside Indigenous Lands (see Figure 4).69 WRI analysis of deforestation and carbon stock found that 27 times more CO2 emissions were produced outside Indigenous Lands than inside from 2000 to 2012. Forest cover loss of 22.5 million hectares in the Brazilian Amazon outside Indigenous Lands resulted in 8.7 billion tonnes of CO2 emitted during those years. In the same period, 311 million tonnes of CO2 emissions were produced from deforestation of about 677,000 hectares of forest on Indigenous Lands.").

[379] Stevens C., Winterbottom R., Springer J., & Raytar K. (2014) SECURING RIGHTS, COMBATING CLIMATE CHANGE, World Resources Institute & Rights and Resources Initiative, 29 ("Brazil's Indigenous Lands therefore play a significant role in keeping CO2 emissions from the atmosphere. One estimate suggests that Indigenous Lands and government-protected areas in the Brazilian Amazon could prevent 27.2 million hectares of deforestation by 2050, an area slightly larger than the United Kingdom. If the carbon in this large forest area were emitted as CO2 , it would amount to approximately 12 billion tonnes of CO2 70—the equivalent of about three years' worth of CO2 emissions from all Latin American and Caribbean countries.71").

[380] Intergovernmental Panel on Climate Change (2019) *Summary for Policymakers*, *in* THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *Special Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., *et al.* (eds.), SPM-30 ("Restoration of vegetated coastal ecosystems, such as mangroves, tidal marshes and seagrass meadows (coastal 'blue carbon' ecosystems), could provide climate change mitigation through increased carbon uptake and storage of around 0.5% of current global emissions annually (*medium confidence*). Improved protection and management can reduce carbon emissions from these ecosystems.").

[381] Soares M. O., Bezerra L. E. A., Copertino M., Lopes B. D., de Souza Barros K. V., Rocha-Barreira C. A., Maia R. C., Beloto N., & Cotovicz Jr. L. C. (2022) *Blue Carbon Ecosystems in Brazil: Overview and an Urgent Call for Conservation and Restoration*, FRONT. MAR. SCI. 9: 1–16, 1 ("While terrestrial ecosystems have been the focus of nature-based solutions, the role of coastal and marine ecosystems remains unaccounted for in several national emission inventories and not included in the National Determined Contributions (NDC) (Duarte, 2017). Over the last decade, ocean and terrestrial ecosystems have sequestered approximately 52% of anthropogenic CO_2 emissions, with average rates of approximately 2.5 ± 0.6 and 3.4 ± 0.9 GtC year^{-1}, respectively (Friendlingstein et al., 2019). However, some processes and ecosystems, such as coastal areas, are not fully accounted for in the global carbon budget. The CO_2 that is captured from the atmosphere and sequestered in coastal and marine environments, mostly vegetated ecosystems such as mangroves, salt marshes, and seagrass meadows, is collectively known as blue carbon (BC) and consists of both organic and inorganic forms (Nellemann et al., 2009).").

[382] National Oceanic and Atmospheric Administration, *Coastal Blue Carbon* (*last visited* 15 June 2023) ("Current studies suggest that mangroves and coastal wetlands annually sequester carbon at a rate ten times greater than mature tropical forests. They also store three to five times more carbon per equivalent area than tropical forests. Most coastal blue carbon is stored in the soil, not in above-ground plant materials as with tropical forests.").

[383] Chatting M., Al-Maslamani I., Walton M., Skov M. W., Kennedy H., Husrevoglu Y. S., & Le Vay L. (2022) *Future Mangrove Carbon Storage Under Climate Change and Deforestation*, FRONT. MAR. SCI. 9: 1–14, 7 ("Our projections showed that, globally, increases in total C stocks (biomass + soil) induced by climate change would exceed emissions from mangrove deforestation between 2012 and 2095 (Table 3). Under a "business as usual" climate scenario these net gains represent an increase of 7.05 ± 7.89% (SSP245) or 7.71 ± 9.47% under a high-end scenario (SSP585) of present day global total C stocks. Total global losses from mangrove deforestation from 2012 to 2095 (Table 1) were estimated to be 61.4 ± 10.1% (SSP245) or 55.6 ± 9.1% (SSP585) of the potential gains in C stocks due to climate change. In contrast, CSR were forecast to decline by 2.60 ± 3.57% under scenario SSP245 and by 6.44 ± 3.63% under scenario SSP585 (Table 1).").

[384] The Economist Group (8 November 2021) *Checking in on ocean-based climate solutions*, ECONOMIST IMPACT, 5–6 ("The potential of the ocean for accelerating decarbonisation, however, merits increased priority in the global climate-change discourse. The High-Level Panel for a Sustainable Ocean Economy (HLP), a multilateral group comprising representatives from 14 oceanic countries, estimates that by 2050 ocean-based climate mitigation and

carbon storage options could make up 21% of the emissions reductions needed to limit global warming to 1.5°C.7 Put differently, this equates to more than all current global emissions from coal-fired power plants worldwide.").

[385] United Nations Framework Convention on Climate Change, *What is REDD+* (*last visited* 18 July 2023) ("'REDD' stands for 'Reducing emissions from deforestation and forest degradation in developing countries. The '+' stands for additional forest-related activities that protect the climate, namely sustainable management of forests and the conservation and enhancement of forest carbon stocks.").

[386] United Nations Framework Convention on Climate Change, *What is REDD+* (*last visited* 18 July 2023) ("The REDD+ Success Story… The UN Climate Change secretariat has been undertaking REDD+ technical assessments for 10 years. In total, 60 developing countries have reported REDD+ activities to the UN Climate Change secretariat. As a result of REDD+ activities, 14 of these countries reported a reduction of almost 11 billion tons of carbon dioxide, almost twice the amount of net greenhouse gas emissions from the United States in 2021, and are now eligible to seek results-based finance.").

[387] United Nations-REDD Programme, *REDD+ MRV and results-based payments* **(***last visited* 18 July 2023) ("In this context, the COP affirmed that the progression of developing country Parties towards results-based actions occurs in the context of the provision of adequate and predictable support for all phases of REDD+ implementation. The COP also reaffirmed that results-based finance provided to developing country Parties for the full implementation of REDD+ may come from a variety of sources, public and private, bilateral and multilateral, including alternative sources.").

[388] United Nations-REDD Programme, *Lima REDD+ Information Hub* (*last visited* 18 July 2023) (See table column title "Entity paying for results" to review groups that are financing results of REDD+ projects).

[389] United Nations-REDD Programme (2013) GUIDELINES ON FREE, PRIOR AND INFORMED CONSENT, Food and Agriculture Organization, United Nations Development Programme, & United Nations Environment Program, 11 ("Consistent with international law, States are required to recognize and carry out their duties and obligations to give effect to the requirement of FPIC as applicable to indigenous peoples; and recognizing the right of forest-dependent communities to effectively participate in the governance of their nations, at a minimum States are required to consult forest-dependent communities in good faith regarding matters that affect them *with a view to agreement*. Appreciating that international law, jurisprudence and State practice is still in its infancy with respect to *expressly* recognizing and requiring an affirmative obligation to secure FPIC from all forest-dependent communities, a blanket application of FPIC is not required for all forest-dependent communities… States should evaluate the circumstances and nature of the forest-dependent community in question, on a case by case basis, through among others a rights-based analysis, and secure FPIC from communities that share common characteristics with indigenous peoples and whose underlying substantive rights are significantly implicated.").

[390] Barletti J. P. S., Vigil N. H., & Larson A. M. (2023) *Safeguards at a glance: Are voluntary standards supporting community land, resource and carbon rights?*, Center for International Forestry Research & International Center for Research in Agroforestry, 2 ("Critics and grassroots sceptics (e.g. the 'No rights, no REDD' movement) centred on two key issues: the potential restrictions in communities' access to forests and forest resources – including potential land grabbing associated with REDD+ as a new source of income – and the attribution of carbon rights that would allow for the commercialization of emission reductions (Corbera et al. 2011; Patel et al. 2013).").

[391] Barletti J. P. S., Vigil N. H., & Larson A. M. (2023) *Safeguards at a glance: Are voluntary standards supporting community land, resource and carbon rights?*, Center for International Forestry Research & International Center for Research in Agroforestry, 4 ("Physical and/or economic displacement is to be "avoided" rather than prohibited and, in most cases, displacements are only considered as such if they involve formally recognized communities. Most standards require compensation or restitution for resettlement that improves or at least restores livelihood levels, although not all require consultations with the affected groups to inform or guide these processes, which, for IPs, infringes upon UNDRIP-recognized rights to self-determination.").

[392] Barletti J. P. S., Vigil N. H., & Larson A. M. (2023) *Safeguards at a glance: Are voluntary standards supporting community land, resource and carbon rights?*, Center for International Forestry Research & International Center for Research in Agroforestry, 4 ("Scheba and Rakotonarivo (2016) report REDD+-related land-use conflicts in Tanzania as part of the wider REDD+ effort. Raftopoulos (2016) reports on one REDD+ project that led to the enclosure of common forests, sparking conflicts between and within villages over land ownership and access; this followed an announcement that community compensation would depend on the area of forest protected (see Ngendakumana et al. (2013) for a similar case in Cameroon). In this context, Beymer-Farris et al. (2012) reveal how punitive conservation efforts have been supported by a discourse that portrays Indigenous Peoples as recent migrants that destroy forests, reflecting a complex and contested history regarding both indigeneity and migration."). *See also* Bezner Kerr R., Hasegawa T., Lasco R., Bhatt I., Deryng D., Farrell A., Gurney-Smith H., Ju H., Lluch-Cota S., Meza F., Nelson G., Neufeldt H., & Thornton P. (2022) *Chapter 5: Food, Fibre, and Other Ecosystem Products*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 5-757 (Table 5.8 Challenges and solutions for REDD+).

[393] Barletti J. P. S., Vigil N. H., & Larson A. M. (2023) *Safeguards at a glance: Are voluntary standards supporting community land, resource and carbon rights?*, Center for International Forestry Research & International Center for Research in Agroforestry, 2 ("Critics and grassroots sceptics (e.g. the 'No rights, no REDD' movement) centred on two key issues: the potential restrictions in communities' access to forests and forest resources – including potential land grabbing associated with REDD+ as a new source of income – and the attribution of carbon rights that would allow for the commercialization of emission reductions (Corbera et al. 2011; Patel et al. 2013).").

[394] Barletti J. P. S., Vigil N. H., & Larson A. M. (2023) *Safeguards at a glance: Are voluntary standards supporting community land, resource and carbon rights?*, Center for International Forestry Research & International Center for Research in Agroforestry, 1 ("Despite mention of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) in UNFCCC decisions regarding REDD+, including the Cancun safeguards, initiatives have not placed importance on the wide scope of rights it recognizes; if respect for UNDRIP were more central – with specific requirements and indicators to monitor progress – standards could catalyse a rights-responsive transformation in climate actions."). *See also* United Nations-REDD Programme (2013) GUIDELINES ON FREE, PRIOR AND INFORMED CONSENT, Food and Agriculture Organization, United Nations Development Programme, & United Nations Environment Program, 15 ("Further, in the context of REDD+, although the term 'FPIC' is not expressly referred to in the Cancun Agreements or in the Appendix on REDD+ safeguards, FPIC is addressed indirectly because the text 'note[s]' that the General Assembly has adopted UNDRIP (which itself sets out the principle of FPIC). Securing FPIC is a means to meet the Cancun Agreements' requirement of countries to promote and support 'respect for the knowledge and rights of indigenous peoples and members of local communities' and to ensure 'the full and effective participation of relevant stakeholders, inter alia, indigenous peoples and local communities.'").

[395] *See* World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 16 ("A large area centred around the central-northern part of Argentina, southern Bolivia, central Chile, and most of Paraguay and Uruguay experienced record-breaking temperatures during two consecutive heatwaves in late November and early December 2022. In Chile, forest fires caused significant damage to the flora and fauna after the burning of the Chilean Palm, a species native to the Valparaíso region.58 In the Bolivian Amazon, during the heatwave from 25 to 30 November, the city of Cobija recorded 37.7 °C on 28 November (the mean monthly maximum is 30.8 °C).59"); *and* World Meteorological Organization (2022) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2021, No. 1295, 20 ("Heatwaves were reported in many parts of the LAC region. In Argentina, several locations recorded 6–8 days in a row with heatwave conditions. An all-time temperature record was set in Cipolletti (43.8 °C) and Maquinchao (38.9 °C) on 22 January.[55] In west-central Brazil, in August 2021, exceptionally high temperatures were reported[56] over several days. For example, in Cuiabá, in the state of Mato Grosso, maximum temperatures reached 41 °C on 24 and 25 August (about 7 °C above normal), accompanied by critically low humidity levels, mainly in the central regions (relative humidity of approximately 8%–11%). On 21 September, Aragarças/Goiás reached 43.0 °C, the highest value for September at this station (the previous highest value was 41.5 °C on 14 September 2019). In Chile, up to 18 heatwave episodes during the year affected different

regions of the country.[57] Some of them were very intense, including those that affected the Santiago region from 11 to 13 April (with a maximum temperature of 31.4 °C), and Valdivia from 2 to 5 February (37.3 °C) and then from 7 to 10 February (35.1 °C). On 27 February, Puerto Williams, Chile (considered the southern-most town in the world), registered its highest temperature on record, since 1961, of 26.1 °C (the previous record being 26.0 °C on 22 December 1984).[58] In Paraguay, a heatwave occurred from 18 to 20 September, with temperatures reaching 38.2 °C in Pedro Juan Caballero. In Peru, on 13 April, Jepelacio (northern Amazonia) reached 34.2 °C (the previous highest temperature was 33.6 °C on 23 November 2016).").

[396] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1708 (Table 12.2).

[397] World Weather Attribution (21 December 2022) *Climate change made record breaking early season heat in Argentina and Paraguay about 60 times more likely* ("The 2022 heatwave has led to large-scale power outages, wildfires and, in combination with the ongoing drought, poor harvests. It is estimated to have led to an increase in heat-related deaths, with the impacts unequally distributed across In different cities and municipalities across South America, people living in some areas – often poorer neighbourhoods – experience higher temperatures than others, as they lack green space, adequate thermal insulation from heat, electricity, shade, and water which can be lifelines during heatwaves…. We find that human-caused climate change made the event about 60 times more Alternatively, a heatwave with a similar probability would be about 1.4°C less hot in a world that had not been warmed by human activities."); *discussing* Rivera J. A., *et al.* (2022) CLIMATE CHANGE MADE RECORD BREAKING EARLY SEASON HEAT IN ARGENTINA AND PARAGUAY ABOUT 60 TIMES MORE LIKELY, World Weather Attribution.

[398] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 17 ("The prolonged dry conditions associated with high temperatures led to record wildfires in January and February in Argentina and Paraguay. There was an increase of 283% and 258%, respectively, in the number of hotspots detected when compared to the 2001–2021 average.61 From January to March 2022, wildfire emissions were the highest in the last 20 years in Paraguay and northern Argentina.").

[399] World Weather Attribution (21 December 2022) *Climate change made record breaking early season heat in Argentina and Paraguay about 60 times more likely* ("With future global warming, heatwaves like this will become even more common and hotter. If global mean temperatures rise an additional 8°C, to a total warming of 2°C, a heatwave as hot as this one would be about 4 times more likely than it is now, while a heatwave that happens approximately once in 20 years would be 0.7-1.2°C hotter than this one."); *discussing* Rivera J. A., *et al.* (2022) CLIMATE CHANGE MADE RECORD BREAKING EARLY SEASON HEAT IN ARGENTINA AND PARAGUAY ABOUT 60 TIMES MORE LIKELY, World Weather Attribution.

[400] United States Environmental Protection Agency (1 August 2022) *Climate Change Indicators: Heat Waves* (Figure 1).

[401] Government of Canada (24 January 2022) *Extreme heat events: Overview* ("Many places in Canada face extreme heat events, often called "heat waves." These events involve high temperatures and high humidity. A changing climate can mean longer and more intense heat events that can be dangerous for your health. Heat events frequently cause death. Heat wave tragedies have killed more than: … 595 people in British Columbia (2021)…")

[402] White R. H., *et al.* (2023) *The unprecedented Pacific Northwest heatwave of June 2021*, NAT. COMMUN. 14(727): 1–20, 1 ("In late June 2021 a heatwave of unprecedented magnitude impacted the Pacific Northwest region of Canada and the United States. Many locations broke all time maximum temperature records by more than 5 °C, and the Canadian national temperature record was broken by 4.6 °C, with a new record temperature of 49.6 °C. Here, we provide a comprehensive summary of this event and its impacts. Upstream diabatic heating played a key role in the

magnitude of this anomaly. Weather forecasts provided advanced notice of the event, while sub-seasonal forecasts showed an increased likelihood of a heat extreme with lead times of 10-20 days. The impacts of this event were catastrophic, including hundreds of attributable deaths across the Pacific Northwest, mass mortalities of marine life, reduced crop and fruit yields, river flooding from rapid snow and glacier melt, and a substantial increase in wildfires—the latter contributing to landslides in the months following. These impacts provide examples we can learn from and a vivid depiction of how climate change can be so devastating.").

[403] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-10 ("It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006."). *See also* Kotz M., Wenz L., & Levermann A. (2021) *Footprint of greenhouse forcing in daily temperature variability*, PROC. NAT'L. ACAD. SCI. 118(32): 1–8, 1 ("Assessing historical changes to daily temperature variability in comparison with those from state-of-the-art climate models, we show that variability has changed with distinct global patterns over the past 65 years, changes which are attributable to rising concentrations of greenhouse gases. If these rises continue, temperature variability is projected to increase by up to 100% at low latitudes and decrease by 40% at northern high latitudes by the end of the century.").

[404] World Weather Attribution (21 December 2022) *Climate change made record breaking early season heat in Argentina and Paraguay about 60 times more likely* ("The 2022 heatwave has led to large-scale power outages, wildfires and, in combination with the ongoing drought, poor harvests. It is estimated to have led to an increase in heat-related deaths, with the impacts unequally distributed across In different cities and municipalities across South America, people living in some areas – often poorer neighbourhoods – experience higher temperatures than others, as they lack green space, adequate thermal insulation from heat, electricity, shade, and water which can be lifelines during heatwaves…. We find that human-caused climate change made the event about 60 times more Alternatively, a heatwave with a similar probability would be about 1.4°C less hot in a world that had not been warmed by human activities."); *discussing* Rivera J. A., *et al.* (2022) CLIMATE CHANGE MADE RECORD BREAKING EARLY SEASON HEAT IN ARGENTINA AND PARAGUAY ABOUT 60 TIMES MORE LIKELY, World Weather Attribution.

[405] Hartinger S. M., *et al.* (2023) *The 2022 South America report of The Lancet Countdown on health and climate change: trust the science. Now that we know, we must act*, LANCET REG. HEALTH AM. 20(100470): 1–35, 20 ("Population exposure to wildfire danger has increased in the past decade driven by the high temperatures and increased incidence of drought in many areas, making wildfire occurrence and spread more likely, and hampering control efforts. This is particularly relevant in SA, which faces a dangerous interplay between intentional human-made wildfires -more closely linked to land use changes and deforestation, as in the Amazon, the Pantanal, and El Chaco - as well as climate-driven ones, such as the 2022's wildfire in Argentina, and Paraguay. Regionally, the population exposure to very high or extremely high wildfire danger in SA has increased in nine of out 12 countries, with a regional average increase of seven more days in 2018–2021 compared to the baseline. However, the number of exposure days across countries vary, Uruguay, Paraguay saw an increase of 3-4 exposure days, vs Argentina and Chile 14–20 days of exposure (indicator 1.2)").

[406] World Meteorological Organization (2022) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2021, No. 1295, 14 ("The 2021 Atlantic hurricane season was very active, with 21 named storms – well above the 1981–2010 average of 14 – including seven hurricanes, of which four were major hurricanes. With about US$ 80 billion in damage (much of which occurred in the United States of America, associated with Hurricane Ida), it was also one of the costliest seasons. It was the sixth consecutive above-normal Atlantic hurricane season and the seventh consecutive year with a named storm forming before the official start to the season on 1 June (Tropical Storm Ana formed on 22 May). On 30 June, Tropical Storm Elsa (later Hurricane Elsa) became the earliest fifth named storm on record. Hurricane Elsa would become the first hurricane of the season on 2 July, and affected several territories in the

Caribbean, including Barbados, Saint Lucia, Saint Vincent and the Grenadines, Martinique, the Dominican Republic, Haiti, Jamaica, the Cayman Islands and Cuba, before moving into Florida/United States.[26]").

[407] World Meteorological Organization (2022) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2021, No. 1295, 14 ("The 2021 Atlantic hurricane season was very active, with 21 named storms – well above the 1981–2010 average of 14 – including seven hurricanes, of which four were major hurricanes. With about US$ 80 billion in damage (much of which occurred in the United States of America, associated with Hurricane Ida), it was also one of the costliest seasons. It was the sixth consecutive above-normal Atlantic hurricane season and the seventh consecutive year with a named storm forming before the official start to the season on 1 June (Tropical Storm Ana formed on 22 May). On 30 June, Tropical Storm Elsa (later Hurricane Elsa) became the earliest fifth named storm on record. Hurricane Elsa would become the first hurricane of the season on 2 July, and affected several territories in the Caribbean, including Barbados, Saint Lucia, Saint Vincent and the Grenadines, Martinique, the Dominican Republic, Haiti, Jamaica, the Cayman Islands and Cuba, before moving into Florida/United States.[26]").

[408] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1751 ("The most common climatic drivers include tropical storms and hurricanes, heavy rains, floods and droughts. Positive climatic conditions also can facilitate migration. Peru, Colombia and Guatemala are among the countries with the largest average displacements caused by hydro-meteorological causes; Brazil had 295,000 people displaced because of disasters in 2019.... Hurricanes have been seen as positive triggers for international migration in CA. The highlands of Peru see different patterns, including daily circular migration to combine the scarce income from agricultural production with urban income, rather than abandoning farm land." (citations omitted)).

[409] Smith A. B. (24 January 2022) *2021 U.S. billion-dollar weather and climate disasters in historical context*, Beyond the Data, CLIMATE.GOV ("In broader context, the total cost of U.S. billion-dollar disasters over the last 5 years (2017-2021) is $742.1 billion, with a 5-year annual cost average of $148.4 billion, both of which are new records and nearly triple the 42-year inflation adjusted annual average cost. The U.S. billion-dollar disaster damage costs over the last 10-years (2012-2021) were also historically large: at least $1.0 trillion from 142 separate billion-dollar events. It is concerning that 2021 was another year in a series of years where we had a high frequency, a high cost, and large diversity of extreme events that affect people's lives and livelihoods—concerning because it hints that the extremely high activity of recent years is becoming the new normal. 2021 (red line) marks the seventh consecutive year (2015-21) in which 10 or more separate billion-dollar disaster events have impacted the U.S. The 1980–2021 annual average (black line) is 7.4 events (CPI-adjusted); the annual average for the most recent 5 years (2017–2021) is 17.2 events (CPI-adjusted).").

[410] George Washington University (2018) ASCERTAINMENT OF THE ESTIMATED EXCESS MORTALITY FROM HURRICANE MARÍA IN PUERTO RICO, Milken Institute School of Public Health, 9 ("Results from the preferred statistical model, shown below, estimate that excess mortality due to Hurricane María using the displacement scenario is estimated at 1,271 excess deaths in September and October (95% CI: 1,154-1,383), 2,098 excess deaths from September to December (95% CI: 1,872-2,315), and, 2,975 (95% CI: 2,658-3,290) excess deaths for the total study period of September 2017 through February 2018."). *See also* Rodríguez-Madera S. L., Varas-Díaz N., Padilla M., Grove K., Rivera-Bustelo K., Ramos J., Contreras-Ramirez V., Rivera-Rodríguez S., Vargas-Molina R., & Santini J. (2021) *The impact of Hurricane Maria on Puerto Rico's health system: post-disaster perceptions and experiences of health care providers and administrators*, GLOB. HEALTH RES. POLICY 6(44): 2 ("The published literature addressing the efects of Hurricane Maria on the Island has exposed the severe vulnerabilities of its health care system [15–19], including lethal gaps in access to medication by patients with chronic diseases (e.g., renal disease, diabetes, respiratory diseases) [11, 20–24] and the interruption of life-sustaining treatments (e.g., dialysis, chemotherapy) [3, 15, 16]. In fact, these failures were partly responsible for the more than 3000 deaths ascribed to the natural disaster [25].").

[411] Cangialosi J. P., Latto A. S., & Berg R. (2021) *Tropical Cyclone Report: Hurricane Irma*, National Oceanic and Atmospheric Administration National Hurricane Center, 16 ("Estimates from FEMA indicate that 25% of buildings were destroyed, 65% were significantly damaged, and 90% of houses sustained some damage. Approximately 75% of the residents in the Keys evacuated before Irma.").

[412] Insurance Bureau of Canada (19 October 2022) *Hurricane Fiona causes $660 million in insured damage* ("Hurricane Fiona is estimated to have caused $660 million in insured damage, according to initial estimates from Catastrophe Indices and Quantification Inc. (CatIQ).").

[413] United States Office of Management and Budget (2022) FEDERAL BUDGET EXPOSURE TO CLIMATE RISKS, 280 ("Based on methodology modifications to update results from CBO (2016),37,38 OMB estimates that annual Federal spending increases on coastal disaster response spending are projected to range from $4-$32 billion (2020 USD) annually,39 with a mean of $15 billion, in 2050.40 By 2075 these annual increases due to projected hurricane frequency reach $22-$94 billion (2020$), with a mean increase of $50 billion. The method for developing these estimates takes into consideration the increased frequency of hurricanes impacting U.S. coastal areas as well as growth in coastal development and real GDP.").

[414] World Meteorological Organization (2022) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2021, No. 1295, 10–11 ("Rainfall in central Mexico was around 40%–60% above normal, while north-west Mexico and Baja California recorded rainfall around 20% below normal (Figure 4a). In the north Atlantic coast and over the Yucatán peninsula, Guatemala and El Salvador, rainfall anomalies ranged from 50% below normal to 20% above normal (Figure 4b). Below normal rainfall was recorded in Belize and Nicaragua, while Costa Rica and much of Panama recorded above-normal rainfall. In the Caribbean region, below-normal rainfall was recorded in Cuba, the Dominican Republic and the small Caribbean islands (Figure 4c). For example, in much of Guadeloupe, annual rainfall was 10%–50% below normal. In South America (Figure 4d), rainfall anomalies of between 20% and 60% below normal were recorded over the central and southern regions of Chile, and 30% to 50% below normal over the south-western Andes of Peru. Below-normal rainfall was dominant over the Paraná–La Plata Basin in south-eastern Brazil, northern Argentina, Paraguay and Uruguay, suggesting a late onset and weak South American Monsoon. Below-normal rainfall conditions dominated the semiarid region of north-east Brazil and the Caribbean coast of the Bolivarian Republic of Venezuela. Conversely, the western side of Colombia, central Amazonia, French Guyana, Suriname and Guyana recorded above-normal rainfall for the year. Some of the observed rainfall patterns were in line with the typical rainfall patterns associated with La Niña conditions.").

[415] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1708 ("Observed precipitation reduction in the Cerrado region impacted main water supply reservoirs for important cities in the Brazilian central region, leading to a water crisis in 2016/2017 (Government of Brazil, 2020) and affecting hydropower energy generation (Ribeiro Neto et al., 2016).").

[416] Internal Displacement Monitoring Centre (2020) 2020 GLOBAL REPORT ON INTERNAL DISPLACEMENT, 52 ("Floods triggered the majority of the 1.5 million disaster displacements recorded in the Americas in 2019, as rivers burst their banks and forced whole communities to flee (see Figure 16). Wildfires also displaced significant numbers of people in the US and Mexico, and burned large tracts of Amazon rainforest in Brazil and Bolivia. Indigenous communities may well have been displaced by the Amazon fires, but information was hard to come by.").

[417] World Bank Group (2022) A ROADMAP FOR CLIMATE ACTION IN LATIN AMERICA AND THE CARIBBEAN 2021-2025, 2 ("Without concerted climate action, by 2050 over 17 million people in LAC could be forced to move to escape slow onset climate impacts,10 swelling migration to cities and potentially increasing urban population growth by up to 10 percent. This would increase the load on basic services in the poorest urban neighborhoods most exposed to flooding, landslides and other climate impacts that are becoming increasingly frequent and severe. At the same time, endemic

and emerging climate-sensitive infectious diseases are projected to increase over the coming decades through the expanded distribution of vectors.").

[418] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 9 ("Rainfall in central and eastern Mexico was around 40%–60% below normal, while in north-west Mexico and the Yucatán Peninsula, rainfall was 40% above normal (Figure 6a). Baja California recorded precipitation that was around 20% below normal in the extreme south, and around 10% to 20% above normal in the rest of the region. In most of Central America, except for some locations in Guatemala, precipitation was between 10% and 40% above normal").

[419] United States Environmental Protection Agency (2021) *Climate Change Indicators: Heavy Precipitation*, 6 ("EPA has determined that the time series in Figure 1 has an increasing trend of approximately 0.5 percentage points per decade ($p < 0.001$) and the time series in Figure 2 has an increasing trend of approximately 0.2 percentage points per decade ($p = 0.007$). Both of these trends were calculated by ordinary least-squares regression, which is a common statistical technique for identifying a first-order trend, and both trends are statistically significant to a 95-percent confidence level.").

[420] Gillett N. P., Cannon A. J., Malinina E., Schnorbus M., Anslow F., Sun Q., Kirchmeier-Young M., Zwiers F., Seiler C., Zhang X., Flato G., Wan H., Li G., & Castellan A. (2022) *Human influence on the 2021 British Columbia floods*, WEATHER CLIM. EXTREM. 36(100441): 1–13, 1 ("A strong atmospheric river made landfall in southwestern British Columbia, Canada on November 14th, 2021, bringing two days of intense precipitation to the region. The resulting floods and landslides led to the loss of at least five lives, cut Vancouver off entirely from the rest of Canada by road and rail, and made this the costliest natural disaster in the province's history. Here we show that when characterised in terms of storm-averaged water vapour transport, the variable typically used to characterise the intensity of atmospheric rivers, westerly atmospheric river events of this magnitude are approximately one in ten year events in the current climate of this region, and that such events have been made at least 60% more likely by the effects of human-induced climate change. Characterised in terms of the associated two-day precipitation, the event is substantially more extreme, approximately a one in fifty to one in a hundred year event, and the probability of events at least this large has been increased by a best estimate of 45% by human-induced climate change. The effects of this precipitation on streamflow were exacerbated by already wet conditions preceding the event, and by rising temperatures during the event that led to significant snowmelt, which led to streamflow maxima exceeding estimated one in a hundred year events in several basins in the region. Based on a large ensemble of simulations with a hydrological model which integrates the effects of multiple climatic drivers, we find that the probability of such extreme streamflow events in October to December has been increased by human-induced climate change by a best estimate of 120–330%. Together these results demonstrate the substantial human influence on this compound extreme event, and help motivate efforts to increase resiliency in the face of more frequent events of this kind in the future.").

[421] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1698 ("Of the 47 million Central Americans in 2015, 40% lived in rural areas, with Belize being the least urbanised (54% rural) and Costa Rica the most (21% rural); 10.5 million lived in the Dry Corridor region, an area recently exposed to severe droughts that have resulted in 3.5 million people in need of humanitarian assistance.") (citations omitted). *See also* Food and Agriculture Organization of the United Nations (2016) *Dry Corridor Central America: Situation Report*, 1 ("The Dry Corridor in Central America, in particular Guatemala, Honduras and El Salvador, is experiencing one of the worst droughts of the last ten years with over 3.5 million in need of humanitarian assistance.").

[422] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group*

II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1699 ("In 2019, the region [Dry Corridor in South America] entered its fifth consecutive drought year, with 1.4 million people in need of food aid. Seasonal-scale droughts are projected to lengthen by 12–30%, intensify by 17–42% and increase in frequency by 21–42% in RCP4.5 and RCP8.5 scenarios by the end of the century.") (citations omitted).

[423] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 15, 16 ("Drought affected several countries in the LAC region during 2022. In Central America, Costa Rica reported unusually dry conditions, mainly along the southern Caribbean coast (with associated meteorological drought conditions).42 In Mexico, the north-east states of Nuevo León and Tamaulipas were the most affected by drought in 2022. According to the Drought Monitor,43 around 30% of Mexico experienced moderate to extreme drought during the whole of 2022, which is in agreement with the Integrated Drought Index (IDI) maps presented in Figure 9. By May 2022, about 56 % of Mexico was affected by moderate to exceptional drought."; "Drought affected Puerto Rico, and by mid-June, 68% of the territory was experiencing a moderate to severe drought; this was the largest area of drought for the island in the 23-year US Drought Monitor (USDM) record.").

[424] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 15 ("In Mexico, the north-east states of Nuevo León and Tamaulipas were the most affected by drought in 2022. According to the Drought Monitor,43 around 30% of Mexico experienced moderate to extreme drought during the whole of 2022, which is in agreement with the Integrated Drought Index (IDI) maps presented in Figure 9. By May 2022, about 56 % of Mexico was affected by moderate to exceptional drought.").

[425] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1704, 1706 ("Exposure of the Brazilian Amazon to severe to extreme drought has increased from 8% in 2004/2005 to 16% in 2009/2010 and 16% in 2015/2016 (Anderson et al., 2018b); a similar trend is reported in other regions (Table 12.3). During the extreme drought of 2015/2016 in the Amazonian forests, 10% or more of the area showed negative anomalies of the minimum cumulative water deficit (Anderson et al., 2018b). This extreme drought also caused an increase in the occurrence and spread of fires in the basin (*medium confidence: medium evidence, high agreement*) (Arag.o et al., 2018; Lima et al., 2018; Silva Junior et al., 2019; Bilbao et al., 2020). Exposure to anomalous fires in ecosystems such as savannahs, which are more fire-prone, increases the exposure and vulnerability of adjacent forest ecosystems not adapted to fire, such as seasonally flooded forests (Bilbao et al., 2020; Flores and Holmgren, 2021)."; "Droughts in 2009/2010 and 2015/2016 increased tree mortality rate in Amazon forests (Doughty et al., 2015; Feldpausch et al., 2016; Anderson et al., 2018b), while productivity showed no consistent change; some authors reported a drop in productivity (Feldpausch et al., 2016), while others found no significant changes (Brienen et al., 2015; Doughty et al., 2015). Nevertheless, the combined effect of increasing tree mortality with variations in growth results in a long-term decrease in C stocks in forest biomass, compromising the role of these forests as a C sink (*high confidence*) (Brienen et al., 2015; Rammig, 2020; Sullivan et al., 2020) (Figure 12.9). Under the RCP8.5 scenario for 2070, drought will increase the conversion of rainforest to savannah (medium confidenc*e: medium evidence, high agreement*) (Anadón et al., 2014; Olivares et al., 2015; Sampaio et al., 2019). The transformation of rainforest into savannah will bring forth biodiversity loss and alterations in ecosystem functions and services (*medium confidence: medium evidence, high agreement*) (Anad.n et al., 2014; Olivares et al., 2015; Sampaio et al., 2019). In the Amazon basin, the synergistic effects of deforestation, fire, expansion of the agricultural frontier, infrastructure development, extractive activities, climate change and extreme events may exacerbate the risk of savannisation (*medium confidence: medium evidence, high agreement*) (Nobre et al., 2016b; Bebbington et al., 2019; Sampaio et al., 2019; Rammig, 2020).").

[426] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 15–16 ("Drought also affected the west coast of subtropical South America, including Chile, where the last

year with above average rainfall was 2006.51 The year 2022 was the fourth-driest year on record for Chile, which is experiencing a 14-year-long megadrought, the region's longest and most severe drought in more than 1 000 years.").

[427] Desbureaux S. & Rodella A. S. (2019) DROUGHT IN THE CITY: *THE ECONOMIC IMPACT OF WATER SCARCITY IN LATIN AMERICAN METROPOLITAN AREAS*, WORLD DEV. 114: 13–27, 18–19 ("Generating electricity is highly water intensive (Fthenakis & Kim, 2010) and several examples over the last years have highlighted the threat water scarcity can represent for electricity provision in the region.[7] When excessive rainfall is followed by floods or landslides, large wet shocks might also cause an increase in power outages because of the damages on infrastructures. We use enterprise surveys to explore the link between droughts and the occurrence of water outages for firms.").

[428] Desbureaux S. & Rodella A. S. (2019) *Drought in the City: The Economic Impact Of Water Scarcity In Latin American Metropolitan Areas*, WORLD DEV. 114: 13–27, 25 ("There are several reasons to expect such a negative impact of droughts on cities' economies. Hydropower still generates more than 50 percent of electricity in Latin America (Al-mulali, Fereidouni, & Lee, 2014). Generally speaking, water is one of the principal inputs to generate electricity, even beyond hydropower.[2] Consequently, water scarcity can lead to electric shutdowns as was recently seen in India or in Brazil.[3] Using Enterprise Surveys for 22 Latin American and Caribbean Countries, we highlight that droughts significantly increase power outages for firms.") *See also* O'Malley I. (13 March 2023) *Scientists Confirm Global Floods and Droughts Worsened by Climate Change*, PBS ("Water stress is expected to significantly affect poor, disenfranchised communities as well as ecosystems that have been underfunded and exploited.For example, the United Nations has said that Somalia is experiencing its longest and most severe drought, an event that has caused the deaths of millions of livestock and widespread hunger. Venezuela, a country that has faced years of political and economic crises, resorted to nationwide power cuts during April 2016 as a result of the drought conditions affecting water levels of the Guri Dam.").

[429] Gillespie P. & Gilbert J. (12 April 2023) *Argentina's Epic Drought Is Pushing Economic Crisis to New Extremes*, BLOOMBERG; *and* Sigal L. & Raszewski E. (9 March 2023) *Argentina's 'unprecedented' drought pummels farmers and economy*, REUTERS.

[430] Souza Gomes M., Fonseca de Albuquerque Cavalcanti I., & Muller G. V. (2021) *2019/2020 Drought Impacts on South America and Atmospheric and Oceanic Influences*, WEATHER CLIM. EXTREMES 34(100404): 1–13, 2–3 ("Soybean was the most affected crop in Rio Grande do Sul, with yield losses above 70% in some areas and from 57 to 40% in other areas compared to previous year's yields. Maize losses were the greatest in the state of Santa Catarina, reaching 43% in some localities, and 15% in the state of Parana, compared to previous year's yields."; "Loss caused by the 2019–2020 drought in the agricultural and cattle ranching sector were estimated at US$ 546 million, mainly because of soybean failure, but also because of decreased yields in maize and sorghum (MAGyP, 2020).").

[431] Gonzalez P., Breshears D. D., Brooks K. M., Brown H. E., Elias E. H., Gunasekara A., Huntly N., Maldonado J. K., Mantua N. J., Margolis H. G., McAfee S., Middleton B. R., & Udall B. H. (2018) *Chapter 25: Southwest*, *in* IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT, Vol. II, Reidmiller D. R., Avery C. W., Easterling D. R., Kunkel K. E., Lewis K. L. M., Maycock T. K., & Stewart B. C. (eds.), U.S. Global Change Research Program, 1101–1184, 1111–1112 ("Higher temperatures intensified the recent severe drought in California and are amplifying drought in the Colorado River Basin. In California, the higher temperatures intensified the 2011–2016 drought,14,56,97,98,99 which had been initiated by years of low precipitation,57,58 causing water shortages to ecosystems, cities, farms, and energy generators. In addition, above-freezing temperatures through the winter of 2014–2015 led to the lowest snowpack in California (referred to as a warm snow drought) on record.47,55,98,100 Through increased temperature, climate change may have accounted for one-tenth to one-fifth of the reduced soil moisture from 2012 to 2014 during the recent California drought.14").

[432] Szeto K., Zhang X., White R. E., & Brimelow J. (2016) *The 2015 Extreme Drought in Western Canada*, BULL. AM. METEOROL. SOC. 97(12): S42–S46, S42 ("Although drought is common over western Canada (Bonsal et al. 2011), the drought that affected the area during the spring and summer of 2015 (Fig. 9.1a) was unusual in terms of its severity, extent, and impacts. British Columbia (B.C.) and Alberta were the most severely affected provinces. Vast areas in southern B.C. were assigned the highest possible (Level-4) drought rating by the B.C. government, several extreme-

low streamflow advisories, and extreme wildfire risk ratings. Stringent water restrictions were in place by the end of June (AFCC 2016). In Alberta, conditions were even drier, and the Alberta government declared the province an Agricultural Disaster Area by early August. The extreme dry and warm conditions also created one of the most active and longest wildfire seasons for western Canada, and some rivers ran at their lowest recorded flows since measurements began 80 to 100 years ago (CMOS 2016). The extreme heat and dryness the region experienced in 2015 have raised concerns as to whether or not anthropogenic climate change (ACC) has increased the risk of extreme droughts in the area; this is the question we attempt to address in this paper.").

[433] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 11 ("The sea level in the Latin America and Caribbean region has increased at a higher rate than the global mean in the South Atlantic and the subtropical North Atlantic, and at a lower rate than the global mean in the eastern Pacific over the last three decades.14 Sea-level rise threatens a large portion of the Latin American and Caribbean population who live in coastal areas by contaminating freshwater aquifers, eroding shorelines, inundating low-lying areas, and increasing the risks of storm surges.15 High-precision satellite altimetry data covering the period from January 1993 to June 2022 indicate that during this period, the rates of sea-level change on the Atlantic side of South America were higher than those on the Pacific side (Figure 8 (right) and Table 2).16 In the South American Pacific region, the rate of change was 2.21 mm ± 0.1 mm per year, and along the west coast of Mexico and Central America, it was 1.92 mm ± 0.1 mm per year, both lower than the global average of 3.37 mm ± 0.32 mm per year during this period. The sea level on the Pacific side of South America is highly influenced by ENSO, and smaller increases are observed during La Niña. Along the Atlantic coast of South America, south of the equator, the rate of change from January 1993 to June 2022, 3.66 mm ± 0.1 mm per year, was higher than the global average. A comparable rate was also observed in the subtropical North Atlantic and the Gulf of Mexico (3.60 mm ± 0.1 mm per year). In the tropical North Atlantic, around Central America and the southern Caribbean, the rate was 3.23 mm ± 0.1 mm per year during this period (Figure 8 (left) and Table 2).").

[434] World Meteorological Organization (2023) STATE OF THE CLIMATE IN LATIN AMERICA AND THE CARIBBEAN 2022, No. 1322, 11 ("In 2022, the global mean sea level (GMSL) continued to rise. The average GMSL rise is estimated to be 3.4 mm ± 0.3 mm per year over the 30 years (1993–2022) of the satellite altimeter record; however, the rate doubled between the first decade of the record (1993–2002) and the last (2013–2022), during which the rate exceeded 4 mm per year.").

[435] Fleming E., Payne J., Sweet W., Craghan M., Haines J., Hart J. F., Stiller H., & Sutton-Grier A. (2018) *Chapter 8: Coastal Effects*, *in* IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT, Vol. II, Reidmiller D. R., Avery C. W., Easterling D. R., Kunkel K. E., Lewis K. L. M., Maycock T. K., & Stewart B. C. (eds.), U.S. Global Change Research Program, 322–352, 327 ("Although storms, floods, and erosion have always been hazards, in combination with rising sea levels they now threaten approximately $1 trillion in national wealth held in coastal real estate (Figure 8.1)25 and the continued viability of coastal communities that depend on coastal water, land, and other resources for economic health and cultural integrity (Ch. 15: Tribes, KM 1 and 2). The effects of the coastal risks posed by a changing climate already are and will continue to be experienced in both intersecting and distinct ways, and coastal areas are already beginning to take actions to address and ameliorate these risks (Figure 8.2).").

[436] Ford J. D., Couture N., Bell T., & Clark D. G. (2017) *Climate change and Canada's north coast: research trends, progress, and future directions*, ENVIRON. REV. 26: 82–92, 83 ("Inhabited primarily by Indigenous populations living in small remote communities, Canada's northern coastline is vast, representing more than 70% of all Canadian coasts. The north coast is a "hotspot" for climate change, with the region experiencing some of the most rapid climate change anywhere globally, and projected future climate changes for the region will continue to be significant (Larsen and Anisimov 2014). Many communities have a high sensitivity to climate change as they are situated on lowlying coasts, they have infrastructure built on permafrost, they have economies strongly linked to natural resources, they have a high dependence on land-based harvesting activities, and they experience socio-economic disadvantages (AMAP 2011; Arctic Council 2013; Lemmen et al. 2008; Mason and Agan 2015). In light of the risks posed by climate change, adaptation is emerging as an important component of climate policy in northern Canada, and encompasses a variety

of strategies, actions, and behaviors that make households, communities, and economic sectors more resilient to climate change (J.D. Ford et al., in press; Labbé et al. 2017).").

[437] National Oceanic and Atmospheric Administration (2020) OCEAN, COASTAL, AND GREAT LAKES ACIDIFICATION RESEARCH PLAN: 2020-2029, Jewett E. B., Osborne E. B., Arzayus K. M., Osgood K., DeAngelo B. J., & Mintz J. M. (eds.), 38 ("Given the inherent vulnerability of the Arctic's simple food web, OA introduces a significant addition- al risk factor to ecosystems already experiencing multiple stressors.").

[438] Fisheries and Oceans Canada Centre of Expertise on the State of the Oceans (2012) CANADA'S STATE OF THE OCEANS REPORT, 2012, 10 ("Canada's cold coastal waters may be particularly prone to acidification due to the natural occurrence of undersaturated waters at shallow depths (Pacific coast), or large freshwater input (Arctic coast). Freshwater input from runoff and ice melt reduces the ocean's capacity to buffer against changes in pH. Runoff may also contain organic matter from land which can also increase acidification.")

[439] Fisheries and Oceans Canada Centre of Expertise on the State of the Oceans (2012) CANADA'S STATE OF THE OCEANS REPORT, 2012, 11 (" In summer along the west coast of Canada, acidic water from depths of 100 to 200 metres upwells onto the continental shelf and into the ocean surface layer. This upwelling water is acidic due to a high concentration of dissolved inorganic carbon. However, the exposure of the continental shelf to this water is expected to be intermittent since the uptake of CO2 by phytoplankton and outgassing of CO2 to the atmosphere remove the excess dissolved inorganic carbon. Nonetheless the combination of undersaturated water at relatively shallow depths and winds that favour upwelling make the British Columbia shelf particularly vulnerable. Over the last century, the depth below which the aragonitic shells of saturation depth or horizon (Ω) — has become shallower by, typically, a 30-50 metres. In the Northeast Pacific Ocean, the saturation horizon is naturally shallow – as little as 100 metres below the surface. Scientists expect the saturation depth to become shallower as global atmospheric CO2 concentrations increase over the coming century, putting organisms close to the surface at risk from ocean acidification.").

[440] Hoegh-Guldberg O., *et al.* (2018) *Chapter 3: Impacts of 1.5ºC Global Warming on Natural and Human Systems*, *in* GLOBAL WARMING OF 1.5 °C, *Special Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 3-263 ("**Ocean ecosystems are already experiencing large-scale changes, and critical thresholds are expected to be reached at 1.5°C and higher levels of global warming (*high confidence*).** In the transition to 1.5°C of warming, changes to water temperatures are expected to drive some species (e.g., plankton, fish) to relocate to higher latitudes and cause novel ecosystems to assemble (*high confidence*). Other ecosystems (e.g., kelp forests, coral reefs) are relatively less able to move, however, and are projected to experience high rates of mortality and loss (*very high confidence*). For example, multiple lines of evidence indicate that the majority (70–90%) of warm water (tropical) coral reefs that exist today will disappear even if global warming is constrained to 1.5°C (*very high confidence*). {3.4.4, Box 3.4} **Current ecosystem services from the ocean are expected to be reduced at 1.5°C of global warming, with losses being even greater at 2°C of global warming (*high confidence*).** The risks of declining ocean productivity, shifts of species to higher latitudes, damage to ecosystems (e.g., coral reefs, and mangroves, seagrass and other wetland ecosystems), loss of fisheries productivity (at low latitudes), and changes to ocean chemistry (e.g., acidification, hypoxia and dead zones) are projected to be substantially lower when global warming is limited to 1.5°C (*high confidence*). {3.4.4, Box 3.4}")

[441] Harvey F. (1 August 2013) *Caribbean Has Lost 80% of its Coral Reef Cover in Recent Years*, THE GUARDIAN ("The Catlin scientific survey will undertake the most comprehensive survey yet of the state of the region's reefs, starting in Belize and moving on to Mexico, Anguilla, Barbuda, St Lucia, Turks & Caicos, Florida and Bermuda. The Catlin scientists said the state of the regions' reefs would act as an early warning of problems besetting all of the world's coral. As much as 80% of Caribbean coral is reckoned to have been lost in recent years, but the survey should give a more accurate picture of where the losses have had most effect and on the causes.").

[442] Wiener J. (4 September 2021) *Food Security Should Open the Conversation About Biodiversity for Coral Reef-Dependent Countries*, IUCN CROSSROADS ("Our very survival, especially those of us from Small Island Developing States (SIDS), is directly linked to the health of our reefs; writes Jean Wiener of Fondation pour la Protection de la Biodiversité Marine (FoProBiM) (Haiti), an IUCN Member organisation. As global citizens, we understand the

ecosystemic value of our coral reefs. This fraction of our ocean floor supports 25% of our ocean's marine life, providing food security for most of the world and supporting the livelihoods for coastal populations.").

[443] National Oceanic and Atmospheric Administration (20 January 2023) *How do coral reefs protect lives and property?*, NATIONAL OCEAN SERVICE ("The coral reef structure buffers shorelines against waves, storms, and floods, helping to prevent loss of life, property damage, and erosion. When reefs are damaged or destroyed, the absence of this natural barrier can increase the damage to coastal communities from normal wave action and violent storms.").

[444] United States Environmental Protection Agency (11 May 2023) *Basic Information about Coral Reefs* ("Coral reefs are among the most biologically diverse and valuable ecosystems on Earth. An estimated 25 percent of all marine life, including over 4,000 species of fish, are dependent on coral reefs at some point in their life cycle. An estimated 1 billion people worldwide benefit from the many ecosystem services coral reefs provide including food, coastal protection, and income from tourism and fisheries. Healthy coral reefs provide: Habitat, feeding, spawning, and nursery grounds for over 1 million aquatic species, including commercially harvested fish species. Food for people living near coral reefs, especially on small islands. Recreation and tourism opportunities, such as fishing, scuba diving, and snorkeling, which contribute billions of dollars to local economies. Protection of coastal infrastructure and prevention of loss of life from storms, tsunamis, floods, and erosion. Sources of new medicines that can be used to treat diseases and other health problems. All of the services provided by coral reefs translate into tremendous economic worth. By one estimate, the total net benefit per year of the world's coral reefs is $29.8 billion. Tourism and recreation account for $9.6 billion of this amount, coastal protection for $9.0 billion, fisheries for $5.7 billion, and biodiversity, representing the dependence of many different marine species on the reef structure, for $5.5 billion (Cesar, Burke and Pet-Soede, 2003).").

[445] United Nations Environment Programme (2018) *Coral reefs: We continue to take more than we give* ("The value of a single hectare of coral reef in terms of tourism, shoreline protection and fisheries is, on average, $130,000 per year, and as much as $1.25 million where the tourism sector is large. Travel and tourism, much of it dependent on reefs, contribute a third of the GDP in the Caribbean for example, and as much as 80 percent in the Maldives.").

[446] United Nations Environment Programme (2018) *Coral reefs: We continue to take more than we give* ("Coral reef ecosystems provide society with resources and services worth $375 billion per year. They house 25 percent of all marine life, feeding hundreds of millions of people; they enable discovery of new pharmaceuticals and provide work and income through the tourism and fisheries industries.").

[447] Climate Adaption Science Centers (27 January 2022) *Coastal Erosion: Coastal Erosion is More Severe Under Climate Change*, United States Geographical Survey ("Detailed Description - More storms and higher seas from climate change create more winds, waves, and floods, leading to coastal erosion. Hurricanes can wash away sandy barrier islands, leaving coastlines and islands unprotected from future storm surges.").

[448] Barragán Muñoz J. M. (2020) *Progress of coastal management in Latin America and the Caribbean*, OCEAN COAST. MANAG. 184(105009): 1–13, 1 ("From an environmental, social and economic point of view, coastal areas in LAC are of key importance. Ecosystems such as mangroves, coral reefs and lagoons that are of particular interest for the conservation of biodiversity are located in coastal marine areas (Elbers, 2011; FAO, 2012; UNEP WCMC, 2016). From a demographic point of view, population concentration in cities within coastal zones has increased dramatically. Between 1945 and 2014 the number of Cities and Coastal Agglomerations (CCA) in LACs has gone from 42 to 420 (Barragán and De Andrés, 2016). During the same period, the population of these CACs has risen from 20 to 180 million (only 140 million people live in cities in the remaining interior territory").

[449] The World Bank (14 April 2014) *Promoting Climate Change Action in Latin America and the Caribbean* ("Within LAC, the Bank continues to provide technical and financial support geared toward scaling up climate change mitigation and adaptation actions and leveraging co-benefits. On mitigation, countries utilize sector actions, including energy, waste, transport, forestry, agriculture, and sustainable use of resources in urban area. Adaptation offers myriad opportunities to enhance resilience to climate change impacts through (i) natural disaster preparedness; (ii) enhanced

technologies and sector capacities to mitigate risks of extreme weather and hydrology change in agriculture, forestry, fisheries, transport, and energy; and (iii) new financial products to boost resilience.").

[450] Oppenheimer M., Glavovic B. C., Hinkel J., van de Wal R., Magnan A. K., Abd-Elgawad A., Cai R., Cifuentes-Jara M., DeConto R. M., Ghosh T., Hay J., Isla F., Marzeion B., Meyssignac B., & Sebesvari Z. (2019) *Chapter 4: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities*, *in* THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *Special Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Masson-Delmotte V., Zhai P., Tignor M., Poloczanska E., Mintenbeck K., Alegría A., Nicolai M., Okem A., Petzold J., Rama B., & Weyer N. M. (eds.), 323 ("Global mean sea level (GMSL) is rising (virtually certain1) and accelerating (high confidence2). The sum of glacier and ice sheet contributions is now the dominant source of GMSL rise (very high confidence). GMSL from tide gauges and altimetry observations increased from 1.4 mm yr–1 over the period 1901–1990 to 2.1 mm yr–1 over the period 1970–2015 to 3.2 mm yr–1 over the period 1993–2015 to 3.6 mm yr–1 over the period 2006–2015 (high confidence). The dominant cause of GMSL rise since 1970 is anthropogenic forcing (high confidence). {4.2.2.1.1, 4.2.2.2}").

[451] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), SPM-14 ("Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971– 2018, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land water storage 8%. The rate of ice sheet loss increased by a factor of four between 1992–1999 and 2010–2019. Together, ice sheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006-2018. (*high confidence*).").

[452] United Nations (14 February 2023) *Secretary-General's remarks to the Security Council Debate on "Sea-level Rise: Implications for International Peace and Security*, Statements ("The danger is especially acute for nearly 900 million people who live in coastal zones at low elevations — that's one out of ten people on earth. Some coastlines have already seen triple the average rate of sea-level rise.").

[453] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1691, 1714 ("Global warming has caused glacier loss in the Andes from 30% to more than 50% of their area since the 1980s. Glacier retreat, temperature increase and precipitation variability, together with land use changes, have affected ecosystems, water resources and livelihoods through landslides and flood disasters (*very high confidence*). In several areas of the Andes, flood and landslide disasters have increased, and water availability and quality and soil erosion have been affected by both climatic and non-climatic factors *(high confidence*)."; "The glaciers of the southern Andes (including the SWS and SSA regions) show the highest glacier mass loss rates worldwide (high confidence) contributing to SLR (Jacob et al., 2012; Gardner et al., 2013; Dussaillant et al., 2018; Braun et al., 2019; Zemp et al., 2019). Since 1985, the glacier area loss in the sub-region is in a range of 20 up to 60% (Braun et al., 2019; Reinthaler et al., 2019b).").

[454] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1712 ("In Argentina, projected changes in the hydrology of Andean rivers associated with glacier retreat are predicted to have negative impacts on the region's fruit production (low evidence, medium agreement) (Barros et al., 2015).").

[455] Castellanos E., Lemos M. F., Astigarraga L., Chacón N., Cuvi N., Huggel C., Miranda L., Moncassim Vale M., Ometto J. P., Peri P. L., Postigo J. C., Ramajo L., Roco L., & Rusticucci M. (2022) *Chapter 12: Central and South America*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), 1718 ("Patagonian ice fields in SA are the largest bodies of ice outside of Antarctica in the Southern Hemisphere. They are losing volume due partly to rapid changes in their outlet glaciers, which end up in lakes or the ocean, becoming the largest contributors to eustatic SLR in the world per unit area (Foresta et al., 2018; Moragues et al., 2019; Zemp et al., 2019). Most calving glaciers in the southern Patagonia ice field retreated during the last century (*high confidence*). Upsala glacier retreat generated slope instability, and a landslide movement destroyed the western edge in 2013. The Upsala Argentina Lake has become potentially unstable and may generate new landslides (Moragues et al., 2019). The climate effect on the summer stratification of piedmont lakes is another issue in connection with glacier dynamics (Isla et al., 2010). Between 41° and 56° South latitude, the absolute glacier area loss was 5450 km2 (19%) in the last approximately 150 years, with an annual area reduction increase of 0.25% yr−1 for the period 2005– 2016 (Meier et al., 2018). The small glaciers in the northern part of the Northern Patagonian Ice Field had over all periods the highest rates of 0.92% a−1. In this sub-region, increased melting of ice is leading to changes in the structure and functioning of river ecosystems and in freshwater inputs to coastal marine ecosystems (*medium confidence: low evidence, high agreement*) (Aguayo et al., 2019). In addition, in the case of coastal areas, the importance of tides and rising sea levels in the behaviour of river floods has been demonstrated (Jal.n- Rojas et al., 2018).").

[456] Oppenheimer M., Glavovic B. C., Hinkel J., van de Wal R., Magnan A. K., Abd-Elgawad A., Cai R., Cifuentes-Jara M., DeConto R. M., Ghosh T., Hay J., Isla F., Marzeion B., Meyssignac B., & Sebesvari Z. (2019) *Chapter 4: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities*, *in* THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *Special Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Masson-Delmotte V., Zhai P., Tignor M., Poloczanska E., Mintenbeck K., Alegría A., Nicolai M., Okem A., Petzold J., Rama B., & Weyer N. M. (eds.), 323 ("Non-climatic anthropogenic drivers, including recent and historical demographic and settlement trends and anthropogenic subsidence, have played an important role in increasing low-lying coastal communities' exposure and vulnerability to SLR and extreme sea level (ESL) events (very high confidence). In coastal deltas, for example, these drivers have altered freshwater and sediment availability (high confidence). In low-lying coastal areas more broadly, human-induced changes can be rapid and modify coastlines over short periods of time, outpacing the effects of SLR (high confidence). Adaptation can be undertaken in the short- to medium-term by targeting local drivers of exposure and vulnerability, notwithstanding uncertainty about local SLR impacts in coming decades and beyond (high confidence). {4.2.2.4, 4.3.1, 4.3.2.2, 4.3.2.3} Coastal ecosystems are already impacted by the combination of SLR, other climate-related ocean changes, and adverse effects from human activities on ocean and land (high confidence). Attributing such impacts to SLR, however, remains challenging due to the influence of other climate-related and non-climatic drivers such as infrastructure development and human-induced habitat degradation (high confidence). Coastal ecosystems, including saltmarshes, mangroves, vegetated dunes and sandy beaches, can build vertically and expand laterally in response to SLR, though this capacity varies across sites (high confidence). These ecosystems provide important services that include coastal protection and habitat for diverse biota. However, as a consequence of human actions that fragment wetland habitats and restrict landward migration, coastal ecosystems progressively lose their ability to adapt to climate-induced changes and provide ecosystem services, including acting as protective barriers (high confidence). {4.3.2.3}").

[457] Hu A., Xu Y., Tebaldi C., Washington W. M., & Ramanathan V. (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NAT. CLIM. CHANGE 3: 730–734, 732 ("In comparison with the BAU case, mitigation of SLCPs can reduce the SLRfull rate by about 18% (from 1.1 cm yr–1 to about 0.9 cm yr–1), and the SLRther rate by about 48% (from 0.29 cm yr–1 to 0.15 cm yr–1), with negligible effect from CO2 reduction before 2050. By 2100, however, CO2 mitigation can reduce the SLRfull rate by about 24% (from 2.1 to 1.6 cm yr–1), and the SLRther rate by about 25% (from 0.4 to 0.3 cm yr–1). The SLCP mitigation would contribute about 24% of the SLRfull rate reduction, and 54% of the SLRther rate at 2100. With mitigation of both SLCPs and CO2, the projected SLR rate is reduced by close to 50% for SLRfull, and 67% for SLRther by 2100.").