nature sustainability

PERSPECTIVE

https://doi.org/10.1038/s41893-020-0497-6

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Evaluating the efficacy and equity of environmental stopgap measures

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Contemporary environmental policy is replete with measures that do not fully resolve a problem but are proposed instead to 'buy time' for the development of more-durable solutions. We define such measures as 'stopgap measures' and examine examples from wildfire risk management, hydrochlorofluorocarbon regulation and Colorado River water management. We introduce an analytical framework to assess stopgaps and apply this framework to solar geoengineering, a controversial stopgap for reducing emissions. Studying stopgaps as a distinct response to environmental crises can help us weigh their merits in comparison to alternative policy and management measures.

Unprecedented environmental challenges, including climate change and mass extinction, have spurred a widespread sense that urgent action is required to avert environmental disasters in the near term. However, today's environmental crises are complex[1,2] and do not lend themselves to simple or quick solutions that will be greeted with broad political and public support. For the past few decades, a widespread response to this dilemma has been to implement what we define to be 'stopgap measures'.

We define a stopgap measure as a measure that:

(1) 'buys time' to implement a more complex or long-term solution (even if that solution is not yet well defined, or agreed upon by all actors);
(2) is put in place to mitigate immediate harm under conditions of perceived exigency;
(3) is acknowledged by key actors to be interim or incomplete.

A stopgap measure, then, is not: doing nothing; mere 'satisficing' without long-term vision; a first step in a solution that needs to be implemented in multiple steps; or reframing a pre-existing measure (such as reframing natural gas as a 'bridge fuel') (see Box 1 and Supplementary Information for examples). It is closest, perhaps, to an emergency repair: a temporary resin for a broken tooth; a temporary bridge erected rapidly when a highway bridge fails; plugging a hole in a boat with rags. Better solutions may be known, but they are difficult or impossible to implement immediately because they are politically contentious or technologically difficult. Further, key actors acknowledge that failure to take some action could worsen the problem or yield irreversible damage.

When implementing a stopgap measure, the key actors involved agree that the measure is not a long-term solution, but rather a strategy for 'buying time' while a solution is devised. This means that there is widespread agreement that a short-term measure is insufficient. The specific context of both the problem and the stopgap will play a role in these determinations. Take the example of a temporary highway bridge: if it is truly a hastily erected structure, and the road is heavily travelled, then it will be pretty easy for actors to agree that it is a stopgap measure. But if the temporary bridge is constructed with durable materials, or the road is sparsely travelled, then its stopgap status becomes more ambiguous. Even in this simplistic example, politics, attitudes towards risk, and an evaluation of technological options all enter into the decision. Whether a measure is a stopgap will be context-specific as well as political; however, this makes stopgaps an interesting category for sustainability researchers to study, as they may well be brought into decision-making about stopgaps.

One common critique of stopgap measures is that they may have side effects or unintended consequences that create problems as large as the disasters they are meant to avert—though perhaps for different parties. Stopgap measures can lead to a redistribution of benefits and harms, raising urgent and often neglected questions about procedural and distributive environmental justice. A second critique is that stopgap measures may provide false assurances by forestalling disaster, thereby diminishing the political will and dedication of resources to solving the root problem. An example of this is the criticism that climate adaptation received when first discussed in the 1990s. While adaptation is understood as a long-term climate response strategy today, a few decades ago, critics worried that the public might conclude that climate change could be adapted to so effectively that they would not be motivated to reduce greenhouse gas emissions[3,4]. A third and related critique is that 'disingenuous stopgaps' aim to prolong a particular status quo for as long as financially profitable. For example, in the mid-2000s, carbon capture and storage (CCS) for coal-fired power plants was considered by utilities for whom the problem definition was 'stranded assets', or pos-

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sessing infrastructure that was no longer profitable due to climate change regulation or disinvestment. On the other hand, CCS for coal appeared as a disingenuous stopgap to groups whose problem definition was climate change and who argued for an immediate phase-out of coal. Finally, there are ethical critiques of whether stopgaps lead down slippery slopes of making terrible outcomes acceptable: critiques of 'conservation triage', for example, argue that triage as a system of decision-making about biodiversity conservation may lead people to accept extinction[5]. While conservation triage decisions are not necessarily stopgap measures, stopgaps can face similar concerns of 'settling for less'.

Stopgaps versus transition management

Given the recent proliferation of stopgap measures, it is surprising that there have been no attempts to study them as a category. There are, however, three established concepts in environmental scholarship that bear some resemblance to stopgap measures: adaptive management, environmental fixes and transition management. Adaptive management was developed by C. S. Holling and collaborators in the late 1970s as an alternative to management approaches with single-value optima, which, in their view, failed to acknowledge the complexity and uncertainty of ecosystem processes[6]. Their alternative was to conceive of natural resource management as a series of experiments[7,8]. Adaptive governance underscores the need to act despite incomplete knowledge of complex systems like ecosystems and societies[9–11]; and in this regard, it is similar to the category of the stopgap measure. But adaptive governance presumes an ever-changing process, rather than a temporary action to buy time to move towards some more normatively desirable state, as the stopgap implies. Adaptive management also presumes that the actions taken could adequately manage the situation dynamically, whereas a stopgap is recognized upfront to be an incomplete solution.

Another relevant concept, the environmental fix, builds on the scholarship of geographer David Harvey, and is concerned with how the capitalist economic system comes up against limits to its growth and continued accumulation—for example, ecological limits—but then attempts to sustain itself by temporary measures, dubbed environmental or socio-ecological fixes, which often involve making use of nature to keep some economic arrangement functioning[12–14]. While some stopgaps may indeed be viewed as environmental fixes, here we allow for a wider variety of interpretations of in whose interests or to what end stopgap measures are executed. Still, the question motivating scholarship on the fix—what work is this measure really doing, and for whom?—points to questions around equity, power relations and structural contexts that also apply to stopgaps.

Scholars have also examined transition management as a series of steps taken, one at a time, that will ultimately yield the desired transition (such as the energy transition from fossil fuels to renewables)[15–17]. Unlike stopgaps, these transition steps are seen as movement toward an ultimate solution, as opposed to a delaying action that forestalls disaster until the right steps can be identified and implemented. With transition measures, it is possible to identify what needs to be done to solve the problem, and the interim measure is part of planned, sequenced actions towards a new state. With stopgaps, on the other hand, the long-term plan is not yet fully identified or agreed upon. A stopgap may eventually become part of a transition being managed, but it does not begin that way. The distinction between stopgap measures and the trio of adaptive management, environmental fixes and transition management serves to highlight the unique character of stopgap measures: none of these other concepts encompasses a measure that is (1) conceived as an emergency intervention, (2) acknowledged to be interim, and (3) arguably buys time for the development of long-term solutions.

As governments and international coalitions continue to embrace stopgap environmental measures, it is essential that scholars examine the role of stopgap measures in environmental governance. Stopgap measures always involve some investment of funds and resources, and hence societies must ask whether those resources could have been better spent on alternative responses to the crisis. Moreover, by comparing stopgaps that succeed in aiding action to those that obstruct subsequent action, scholars can help to design stopgap measures that promote long-term and equitable outcomes. Relatedly, considering stopgap measures as a coherent category can help us characterize and avoid situations where 'disingenuous stopgaps' are used to purposely forestall action. Finally, creating a body of knowledge about ethical trade-offs and power relations within stopgap measures can help to foreground the question of who benefits and who is harmed by stopgap measures, as well as the crises they are meant to temporarily avert.

Box 1 | Selected examples of diverse stopgap measures

Asteroid Grand Challenge. Congress directed NASA to find at least 90% of the potentially hazardous near-Earth objects by 2020. NASA launched a 'Grand Challenge' for the private sector and the public to devise a way to detect asteroid threats; this is a stopgap in the face of the current inability to fund an expensive space-based telescope.

Bovine rewilding. In Millingerwaard, a Dutch nature reserve, Galloway cattle are present as a stand-in for grazing megafauna that may be introduced at a later time, when researchers may be able to de-extinct the auroch, a species that used to inhabit European grasslands.

Conservation hatcheries for salmon. Fish hatcheries are used to support salmon populations, but a long-term solution would involve restoring habitat.

Forestry carbon offsets. While investments in soil health and reforestation are long-term climate solutions, forest carbon offsets in particular are an instance of pathways for reductions in the near term while new technologies and longer-term solutions emerge.

Generators in the wake of Hurricane Maria. After Puerto Rico's power grid was damaged in the 2017 hurricane, hasty repairs to maintain function and diesel-power generators were relied upon as a stopgap, while a vision for a long-term, decentralized, renewable grid emerged.

Nuclear waste interim storage. With long-term nuclear waste storage in political gridlock, nuclear waste is stored in the United States in numerous interim storage sites, awaiting construction of a permanent repository.

Salton Sea mitigation water and management plan. When a deal was struck to transfer water from rural areas in southeast California to urban areas, parties negotiated a 15-year period of paying farmers to fallow crops to provide inflows to the Salton Sea, a lake with no outflows. This period was intended to buy time for a permanent solution; however, that was not negotiated, and now the sea faces rapid shrinking and ecological decline.

Additional information is provided in the Supplementary Information.

Illustrative examples of stopgap measures

To illustrate what we can gain analytically and practically from categorizing particular measures as stopgaps, we offer three examples that vary in context and scale (see Box 1 and Supplementary Information for further examples). In these cases, we elaborate (1) how the measure is a stopgap, from the perspectives of multiple actors, and (2) how viewing it as such can bring forward important dimensions around the equity and politics of the measure.

Power shutoffs for wildfire prevention in California. In October 2019, two million people in California faced 'public-safety power shutoffs' (PSPS) when the utility Pacific Gas and Electric (PG&E) shut off electrical lines as a safety measure to avoid sparking wildfires during a dangerously dry wind event. PG&E, which in 2019 filed for bankruptcy protection and is facing US$30 billion in liabilities from previous fires started by its equipment, took the measure out of an 'abundance of caution'. Notably, the thresholds that were used to decide upon the power shutoffs appear to be low enough that these blackouts would be a regular feature of life in a warming climate[18].

Public-safety power shutoffs are a clear example of a stopgap: they were enacted to avoid immediate harm and to buy time to pursue longer-term actions necessary to building a climate-safe grid, including grid maintenance, upgrades and vegetation work, which PG&E has estimated would take 10 years[19]. As energy analyst Julie McNamara wrote, there are "no immediate full fixes at hand"[20]. The problem definitions include climate change, building in the wildland–urban interface, wildfire risk management more generally, and chronic underinvestment in power infrastructure. The stopgap is expected to be in place to buy time to confront at least the latter. PSPS is not simply a transition measure, as all the necessary actions are not yet clear; it is rather a stopgap measure.

These blackouts themselves have a cost, and while that cost has not yet been definitively calculated, the blackouts are expected to cost residential consumers tens of millions, and the impact on California's economy could be US$1–2 billion[21]. Viewed through the lens of equity, the shutoffs are concerning because the burden of dealing with no power falls disproportionately upon vulnerable people such as those depending on medical equipment, people who cannot go to work and will lose wages, people who cannot afford to replace perishable food, and children and seniors. The stopgap shifts the costs of delayed maintenance from the utility to communities[22].

Hydrochlorofluorocarbons as a stopgap in phasing out chlorofluorocarbons. In the late 1980s, governments were negotiating limits on ozone-depleting chemicals, particularly chlorofluorocarbons (CFCs), under the Montreal Protocol. The initial 1987 Protocol cut CFC production and consumption by half, and was subsequently tightened in 1990 to phased elimination except for a few essential uses. The development, testing and application of viable alternative chemicals thus became a matter of urgency for industry. CFCs were used in hundreds of distinct applications, many involving equipment or processes that were finely tuned to the precise properties of the CFC used. Contrary to widespread belief, there were no ready-to-go, or 'drop-in' alternatives for most uses at the time the controls were negotiated[23]. Two classes of potential alternative chemicals similar to the CFCs were known: the hydrofluorocarbons (HFCs), which did not destroy ozone; and the hydrochlorofluorocarbons (HCFCs), which destroyed ozone only 3 to 15% as much as the CFCs. Some CFC uses could be replaced quickly by HFCs, which eliminated damage to ozone and thus were not a stopgap for this issue. For some CFC uses, however, the only identified alternatives were HCFCs. Although it was expected that non-ozone-depleting substitutes to HCFCs would be developed eventually, these were not immediately available. As a result, cutting CFCs required large increases in HCFC production and use, even though these would later have to be reversed and eventually phased out.

Firms were reluctant to make the needed investments in equipment to produce and use HCFCs because they were afraid of being compelled to make steep cuts in HCFCs as soon as second-generation alternatives became available—wiping out the new investments they were being asked to make to help cut CFCs. To avoid this bait-and-switch, major producer and user firms demanded and received commitments to long enough product lifetimes for HCFCs to amortize their initial investments. The 1992 Protocol amendments implemented this agreement by enacting an HCFC control schedule that cut gradually to near-zero over 25 years—plus an extra 10-year period, called a 'service tail', in which the remaining 0.5% of baseline consumption was allowed for continued maintenance and service of existing equipment[24].

The long lifetime granted to the better but imperfect HCFCs outraged some environmental advocates, and it illustrates the power of industry. But the strategic logic of granting a long lifetime to HCFCs to facilitate rapid reduction of the CFCs was solid[25]. Subsequent treaty amendments slightly tightened the initial reduction schedule, but the deal largely held. As the agreed phasedown dates approached, industry representatives argued for extensions, but did not bring their full political muscle to bear. The treatment of HCFCs is a striking example of a stopgap measure that met the immediate need without obstructing the subsequent shift to more complete and durable solutions.

Colorado River water management. The Colorado River, an essential source of water to 40 million people in the southwestern United States and northwestern Mexico, is over-allocated, with more water committed than is actually available in a typical year. Allocations of Colorado River water date back to a 1922 agreement that allocates water among the seven basin states. This agreement was made at a time of high water flows, historically, and when demand was vastly lower than today. As California grew, it began to use more than its allotment. The Secretary of the Interior in 2005 directed the seven basin states to come up with a shortage sharing agreement. In 2007, the 'interim guidelines' were introduced, which prescribe cuts of water deliveries to certain states should levels at Lake Mead fall below specified amounts. These interim guidelines expire in 2026. In 2019, a Drought Contingency Plan (DCP) was signed to sketch out how to share water in the event of levels of Lake Mead falling even further, with cutbacks first triggered at 1,075 feet. However, this was still primarily a plan to buy time to share possible future cutbacks while the 2007 guidelines are re-negotiated. In fact, under the DCP, some farmers may go back to pumping groundwater, which would be unsustainable[26].

The 2007 interim shortage sharing agreement was what could be accomplished politically at the time. The agreement could minimize adverse effects of water shortages in the short term, and within a year-to-year context, it may appear as a complete solution. However, this near-term fix was understood to be a stopgap, because key actors agreed that it is insufficient to manage longer-term water shortages, especially with climate change, which has become part of the wider context and problem definition. A do-nothing situation would also not be tenable, because it would result in insufficient water for lower basin states. A durable water conservation framework for an era of climate change would require consideration of groundwater use, rethinking of state water law, and more. Rather than serving as one step towards a longer-term goal, both the interim agreement and the DCP are stopgaps to buy time for the negotiation of a longer-term water conservation arrangement.

The original 1922 Colorado River Compact had "equitable division and apportionment" at its centre, though the regime that sprung from it has a history of inattention to tribal water rights[27], and Mexico was an afterthought. Still, during the interim agreement, some farmers and conservation organizations have found ways to conserve more water, as have many municipal users. The DCP could be considered an example of a stopgap that was explicitly political and had attention to procedural and distributive equity, in that many stakeholders, from farmers to tribes to conservationists collaborated on it; it was far more inclusive of Mexico and tribal authorities than previous negotiations, though it still featured uneven inclusion and participation. It was celebrated as a political victory that offers stability through 2026, and the process of working out the latest stopgap may offer additional social and political infrastructure for collaboration. Interestingly, researchers studying the process found that a year of increased precipitation and 'good hydrology' during DCP negotiations decreased urgency and increased short-term thinking, which served as a barrier to collaborative governance[28]; this further illustrates how stopgaps depend on both social and biophysical context.

A framework for evaluating stopgap measures

In each of these examples, policymakers felt the need to buy time in the face of an impending environmental crisis. As stopgap measures become increasingly common, decision-makers, civil society groups and publics will continue to need to weigh the pros and cons of stopgap measures against other types of measures. They also may want to weigh in on the design of stopgap measures so that they are more likely to lead to longer-term, sustainable and equitable solutions.

We suggest a flexible eight-point framework with which to evaluate proposed stopgap measures. We developed this framework through an iterative process at a workshop in November 2018. The authors of this Perspective each brought examples of possible stopgap measures with which we were familiar from our experience in environmental policymaking, environmental management and political theory. We analysed the examples for commonalities and developed the definition and framework. The examples also helped illustrate what does not count as a stopgap (see Supplementary Information). We conducted a future scenario exercise on a particularly contentious stopgap, solar geoengineering, one that surfaced many needs that our framework aims to address: (1) understanding how measures aid or obstruct subsequent solutions; (2) evaluating the effectiveness of stopgaps in mitigating deficiencies in the near term; and (3) taking into account political issues, neglect of constituencies or values, side effects, and the incomplete consideration of the problem.

One use of this framework is to prompt multi-stakeholder deliberation during the design and evaluation of stopgap measures and alternative approaches. Some elements of the framework will commonly lack simple yes or no answers; in those cases, the framework can serve as an impetus for further research and policy analysis.

Framework.

1. Effectiveness in mitigating deficiencies in the near term: will the stopgap address the problem temporarily?
2. Risks and harms: does the stopgap bear ecological, social, economic, political or other risks?
3. Distributional effects: does the stopgap neglect constituencies or values? Whom does it affect? Who wins, who loses, who decides, and how?
4. Trade-offs: can the stopgap offer a cost-effective pathway towards an economically viable permanent solution?
5. Obstructiveness: will the stopgap obstruct subsequent solutions? Are there ways it acts as a barrier, and is there consensus on this?
6. Facilitation of long-term goals: will the stopgap aid and motivate subsequent progress toward a desired end?
7. Procedural mechanism: does the stopgap build in a procedural mechanism to move from the interim to long-term solutions?
8. Process to evaluate long-term solutions: does the stopgap proposal include a process for evaluating both the long-term solutions and the pathways to get to them?

Applying the framework to solar geoengineering. To demonstrate the utility of this framework, we apply it to one of the most contentious environmental stopgap measures under discussion today: stratospheric aerosol injection, one particular type of solar radiation modification (SRM, also called solar geoengineering, which includes stratospheric aerosol injection methods as well as other albedo modification measures like marine cloud brightening)[29,30]. We have chosen stratospheric aerosol injection because scientific bodies, such as the National Academies of Sciences, are considering research recommendations on SRM that include stratospheric aerosol injection, and we expect it to receive further international attention if current climate policy trends continue.

Stratospheric aerosol injection has received modest scientific attention over the past decade, with several studies using climate models to explore potential mechanisms and side effects. The dominant framing is one of a stopgap: a stratospheric aerosol injection program that could 'shave the peak' off of warming and buy time to cut emissions and to scale up carbon dioxide removal technologies[31]. This stopgap framing is reflected in the Intergovernmental Panel on Climate Change (IPCC)'s *Special Report on Global Warming of 1.5 °C* (SR1.5), for example, in which it assessed SRM "in terms of its potential to limiting warming below 1.5 °C in temporary overshoot scenarios as a way to reduce elevated temperatures and associated impacts". This IPCC report underscored that "SRM would only be deployed as a supplement measure to large-scale carbon dioxide removal," and emphasized that the literature only supports SRM as a supplement to deep mitigation in overshoot scenarios[29]. Other scholars have critiqued this peak-shaving framing, likening it to subprime lending and suggesting that it comes with a risk of increasing 'climate debt'[32] as well as raising ethical questions over participation and uneven burdens.

We apply the framework with reference to a particular scenario in which strong emissions reductions are implemented immediately, carbon dioxide removal is ramped up starting in 2050, but warming would still peak at 2.7 °C near the end of the century. A temporary deployment of stratospheric aerosols limits warming to 1.5 °C until enough carbon has been removed to maintain these temperatures without continued stratospheric aerosol injections. This scenario is modelled by MacMartin et al.[33]. If this was the specific SRM proposal, how would it look through the lens of our proposed framework?

1. Effectiveness in mitigating deficiencies in the near term: modelling efforts give a high confidence that a well-implemented stratospheric aerosol injection program would limit warming to 1.5 °C, and would address some of the most severe climate impacts of a temporary temperature overshoot: the IPCC SR1.5 points to extreme local temperatures, rate of sea level rise and intensity of tropical cyclones[30]. However, it would not mitigate all near-term climate effects, most especially ocean acidification.
2. Risks and harms: the stopgap poses several types of direct risks, including ozone depletion[34], cirrus cloud interactions[35], suppression of the hydrological cycle[36], effects of increased diffuse sunlight[37] and termination shock in the case of poor implementation[38]. The severity of these risks is highly uncertain and represents a clear research priority. Indirect risks are hard to quantify; many of them inhere in the details of the chosen stratospheric aerosol deployment scheme and how it is implemented[39]. Risk assessment must also take into account the counterfactual climate change scenario.
3. Distributional effects: SRM has the potential to affect everyone on the planet, and the science is uncertain about the particular distributional effects. MacMartin et al.[33] acknowledge that the simulations used are not well equipped to resolve specific regional discrepancies, but increased deployment of stratospheric aerosols comes with increased risk of some regions having less or more precipitation than in the reference scenario. The uneven impact across regions and communities and the lack of a procedural mechanism to address this is seen as one of the key challenges to both governance and legitimate implementation[40].

4. Trade-offs: SRM is hypothesized to have the potential to reduce the cost of decarbonization by lengthening the time during which clean technologies and carbon capture techniques can be developed[38].
5. Obstructiveness: there is no consensus on whether stratospheric aerosol deployment would obstruct subsequent solutions (in this case, progress on mitigation and carbon removal, and perhaps adaptation). On one hand, there is a literature suggesting that it will have 'mitigation deterrence' effects, via elites making decisions to use it for continued production of fossil fuels[41]. But there is also a counter argument that stratospheric aerosols need not necessarily obstruct future climate action, and that even with this danger of shifting resources away from mitigation, the possible benefits to the global poor still justify further research on geoengineering[42].
6. Facilitation of long-term goals: early evidence suggests that SRM via stratospheric aerosols may have the potential to facilitate long-term temperature goals of the Paris Agreement, but as the IPCC SR1.5 notes, at present there are significant uncertainties around technological maturity, side effects and governance[29]. Halting ocean acidification is another goal related to climate change, which is another reason why SRM cannot be the main policy response to climate change: ocean acidification would continue to be driven by increases in atmospheric CO_2 even if temperatures were kept down[43].
7. Procedural mechanism: stratospheric aerosol injection is in the early stages of model-based research, and so has not yet been proposed in conjunction with a procedural mechanism to move from the interim to long-term solutions. The scenario in MacMartin et al.[33] proposes that the stopgap stratospheric aerosol injection tapers off as carbon removal ramps up, but as this is a modelling paper, it provides no formal mechanism to ensure this. Theoretically, this mechanism could be incorporated in a yet-to-be-developed governance framework[44].
8. Process to evaluate long-term solutions: a process for evaluating long-term goals would need to be part of both the science and governance of stratospheric aerosol injection, in conjunction with the wider science community and broader publics. Some of the early work around developing theoretical feedback control mechanisms[45], and monitoring of stratospheric aerosols, could inform evaluation of the pathways.

Applying this framework to stratospheric aerosol injection makes clear that the answers do not just depend on the stopgap measure itself, but also depend on the rapidly evolving world (or context) into which the stopgap might be deployed. The exploration of MacMartin et al.[33] concluded that model simulations indicate "a limited deployment in addition to mitigation could lead to a climate much more similar to a 1.5°C-climate achieved through mitigation than either is to a 3°C world"[38]. However, the constraint of "limited deployment" rests upon the assumption that the stopgap is deployed in addition to drastic emissions reductions. At this point in time there is no evidence of any substantial mitigation being set in motion, and even under the commitments in the Paris Agreement the planet is on track for 3.2 °C warming this century[46]. Weighing the risks and costs of solar geoengineering stopgaps against the benefits in terms of averted warming, as well as identifying what scale of stopgap might be needed, depends on the emissions trajectory for the planet. That trajectory is incredibly uncertain.

This framework highlights the social, political and temporal contexts of proposals that may otherwise be framed as purely technical matters. In practice, the results from using this framework will be perceived differently by different groups[47], and will not be acted upon consistently by policymakers[48]—this is an inevitable feature of political processes. Still, a shared framework has the potential to be used by publics, civil society groups and policymakers to advocate for a nuanced consideration of stopgap measures that includes consideration of equity through space and time.

Box 2 | Questions for a stopgap measures research agenda

- What are the assumptions, logics, policies and calculations that serve to justify stopgaps and render them worthwhile investments?
- By what mechanisms do stopgap measures move towards long-term solutions?
- What are the temporalities of stopgaps? When do measures that were proposed as stopgaps lose their stopgap character and simply become business as usual?
- Under what conditions do stopgaps work, and according to whose values and criteria?
- Are stopgaps in environmental policymaking fundamentally different from other policy domains (for example, foreign or economic policy)? If so, how?
- Do certain publics, or environments, benefit more than others from stopgap measures?
- What methods can be used to assess vested interests?
- Is it realistic to expect that policymakers refrain from 'doing something', and instead simply admit that 'doing the right thing' is impossible?
- Can risks from stopgaps, and in particular who bears them, be better quantified? Where are the limitations in data and understanding?
- Are there examples of stopgaps that became permanent rather than temporary measures, either because they were unexpectedly successful, created path dependence, or their intended use as stopgaps was forgotten? What about the reverse—measures once thought permanent that are now considered stopgaps?
- How can one determine or predict when a stopgap ceases to be viable? Are there measurable tipping points for a particular system?

The need for research on stopgap measures

By applying our framework to the proposed stopgap measure of peak-shaving stratospheric aerosol injections, we uncovered several research gaps and governance challenges. The framework makes clear that an enormous amount of research remains to be done before civil society and policymakers can decide whether to pursue the stopgap of stratospheric aerosols. This will take time, and the time may be at odds with emergency discourse.

While stopgap measures are commonly framed as technical or engineering interventions (HCFCs, power shutoffs, solar geoengineering and so on), the technologies themselves are only one aspect of the necessary analyses. Indeed, if the debate about stopgaps is limited to technical discussions of environmental outcomes, without examining who wins and who loses, and without asking who is making the decisions, then the decisions and outcomes that result could be unacceptable to the majority or egregiously unfair.

If stopgap measures become a feature of twenty-first century environmental governance, as we think they might, it makes sense to study them as a collective category. By researching environmental stopgaps, scholars can explore how their design could be improved and analyse what the increasing use of stopgap environmental policies reveals about possible systemic flaws in contemporary political approaches to environmental policy. A number of future research questions emerge from our recognition of stopgap measures as a policy category (Box 2). The temporal dimensions of stopgaps lend the topic to methods not only from disciplines like history, geography and political science, but also from the field of future studies, such as scenario analysis and backcasting, as well as participatory methods designed to enable collaborative environmental planning in the present. As global environmental problems continue to be framed and perceived as crises, stopgap measures will continue to proliferate. The foundation of a sustainable future will depend on inclusive discussion of the efficacy and ethics of stopgap measures.

Data availability
Descriptions of the case studies considered appear in the Supplementary Information. Full materials are available from the corresponding author.

Received: 19 August 2019; Accepted: 21 February 2020;
Published online: 23 March 2020

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Acknowledgements
Primary funding was supplied by UCLA's Institute of the Environment and Sustainability and The Nature Conservancy NatureNet Science Fellows program. B.K. was supported in part by the National Science Foundation through agreement CBET-1931641, the Indiana University Environmental Resilience Institute, and the 'Prepared for Environmental Change' Grand Challenge initiative. The Pacific Northwest National Laboratory is operated for the US Department of Energy by Battelle Memorial Institute under contract DE-AC05-76RL01830. E.A.P. was supported in part by the Open Philanthropy Project.

Author contributions
H.J.B. coordinated the paper. L.J.M. contributed to the organization and writing of the paper. O.G., P.K., L.K., W.K., B.K., J.N., E.A.P., C.J.P., D.L.S., L.S. and S.T. contributed substantially to the development of the framework and its presentation.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information is available for this paper at https://doi.org/10.1038/s41893-020-0497-6.

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