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Voices

Overshooting tipping points: Thresholds and impacts

Anthropogenic impacts have perturbed the planet to the edge of the known "safe operating space" for human civilization, and it is now practically certain that global climate will overshoot the "safe" temperature limits of the Paris Agreement. In this unprecedented future, there is a growing risk of crossing tipping points into a new, and potentially irreversible, state. This Voices asks, where are the thresholds, and the potential broader impacts, of crossing tipping points in an overshoot world?

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Finding transformative pathways to avoid overshoot

Given the lack of mitigation action to date, inadequate climate commitments by developed countries, and a development model that remains coupled to CO_2 emissions, overshooting 1.5°C is indeed fast becoming inevitable. But, it is not yet the time to succumb to a feeling of hopelessness, despite a growing likelihood of countless lives lost, homes and ancestral lands destroyed, and species never to be seen again. Rather, now is the time to find transformative pathways toward a better trajectory for people and planet. Inequities and injustices that will be perpetuated by the climate crisis this century are existential threats that must be recognized and avoided. That means limiting warming to below 1.5°C as much as possible, and continuing to act to bring temperatures back to the baseline levels within which life on Earth has flourished.

The biggest priority of transformative pathways remains a rapid, but just, phase-out of fossil fuels. This cannot be undertaken without the harder work of shifting development paradigms and reconfiguring value systems, including how colonial modernity has led people relate to each other and to nature. Much work needs to be done to model the kinds of radical interventions needed in the global economic and governance systems to move onto safer and more equitable pathways. Thankfully, around the world there remain value systems that can be used to inspire these pathways, such as ubuntu from southern Africa, buen vivir from Latin America, and the Māori concept of kaitiakitanga. Whilst many scientists may feel the fatigue of constantly saying that we need "transformative change," this is and will be the case. The longer that inaction remains the default, the more radical the requisite interventions get, and the more that will be lost and cost.

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A race to keep permafrost carbon safely frozen

Permafrost has caught the world's attention. Daily headlines warn of zombie diseases, wildfires smoldering under snow, and methane bubbling from the Arctic seafloor. Given how fast things are changing, I am grateful the world is watching. Indeed, the permafrost zone is warming three times faster than the global mean, and it contains four times as much carbon as global cumulative emissions since the Industrial Revolution—some 3 trillion tons. The only way to keep that carbon in the ground is to keep the ground frozen. That will require a precipitous drop in emissions.

However, headlines do not reflect all that is at stake or our prospects of success. The permafrost zone is not just a pile of greenhouse gas precursors, it contains more than half of all remaining terrestrial and marine wilderness. Likewise, millions of people from hundreds of cultures depend on stable ground and reliable snow for their food, transportation, and way of life. Saving permafrost is about protecting our fellow humans and the integrity of the global biosphere.

So, what can be saved? Hasn't the fuse already been lit on the permafrost time bomb? Explosive metaphors miss the mark. Instead, think of permafrost as a freight train. A 3°C push locks us into 400 billion tons of extra CO_2 through the end of the century—the same as adding a new U.S. or China to the emissions tally. A 1.5°C push yields 150 billion tons—a 60% savings. At 1°C or less, the train rolls backward,

and permafrost keeps sucking carbon from the atmosphere. The race is on because you cannot negotiate with the melting point of ice.

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Are there thresholds in the Atlantic overturning?

The Atlantic Meridional Overturning Circulation (AMOC) brings large volumes of warm upper waters into the North Atlantic, compensating the flow of cold water to the south, and has been proposed as a key tipping element of the Earth climate system. In 1961, it was suggested that the AMOC could be bistable—with either a modern-like state with a strong overturning or a much-weakened state possible in today's climate. Paleoclimate data supports the idea that the AMOC can transition abruptly, possibly in response to freshwater input from melting ice. What is the fate of AMOC under continued global warming? Could it abruptly collapse as it has in the past? Would a collapse be irreversible for centuries or millennia as was suggested in simple conceptual models? A collapse would cause widespread changes, including shifts in tropical precipitation patterns and a reduction in the biological productivity that supports North Atlantic fisheries. The most sophisticated models of the ocean-atmosphere system suggest that while the AMOC will likely weaken in response to high-latitude warmth and meltwater from the Greenland ice sheet, the change will be gradual and reversible if the climate system recovers. However, many of these same models struggle to reproduce the past weakening of AMOC. So, tipping-point or threshold behavior in the AMOC cannot be ruled out in the real world. And even a steady AMOC weakening can impact climate and ocean productivity. More generally, we are already seeing the climate impacts of steady warming, which will increase with each additional increment of warming beyond 1.5°C. Hence, tipping points or no tipping points, aggressively reducing greenhouse gas emissions in the next decade is imperative.

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Boreal forests reached a tipping point already

The boreal biome is a policy-relevant tipping element; its extent and function are highly sensitive to climate warming and impact human welfare regionally and globally. Predicted temperature thresholds for widespread boreal forest change (i.e., a boreal forest tipping point) are uncertain, ranging from 1.5°C to 5°C above pre-industrial levels. The summer of 2023 was the first time global average temperatures exceeded the 1.5°C threshold. The consequences of this in the boreal forest were staggering, with record breaking temperatures and widespread, catastrophic wildfires. In large-fire years, like 2023, the vastness of burning releases large quantities of carbon while deeper burning into these carbon-rich organic soils releases legacy carbon that was previously locked away from the atmosphere, which undermines the vital carbon sink provided by the boreal biome. Wildfire-induced permafrost thaw is also often irreversible in ecosystem-protected permafrost, which can lead to large additional post-fire carbon emissions.

The 2023 boreal fires in Canada mark a prime example: wildfire consumed 18.5 million hectares of forested land, ~8 times more than the 25-year average of 2.2 million hectares. Societally, 200,000 Canadians were evacuated as climate change refugees and millions more suffered from extremely poor air quality. In terms of ecosystem function, CO_2 emissions from these fires exceed CO_2 uptake by Canada's boreal forests, equivalent to three times Canada's annual CO_2 emissions. In essence, 1.5°C changed Canada's boreal forest from a vital carbon sink into a significant carbon source. This underlines the urgency of climate warming; globally relevant functions in the boreal biome cannot be maintained when the threshold of 1.5°C is crossed.

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Not tipped yet: West Antarctica in an overshoot world

The West Antarctic Ice Sheet contains so much ice that if it was melted completely, global sea levels would rise by more than 3 meters. This would challenge Earth's habitability along coastal areas. The ice sheet has also been identified as a tipping element, where, once a critical threshold has been crossed, further ice loss cannot be halted, even if climate conditions were to be reduced below the critical value. An overshoot climate warming could cause this tipping point to be crossed, and thereby an eventual collapse of the entire West Antarctic Ice Sheet. The ongoing ice loss of the Amundsen Sea glaciers in West Antarctica has raised concerns that this collapse might already be under way. In a detailed analysis together with colleagues, we found that this is likely not the case yet, which is good news! However, and this is worrying, we found that, if current ocean and atmospheric conditions are maintained, the collapse could start in the next centuries, simply if we wait. Here, timescales are important—we don't know yet how fast the collapse is going to be: if the West Antarctic Ice Sheet were to collapse in millennia rather than centuries, it opens a window of opportunity to prevent some of the worst impacts on humans and ecosystems in coastal regions. We suspect, based on previous studies, that the timescales of collapse will strongly depend on the amount of warming in the future. This would mean that overshooting could cause the onset of irreversible collapse of West Antarctica, but reducing climate conditions thereafter may help us to avoid the highest possible rates of sea level rise from Antarctica.

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Uncertain predictions hindering adaptation in Sahel

In the Sahel, sustenance of local communities is based on rain-fed agriculture, making the region uniquely vulnerable to climate change. Climate projections for the region show temperatures likely exceeding 2-degree warming above preindustrial levels, with a new precipitation regime characterized by more cumulated rainfall concentrated in fewer intense events, resulting in more frequent and impactful floods, droughts, and heatwaves. This new climate state is expected to emerge even in low-emission scenarios, and further climate shifts are predicted in moderate-to-high emission scenarios, leading to an increase in food insecurity that would exacerbate the already existing risk of conflict and migration. In this respect, reliable climate predictions for the coming decades are a key asset for local societal adaptation to climate and environmental transition.

However, the estimation of the amplitude of the change is affected by large uncertainty, which propagates to the estimation of the time of emergence of the climate shift. State-of-the-art climate models still struggle to accurately represent some physical processes (e.g., the global interhemispheric thermal gradient) and feedbacks (e.g., the radiative impact of atmospheric aerosols and vegetation) controlling the climate dynamics in the Sahel. In addition to the adoption of timely climate mitigation measures to contain climate impacts, it is crucial to fund more basic research of the climate system to produce constrained predictions and not nullify progress in the implementation of climate adaptation measures in the Sahel.

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How to plant a trillion trees in a day?

Humanity has cut down >2.5 trillion trees. In a testament to our narcissism, we have debated whether we should restore the forest to offset our carbon emissions to avert the dangerous consequences of climate change upon us, while in reality the restoration of the global forest should be a moral and ethical imperative: we took the trees down, we have to put them back.

Remarkably, >2 billion acres of land are available for restoration, which can home >1 trillion trees. Unfortunately, such a restoration remains an impossibility. At the current rate of ~1.9 billion trees planted a year, it will take us 526 years to plant the trillion trees, which at the lower price range of $0.2 to $2USD per seedling will carry a price tag of $0.2 to $2 trillion dollars; an unbearable cost for any institution, government, or individual to adsorb.

However, there is an alternative pathway to reaching this target: the general public. As daunting as restoring the world's forest may appear, it equates to every person in the world planting just ~130 trees; a 10 h job for an average volunteer in our planting events. Tackling this pathway requires shifting resources towards developing new method and tools (e.g., behavioral hooks to increase participation, innovations for land preparation, seedling production, irrigation, weed suppression, etc.). Citizens can not only provide the manpower to do the job, but the price tag of the project can be more manageable if cost is absorbed individually. Furthermore, it will allow people to gain stewardship over the future of nature. Massive planting events in India, Pakistan, Ethiopia, and Bhutan prove the concept. Restoring the world's forests is possible, but it will require getting our hands dirty, figuratively and literally.

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Adaptation pathways for planning under overshoot

In an overshoot world, the impacts of climate change, hazards, and shocks will be increasingly compounding and felt across sectors, systems, and borders. This undermines progress towards achieving the Sustainable Development Goals and highlights the systemic nature of risks. It calls for a paradigm shift in how we assess and manage risks: from hazard-by-hazard and sectoral approaches to a systems approach that takes a whole-of-society perspective and treats adaptation as an integral part of understanding risks.

Adaptation will have limits, critically depending on our success to reduce greenhouse gas emissions, to develop sustainably and to transform. To prepare for what to do, when the ways in which we were used to managing our world hit a threshold (i.e., a trigger for action), practitioners and scholars have advanced adaptation pathways. Pathways define sequences of actions, which can be implemented progressively depending on future dynamics. Developing pathways together is found to promote collaborative learning and strengthen the capacity to anticipate and act on changes.

Our choices will inevitability cause trade-offs, calling for an inclusive societal debate on what we value, want to protect, aspire to, and need to change, in order not to perpetuate structural marginalization and vulnerabilities. The key thresholds will be our imagination for just and transformative adaptation pathways. A compounding uncertainty will be who and what to trust in a world of competing truth claims, disinformation, and deep fakes. The tipping points will be around situations where we fail to uphold the social contract and ecosystem functions that our societies depend on. Our hope lies in understanding systemic risks in an overshoot world and identifying emerging leverage points for systemic resilience.

DECLARATION OF INTERESTS

The authors declare no competing interests.