nature

NEWS | 02 January 2025

Climate engineering faces hostility — here's how scientists say it might move forwards

Questions about effectiveness, risks and regulation must be answered before Sun-dimming technology can be developed, according to researchers.

By Alix Soliman

Critics say that strategies to artificially shield Earth from sunlight are a distraction from carbon-cutting. Credit: Tui De Roy/Nature Picture Library

Climate engineering has long been seen as the rogue approach to global warming. Public opposition has stymied field experiments of this strategy, which aims to artificially cool the Earth. Dozens of countries have called for an end to the development of climate-engineering approaches. Critics say that such projects could have disastrous unintended consequences.

Even so, some scientists say that climate-engineering methods, such as lobbing particles into the atmosphere to reflect sunlight, might provide humanity with an eleventh-hour option to avoid global tipping points. For this method to be a viable path forwards, large knowledge gaps must be filled.

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"We need to know enough about climate intervention that, should it ever be deployed, we know how to do it in a way that has the maximal benefits and the minimal harm," says Jessica Gurevitch, an ecologist at Purdue University in West Lafayette, Indiana, who emphasizes that climate engineering should not replace cutting carbon emissions.

At the American Geophysical Union (AGU) meeting in Washington DC, in December, scientists discussed the research questions to be answered and the policies that must be put in place for climate engineering to be properly vetted. Here's what scientists at the meeting and elsewhere say needs to happen.

1. Determine how climate engineering would be done

In 2024, Earth surpassed 1.5 °C of warming, a critical benchmark in planetary safety. One strategy proposed to cool the Earth focuses on increasing the amount of sunlight reflected into space. Among the most studied approaches is one that calls for shooting reflective particles into the stratosphere, the atmospheric layer extending from roughly 10 to 50 kilometres above Earth's surface.

The idea has a natural analogue: the 1991 eruption of Mount Pinatubo in the Philippines belched at least 17 million tonnes of sulfur dioxide into the stratosphere and cooled Earth's surface for about 2 years.

But modelling studies disagree on how much particulate matter would need to be injected into the stratosphere to achieve a given amount of cooling. Nor is it clear when and where these particles should be deployed, or how they would evolve in the atmosphere over time. It will take many more modelling studies to reduce uncertainty about how the strategy would be used, says Walker Lee, a climate researcher at the National Center for Atmospheric Research in Boulder, Colorado. Researchers know even less about other Sun-reflecting strategies, such as blowing ocean salt spray into the air to brighten marine clouds.

2. Understand the dangers

Scientists say it's still unclear which poses a greater risk: global warming or a large-scale technological attempt to reverse it. The way to find out, researchers say, is to study every possible ramification of the proposed climate-engineering strategies and weigh them against the impacts of global warming. But there's an acute need for more studies assessing how climate engineering could affect biodiversity, human health and weather patterns, Gurevitch says.

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A few such studies have begun already. At the AGU meeting, a team from the University of Cape Town in South Africa presented unpublished research on how particle injection would affect a low-pressure weather system that helps to produce monsoon rainfall that is crucial for farmers in Africa. The researchers ran various climate simulations and found that both global warming and injecting particles into the stratosphere would reduce the key weather system's frequency. But the climate-engineering strategy might do so to a lesser extent and could thus mitigate this particular impact of climate change, the team found.

Also at the meeting, Andrew Feder, a climate-engineering researcher at Colorado State University in Fort Collins, presented an investigation of the effects on tropical cyclones of injecting particles into the stratosphere. The modelling study, which has been posted as an unreviewed preprint[1], found that such an intervention could create "novel risks", Feder says, including the possibility of a "permanent El Niño", which might lead to more-intense storms in the east Pacific Ocean.

3. Establish rules and oversight

There are no global regulations on climate engineering, and international negotiations are at a deadlock. As a result, a handful of start-ups have kicked off artificial-cooling campaigns without any oversight. For example, Make Sunsets, a company based in Box Elder, South Dakota, launches balloons filled with sulfur dioxide particles and sells them as 'cooling credits'. Although its small scale is unlikely to have global impacts, the operation is a sign that legal systems are lagging as potentially Earth-changing technologies enter the market.

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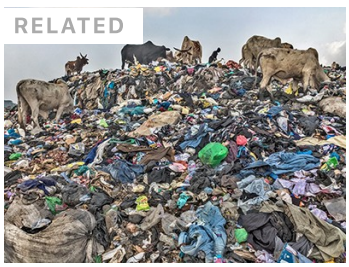

"We have to prevent premature or poorly governed deployment that could have disproportionate impacts on vulnerable regions," says Nana Ama Browne Klutse, a climate scientist at the University of Ghana in Legon.

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Some sceptical nations have suggested a halt to outdoor experiments and want the United Nations Environment Programme to provide oversight, according to an analysis[2] published on 2 January in *Science*. But other nations view climate-engineering strategies as possible solutions, favour experimentation and lean towards oversight by the Intergovernmental Panel on Climate Change or the World Meteorological Organization, the analysis says. For now, both the governance and the science are up in the air.

doi: https://doi.org/10.1038/d41586-024-04254-9

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2. McLaren, D. & Corry, O. *Science* **387**, 28–30 (2025).

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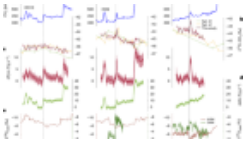

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Nature (*Nature*) | ISSN 1476-4687 (online) | ISSN 0028-0836 (print)