

Emergence of polycentric climate governance and its future prospects

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The international climate regime represented by the United Nations Framework Convention on Climate Change has been widely critiqued. However, 'new' dynamic forms of climate governing are appearing in alternative domains, producing a more polycentric pattern. Some analysts believe that the new forms will fill gaps in the existing regime, but this optimism is based on untested assumptions about their diffusion and performance. The advent of polycentric governance offers new opportunities for climate action, but it is too early to judge whether hopes about the effectiveness of emerging forms of climate governance are well founded.

It is a truism that humanity is struggling to govern climate change. In spite of all the resources invested in the regime centred on the United Nations Framework Convention on Climate Change (UNFCCC), emissions continue to rise, dramatically reducing the probability of remaining within 2 °C above pre-industrial temperatures¹. Achieving the emissions reductions that are factored into many low-concentration pathways arguably requires new and much more 'integrated and aggressive'² forms of governance (that is, modes and mechanisms to steer society)³. But where will these new forms originate, how will they diffuse, and what factors will shape their ability to perform as hoped?

Most analysts used to assume that the innovative thrust in governance would spring from a comprehensive global climate regime⁴. However, even before the failure of the 2009 Copenhagen conference, some international relations scholars had moved on from the idea of a single, monocentric regime to consider multiple, interlocking 'regime complexes', such as those focusing on trade, energy, and climate⁵⁻⁹. What is striking about this strand of work is that while it hints at the potential of more pluralistic forms of governing⁹, its scale is still international and its underlying ontology remains essentially top down and state centric.

While this is clearly an important and flourishing perspective, there is a growing belief that it is only a partial one, and that the landscape of climate governance has extended beneath the international level¹⁰ through changes initiated by numerous actors from different backgrounds, such as business, local government, and civil society. Armed with less top-down, more governance-centred analytical frameworks, social scientists have started to chart the changing landscape of climate governance, now increasingly populated by novel forms, including emissions trading systems¹¹, off-setting standards, emissions registries, carbon-labelling schemes, and collaborations between cities^{4,12}. These efforts have spilled back into the UNFCCC negotiations to some degree, with discussions on climate action pre-2020 engaging with non-state actors more deeply (for example, through so-called technical expert meetings and the UNFCCC Secretariat's web portal: Non-State Actor Zone for Climate Action; <http://climateaction.unfccc.int>).

The argument that to become more effective, climate governance *in toto* should become more diverse and multi-levelled is not new¹³⁻¹⁵. Economists have long debated the theoretical merits of linking national and/or regional emissions trading systems¹⁶. Political theorists have also emphasized the advantages of governing from the 'bottom up' — more scope for experimenting, a better fit with local priorities, and so on — for considerably longer¹⁷. What has changed is that fresh empirical efforts are now revealing that the emergence of such forms of governing has a solid basis in empirical reality, and the overall landscape of climate governance has started to exhibit some of the characteristics of polycentricity foreseen by Elinor Ostrom, that is, more diverse, multi-levelled, and with a much greater emphasis on bottom-up initiatives¹⁸.

A vibrant and energetic debate is underway concerning the merits of a more polycentric approach to climate governance, only some of it reported in the IPCC's Fifth Assessment Report. In stark contrast to discussions centred on the UNFCCC, this debate is exciting precisely because it appears to offer empirical validation for a broader narrative of dynamism in a world disillusioned with the UNFCCC process^{4,19}. However, we believe that the challenge confronting scholars of the new climate governance is to ensure that this positive narrative remains empirically informed and attentive to the tendency for over-enthusiasm to creep into studies of innovative activity²⁰.

In this Perspective, we directly address the challenge of ensuring that expectations remain informed by evidence by critically reflecting on the opportunities created by, and the limitations inherent in, the new forms of governing. We draw on insights from two even more recent strands of research, broadly covering the national (including sub-national) and the transnational domains, and relate them to the findings emerging from the first (and much older) strand of work on international/global governance noted above. We argue that much deeper connections between them are needed to understand better the opportunities and pitfalls of both the new and the older climate governance. To that end, we reveal that existing work on the new governance has uncovered many new and important insights, but is yet to comprehend the complex interconnections between the transnational, national, and international domains.

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In seeking to encourage a more holistic and reflexive understanding of climate governance, we examine how far the three strands address three important, cross-cutting topics, relating to:

- **Distribution:** What forms of governing are emerging, when, and in which sectors and/or countries? How new are they?
- **Initiation, origins and invention:** Why are the new forms of governing emerging and through which mechanisms are they diffusing and/or scaling up?
- **Performance:** What do they actually add up to, for example, in terms of emissions reduced?²¹ More broadly, are they filling 'gaps' in the regime²² or reproducing what is already there?

We reveal that work on the new climate governance is addressing the first of these topics, but should do more to tackle the other two. We find that the three strands (international, transnational, national) are broadly complementary in their approach, but much deeper collaboration, organized around shared terms and concepts, is required to produce a more holistic picture. In the final section, we explore the most important policy-relevant research gaps that emerge from our analysis.

Strands of work

One of the most dynamic strands of research activity concerns transnational forms of governance²³. For Abbott²⁴, these span national borders, dissolve the traditional analytical divide between public and private spheres, and are decentralized. Analysis of a number of databases^{4,23–25} reveals that these transnational initiatives are numerous and highly diverse in form (ranging from setting rules to sharing information) and scale (from global down to city level). Most are relatively new (post-2005) and are mainly mitigation focused²³. Most have been initiated by actors in industrialized countries, albeit with the active participation of actors from the global South^{23,26}. For example, six countries (Bangladesh, Canada, Ghana, Mexico, Sweden, and the United States) and the UN Environment Programme launched the Climate and Clean Air Coalition in 2012 to promote action on short-lived climate pollutants by state and non-state actors. Projects are being implemented to reduce levels of black carbon, methane, and hydrofluorocarbons across a membership (in 2013) that has expanded to 43 states and 53 non-state partners^{27,28}.

Another equally dynamic strand of research focuses on the public policy-making activities of nation states, including local governments. Until recently, the literature on national policy offered only broad overviews of whole countries and/or non-cumulative case studies of specific policies and instruments. But attempts are now being made to assemble a fuller and more detailed picture, also based on large databases. These reveal much greater dynamism than many originally assumed. For example, The Globe's database reveals that there were 487 climate change-related laws and policies in 66 countries in 2013, up from only 40 in 1997²⁹. Around 30 new policies are being adopted each year, with non-Annex 1 countries being especially active. Similar findings have been uncovered in a comparable database produced by Dubash *et al.*³⁰, which confirms that adoptions are occurring faster in non-Annex 1 countries and indicates that the share of world population covered by national policy doubled between 2007 and 2012. Moreover, states are not only actively innovating in relation to mitigation — the number of new national adaptation strategies has also grown spectacularly in the past decade³¹.

The rediscovery of the state as a dynamic site and catalyst of governing is a little unexpected, especially for those who identify states as a primary cause of governance failure³². These findings tie in with Green's suggestion³³ that global climate governance is a positive-sum game where governance efforts by state and non-state actors grow simultaneously and in a mutually reinforcing manner.

Together, these findings emphasize the need to work across all three strands of the new climate governance literature.

Distribution

These two strands of research suggest that there is a new climate governance emerging (that is, dating mostly from the mid-2000s), although we certainly do not wish to over-stress its novelty (some national policies predate the UNFCCC)^{34–38}. In fact, we firmly believe that now is the right time to debate the most appropriate analytical categories to measure the distribution of the new climate governance.

At national level, attempts to open up the analytical category of 'policy' — which tends to be 'black boxed' by those who focus on international processes — reveal that it can be characterized in multiple ways: some policies are legally binding whereas others are not; some are adopted by national policymakers, others by sub-national actors such as local governments and city mayors; some are explicitly labelled as climate policy whereas others are primarily seen as relating to older policy areas (finance, transport, housing, or forestry)^{39,40}.

Although these distinctions may appear subtle, the multidimensionality of policy is important, perhaps revealing underlying political motives. Dubash *et al.*³⁰, for example, have found that non-binding strategies are being adopted at a much faster rate than legally binding policies. Variation is also evident in the sense that countries with very similar emission reduction targets routinely employ different mixes of implementing instruments that are harnessed by these policies⁴¹. Variations in policy type may also reveal politicians' expectations about implementation and, eventually, performance⁴². Although the existing distribution and internal characteristics of policy have probably not had a very significant effect on net emissions (relative to non-policy effects — see below), they may nevertheless open up new political opportunities to collaborate, such as by linking similar instruments (such as emissions trading) in different countries.

Two important challenges remain for those working on national policies. First, scholars must find better ways to define and track policy adoptions and innovations — an under-appreciated challenge when policy-making activity is constant and no single actor is responsible for collecting comparable data. As the international regime shifts to a more bottom-up architecture, with each party pledging and reviewing its own policy commitments (in UNFCCC speak: 'intended nationally determined contributions'), we expect this hitherto largely academic task to become considerably more policy relevant. Second, having collected comparable data, explanations for what is causing observed differences can be sought — a precondition for altering, through purposive steering, the future orientation of governance. Again, experience suggests that explanations will take time to derive. Decades of comparative policy analysis suggest that cross-national variations are likely to arise from a complicated nexus of factors that are internal and/or external to particular countries⁴¹.

Those working on transnational governance have also begun to reflect on the distribution of non-state initiatives. As territorial categories are assumed to be less relevant, other categorizations have been invented. Abbott²⁴, for example, reveals that transnational initiatives perform myriad functions, including some (such as rule-making and implementation) that are usually considered to be the preserve of states. Two, however, stand out: capacity building and information sharing¹² — governing functions where the state's comparative advantage is relatively low, especially at a restricted spatial scale. This finding suggests that actors may be self-organizing around a mutually beneficial division of labour, as envisaged in Ostrom's conceptualization of polycentricity^{18,43–45}.

Finally, much like the databases of policy activity, most (but not all⁴⁶) studies of transnational governance offer rather static snapshots that struggle to account for the dynamic processes of evolution,

diffusion, and performance. For example, how do they spread across borders and in which countries are they most active? What factors help to bring about the mutual learning from these processes of experimentation, without which the oft-claimed advantages of polycentrism⁴⁷ might not emerge? And who remains actively involved once a scheme is up and running, for how long, and why?

Origins

The two new strands of literature would seem to bear out the general claim that climate governance has become more polycentric^{48,49}. Why it has become so is much less clear, not least because both strands offer partial perspectives. This constitutes a significant research gap. In environmental social science, two broad categories of motivation to engage in multi-actor governance are normally cited: financial and non-financial⁵⁰. How well do these carry across to the new climate governance? As regards to transnational governance, most scholars are still identifying potential sub-categories of motivation, including moral concerns, fear of new regulation (or the opportunity to secure first-mover advantages by shaping it), the pursuit of direct financial rewards, indirect or 'non-climate' benefits (for example, reputational enhancement), and the satisfaction of consumer expectations^{4,23,24,33}.

Studies of the emergence of new national policies have also hypothesized — but not yet fully tested for — similar meta-motivations. Dubash *et al.*³⁰, for example, mention the need to comply with UNFCCC requirements, the desire to reap competitive advantages, and/or indirectly empower pro-environmental political actors (see also ref. 51). Studies of specific policy innovations have tried to disentangle these motivations using large *n* statistical techniques^{52,53}. We have already noted how such studies tend to gloss over the subtle but important differences between and within individual policies; analysts are also becoming more aware of their insensitivity to slow processes of refinement as policies diffuse and take root in particular jurisdictions⁵⁴. Case study analyses have shown that groups advocating particular policy instruments (such as emissions trading¹¹) drive these processes, often in collaboration with policy entrepreneurs^{55,56}.

Centre stage in these policy adoption processes are (sub)national politicians — a distinct actor category all too often ignored by transnational and international scholars. One of the enduring puzzles in public policy analysis is what motivates politicians to address climate change: to claim credit by adopting successful and innovative policies, to avoid blame for things that go wrong, or to generate a long-term policy legacy⁵⁷? Howlett⁵⁸ argues that when it comes to long-term problems such as climate change, where the causal chains connecting specific policy interventions and impacts are convoluted, politicians will normally opt to do nothing (or at the most, very little) rather than something bold (such as adopt a binding medium-term emissions target) for which they might eventually be blamed by powerful interest groups and/or voters.

But if this blame-avoidance motivation is really as common as Howlett suggests, what is driving the new policy activity noted above? Are politicians engaging in complex forms of political risk management, for example, by emulating and learning from what other countries are doing⁵⁹ — a form of diffusion that might in turn enable greater polycentrism? Or are they, as Dubash *et al.* seem to indicate³⁰, engaging in a more negative form of policy innovation, which is symbolic and/or simply intended to capture funding from abroad⁵⁸? Researchers have not dug deeply enough into specific cases to reveal which explanations hold true.

Interestingly, the proximate trigger to initiate many new transnational schemes also derives from state action, chiefly from local governments²³. In their database, Hale and Roger²⁵ estimate that approximately a third were originally initiated — or 'orchestrated' — by state bodies and/or international organizations (for example, the World Bank) established by states. This finding hints at two intriguing possibilities. One is that national politicians may be making much more complex political choices about credit and blame across

different many types of governance (that is, national policy versus transnational, and so on). Another is that the politicians who do wish to act may be engaging in subtly different (that is, domain specific) forms of state steering to deliver functional polycentric governance. If true, these interventions would seem to go well beyond the baseline tasks commonly identified in polycentric theory, such as guaranteeing due process, collecting data, and helping to scale up successful innovations^{60,61}.

Performance

As faith in a multilateral approach declines and governance becomes more polycentric, some theorists have suggested that gaps in the former may, under certain favourable circumstances, be plugged by the latter⁴⁷. However, before we raise our hopes, we should better understand how the new forms of governing are actually (not) performing^{62,63}. This vital evaluation task is proving to be technically complex^{64,65} and politically sensitive^{66,67}, so much so that even for the UNFCCC, now more than 20 years in the making, it is difficult to make definitive statements about performance.

At present, much climate policy evaluation relies on states self-reporting their activities and achievements to the UNFCCC. This work is driven by the immediate political pressure to fulfil international commitments, hence the heavy emphasis on very broad compliance exercises^{66,68}. These exercises have in turn informed academic studies that have sought to construct indices showing the countries (but typically not the specific national policies) that have generated the greatest net emission reductions⁴¹. Other researchers are now building on this work to go beyond broad correlates of performance to examine the interaction between the effects of state characteristics (income levels, democratic institutions, and so on) and international factors (international agreements, policy diffusion, and so on) — a complex task that requires panel data covering many countries and long time periods⁶⁹.

There are few comparative data with which to evaluate the performance of individual policies, and thus actively support governance innovation through polycentric experimentation^{41,62,70–72}. However, a recent systematic review⁷³ found that those policies that perform the best are well timed, embody progressively ambitious targets, and offer flexibility to target groups.

Eventually, a political cost may have to be paid for not investing in stronger performance assessment capacities. Recall that both Ostrom^{18,48} and the IPCC⁷⁴ underscore the political importance of revealing the potential co-benefits of acting (for example, health or economic competitiveness) as a means to overcome public acceptability concerns. However, because accurate and timely *ex post* policy evaluations of such benefits are often lacking^{65,75}, politicians do not necessarily have the evidence of co-benefits to hand to muster a strong political case for policy innovation. There is a paradox at work here, because one of the reasons for this knowledge gap is that governors (including politicians) are often unwilling to invest in long-term *ex post* evaluation capacities⁷⁶, in case they reveal *inter alia* embarrassing levels of underperformance⁷⁷.

In the transnational governance domain, even less is known about performance^{23,78}. Unlike national policy, where some forms of evaluation are at least routinely undertaken, no single actor has yet felt compelled to lead. More fundamentally, scholars disagree on how even to approach the topic. Beisheim and Campe⁷⁹ argue that in principle there are several analytical entry points, with the difficulty of measurement significantly increasing as one moves along the impact chain from policy and governance outputs, to outcomes and impacts. For national policy, 'tonnes of emissions reduced' is a common outcome measure. But among governance scholars, who tend to focus on 'soft results'⁵⁰ such as learning, trust and legitimacy, there is concern that emissions — and thus outcomes — may be the wrong place to start²³, given the very mixed motives for adopting policies in the first place. Green, for example, suggests that analysts should focus on the outputs

of transnational governance, and assess these over time, on the basis that the objectives and activities of such arrangements are often not directly intended to trigger emission reductions, but rather offer indirect (or 'process') contributions (for example, sharing knowledge, enhancing awareness, and so on)³³. Yet without a source of comparable and transparent information on outcomes, it will be very difficult to verify Ostrom's (big) claim that the effects of polycentric governance are "slowly cumulating and can be expected to increase their contributions over time"¹⁸.

As the debate about performance advances, some fairly simple proxy measures could be tested. For example, as a first-order, output-based measure of performance, we might explore whether the new forms of governance incorporate rigorous monitoring and evaluation procedures. The two strands of literature suggest that both national and, in particular, transnational governance, tend not to^{23,77}. Second, at an even more basic level, do the forms endure long enough to perform? Although many bottom-up environmental initiatives emerge, experience suggests that many quickly and quietly 'sink'⁸⁰, particularly when states withdraw support. Many of the public-private partnerships adopted at the Johannesburg World Summit on Sustainable Development in 2002 have suffered this fate⁸¹. New work on the lives⁸² of national policies, which could be extended to the transnational domain, is shedding light on their perilous existence⁸³. Biesenbender and Tosun⁸⁴ have revealed that national interest groups dominate post-adoption processes by exerting downward pressure on policy standards. States tend to respond to this pressure by quietly pulling back from an international norm, rather than openly withdrawing from it.

Although much more work on performance is required, three important things are already known. First, all of the new forms of governance evidently have weaknesses and hence are not without risk. By the same token, although huge gaps remain in understanding precisely what works, polycentric governance is unlikely to be a panacea⁸⁵. Second, performance evaluation appears not to self-organize as easily from the bottom up as Ostrom claimed it would⁸⁶. Indeed, one of the largest meta-analyses of climate policy evaluations⁷⁶ suggests that non-state actors, such as academics and consultants, are unwilling and/or unable to fill in the resulting gaps in the baseline evaluation that polycentric theory assumes states will deliver. Their reluctance is especially marked in relation to the more reflexive types of evaluation that challenge extant policy goals⁸⁷. Third, the three domains of governing are much more interdependent than was originally foreseen. Moreover, if Biesenbender and Tosun's argument about states preferring to quietly pull back from international norms is correct⁸⁴, national politicians looking for a window of opportunity to engage in national policy innovation could be condemned to wait for the next cycle of international negotiation to (slowly) reach agreement.

Moving forward

We have shown that each governance domain has attracted its own strand of scholarship. Much research effort has — rightly in our view — been invested by each strand into mapping the expanding universe of cases within each. This activity has confirmed that much of the activity within the transnational and (sub)national domains is new, in that it dates from the mid-2000s. This inspires hope that climate governance *in toto* is more active than critics transfixed by UNFCCC-related meetings have assumed. It has also added empirical flesh to Ostrom's claim that climate governance has become considerably more polycentric⁴⁸ — a phenomenon that scholars working in the separate streams were struggling to account for using their own internal analytical categories. Research has shown that the advent of new forms of climate governance has made the overall landscape more polycentric, spanning many spatial levels (international, national, and so on) and working through many modes (markets, networks, and hierarchies) and domains of action (public policy, transnational governance). This pattern bears out many, but not all, of Ostrom's predictions.

As new research in the separate strands emerges, two analytical challenges cry out for greater attention. The first is to build bridges between the strands to better understand the interaction between the three governance domains. For example, that many of the transnational initiatives have emerged in the shadow of state action bears out earlier predictions that transnational and state-led governance are likely to be tightly interconnected⁸⁸. Similarly, data on national policy activity (itself collected via transnational action — such as The Globe and Climate Action Tracker) has allowed academics to reveal the timing and extent of national policy activity. However, at present, academics have barely typologized the many possible forms of interaction between the domains, let alone traced them out empirically or explained their causes. In principle, at least four types of interaction between actions across the domains are possible: they could complement one another without actually interacting; they could merge; they could compete and conflict with one another; or some could actively replace other types²². These forms of interaction — termed co-existence, fusion, competition, and replacement, respectively⁴² — could form the basis of a common programme of research. Ostrom¹⁸ was generally optimistic, believing that the net result of the interactions would be synergistic and hence 'cumulatively additive', but we believe that the jury is still out on this matter.

The axis of interaction running between international governance, exemplified by the UNFCCC, and the other two domains, appears to be especially influential. There is plenty of case-specific evidence (and much speculation) that international processes (be they active in the form of new commitments, or vice versa) matter immensely for other governance domains. For example, Moncel and van Asselt⁵¹ have claimed that the UNFCCC has indirectly catalysed action in other domains. But how, why, and when these side effects matter remains a matter for conjecture. For example, are the countries that are seeking to push the UNFCCC process also the most active adopters of national policy and/or incubators of transnational governance? Does the perception that a particular state is pulling back from international cooperation nudge domestic actors into governing through other domains, as appears to be the case in some US states²⁴? Process-tracing work on the timing and sequence of these interactions would indicate where the main impulses arise⁸⁹. Either way, exploring the interactions empirically — perhaps even statistically — will offer a more informed basis on which to understand climate governance⁹⁰ than dichotomous modes of thinking that assume that monocentric governance is broken and transformative governance must be polycentric⁹¹.

A second challenge is to understand better the role(s) played by states in the three domains. It is surprising that this question should have arisen so quickly, given that previous work has assumed that governance is usually enacted 'without government'⁹². The strand of work on transnational governance has tended not to explore state roles that deeply, having implicitly embraced a 'small state' framing of governance. But more detailed work is now shedding light on the multiple, sometimes overlapping roles that state politicians and bureaucrats play. For example, through new climate governance work, we are now appreciating that so-called leader states that engage in policy innovation also work through international organizations (such as the World Bank) and supranational bodies (such as the European Union) to 'orchestrate' new forms of transnational governance⁹³.

Scholars accept that even polycentric orders need some 'legal framework'^{60,61}. But some states are offering a good deal more. They are actively nurturing national policy inventions by: working with policy instrument constituencies (emissions trading and feed-in tariffs⁵⁴ being prominent examples); facilitating their diffusion by creating learning capacities in organizations such as the Organisation for Economic Co-operation and Development, the World Bank, and the European Commission; and encouraging learning by establishing bodies with a capacity to evaluate, such as the European Environment Agency⁶⁶. While these may appear to be subtle activities, we surmise

that they are likely to be politically demanding⁶⁷, and certainly no less tricky than crafting international regimes. Understanding the choices lying behind them will require a much better understanding of the behaviour of politicians and senior bureaucrats. Fresh work is needed on which factors — electoral, economic, ideological, or legal — tip the balance from claiming credit, to avoiding blame, to seeking legacy effects. Subsequently, what determines their willingness to lead (or to stymie) efforts to govern transnationally, compared with national or international action? We believe that searching for more conditional explanations for state (in)action across a wider variety of contexts, including emerging democracies⁹⁴, is a more productive way to understand the promise and limits of polycentric governing than simply assuming that initiatives will come either from the top or the bottom.

A fuller and firmer appreciation of the inherent messiness of the interactions between the three domains will greatly enhance our collective understanding of the new governance; knowledge that, if translated into governance design activities, could inform the Paris conference in 2015. For researchers, it implies a need to build stronger bridges between the research strands, and work on mitigation and adaptation (the latter being especially under-represented in our stock take). Bridge building is not a trivial task — concepts developed in the national policy literature will need careful translation into the transnational realm, and vice versa. But by illustrating the extent to which each strand speaks to the shared analytical puzzles of distribution, initiation, and performance, we have shown that although all three are guilty of concept stretching⁹⁵, they are nonetheless essentially complementary — an encouraging foundation for future collaboration. Indeed, the welcome shift from single cases to more comprehensive databases suggests that convergence is eminently possible in the short term. Further breakthroughs will, we believe, be made when larger *n* quantitative studies are connected to qualitative analyses of individual cases⁹⁶. Hale and Roger's²⁵ insightful analysis of the most dynamic orchestrators of transnational governance offers a very good example of what can be learnt by creatively mixing methods.

For practitioners, messiness in governance implies that some of the initially high hopes that bottom-up forms of governing would magically spring up and save the day, should be tempered. Unfortunately, given the acute urgency of moving the world onto a path of radical decarbonization, it could be some time before the precise circumstances in which the new forms of governance are emerging and performing are sufficiently understood. Political efforts to catalogue and evaluate the new climate governance should be strengthened, building on existing activities both within (for example, the Non-State Actor Zone for Climate Action) and outside the UNFCCC. In the meantime, and knowing what social scientists are beginning to discover about the dense and messy interconnections between the three domains, it would, as Ostrom reminded us just before her untimely death, be extremely unfortunate if there was any let-up in the diplomatic efforts to craft an ambitious international agreement in Paris.

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A.J. and D.H. conceived and designed the paper, contributed materials and wrote it. M.H., H.v.A., T.R., J.S., J.T., J.F. and E.B. contributed materials and wrote the paper.

Additional information

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Competing financial interests

The authors declare no competing financial interests.