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Radical interventions for climate-impacted systems

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Standard solutions to the threat of >1.5 °C global average warming are not ambitious enough to prevent large-scale irreversible loss. Meaningful climate action requires interventions that are preventative, effective and systemic—interventions that are radical rather than conventional. New forms of radical intervention are already emerging, but they risk being waylaid by rhetorical or misleading claims. Here, to encourage a more informed debate, we present a typology of radical intervention based on recent studies of resilience, transition and transformation. The typology, which is intended to be provocative, questions the extent that different interventions can disrupt the status quo to address the root drivers of climate change.

Many regions of the world will be unrecognizable, and some will be increasingly uninhabitable, as global average temperatures rise 1.5 °C or more above pre-industrial levels[1]. The burden of vulnerability is falling disproportionately on island and archipelago populations of the Pacific and the Caribbean, delta communities in South and Southeast Asia, conflict and drought-affected populations in Africa and India, and disadvantaged communities and indigenous peoples across Australasia, Eurasia and the Americas[2].

Ever-clearer evidence of catastrophic climate impacts has not, however, induced the necessary responses. Multinational fossil fuel producers and recalcitrant states continue to contest climate science, and invest heavily to redirect blame and responsibility away from themselves[3]. In many nations, climate-driven disasters and scientific confirmation of temperature shifts have also failed to catalyse policies and votes, refuting assumptions that crisis and evidence will inevitably drive collective commitment and action[4,5].

Conventional interventions are simply not fast nor deep enough to slow climate change and build climate resilience; instead radical interventions are required. However, what is 'radical' can be elusive. For example, while geoengineering and biotechnological innovations to achieve urgent harm minimization—such as seeding clouds to generate shade, or growing artificial coral reefs—are often referred to as radical, they can really only address the symptoms of climate change. By contrast, interventions that get closer to addressing the root drivers of climate change—such as fossil fuel bans and degrowth policies—are also ambiguously branded as radical but in a way that disparages them as extreme or infeasible. Proper interrogation of what constitutes 'radical' is critical, because without it, the concept risks being misunderstood or misappropriated by vested interests to deter more effective intervention.

In this Perspective, we argue for the need to reclaim and recast what radical means in solving climate problems. We draw our understanding of radical from the Latin adjective *radicalis*, meaning 'of or relating to a root', to identify interventions that address the underlying root drivers of a problem rather than its proximate causes and symptomatic effects[6–9]. In the case of climate change, the dominant proximate causes are fossil fuel consumption and land-clearing, while the proximate impacts include heatwaves, sea level rise, ocean acidification, flooding and storm surge, disasters, human and animal migration, ecological disruption, and water, food and energy insecurity. The root drivers are, in turn, capitalism and materialism, asymmetrical power relations and lock-in of exploitative and extractive systems[10–14].

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Radical interventions to address climate change are a substantial challenge because the root drivers are deeply embedded in existing societal structures, practices and values at multiple scales, and manifest in diverse ways—including as constraints on women's reproductive rights, through irresponsible practices of technological innovation and overconsumption, and via political obsessions with 'small' government. However, root drivers are often spatially and temporally disarticulated from everyday experiences of proximate causes and effects. Interventions that influence and change root drivers—which are historical, political and socio-economic—require systemic change and structural transformation of human–human and human–nature relationships. A critical challenge for many researchers and practitioners is to understand how to radically intervene to change these fundamental drivers.

Here, we directly address the challenge of facilitating a more radical approach to intervention. Social and political ambitions to intervene more effectively are emerging[15–17] and need greater scientific and policy support. To facilitate their emergence and consolidation, we define radical interventions as those that ultimately address the root causes of climate change along structurally transformative and systemic pathways. Our intended audiences are researchers, practitioners, activists, policymakers and financiers designing targeted investment and action across scales. We draw on multiple strands of research, covering social–ecological systems analysis, work on social–political transitions and the latest IPCC reports. We argue that, despite crucial advances in understanding intervention points in complex systems (for example, refs. [6,9]), a critical perspective on the opportunities and challenges of radical intervention in climate-impacted systems remains limited. To that end, we outline a new typology of radical climate intervention. The purpose of the typology is to introduce a new way of thinking about the different depths of intervention and their impacts, so as to ensure that all radical options are assessed rigorously and systematically. We also explore how radical interventions can be better facilitated and communicated in ways that diverse social actors can appreciate, adopt and support.

The art of the possible

Different research strands across multiple disciplines are now informing policy debates and generating public enthusiasm about the mechanics of radical intervention. Influential strands of social science, for example, focus on producing desirable transitions and transformation, triggering or avoiding social tipping points, and escaping traps[6,10,11,18–20]. Parallel streams of biophysical science complement this work by exploring how interventions that manipulate thresholds, feedbacks or drivers can produce profound and potentially positive differences in overall system dynamics[9,21,22] (Fig. 1).

By focusing on multiple and overlapping stressors, climate and sustainability researchers have studied a range of systems to reveal how feedbacks can cause nonlinear responses to drivers[22–24]. Feedbacks bend the shape of the response curve that characterizes the relationship between the strength of drivers and the resulting equilibrium state of a social–ecological system. As reinforcing feedbacks increase in strength, the response curve bends. Importantly, strong feedbacks can generate step-like thresholds or can fold the response curve further to create alternate stable states[21]. Interventions can thus be designed to manipulate thresholds, feedbacks and drivers in climate-impacted systems (Fig. 1).

While such scholarship is now a dynamic and vibrant field in the climate arena, the field's antecedents are located in much older theories of transformations of societies and economies (for example, refs. [25,26]). Building on these foundations, current research focuses on how transitions to sustainability generally occur, analysing the role of past transitions[10], path dependency[11], crisis opportunities[20] and future visioning[19]. Specific lines of enquiry centre on interventions to produce decarbonization transitions within particular sectors, such as food systems[27], energy[28] and cities[29].

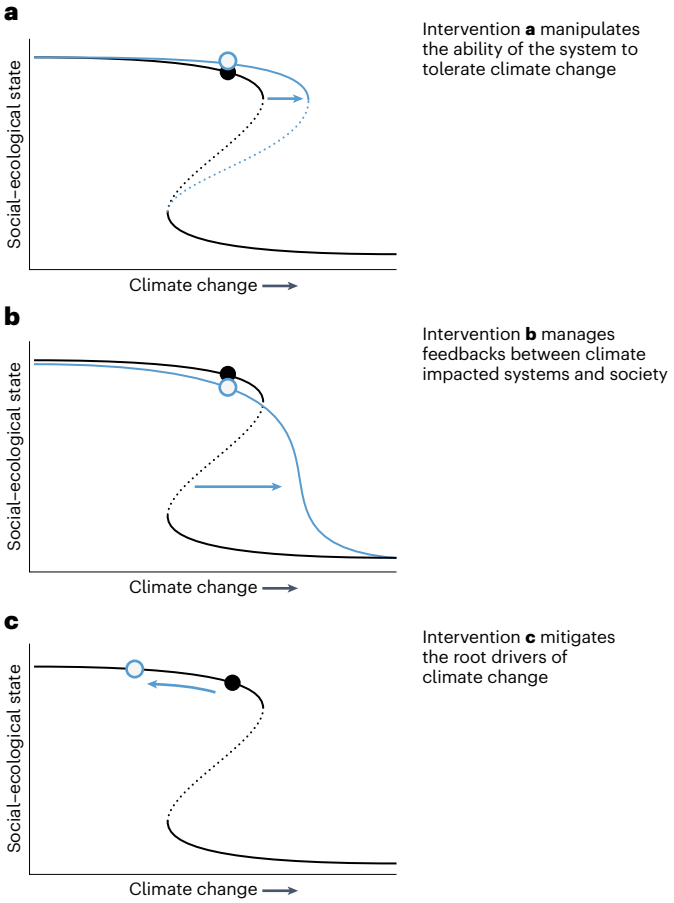

Fig. 1 | System effects of common modes of climate intervention. a–c, The nonlinear equilibrial response of a social–ecological system (*y* axis) is plotted as a function of the strength of multiple interacting climate drivers (*x* axis). The blue lines indicate an alternative response curve, modified by interventions, and the blue and black dots show the shift in the state of the system (for a given intensity of climate change) due to interventions. Different climate interventions can shift thresholds to avoid (or trigger) transitions (**a**), manipulate feedbacks to change the shape of the equilibrial relationship between drivers and system state (**b**), or reduce climate change drivers to avoid transgressing thresholds (**c**). Importantly, modifying thresholds and feedbacks (**a** and **b**) to tackle proximate impacts and causes will rarely have lasting or meaningful system effects unless the root drivers of climate change are also addressed (**c**).

The potential of different modes of intervention are shown in Fig. 1, each with different implications for low-carbon and climate-resilient futures. Modes include: shifting thresholds to avoid (or trigger) transitions (Fig. 1a), manipulating thresholds to change the equilibrial relationship between drivers and system states (Fig. 1b) or fundamentally reducing root drivers to avoid transgressing a social–ecological threshold (Fig. 1c).

In focusing on desirable social transitions, geographers have explored how NGOs and retailers can pressure key corporations to agree to zero-deforestation, thereby encouraging transgression of the threshold of acceptability of ecosystem-based climate mitigation across a supply chain[30]. Political scientists have interrogated how improving the diversity and critical mass of influential actors in policy subsystems can improve local acceptability of forest-based climate mitigation[31]. Communication scholars have demonstrated how climate narratives and visuals can strengthen community understanding of longitudinal change, thereby improving feedback between climate-impacted systems and society[32,33]. And sociologists have highlighted how shareholder activism can manipulate economic drivers by controlling the financial and fiscal underpinnings of large corporations[34].

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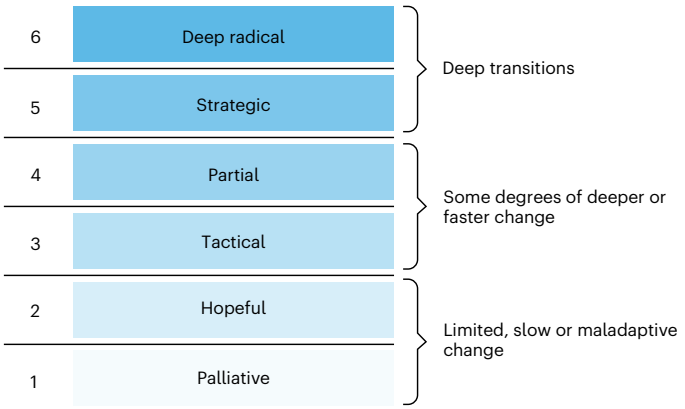

Fig. 2 | Different types of radical climate intervention. Debates about radical intervention invoke at least six different interpretations of 'radical'. These different interpretations can be viewed as a typology, with each type reflecting the extent to which the intervention disrupts the status quo to address the root drivers of climate change.

Importantly, transdisciplinary findings on many of these interventions are now directly informing IPCC synthesis on the systems and conditions for transformational change[1]. Transdisciplinary researchers have also recently converged on the key conclusion that tackling proximate impacts and causes through modifying thresholds and feedbacks (Fig. 1a,b) will rarely have lasting or meaningful effects unless the underlying drivers (for example, of capitalism, power asymmetry and exploitative and extractive lock-in) are also addressed (Fig. 1c)[10,11]. This conclusion aligns with Stoddard et al.'s 2021 assertion[14] that three decades of climate action have failed to stem global emissions as a consequence of ignoring such drivers.

Armed with this realization, researchers across all streams are now beginning to outline an ambitious agenda for radical intervention. Many analysts are forcefully arguing that fundamentally challenging climate change will require disruption of hitherto overlooked contextual or 'landscape' drivers such as capitalism, colonialism and global inequality[10,11,35]. Some are calling urgently for more empirical research on how to implement radical intervention at scale[13,36]. Others are dismantling the assumption that radical interventions are universally desirable by showing how different actors can resist and reinterpret transformational change[37]. Taken together, these imperatives emphasize the need to develop a new way of understanding and sifting through the current suite of climate interventions to progress a truly radical agenda.

Shades of radical

Now that we have properly justified 'radical' and explained common modes of intervention, the immediate challenge is to ensure that all radical options are assessed rigorously and systematically. Across different strands of research, the term is often used but rarely defined, with multiple implied definitions and aspirations. This lack of consistency has ultimately produced a menu of radical intervention choices, but with no explicit guidance on how to select most effectively from among them. We discern that scholarship on radical interventions invokes at least six different meanings of the term and, inspired by Arnstein[38], propose that these different forms of radicality can be viewed as a typology (Fig. 2). Our six types simplify a complex reality, but assist in illustrating that: (1) there are many different shades of radical; and (2) some proponents of intervention are limiting their ambition to intervene at the slow or potentially maladaptive end of the spectrum.

The internal logic of the typology is based on our definition of radical: interventions that ultimately address the root causes of climate change through structurally transformative and systemic pathways. Our logic also reflects the realization that tackling symptoms and causes by intervening in thresholds (Fig. 1a) and feedbacks (Fig. 1b) will rarely have lasting or meaningful impact unless the underlying drivers (Fig. 1c) are also addressed[10,11,13,14]. The different types in Fig. 2 reflect the fundamental differences between different depths of intervention and their impacts. In other words, each type reflects the extent to which the intervention disrupts the status quo to address the root drivers of climate change. However, the typology does not assume that we must start at the bottom nor pass through every type to get to deep radical.

Palliative intervention

At the bottom of the typology is (1) *Palliative intervention*. Governments and donors are now promoting the development of extreme scientific and technological solutions for the express purpose of adapting to climate change and delaying the worst possible outcome (for example, social and ecological collapse). Contemporary examples include unproven technologies such as carbon capture and storage[39] alongside geoengineering and bioengineering stopgaps, such as warm-water berms for glaciers, site-specific solar radiation management for coral reefs, and cryopreservation for temperate forest species[40–45]. These illusory forms of so-called radical solutions have received substantial support from fossil fuel nations, industries and organizations[46]. However, while palliative interventions seek to manipulate people–climate thresholds and feedbacks, they do not address root drivers, and are therefore implausible as a means of achieving the urgent goals of limiting GHG emissions and preventing the worst climate outcomes. Even though some of these interventions might be necessary for short-term adaptation, they cannot be considered radical in that they seek only to minimize the impacts, rather than address the root drivers of climate change. Some researchers have highlighted how these types of intervention can create placebos that distract attention from systemic problems, allowing us to continue the same economic and technological behaviours that got us here in the first place, and potentially creating a whole new system that we have no idea how to control[47,48]. Other experts question the role of science advocacy in these technologies and call for more cautious use of public and private investment[49–51].

Hopeful intervention

At this place in the typology, (2) *Hopeful intervention*, it is believed that it is possible to address the climate emergency through an assortment of soft economic changes (carbon accounting schemes, renewable energy and clean technology targets) and nature-based solutions (such as incentivizing corporations to sequester carbon or undertake regenerative design). For example, local coastal resource cooperatives are distributing low-cost renewable energy technologies (for instance, solar photovoltaics, LED lighting) to reduce the uptake of high-carbon fuel and emissions[52]. Governments and entrepreneurs are investing in production and uptake of low-carbon fuel, food and feed alternatives (for example, solar, wind, hydrogen and land-based seaweed aquaculture)[53]. Transnational bodies are funding communities to undertake restoration of peatlands, forests, wetlands, mangroves and seagrasses to encourage community commitment to nature-based carbon sequestration[54]. Such interventions are gaining in prominence because economists, scientists, philanthropists and governments are promoting them—and because they are immediately actionable and offer hope[23,55,56]. Clearly, actionability and positivity are important for a time-sensitive and politicized issue such as climate change. However, there is a trade-off between speed of implementation and depth—while 'hopeful' interventions move some distance towards encouraging resource users, households and communities to address the underlying drivers of climate change, they remain incremental and conservative in that they fail to disrupt the status quo and are clearly not working fast nor deep enough to slow climate change. In other words, 'hopeful' interventions are important and can generate beneficial outcomes but, on their own, are unlikely to lead to transformational change[6]. Holes in some of the assumptions underpinning many of these solutions are also beginning to appear,

mainly due to a lack of before-and-after research, insufficient financial and human capital, and lack of policy coherence and support[57,58].

Tactical intervention

Type 3, *Tactical intervention*, represents radical actions that seek to be disruptive. Tactical interventions raise awareness of the need to address root drivers, although these interventions typically stop short of actually doing so. An inventory of tactics includes direct community action, civil disobedience, and scientific and elite protest[59]. Examples comprise the Fridays for the Future movement, the youth climate movement and the proposed scientific moratorium on climate change research[28,60,61]. These efforts aim to disrupt business-as-usual to force declaration of a climate emergency, compel divestment from fossil fuel investment and sponsorship, and increase public awareness and engagement with climate action. Targets typically include powerful corporations, governments, banks and voters[62]. However, while tactical interventions also seek to manipulate social thresholds and feedbacks[63], they are a prior step—creating the conditions for society to address root drivers. In some cases, tactical approaches have been discounted or actively undermined by interest groups who misrepresent them as destructive, lacking in public support or against received wisdom[64,65]. Nevertheless, tactical interventions create powerful social movements that increase the moral pressure and economic incentive for climate action. Social movements such as Via Campesina, for example, are an important approach in mobilizing society toward more radical change[66,67].

Partial intervention

Type 4, *Partial intervention*, builds on type 3 by actually banning fossil fuels—but with no further attempt to address the economic structures that encourage fossil fuel extraction and consumption, nor to guide the social transitions required for displaced workers. In other words, existing power relations and socio-economic structures remain in place. Here, interventions begin to look much more radical although symbolism can still be very much at play. For example, endless time and effort has been devoted to an often symbolic debate over the social impacts of banning fossil fuel extraction and consumption, rather than the underlying drivers of capitalism, exploitation and consumerism fuelling these patterns. In some countries, these simplistic debates have led to decades of climate inaction[68]. However, eliminating fossil fuels will not necessarily change the economies, power structures and international relationships driving climate change. In other words, even if all coal mining stopped immediately, there is no guarantee that another form of technological intensification, exploitation and waste will not emerge to take its place. Simple fossil fuel bans unaccompanied by broader structural adjustment (such as regional transition plans and super-profits taxes) can create the impression of progress and absolve governments, in particular, of broader interventions for more sustainable and just societies[10–14]. Moreover, such bans can also be deliberately misappropriated by industries and governments to keep more radical interventions—as discussed below—off the table. For example, simplistic claims that fossil fuel bans will incur human development costs are often used to close down more nuanced debates about the social and environmental benefits of such bans[69].

Strategic intervention

At type 5, it is possible to get closer to true radical with increasing degrees of disruption to address root causes. Here, concerned global citizens can support (5) *Strategic intervention* to correct corruption and power asymmetries by restoring accountability, legitimacy, integrity and transparency to governance. This means paying attention to 'how we govern', which is how society minimizes vested interests and power inequities and maximizes marginalized interests and transparency. Since power can often lead to corruption, maintaining governance integrity is an ongoing process. Examples include governance integrity and anti-corruption bodies, and transparency and conflict-of-interest disclosure provisions. Fung[70], for example, prescribes the generation of a 'civic immune system' whereby an ecology of transparency, accountability and monitoring mechanisms can enhance democracy and minimize regulatory capture and other abuses of power. The United Nations, for instance, could strategically intervene to exclude for-profit interests (such as fossil fuel corporations) from involvement in formulating climate change policies under the Framework Convention on Climate Change. The World Health Organization has already strategically excluded tobacco companies from the Framework Convention on Tobacco Control, with substantial positive effect—this intervention has helped to reduce global tobacco use among men from 50% in 2000 to 38.6% in 2018, and among women from 16.7% in 2000 to 8.5% in 2018[13,71]. These interventions act to strategically correct the asymmetrical political economic relations that drive exploitative and extractive systems[68]. Such strategic interventions can be both targeted at climate governance and mainstreamed through all types of governance[72].

Deep radical

Finally, at type 6, we find *Deep radical* interventions that address the root drivers of climate change through overturning capitalist, exploitative and extractive systems[10,13,19]. It is important here not to convey 'deep radical' interventions as unrealistic—in fact, such interventions are on the increase, with governments, communities and non-profits already designing and implementing social and environmental change through emancipatory, social justice and redistributive policies. Examples include:

(1) *Interventions that tackle capitalism and materialism*. To achieve emissions reductions consistent with the Paris Agreement, some high-income countries are actively beginning to consider degrowth and post-growth policies. Such policies are based on strong evidence that economic activity, measured through gross domestic product (GDP), can be decoupled from energy use[69]. In other words, past a certain point—which high-income countries have long exceeded—the correlation between GDP and social indicators breaks down or becomes negligible. Spain, for example, already outperforms the United States in key social indicators (including a life expectancy that is five years longer), despite having 55% less GDP per capita[73]. Degrowth and post-growth policies organize economies around principles of equity and sufficiency rather than GDP[74]. Examples include shortening the working week (as trialled in France and New Zealand) and investments in non-motorized and public transport (as achieved in the Netherlands and Chile)[29]. Such interventions are radical because they use substantially less emissions than other modes of work and transport but deliver elevated levels of human wellbeing[75], thereby challenging the dominant premise that economic growth is coupled with wellbeing and must be pursued at all costs[73].

(2) *Interventions that tackle asymmetrical power relations*. Deep radical interventions also address inequality. Robust examples include basic income schemes, progressive income and wealth taxes, and resource taxes as employed in Scandinavian countries. Such measures work by curtailing the power of capital and encouraging post-growth investments and reorientations beyond capital accumulation[74,76]. More recent examples, such as family voucher schemes, also seek to bypass traditional patterns of rent-seeking and patron–client relations. With a modest expenditure of around 0.5% of GDP, for example, the Bolsa Família Program in Brazil has conditionally linked education and health care through family cash transfers, thereby addressing one of the root causes of climate change (inequality) while severely reducing vulnerability to drought[77]. By 2015, food poverty was reduced for approximately 14 million families (56 million people) in 5,000 municipalities through encouraging family-led uptake of both health care and education[78]. At risk during the Bolsonaro regime of 2018–2022, Brazil's new political leadership has

promised ongoing revitalization of this important intervention, highlighting both what is possible and how protracted radical change can be.

(3) *Interventions that tackle lock-in of exploitative and extractive systems*. Deep radical interventions also seek to overturn exploitative and extractive systems. Interventions over the past three decades to establish community governance over more than 400 million hectares of forest across the Global South[79–81], for example, have promoted interlocking social and political approaches to limit carbon emissions, reinforced indigenous and community efforts to overthrow exploitative and extractive systems, and prevented wider degradation[10,82]. Attempts to encourage extractive regions to transition to alternative economies and livelihoods (for example, sustainable farming, renewable energy) have an enduring history. In the 1930s, for example, the US Tennessee Valley Authority navigated the water catchment out of the Great Depression through innovations in education, agriculture and energy use, an intervention often heralded as a large-scale success despite mismanagement of social impacts. In the 1990s, the Australian Government transitioned more than 12 forest ecosystems toward more sustainable use and livelihoods through a series of regional forest agreements and funds to encourage communities to shift to new industries[83]. These interventions work best when they ensure that communities are not excluded nor left in over-extractive poverty traps in the rush to transform[37,84].

This list is not exhaustive—rather, it is a work in progress designed to provoke researchers, practitioners, activists, policymakers and financiers to think more critically about radical intervention. Importantly, there is a strong role for science in all of these interventions—many of these 'deep radical' examples began as small-scale experimental programmes supported by scientific and government funding and in cooperation with communities and industries.

A global challenge for science and policy

Scientists and policymakers must continue to interrogate the extent to which different interventions address the underlying root drivers of climate change, and do so in a more rigorous and systematic way. As the full spectrum of interventions takes shape, two analytical challenges demand attention. The first is to understand if or how the different interventions can work synergistically to approach the root causes of climate change. Evidence so far suggests that radical interventions work by generating alternative courses of action, connecting conventional actions to new ones, mobilizing new actors and leveraging existing actions to greater effect[19,62,85]. Synergies and scale can be realized by drawing together different projects, programmes, policies, technologies and commodities, through new incentives, institutions and information[86,87]. In some cases, the different elements are additive (that is, if one element is absent, there can still be some positive outcomes) and the potential for interactive, synergistic and transformative effects is high[88]. Ambitious renewable energy development in Small Island Developing States of the Pacific, for example, has already strengthened the position of those nations as a bloc in global climate change negotiations[1]. In other cases, one action may preclude or at least make another less likely, or actually undermine a different intervention. However, because outcomes are nonlinear and systemic, understanding how they work together as a group and over time remains challenging[6]. Chapter 18 of the latest IPCC report[1] highlights that complex synergies and trade-offs between different interventions, and how to manage them, remain a critical gap and source of uncertainty.

A second challenge is to understand how to expand legitimacy for deep radical intervention. The term 'radical' remains incorrectly, negatively and inconsistently associated with either extremist and reactionary activity (such as insurgency and civil disobedience[28]) or new and untested techno-fixes (such as space-based solar geoengineering[89]). We have reclaimed it here, referring back to its Latin roots, to reflect deep and transformational change. There is now serious appetite for deep radical intervention, as we define it here, and substantial likelihood of broad-scale acceptance. Grassroots climate movements and youth social movements, for example, are gaining support partly due to political dissatisfaction and partly as a pragmatic response to the intersecting COVID-19 and climate crises that have interrupted supply chains, restricted travel and forced a rediscovery of community for many people[34]. At the global level, revitalized climate leadership is stimulating an end to international support for coal, and regional strategies for industry emissions reduction, renewable energy investment and carbon sink protection and restoration[15–17]. Rapidly falling economic costs of renewable energy sources, and moves by investors away from high emissions intensity sectors and stranded assets, promise to further expedite the phasing out of fossil fuel production and consumption[90]. The work ahead, however, is an epic task. A market segmentation approach, which engages the underlying values of multiple influential audiences to enhance acceptability, could begin to shift attitudes toward deep radical intervention[91–93]. Socially and politically ambitious post-growth scenarios (especially at local, regional and national scales) could also play an important role by providing a counterfactual to the green growth and technological scenarios currently populating mainstream climate mitigation models[73,75,94,95]). Yet, surprisingly, very little work explicitly focuses on how to build knowledge about, and acceptance of, deep radical intervention.

Unfortunately, the acute urgency of climate change has tended to trigger rhetorical claims about some interventions, many of which are still in their infancy and not sufficiently understood. It is critically important that proposed interventions are tempered with a more nuanced understanding of radical. Efforts to catalogue and evaluate all interventions should be strengthened, drawing together demonstration projects, more experimental designs and interdisciplinary perspectives. As community needs and interdisciplinary studies attest, the rallying cry for more radical intervention is an opportunity not to be wasted.

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Author contributions

T.H.M. conceived the idea and led the analytic design. K.B, W.N.A., M.C.L. and T.P.H. led the development of concepts and ideas across the disciplines. All authors drafted, reviewed and edited the paper.

Competing interests

The authors declare no competing interests.

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