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Perspective

Addressing path dependencies in decision-making processes for operationalizing compound climate-risk management

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SUMMARY

The need for a compound risk governance system and management practice is argued in this paper. We find that, historically, risk management strategies have been developed for single hazards and are often subject to path dependency. It is thus difficult to adapt them to a situation that has compound risks. The lack of attention to compound risks in current risk management practices often leads to potential side effects—positive or negative—on other risks and can also result in related management strategies being overlooked. This can ultimately cause barriers to larger transformational adaptation efforts and lead to the intensification of existing societal inequalities or to the creation of new ones. To alert policy- and decision-makers to the need to move toward compound-risk management strategies, we argue that risk management must explicitly highlight various elements of path dependencies, the positive and negative side effects of single-hazard risk management, the appearance of new social inequalities, and the intensification of existing ones.

INTRODUCTION

In risk research, more attention has been paid to compound extreme weather and climate events in recent years—for two reasons: the potentially substantial losses these events can cause and the resulting complexity and non-linearity of managing and recovering from large compounding events.[1,2] In addition, these events have multiple causes from different scales, sources, and time frames.[1] The 2012 Special Report on Climate Extremes (SREX) of the Intergovernmental Panel on Climate Change (IPCC) opened the debate on compound/correlated/complex weather events.[3] Compound weather and climate events can be defined as "a combination of multiple drivers and/or hazards that contributes to societal or environmental risk" ([1], p. 469). As compound weather and climate events are connected in terms of physical processes, a more dynamic perspective of the hazard events is often required.[4] The complexity increases when compound events are influenced by multiple physical processes, such as rainfall, wind speed, temperature, and adiabatic processes, etc.[5,6] These physical processes are interconnected and mutually reinforcing; for example, the magnitude of a flood event can be influenced by soil dryness or the occurrence of extreme wet and cold events.[5,7] As climate change interacts with the different physical processes, its complexity increases.[1] A warmer climate will influence and increase the impact of most physical processes; for instance, there may be increased rainfall events in the fall after a summer that is long and dry due to prolonged heat waves.[8–10] Overall, compound events can be distinguished by how they arise and interact. They may be: (a) preconditioned (e.g., a flood event caused by a drought event); (b) multivariate (e.g., drought and heatwaves occurring at the same time); (c) temporally connected (e.g., caused by several tropical cyclones); or (d) spatially connected (e.g., multiple flood events.[11] Compound events are also complex in that they connect a variety of natural processes, spatial scales, and temporal factors such as prolonged drought events that can trigger flooding. [11,12] Various events in recent years, such as hurricanes Harvey and Irma, different false springs in Europe, or various connected drought and heatwave events across the globe, have shown the limitations of societal and environmental capacities to cope with and adapt to climate change.[1,12–15] The occurrence of such compound events has increased the frequency and magnitude of hazards.[16–18] As compound weather and climate events combine different extremes, they have a cumulative impact that is much higher than that of a single event; they can cause higher losses and damages than single events, and with our current decision- and policymaking directions, we are unprepared to manage them.[12]

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Moreover, compound weather and climate events encourage cascading social processes, with high-impact events creating further socio-cultural, economic/financial, and political effects, as well as stress to individuals.[19] Having to live with more extreme and frequent compound events will be particularly problematic for low-income households, which are more likely affected by hazard events, often less prepared, and frequently unprotected by technical mitigation measures.[20–22] Subjectively, people see an initial event as discrete, but by the second or third event the initial disaster is no longer understood as a singularity but becomes intertwined in its effects and historical meaning with other events. Objectively, the domino effect of disasters not only poses particular problems for recovery trajectories (whereby people have not begun to recover from the first disaster before the second or third hits) but it also exposes preexisting limitations for both short-term mitigation and long-term trajectories for social recovery ([19], p. 24).

Major drought events, for example, affect soils and forest health, which can trigger future flood events as soil and forest conditions become unable to provide their traditional regulation functions.[23,24] In such cases, drought events can lead to a positive feedback loop for future flood events, as crusted soil leads to greater runoff.[1,25,26] On the other hand, floods often occur in multiple spatial areas (like the Alpine summer floods in 2005), and this exhausts the blue-light organizations, making it impossible for them to cope with all the various flood events at the same time.[27] The outcome in such situations is much higher losses compared with those that result from a single-catchment flood event.

To date, however, most risk assessments have been based on the understanding of a single independent hazard process. Many risk management approaches thus fail to take into account the positive or negative consequences that a given single hazard process might have for another hazard as well as for management efforts related to it. For example, decisions taken in the course of drought risk management could have negative impacts on future flood events, or vice versa.[26]; the implementation of Nature-Based Solutions (NBS) in flood risk management could have positive impacts in terms of reducing the risk of future drought events.[28]

Over time, risk management of individual hazards has become path-dependent and based on engineering solutions. Hence, although alternative approaches are available, infrastructure, knowledge, and institutions have evolved and become more and more interconnected, resulting in this particular practice taking hold.[29] Engineering solutions are often easier to implement in currently used decision-making processes than innovative alternatives, such as NBS, like wetlands, trees, and natural retention areas, etc. NBS could be implemented to manage risks emerging from different types of hazards within a compound event. However, NBS need space for implementation, and this space is often privately owned, which may cause conflicts and/or long-term negotiation processes.[30,31] Engineering solutions, on the other hand, require less or no privately owned land, and are well-known within the public administration for their efficiency in risk reduction.[32,33] Overcoming such path dependencies is thus crucial, and risk-management decisions should be checked at every stage against a variety of alternatives, particularly those best suited to addressing compound climate risks.

In this perspective paper, we aim to extend the current debates within the climate-related risk management sphere. We demonstrate the importance of compound risk management and the decision-making processes related to it. We show how several concepts can be integrated to improve risk management. As mentioned, strategies to reduce losses caused by natural hazard events have often focused, to date, on single hazard events; and this, in turn, has the potential to create inefficient and problematic effects within the risk management system itself. A limited perspective of this kind can increase the vulnerability of individuals and communities. We emphasize, in particular, the importance of establishing a compound risk management approach and of overcoming the potential path dependencies of current single risk-management approaches.[29] Indeed, by definition, path dependencies lock in on sub-optimal paths—paths that are inefficient or that exacerbate inequalities within a country or a community by increasing the social vulnerability of individuals and communities and hindering their recovery after an event has occurred .[34,35] A key focus is thus on the questions: (i) how can path dependencies be avoided or overcome? and thus (ii) how can a compound risk management system be enabled in practice to ultimately help prevent escalation of economic losses and social inequalities as climate change intensifies. With this in mind, we conducted a critical review of the literature on the need for, and the challenges involved in, compound weather and climate risk management, and its practical implementation.[36] On this basis, we outline the positive aspects of developing a compound risk management approach with, as follows: (i) an overview of the current limitations in disaster risk management in terms of compound weather and climate risks; (ii) the risk of path dependency and its potential negative socially implications; and (iii) how these challenges and negative consequences can be overcome using a compound risk management strategy.

THE ROLE OF PATH DEPENDENCY IN DISASTER RISK MANAGEMENT

According to Hanger-Kopp et al. ([29], p. 2) path dependency is: a process that has the property of staying on a particular [trajectory], so that past decisions and contingent events pre-determine what further steps may be taken. [Under such circumstances] technologies, policies, or governance modes are locked-in [and] self-reinforcing mechanisms contribute to their reproduction and diminish the range of likely alternatives.

A core problem is that "path dependency manifests as resistance to changing the way things have always been done, even if business as usual seems to be increasingly maladaptive" ([37], p. 2). In approaching path dependency, the idea is to understand and assess why it is difficult or almost impossible to redesign certain modes of governance or decision-making as they arise over time.[38] Path dependencies are often a key barrier to adapting to changing risks in the future, and they thus hinder the introduction of adequate disaster risk reduction measures. Decisions that create path dependency can even have negative consequences (e.g., losses) for another hazard or create cascading effects which result in higher losses.[34] The core of the problem of path dependency is that it is self-reinforcing, namely, it ensures that "further steps will be taken along the same path" ([38], p. 96) by decision-making entities, and this plays a crucial role in the failure to adequately address disasters and disaster risk management. Indeed, several interrelated self-reinforcing mechanisms may be at play to varying extents. Some are more closely tied to the technology in place, for instance, high up-front costs, learning, and network effects, whereas others are related more to the associated institutions, for example, political authority and institutional density.[29]

In disaster risk management, self-reinforcing mechanisms support the "accumulation of vulnerability and exposure within a system over time" ([34], p. 2). Frequently, however, these connections and interactions are overlooked in the decision-making process. One example is the connection between SARS-CoV-02 pandemic and climate risks.[39] In 2020 the SARS-CoV-02 pandemic was highly influential in the emergency planning for tornados, posing such questions as: how and where can people be evacuated during the lockdowns? who will be driving the buses for homeless people during tornado season lockdowns? and how should those who test positive for Sars-CoV-02 be dealt with in the shelters?[40]

A classic example of path dependency in disaster risk management is the focus on structural engineering solutions, which is often based on a standardized design level, and leaves limited possibilities for further adaptation strategies, which are needed to confront the impacts of a warmer climate.[29,41,42] Hazard events with a higher intensity in particular cannot be covered by existing structural engineering solutions. In the worst case, those structural measures could even reinforce the natural hazard process (or any other hazard process). For example, under intensive rainfall, dams or reservoirs used for water supply during periods of drought have a much higher susceptibility to failure, as they strain against the weight of the increased volume of water.[26] On the other hand, if intensive rainfall is expected, dams can usually release water to prepare for the flood wave. Releases can, however, worsen the situation if a drought event follows, as the dam or reservoir cannot fulfill its major function of water supply. Such was the case in Kerala, India, in 2018.[43] It is impossible or almost impossible to adapt decisions that lead to path dependency without an enormous expenditure of resources (e.g., personal, financial, technological, etc.).[44] Disaster risk management is often subject to path dependency, both institutionally and structurally, as engineering solutions have lifespans of up to 80 years and any adaptation to a chance event would be extremely costly.

Consequently, path dependency in disaster risk reduction often reinforces or encourages vulnerability and exposure within a region. This can have negative consequences for low-income householders.[34] who, in many cases, are more prone to hazards and more greatly affected by past events.[21] They also suffer more from hazard events compared to other social groups.[21,45–48] Some possible reasons are: (a) lower social capital; (b) lack of financial resources; (c) lack of insurance on which to claim; and (d) delayed financial support from the public administration. Low-income householders are also more likely to live in hazard-prone areas with a lower level of protection.[49,50] or are more often affected by planned relocations.[20] This is highly problematic if decisions in risk management have created a lock-in situation, as this makes it almost impossible to break the current path to find an effective response to the new circumstances, to

Table 1. Potential implications of a compound risk approach for the five strategies in risk management

Risk management strategy	Examples	Aim of the measure for a single-hazard perspective	Aim of the measure for a compound perspective	Potential implications for a compound risk approach
Prevention	Relocation of residential and non-residential properties.	Sudden decrease in the number of exposed residential and non-residential properties affected by a single hazard event	Permanent and future-oriented decrease in the number of exposed residential and non-residential properties affected by different hazards	Integration of compound events into planning and policy decisions
Defense	Implementation of subsurface storages	Technical mitigation measures, such as flood dams	Reduce the peak flows and store water for potential drought events	Consideration of cascading effects and interactions
Mitigation	Implementation of building adaptation strategies	Implementation of property-level flood-risk adaptation (PLFRA) measures	Implementation of property-level measures showing high efficiency for compound events	Selection and development of adaptation measures that can be used for compound events
Preparation	Take actions to improve risk awareness of compound events through training, evacuation strategies, risk communication	Reduce potential losses from a single hazard	Reduce potential losses of compound events	Enhanced cooperation and communication between the public sector and society
Recovery	Financial schemes (e.g., insurance payments, government relief subsidies, micro credits, buy-out schemes etc.) for recovery—focusing on the impacts of compound events	Reduce potential losses from a single hazard	Reduce potential losses from compound events	Improve efficiency of fiscal measures

adapt to higher temperature, or to take actions to reduce social inequalities. There is thus a strong need to understand—well in advance—how path dependency can be avoided.

TOWARD COMPOUND RISK MANAGEMENT TO AVOID PATH DEPENDENCY

Compound weather- and climate-related events are hardly ever considered in current risk management strategies.[51] Compound risk management is vital in order to expand current perspectives within disaster risk management and thereby tackle intensifying climate-related risks in the future. The aim of a compound risk management strategy is to consider different hazards and their interactions within the decision-making and planning process, with the ultimate goal of reducing the overall level of climate-related risk for a specific community. Compound weather- and climate-related management must be holistically implemented in all five components/stages of natural hazard risk management strategies[52]: (i) prevention (e.g., spatial planning); (ii) defense (e.g., technical mitigation measures); (iii) mitigation (e.g., natural flood management); (iv) preparation (e.g., disaster management plans); and (v) recovery (e.g., rebuilding strategy). Table 1 provides an overview of the strategies that constitute compound risk management at each stage.

First, the **prevention** strategy aims to reduce the negative consequences of natural hazard events with the help of planning instruments or relocation policies. The main objective is to reduce (or avoid) the exposure of residential and non-residential properties. To date, risk prevention has mostly focused on reducing the risk of only one type of hazard at a time, thus excluding the perspective of compound events and the potential impact of climate change. Such a change of perspective would mean that relocation policies, for example, would need to address not only one risk within their current strategy but also the potential long-term impacts for the relocators under climate change, as the relocators might need to relocat again.[31,53]

Second, the **defense** strategy focuses on technical solutions, such as dams or dikes. Within a compound risk management perspective, the selection process of technical solutions should address the potential impacts of compound events; the management (operational) process, too, needs to include a compound perspective. In particular, the defense strategy shows the highest risk of path dependency as well as disproportional negative consequences for other types of hazards.

Third, the **risk mitigation** strategy aims to address the implementation of risk reduction measures, such as property-level risk adaptation measures, to improve the resilience of buildings.[54] Thus far, the selection process to improve the resilience of buildings has often focused only on one single type of hazard, mostly flooding. Here, the solutions are not always suitable for other types of hazards. For example, metallic doors, concrete stairs, or timber block construction, which show a strong resistance to different types of hazards[55] are rarely implemented.

Fourth, the **preparation** strategy focuses on the proactive planning of emergency management if an event occurs. The key areas of attention are evacuation, early warning, individual training, plus risk communication between the public administration and society at large. Within a compound risk management paradigm, blue-light organizations (such as fire brigades) would need equipment that can be used for different types of hazards. Early warning systems as well as communication strategies need to address the compound effect of different hazards to a society, such as the impact of a long-lasting drought and other extreme weather conditions, an example being Hurricane Ophelia which triggered forest fires in Portugal and claimed 50 casualties.[56] Often, early warning or communication systems still focus only on one type of hazard.

Fifth, the **recovery** strategy strongly focuses on financial support for individuals after a hazard event. Financial schemes, such as insurance or government relief payments, often aim to reduce the individual financial burdens for one type of hazard, for example, flood insurance schemes. A compound perspective would require financial schemes to address not just one type of hazard, but the potential losses from compound events; this would need an improvement in the current efficiency of fiscal measures, as losses from compound events are much larger than from single ones.

This requirement will further increase the current complexity of risk management in terms of data, knowledge, expectations for future developments, and close collaborations between the different actors dealing with these various aspects across governance levels (national, regional, and local). Moreover, a shift from the static toward the dynamic perspectives of risk management is needed. For example, at the present time, future land use or socio-demographic changes are not always included in the development of risk management strategies and decisions are often based on the current situation only.[57,58] Another key aspect reflects the political process of managing compound and weather-related events. Flood risk management, for example, is highly institutionalized in many flood-prone countries with national, regional, and local authorities being responsible for different tasks. Sometimes, however, local stakeholders or private actors manage drought risk, rather than there being any involvement from the public administration. A key drawback is the lack of policy coordination between and among the different natural hazard risk management strategies; frequently there is also a lack of long-term adaptive perspective within different hazards regimes.[59]

Generally, most communities have not managed their risks in an integrative or systematic way. Droughts and floods are often managed by agencies that rarely collaborate or even communicate (see e.g., for Austria[42]). Such a siloed approach makes it much harder to exploit measures that can protect against both threats. For instance, flood risk management focuses on land use planning and is increasingly risk-oriented and proactive, whereas drought management focuses mainly on water supply and agriculture and often consists of reactive emergency responses.[26,60,61] To achieve a more holistic perspective to manage the large and growing compound risks, changes in governance structures and procedures will be required. Adaptive and integrative risk governance can help address the key gaps and challenges associated with the understanding and management of compound risks, in particular the inadequate knowledge base, underlying complexities, and associated ambiguities.[62]

Policy strategies that focus exclusively on one hazard frequently downplay its consequences. One possible way of integrating these strategies is to use a socio-physical narrative of the risks, such as stress, burnout, fear, etc.[12,63] Another example would be the use of new methodological approaches to design protection schemes that integrate simultaneous (or near-simultaneous) occurrences of different hazard events like storm surges and river discharge peaks.[64] Concepts like adaptation pathways, storylines, or stress tests explore future developments, look out for potential path dependency, and enable decision-makers and stakeholders to find decisions even under deep uncertainties.[12,29,65]

ADAPTATION PATHWAYS, STORYLINES, OR STRESS TESTS FOR OPERATIONALIZING COMPOUND CLIMATE-RELATED RISK MANAGEMENT

Path dependency usually analyzes past decisions that lead to lock-in situations, whereas adaptation pathways focus on the future and aim to avoid path dependencies. Various recent methods focus on the forward-looking perspective; the most important of these are adaptive pathways, storylines, and stress tests. These three methods include the different complex interactions of compound weather events, their impacts, and their influence under climate change.[12,66] The adaptation pathways concept (e.g.,[67–70]) is one idea of how to break the current siloed approaches in risk management and potential path dependency.[29] The idea behind adaptation pathways is to develop different trajectories or alternative solutions—based on different climate conditions—for the future planning of risk management.[67,71] The concept integrates future developments (e.g., different climate conditions, land use changes, socio-demographic changes, societal needs) into a decision-making process whose aim is to find effective and efficient risk reduction measures ([67,68,70]). The main reason for adaptation pathways is to integrate a more dynamic perspective of risk management, including a planning process, under deep uncertainties.[67,68,72] The latest developments in the adaptation pathways literature include the idea of integrating a backward-looking perspective into the process to identify path dependencies and to overcome any that emerge.[29] The concept of the backward-looking adaptation pathway encourages users to explore the root causes of vulnerabilities within a community/region and of the lock-in decisions made in the past. This knowledge is needed to avoid decisions in risk management that might encourage further path dependencies. In Saint-Martin (Caribbean), for example, when the region was hit by various tropical cyclones like Irma in 2017, past decisions led to enormous losses being suffered, especially by low-income householders.[34] Decisions in disaster risk management can cause long-term vulnerabilities and allow them to accumulate, and this is what so often exacerbates social inequalities.[34,73]

A second commonly used method for developing forward-looking risk management approaches is storylines. Storylines of extreme compound events can be defined as ''a physically self-consistent unfolding of past events, or of plausible future events or pathways'' ([74], p. 557). Storylines are often used for event analysis.[66] The conceptual idea of storylines is to translate the complex physical processes of natural hazard events, influenced by natural climate variability and anthropogenic climate change, into an event-oriented rather than a pure probabilistic debate.[74,75] Storylines aim to focus on the uncertainties of the physical processes based on exploratory experiments.[75] The advantage of using storylines is to provide plausible future scenarios or pathways based on historically observed information and events providing subjective-descriptive future outcomes.[65,76] This is done by focusing on specific drivers, which are important in the case of deep uncertainty in compound risk management.[75] In terms of compound events, storylines are used to understand the potential impacts of the complexity of compound weather- and climate-related events as well as how community resilience can be increased.[66]

Thirdly, stress tests can support the robustness of the decision-making process. Stress tests help to identify the connections between different items in a system, such as how communities and regions or urban and rural are linked, potential reserve resources, and how different sectors are dependent on each other. This also includes the potential aspect of ''unexpected'' developments that should be considered in the planning and decision-making process.[12] The stress test can be used to explore the ''weakest'' points in the system. It not only includes the type of measure that might fail to respond to the hazard event; it also helps to spot potential path dependency in the current risk management strategy. Additionally, the stress test includes an assessment of potential impacts—that is, not only financial losses but also who is affected in the communities (low-income or high-income householders). The outcome of the stress test would help the decision-making process to recognize and integrate (and thereby avoid) potential path dependency and at the same mitigate the risk of social inequalities caused by it.

DISCUSSION AND CONCLUSIONS

This perspective set out to discuss why we need compound risk management approaches, the importance of avoiding the risk of path dependency among the different hazards, and how this system might look. According to our findings, operationalizing compound risk management requires new approaches in the decision-making processes, as collaboration among even larger and more diverse sets of stakeholders will be required in the near future and existing path dependencies have to be addressed. This requires the further development of established techniques, such as adaptation pathways, storylines, and stress tests as well as the gathering of new and more complex empirical and model-based data. Risk management needs to particularly address all four characteristics of compound and weather-related events (preconditioned, multivariate, temporally connected, and spatially connected), rather than focusing on only one of them. Additionally, the current research on compound and weather-related events needs to incorporate not only various physical components but also dynamic perspectives about vulnerability and exposure.[77,78] Furthermore, these three methodologies show considerable advantages for use in risk management. All three approaches, however, are also very complex in terms of designing and using them in the decision-making process. Most importantly, they require large qualitative and quantitative datasets. They are often time- and resource-intensive and additionally require resources and knowledge to use them. There are particularly large barriers to introducing these approaches into the existing governance structures, especially in contexts with high path dependency.

Beyond implementation challenges for these specific approaches, the main barriers to a compound risk management system are manifold, but most of them are rooted in the prevailing institutional framework. Most countries have specific regulations, financial schemes, and administration units that deal with one specific hazard.[42] The outcome is that compound hazards are typically excluded and go unrecognized within emergency management plans or land use plans.[79] As decisions are often based on single hazards, the decision-making process can create different aims and priorities for activities to reduce the risk level, and this could potentially result in the highest risks being overlooked or a mechanism being reinforced. Another key point involves the lack of communication and the unsatisfactory partnerships among the different actors responsible for dealing with disaster risk management. This is because of a lack of policy coordination and integration that can often avoid or hinder collaboration to manage the different hazards within a compound risk management framework. These barriers to coordination can include a lack of interest, incentives to maintain secrecy, administrative turf wars, and partisan politics.[80] Finally, the institutional framework also often discourages sharing of data and knowledge among the different actors and stakeholders who engage in risk management.[81]

The shift toward a compound risk management perspective has at least two benefits.

First, compound risk management acknowledges that for risks to be adequately managed, their interconnected nature must be recognized and that cooperation and co-management must be: (i) fostered across the institutional and administrative boundaries of risk management through inclusive channels; and (ii) the building of inclusive communication channels to engage decision-makers and stakeholders across interdependent sectors and knowledge communities in order to account for different values and risk perceptions.[82,83]

Second, compound risk management helps to foresee path dependency and the risk of increased social inequality. Future-looking socio-physical approaches can anticipate path dependency and enable decision-makers to overcome lock-ins. The advantages of using compound risk management can be, for example, well-designed infrastructure that avoids major traffic jams after large compound wildfires and landslide events.[12] The shift of the perspective on compound risk management would also support the identification of current and potential future path dependencies, as, by definition, dealing with compound risks requires alternatives to be considered and to go beyond the traditional actors involved in a single-hazard approach.

Overall, we raise several points regarding the enabling of a compound risk management perspective in terms of data- and knowledge-sharing and also cooperation and co-management across institutional and administrative boundaries. Institutional changes enabling compound risk management strategies should then be able to prevent entry into new lock-ins and facilitate new structural measures, either gray or NBS. Path dependencies cannot be fully avoided, but approaches to compound risk management may reduce the risk of negatively perceived lock-in. Ultimately, a residual risk of path dependency on a sub-optimal path may occur as we gain new knowledge and also as actor constellations and preferences shift over time and formerly good solutions are no longer perceived as such. Opportunities to change existing lock-ins of infrastructure are, by definition, external and may occur at the end of the lifetime of the infrastructure or be due to insufficient protection levels caused by increasing risks. Operationalizing a compound risk management approach requires an integrative, adaptive, and participatory governance system. Nevertheless, participation has the challenge of slowing down the implementation process. On the other hand, including a future-oriented risk management would expand our decision-making potential, especially to avoid path dependency and social inequalities, which have a much longer negative impact.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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