



Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

News & Highlights

1.5 °C Looks Inevitable

Sean Cummings

Senior Technology Writer

The 1991 eruption of Mount Pinatubo, a volcano in the Philippines, belched so much SO₂ into the stratosphere that it cooled the entire Earth. Approximately 1.36×10^7 t of the gas reacted with water to form a planet-wide blanket of aerosol particles that absorbed and scattered sunlight, lowering the average global temperature by 0.6 °C for nearly two years [1–3]. Now, according to a new report on the state of the global climate system from an international team of researchers [4,5], drastic emissions reductions or additional major volcanic eruptions are effectively the only way to prevent the Earth from passing 1.5 °C of warming, a key goal of the Paris Agreement [6–8], within about five years—and the latter would only delay it by a few years.

The report, published in June 2025 in the journal *Earth System Science Data*, is the latest in a series of papers aiming to provide annual updates on key indicators of climate change. The effort mirrors that of the Assessment Reports produced by the Intergovernmental Panel on Climate Change (IPCC) [9], but at a higher frequency. “The IPCC reports are published every five to eight years, and we are in times where that is too slow,” said Joeri Rogelj, one of the new report’s 61 coauthors and professor of climate science and policy at Imperial College London (London, United Kingdom). “With global warming nearing key limits in the Paris Agreement, we consider it essential to give this annual update of where we stand.”

The report comes on the heels of the first year, 2024, in which the average global temperature reached 1.5 °C above preindustrial levels [4,10,11]. While hitting that threshold in a single year does not mean it has been crossed for good, the world is currently on track for that to happen in roughly five years. To maintain even a 50% chance of avoiding that outcome, the report contends, humanity could only afford roughly three more years at the current rate of global carbon emissions [4]. After that, emissions reductions alone would no longer suffice to limit global warming to levels that would avoid the worst impacts on people and the planet—the only way to do that would be through removing CO₂ from the atmosphere [11]. “What this is effectively telling us is that there is, in practice, a 100% chance we are blowing past 1.5,” said Daniel Swain, a climate scientist and researcher at the University of California Agriculture and Natural Resources in Davis, CA, USA, who is also affiliated with the University of California, Los Angeles, Institute of the Environment and Sustainability and the National Science Foundation’s National Center for Atmospheric Research in Boulder, CO, USA. At this point, Swain said, avoiding that

increase “is simply not possible, short of some planetary catastrophe that could be even worse than what we are currently seeing associated with climate change.”

To keep pace with the growing demand for energy, global burning of fossil fuels has continued to climb; this consumption, along with ongoing deforestation, has pushed annual greenhouse gas (GHG) emissions to new all-time highs (Fig. 1) [4,5,11,12]. At the same time, improvements in air quality control have reduced the concentration of aerosol pollutants in the atmosphere, but also the cooling effect they brought [4], akin to that of the Mount Pinatubo eruption.

The result? With 2024 leading the charge, the last ten years rank as the hottest ten on record—1.24 °C above preindustrial levels when averaged together, with over 98% of that warming attributable to human actions [4,10]. In that decade, those actions heated the Earth by 0.27 °C [4], with the rate of warming from 2012 to 2024 roughly twice that of the 1970s and 1980s [12]. The remaining amount of CO₂ that could still be emitted before locking in 1.5 °C of warming, known as the ‘carbon budget,’ is now estimated to be 80% smaller than in 2020 [11]. “Where reality has been different from our central expectation is in how much warming we have seen over the past few years,” Rogelj said. At the same time, he added, even though recent warming has exceeded central estimates, it has remained within the range of expected possibilities. “The trends are worryingly unsurprising.”

While remaining below 1.5 °C of warming was the ideal, the Paris Agreement’s most crucial goal was to limit global warming to well below 2 °C [6,8]. At the current rate of emissions, the models suggest it would be too late to avoid passing that higher threshold as well in about 20 years [11]. Guided by the existing set of global climate policies currently being implemented, the increase would reach around 2.9 °C by the end of the century (by a median estimate) [13]. “We have been eyeballing this two-and-a-half to three-degree trajectory for a few years now, which is frustrating, because we really ought to be on a track towards a lot less warming than that,” Swain said. “2.7 is still a pretty catastrophic level of warming—it means about a doubling of the warming we have seen so far, and the impacts of that second increment will be much greater than the first.”

Each additional degree of warming means more frequent and intense versions of the extreme weather events of the past several years (e.g., heat waves and flooding), as well as exacerbated environmental degradation and loss of biodiversity. Released in 2023,

<https://doi.org/10.1016/j.eng.2026.02.004>

2095-8099/© 2026 THE AUTHOR. Published by Elsevier LTD on behalf of Chinese Academy of Engineering and Higher Education Press Limited Company.

Key indicators of global climate change 2024: What's changed since AR6?

Human induced warming is increasing at the **unprecedented rate** of over 0.2 °C per decade, the result of greenhouse gas emissions being at an all-time high over the last decade, as well as reductions in the strength of aerosol cooling.

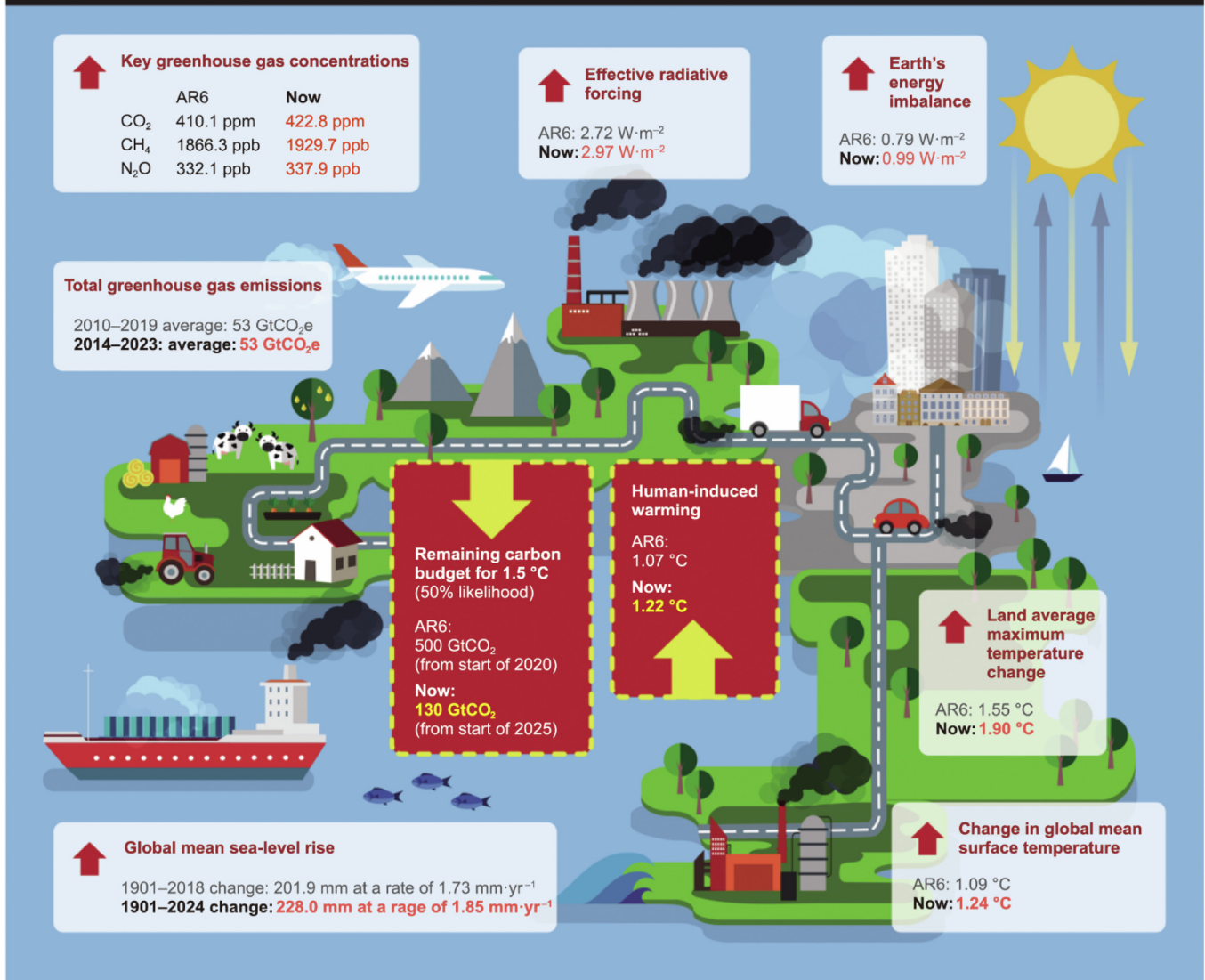


Fig. 1. This graphic illustrates how the state of the global climate—represented by factors like GHG concentrations and emissions, sea-level rise, and land surface temperature—have changed since the release of the United Nations (UN)'s Sixth Assessment Report (AR6), the final part of which was released in early 2023. Notably, in a conundrum for public health, reductions in air pollution have reduced the cooling effect afforded by aerosol pollutants. Credit: Forster et al. 2025 (CC BY 4.0) [4].

the Sixth Assessment Report from the IPCC estimated that 2 °C of warming, compared to 1.5 °C, would expose several hundred million additional people to climate risks by 2050 and put twice as many plant species and three times as many insects at risk of losing at least half their habitat [7].

Climate experts also worry about the increasing odds of triggering irreversible, self-reinforcing feedback loops, such as tropical rainforest die-off and permafrost thaw, both of which release yet more GHG [14,15]. Then there is the increasingly possible shutdown of the Atlantic meridional overturning circulation [16], an ocean current responsible for keeping European seasonal

temperatures and tropical rainfall patterns stable. “There are some dragons lurking out there,” Swain said.

Although the best-case scenario of remaining below 1.5 °C now appears all but impossible, if there is any good news in the new report, it is that previous worst-case outcomes of four or five degrees of warming have also become unlikely. While global emissions are still rising, their rate of increase has slowed since the 2000s—enough so that, the report concludes, emissions may well hit their peak and begin to decline by 2030 [4].

One reason for this is that coal and oil's slice of the global energy mix continues to give ground to renewable and other less

polluting energy sources. The International Energy Agency (IEA) expects solar and wind power to become the two largest global sources of energy by 2035 [17]. It also predicts that global demand for combustible fossil fuels may peak in 2027, even with the consumption of jet fuel continuing to increase [18]. Electric vehicle (EV) sales hit a record 17 million in 2024 and are on track to account for a quarter of all automobile sales in 2025; the accelerating switch to EV use is projected to displace 5.4 million barrels of oil per day of global oil demand by 2030 [19]. Meanwhile, oil consumption by the 38 member nations of the Organization for Economic Co-operation and Development—generally among the world’s wealthiest—is projected to drop by 1.7 million barrels per day by 2030 [19].

The current shift from fossil fuels is particularly pronounced in China, a major oil consumer that has played a significant role in driving global demand over the past decade. But the IEA forecasts a change, with Chinese oil consumption peaking in 2027, largely due to surging EV sales and deployment of high-speed rail and natural-gas-powered trucks [18]. Concurrently, the country’s carbon output may peak sooner than previously expected. An analysis from Carbon Brief published in May 2025 found that China’s CO₂ emissions dropped 1% over the previous 12 months [20].

China’s emissions have fallen before, typically during periods of economic stress, but have consistently rebounded. This time, for the first time, its emissions dipped due mainly to the booming growth of clean energy generation from wind, solar, and nuclear power sources, which has now outpaced the growth of the country’s demand for electricity [20]. In 2024, China installed 278 GW of solar panels and 80 GW of wind turbines, both national records [20] and more than the entire rest of the world combined that year [21]. The country presently has the 11 largest solar facilities on Earth and almost as many nuclear reactors under construction as the rest of the world combined [17]. “Since China is really increasing its renewables, if there is no surge in industrial production, then China will peak before 2030, as promised,” said Philippe Ciais, an associate director at France’s Laboratory of Climate and Environmental Sciences in Saint-Aubin. “And, if China does this, global emissions should also peak or plateau.”

Despite its impressive buildout of renewables, China continues to add new coal-fired power plants and remains off-track to meet its initial Paris Agreement pledge to reduce its carbon intensity—the emissions per unit of economic output—by 60% to 65% below 2005 levels by 2030 [20,22]. If its recent emissions drop continues, however, it would mean China has met its goal of peak emissions before 2030 [7]. But that drop could still easily reverse, the Carbon Brief analysis notes, depending on the climate policies in China’s next 5-year plan, how the nation responds to international trade conditions, the growth of emissions outside of the power sector, and whether renewables continue to outpace rising power demand [20].

The global future remains equally uncertain. Based on data from Carbon Monitor, an online tool he helps manage that tracks national and global CO₂ emissions, Ciais said that emissions in the US and European Union (EU), both on the decline for years [23], have risen slightly this year [24]. Meanwhile, emissions in India, which rose 8% last year, have been either stable or decreasing in 2025 [24]. “It is complicated,” he said. “Even on a year-to-year basis, it is not completely straightforward to know how emissions will change.”

Looking beyond the year-to-year scale, pledges made by nations at 28th Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP28), 2023’s iteration of the annual UN climate conference, include rapid, stringent emissions reductions that could cut warming rates in half over the next 20 years [4] and triple global renewable energy generation by 2030 [8]. However, Rogelj said, even if all countries fully imple-

mented every climate goal they have promised, the average rise would still end up at roughly 1.9 °C of warming—and with that not happening, the rise is tracking to roughly 2.8 °C by 2100 [13]. The IEA expects oil, gas, and coal to account for less than 60% of energy needs by 2050, down from 80% at present [17]. That means up to 59% of energy production would still be emitting planet-warming gases into the atmosphere. “If we want to stabilize the climate, it is not about stabilizing or decreasing emissions, it is about bringing emissions to zero, and this is very far from happening,” Ciais said. And the demand for energy continues to balloon, much of the increase tied to the accelerating rush to integrate artificial intelligence into all things digital [25]. “Renewable energy is taking off—that seems to be unstoppable, because ultimately it is just cheaper than other forms of energy,” said Swain. “The problem is, so far, it is not replacing dirty energy—it is just whetting our rapidly increasing appetite for overall energy use.”

The IEA projects that oil demand will keep growing until 2030, and that oil production will rise to meet it [18,19]. That production growth will likely come mostly from Saudi Arabia and the US [18], the latter encouraged by the current administration’s fossil fuel promoting policies. In addition to—again—dropping out of the Paris Agreement, US president Donald Trump has repeatedly urged other nations to embrace American fossil fuel imports, while his administration works to push through permits for oil pipelines and liquid natural gas depots [26], and to pave the way for more drilling on public lands and in federal waters [17].

The Trump administration is also moving to deregulate domestic emissions and eliminate the tools that enable regulation in the first place, while also ramping up regulation on and eliminating previously allocated funding for renewable energy projects. Most notably, the US Environmental Protection Agency (EPA) has stated its intention to void a milestone federal ruling stating that warming by GHG poses a threat to public health [27]. The rule, known as the “endangerment finding,” has provided the basis for federal regulation of emission sources since 2009 and could be officially revoked in 2026. Other recent anti-climate actions under the Trump administration include a pending budget for 2026 that cuts funding for several observatories [28] and satellites [29] that track GHG in the atmosphere and monitor climate, more stringent review processes for renewable energy projects [30], proposals to erase limits on GHG emissions from power plants [31], and, in defiance of a UN requirement for developed nations to provide annual emissions data, to stop requiring industrial polluters to report their emissions [32]. “Under the current administration, the US has utterly abdicated its climate change responsibilities,” Swain said. “My most optimistic take on this is that as the US relinquishes any claim to leadership in this space, other countries will see an opportunity to be global leaders—there is now a geopolitical advantage to leading in the climate space.”

Some signs indicate the international community may adopt this outlook. World leaders from 60 nations convening to discuss energy security in London in April 2025 mostly ignored words from the US lauding American fossil fuel products; some said they considered the US “out of step” with the global shift towards clean energy [33]. At the Africa Climate Summit in September 2025, leaders of African nations announced their intention to raise 100 billion USD from African finance institutions and private banks to spur development powered by renewable energy, in a bid to industrialize Africa without the emissions that have historically accompanied industrialization [34]. In July 2025, China and the EU issued a joint statement reaffirming the importance of the Paris Agreement and pledging to submit new GHG emission reduction targets in advance of 30th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP30) in Brazil [21]. Following through on this promise, on 24 September 2025, China announced to a UN climate summit the country’s first

absolute targets for reducing its total GHG emissions: the pledge includes cutting GHG emissions by 7% to 10% below peak levels by 2035, achieving carbon neutrality before 2060, and, by dramatically increasing wind and solar power capacity, growing the share of non-fossil fuels in its energy consumption to more than 30% by 2035 [35,36].

Research suggests that ambitious climate action may prove overwhelmingly popular among the global public: one estimate suggests that 89% of the global population wants stronger climate action from their national governments, a level of support typically underestimated by both leaders and civilians [37,38]. Indeed, breaching the 1.5 °C threshold only provides reason for even greater concern and action, climate experts say. “Surpassing 1.5 is a failure of sorts, but it is not a reason to say, ‘Oh well, all hope is lost, time to give up.’ Each additional tenth of a degree matters more than the last,” Swain said. “At higher levels of warming, it gets progressively more important to keep it from warming further—the past is the past, the question is what happens moving forward.”

References

- [1] Global effects of Mount Pinatubo [Internet]. Greenbelt: NASA Earth Observatory; 2001 Jun 14 [cited 2025 Oct 8]. Available from: <https://earthobservatory.nasa.gov/images/1510/global-effects-of-mountain-pinatubo>.
- [2] Williams SCP. Geoengineering research moves from laboratory to field. *Engineering* 2023;27:3–5.
- [3] O'Neill S. Solar geoengineering to reduce global warming—the outlook remains cloudy. *Engineering* 2022;9:6–9.
- [4] Forster PM, Smith C, Walsh T, Lamb WF, Lamboll R, Cassou C, et al. Indicators of global climate change 2024: annual update of key indicators of the state of the climate system and human influence. *Earth Syst Sci Data* 2025;17(6):2641–80.
- [5] Indicators of global climate change 2024: annual update of key indicators of the state of the climate system and human influence [Internet]. Göttingen: Earth Syst Sci Data; 2025 Jun 19 [cited 2025 Oct 8]. Available from: https://www.earth-system-science-data.net/about/news_and_press/2025-06-19_indicators-of-global-climate-change-2024-annual-update-of-key-indicators-of-the-state-of-the-climate-system-and-human-influence.html.
- [6] O'Neill S. COP26: some progress, but nations still fiddling while world warms. *Engineering* 2022;11(4):6–8.
- [7] Palmer C. Latest climate report sounds alarm on closing window for mitigation. *Engineering* 2023;30:7–9.
- [8] Bourzac K. COP28 makes it official: fossil fuels cause climate change. *Engineering* 2024;37:3–5.
- [9] The Intergovernmental Panel on Climate Change (IPCC). Reports [Internet]. Geneva: The Intergovernmental Panel on Climate Change (IPCC); undated [cited 2025 Oct 8]. Available from: <https://www.ipcc.ch/reports/>.
- [10] World Meteorological Organization (WMO). WMO confirms 2024 as warmest year on record at about 1.55 °C above pre-industrial level [Internet]. Geneva: World Meteorological Organization (WMO); 2025 Jan 10 [cited 2025 Oct 8]. Available from: <https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level>.
- [11] Carrington D. Only two years left of world's carbon budget to meet 1.5 °C target, scientists warn [Internet]. London: The Guardian; 2025 Jun 20 [cited 2025 Oct 8]. Available from: https://www.theguardian.com/environment/2025/jun/18/only-two-years-left-of-world-carbon-budget-to-meet-15c-target-scientists-warn-climate-crisis?utm_term=.6853edb8e6f79df1ee8d17d17bfd020&utm_campaign=USMorningBriefing&utm_source=esp&utm_medium=Email&CMP=usbriefing_email.
- [12] Harley S, Egan R. Global carbon emissions on track to exhaust 1.5 °C budget in three years, study warns [Internet]. Douglas: Phys.org; 2025 Jun 18 [cited 2025 Oct 8]. Available from: <https://phys.org/news/2025-06-global-carbon-emissions-track-exhaust.html>.
- [13] United Nations Environment Programme. Emissions gap report 2024: no more hot air... please! With a massive gap between rhetoric and reality, countries draft new climate commitments. Report. Nairobi: United Nations Environment Programme; 2024.
- [14] Poynting M, Stallard E. Tropical forests destroyed at fastest recorded rate last year [Internet]. London: BBC; 2025 May 21 [cited 2025 Oct 8]. Available from: <https://www.bbc.com/news/articles/c0l1nngl6713o>.
- [15] Welch C. Arctic permafrost is thawing fast. That affects us all [Internet]. Washington: National Geographic; 2019 Sep [cited 2025 Oct 8]. Available from: <https://www.nationalgeographic.com/environment/article/arctic-permafrost-is-thawing-it-could-speed-up-climate-change-feature>.
- [16] Carrington D. Collapse of critical Atlantic current is no longer low-likelihood, study finds [Internet]. London: The Guardian; 2025 Aug 28 [cited 2025 Oct 8]. Available from: <https://www.theguardian.com/environment/2025/aug/28/collapse-critical-atlantic-current-no-longer-low-likelihood-study-finds>.
- [17] Gelles D, Sengupta S, Bradsher K, Plumer B. There's a race to power the future. China is pulling away [Internet]. New York City: New York Times; 2025 Jun 30 [cited 2025 Oct 8]. Available from: https://www.nytimes.com/interactive/2025/06/30/climate/china-clean-energy-power.html?mc_cid=13ce23f388.
- [18] International Energy Agency (IEA). Amid rising geopolitical strains, oil markets face new uncertainties as the drivers of supply and demand growth shift. Report. Paris: International Energy Agency (IEA); 2025.
- [19] International Energy Agency (IEA). Oil 2025 executive summary. Report. Paris: International Energy Agency (IEA); 2025.
- [20] Myllyvirta L. Analysis: clean energy just put China's CO₂ emissions into reverse for first time [Internet]. London: Carbon Brief; 2025 May 15 [cited 2025 Oct 8]. Available from: <https://www.carbonbrief.org/analysis-clean-energy-just-put-chinas-co2-emissions-into-reverse-for-first-time/>.
- [21] Sengupta S. As US retreats on climate, China and Europe pledge to go green together [Internet]. New York City: New York Times; 2025 Jul 24 [cited 2025 Oct 8]. Available from: https://www.nytimes.com/2025/07/24/climate/china-eu-joint-climate-statement.html?campaign_id=54&emc=edit_clim_20250727&instance_id=159337&nl=climate-forward®i_id=23208220&segment_id=202713&user_id=c337f9018c6147a6190e95d52f2d89a9.
- [22] Liu H, Evans S, Zhang Z, Song W, You X. The carbon brief profile: China [Internet]. London: Carbon Brief; 2023 Nov 29 [cited 2025 Oct 8]. Available from: <https://interactive.carbonbrief.org/the-carbon-brief-profile-china/index.html>.
- [23] climateactiontracker.org [Internet]. Cologne: Climate Action Tracker; c2024 [cited 2025 Oct 8]. Available from: <https://climateactiontracker.org/>.
- [24] carbonmonitor.org [Internet]. Bristol: WeDoData; 2025 Oct 8 [cited 2025 Oct 8]. Available from: <https://carbonmonitor.org/>.
- [25] Leslie M. More data centers may boast their own power plants. *Engineering* 2025;52:3–5.
- [26] Palmer C. US liquid natural gas infrastructure booms amidst uncertain demand. *Engineering* 2025;50:3–5.
- [27] Joselow M, Friedman L. In game-changing climate rollback, EPA aims to kill a bedrock scientific finding [Internet]. New York City: New York Times; 2025 Jul 29 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/07/29/climate/epa-endangerment-finding-repeal-proposal.html>.
- [28] Dzombak R. After 7 decades of measurements from a peak in Hawaii, Trump's budget would end them [Internet]. New York City: New York Times; 2025 Jul 17 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/07/17/climate/budget-cuts-climate-observatories.html>.
- [29] Mulkey SK. Two valuable satellites are in 'perfect health.' They may be scrapped [Internet]. New York City: New York Times; 2025 Sep 5 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/09/05/climate/trump-climate-satellites.html>.
- [30] Plumer B. Interior dept. to put wind and solar projects through stricter political review [Internet]. New York City: New York Times; 2025 Jul 17 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/07/17/climate/interior-dept-wind-solar.html>.
- [31] Friedman L. EPA axes Biden's climate and pollution limits on power plants [Internet]. New York City: New York Times; 2025 Jun 17 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/06/17/climate/epa-power-plants-mercury-carbon-trump.html>.
- [32] Joselow M. EPA to stop collecting emissions data from polluters [Internet]. New York City: New York Times; 2025 Sep 16 [cited 2025 Oct 8]. Available from: <https://www.nytimes.com/2025/09/16/climate/epa-emissions-data-collection-halt.html>.
- [33] Mathiesen K. Trump's efforts to split Europe and China on clean energy fall flat [Internet]. Arlington: Politico; 2025 Apr 25 [cited 2025 Oct 8]. Available from: https://www.politico.eu/article/trump-efforts-to-split-europe-and-china-on-clean-energy-fall-flat/?mc_cid=eb45759426.
- [34] Akana D. Leaders pitch homegrown solutions at Africa climate summit—and \$100b to back them [Internet]. Menlo Park: Mongabay; 2025 Sep 9 [cited 2025 Oct 8]. Available from: <https://news.mongabay.com/2025/09/leaders-pitch-homegrown-solutions-at-africa-climate-summit-and-100b-to-back-them/>.
- [35] Sengupta S. China for first time promises to reduce its greenhouse gas emissions [Internet]. New York City: New York Times; 2025 Sep 24 [cited 2025 Oct 10]. Available from: <https://www.nytimes.com/2025/09/24/climate/china-emissions-targets-paris.html>.
- [36] You X. China pledges to cut emissions by 2035: what does that mean for the climate? [Internet]. London: Nature; 2025 Sep 26 [cited 2025 Oct 10]. Available from: <https://www.nature.com/articles/d41586-025-03166-6>.
- [37] Carrington D. 'Spiral of silence': climate action is very popular, so why don't people realise it? [Internet]. London: The Guardian; 2025 Apr 22 [cited 2025 Oct 8]. Available from: <https://www.theguardian.com/environment/2025/apr/22/spiral-of-silence-climate-action-very-popular-why-dont-people-realise>.
- [38] Deng A. Underestimating support for climate action limits political decision making, study says [Internet]. London: The Guardian; 2025 Sep 2 [cited 2025 Oct 8]. Available from: <https://www.theguardian.com/environment/2025/sep/02/politicians-underestimate-support-climate-action-limiting-policies-study>.