Towards a more integrated research framework for heat-related health risks and adaptation

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Advances in research on current and projected heat-related risks from climate change and the associated responses have rapidly developed over the past decade. Modelling architectures of climate impacts and heat-related health risks have become increasingly sophisticated alongside a growing number of experiments and socioeconomic studies, and possible options for heat-related health adaptation are increasingly being catalogued and assessed. However, despite this progress, these efforts often remain isolated streams of research, substantially hampering our ability to contribute to evidence-informed decision making on responding to heat-related health risks. We argue that the integration of scientific efforts towards more holistic research is urgently needed to tackle fragmented evidence and identify crucial knowledge gaps, so that health research can better anticipate and respond to heat-related health risks in the context of a changing climate. In this Personal View, we outline six building blocks, each constituting a research stream, but each needed as part of a more integrated research framework—namely, projected heat-related health risks; adaptation options; the feasibility and effectiveness of adaptation; synergies, trade-offs, and co-benefits of adaptation; adaptation limits and residual risks; and adaptation pathways. We outline their respective importance and discuss their benefits for health-related research and policy.

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Introduction

There is mounting evidence that more frequent and severe heat extremes across the globe have contributed to an increase in mortality and morbidity.[1–4] A wealth of epidemiological and climate impact studies has revealed the relationships between environmental conditions and heat-related health outcomes, although these studies are primarily from the Global North.[5–7] Similarly, there is a growing body of literature providing burgeoning evidence of health adaptation taking place in different regions and contexts across the globe.[7–12] In the past 3 years, research has pointed to the ongoing fragmentation and uncertainties in how we study heat risks and related adaptation responses, and several papers have called for more integrated perspectives.[13–15] For example, Vanos and colleagues[14] called for a set of diverse methods to model human responses to heat-related health impacts and stressed the need for improved linkages among physiology, epidemiology, and climate science. Crucial challenges remain in making and evaluating such models and providing robust evidence about which (sets of) adaptation measures can reduce risks, particularly in the context of future global warming and socioeconomic developments.[7] Although these calls for more integrated perspectives are much needed, we argue in this Personal View that they are not far reaching enough to ensure timely research that enables equitable, adequate, and effective adaptation responses to reduce future risks. This work requires a transformative perspective to build interlinkages across research domains that transcend the causes of risks and solutions.[16,17]

Assessing heat-related risks and unpacking the solution space for responding in an equitable and just manner is crucial if the next generation of heat-related health research wants to increase its relevance to policy. Such developments are already emerging in other fields of research, most noticeably in the context of water-related risks and sea level rise.[18,19] In this Personal View, we build on our comprehensive review of heat-related health scientific literature for the Intergovernmental Panel on Climate Change sixth assessment report[20,21] and consider advancements in other fields of research. Through iterative discussions and the thematic clustering of ideas and concepts, we have identified the following six inter-related building blocks that form a holistic perspective for heat-related health research. We explore the status of knowledge for each building block, articulate how these could be brought together, and reflect on the benefits and challenges of doing so. Figure 1 offers a conceptual overview of the six building blocks for integrated research on heat-related health risk and adaptation.

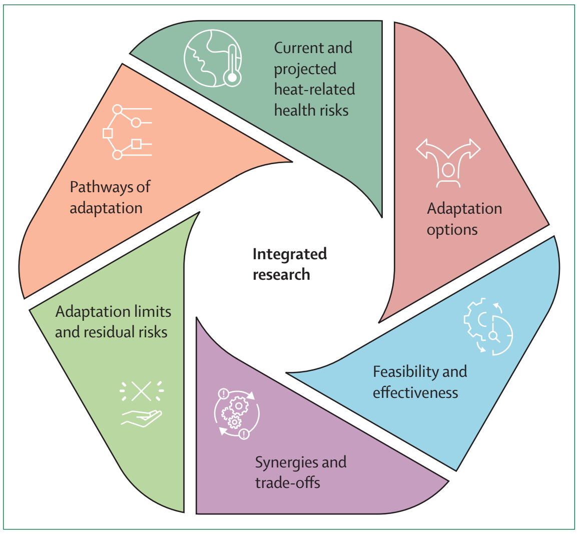

Figure 1: **Key building blocks from the scientific literature for generating integrated research on heat-related health risks and adaptation**

Current and projected heat-related health risks

Traditionally, research on heat extremes and health has focused on this first building block, aiming to understand heat-related health impacts and risks with a range of epidemiological models, extreme event attribution, climate scenarios, and occasionally plausible future shared socioeconomic pathways (SSPs).[22–26] Research has also shown how climate scenarios in combination with socioeconomic scenarios (eg, the SSPx-y matrix) greatly affect risk severity,[25,27,28] although large uncertainties remain on the magnitude and timing of these risks.[14]

There has also been an increasing understanding of the role of physiology and natural adaptation to heat, with some studies considering mortality rates with and without adaptation (in which adaptation is modelled by assuming that the temperature thresholds for extreme heat increase over time).[2,29]

Although quantifying the impacts of extreme heat and understanding where and who is affected, and what this means for prioritising policy action is important, there is also a tendency to study heat-related health risks in isolation. Consequently, adaptation responses are typically geared towards specific health risks, but often the most profound consequences are the result of extreme heat compounded by other extremes, such as high humidity, or environmental stressors, such as air pollution.[30]

We suggest that heat–health modelling approaches, although well established in the realm of literature on risks and impacts,[25,31] should be more sensitive and inclusive of other building blocks, and consider adaptation options, their feasibility, effectiveness, and pathways of adaptation.[31] We outline why this inclusion is important and how it can be implemented in the following sections.

Adaptation options

The second building block centres on the question of what kind of adaptation options exist to equitably reduce risks related to heat extremes. Research in this area is rapidly evolving, with most studies having identified a range of options either implemented or planned in practice, including technical (eg, air-conditioning, insulation, and green walls), societal (eg, heat-proof urban planning and development and relocation), individual and behavioural (eg, acclimatisation, heat awareness, and heat protection), and institutional and economic (eg, legislation, health systems, subsidies, and finance) options.[32] In addition, there are options such as early warning systems, which encompass both technical and behavioural types, given the needs for both technically reliable alerts triggering mechanisms and population responsiveness to such alerts to reduce risk exposure.[13]

Similarly, some adaptation options are small changes to existing practices (eg, cooling stations or heat alerts), whereas others are more transformative in nature (eg, urban greening). Some measures are quick to implement in the near term (eg, changing clothing), whereas others are substantially more time consuming (eg, green infrastructures).[33,34] Hence, moving forward, we need to understand not just which options are available, but also what is already in place and how these options work together in various combinations.

Therefore, this building block is not only about what kind of adaptation options exist but how these options have emerged, been planned, and possibly implemented in a given context. This block requires a contextualised understanding of the health response options already in place, sometimes for a long time, creating a path-dependent starting point that connects directly to the third building block.

Feasibility and effectiveness

Understanding the feasibility and effectiveness of adaptation options is important to make evidence-informed decisions. There is some literature on these aspects, but it is underdeveloped, biased towards technical options, and mostly disconnected from scenarios related to future warming.[35]

Effectiveness in the narrow sense refers to the ability of adaptation options to reduce health risks and should ideally be measured against a baseline and compared across different levels of warming. For example, studies have shown an increased heat tolerance among individuals in Mediterranean and US regions over the past 40–50 years.[8,9] Assessments of effectiveness have primarily been done for some technical measures, such as air-conditioning,[36] natural ventilation,[37] and changing sleeping habits,[38] and in some geographical contexts (eg, the Mediterranean region), but our understanding of effectiveness in general, among vulnerable groups, and specifically in the longer term and for institutional options is poor. Adaptation is vaguely modelled in extant research and whether particular factors, such as population density, health-care facilities, proximity to water, housing quality, and green space actually modify (ie, reduce) the effect of extreme heat on health outcomes is unclear.[39] Yet, understanding the effectiveness of the range of combinations of adaptation options under different levels of warming and socio-economic developments will be crucial to inform decision making. Such assessments require careful considerations of temporal effects, as some measures are effective in the near term but might only have a short lifetime or turn out to be maladaptive in the future,[40,41] for example, air-conditioning versus passive cooling.[32,41,42]

The feasibility of implementing adaptation measures (ie, establishing which barriers and opportunities exist) has become an increasingly important topic in adaptation research over the past 5 years.[43] Better understanding of the feasibility of adaptation options allows for balancing between the feasibility of options and their effectiveness in a given context. For example, adaptation options such as urban greening, which require transformational changes, might be highly effective at reducing risks,[44] but the feasibility of implementing these options in the short term is generally low (due to high economic costs, political resistance, little space, etc).[45] Similarly, some options that are highly feasible could be low in their effectiveness, or highly effective in the short term, but maladaptive at later stages.[46]

As feasibility could change in the future (eg, as a result of different socioeconomic and political developments), this variation needs to be considered.[47] Feasibility and effectiveness assessments should be better connected in a given context to the magnitude of climate risks and should cover a range of adaptation options.

Synergies and trade-offs

Health impacts and adaptation responses cut across many of the UN Sustainable Development Goals (SDGs), and many adaptation options have health synergies, trade-offs, and co-benefits beyond reducing health risks. For example, investing in urban greening to reduce the urban heat island effect improves mental health, offers possibilities for rainwater storage, facilitates recreational use and cycling, raises local housing prices, and improves overall livability in cities.[48] At the same time, urban greening might create reservoirs for new infectious diseases, increase risks of urban fires, increase water demand during droughts, take costly space from urban development, and contribute to green gentrification. Some adaptation measures have substantive co-benefits and can, therefore, be more easily mainstreamed with other non-climatic efforts, thereby increasing their feasibility. For example, there are plans to transform cities in response to the COVID-19 crisis, providing windows of opportunity to make green investment decisions that also improve heat-related health adaptation.[49,50]

Synergies, trade-offs, and co-benefits are increasingly recognised as important elements in planning for adaptation.[51] Cataloguing and critically assessing the synergies and trade-offs of adaptation measures, particularly in the context of the SDGs, needs to play an important role in prioritising options that have more co-benefits, or create new opportunities for mainstreaming. This assessment will allow us to assess if some options will have positive or negative impacts elsewhere or might become maladaptive over time.

Adaptation limits and residual risks

Many adaptation options are able to reduce risk up to a given amount of environmental change; after reaching threshold conditions (in some cases the design conditions), they do not perform well anymore, and additional or other actions are needed. This effect is sometimes referred to as an adaptation tipping point.[52] The presence of adaptation tipping points and limits means that in many cases there will be residual risks even after adaptation has been fully implemented (ie, risks that remain after adaptation has taken place). Specific to health adaptation to heat, there are upper physiological limits that arise from sustained exposure to extreme heat when metabolic heat cannot effectively be shed.[53,54] Although fully eliminating risks is often desirable, this option might simply be impossible due to societal and economic constraints and the wide diversity of local conditions that characterise health risks over time.[53] In some instances, the degree of investment is so substantive that, even if high degrees of adaptation are successfully implemented, residual risks remain. For example, the cooling effect of urban greening might not be enough to contain urban temperatures at a level sufficient to protect human health.[55]

Suboptimal choices must be made if some adaptation options are no longer feasible or effective in a given context. The degree of adaptation needed will also depend on how much residual risk society is willing to accept, and what gets prioritised is often a political choice. There is, for example, very little literature on last resort adaptation options or the moral implications of accepting residual risks and their extent in different contexts. The political choices that lead to (not) selecting some adaptation measures and the feasibility aspects that give rise to residual risks remain underexplored.

Assessing residual risks by unpacking the limits to adaptation and the feasibility and effectiveness of portfolios of adaptations is crucial to assess the extent of possible residual risks.[56] Estimating the amount of residual health risk after adaptation in various local contexts is important to anticipate, decide, and plan accordingly. Framing research and discussions on adaptation limits in the context of the solution space offers a way to explore the limits of some adaptation measures at a given point in time and space to avoid lock-in pathways in which residual risks are increasing over time or come as predictable surprises.

Pathways of adaptation

Our understanding of the projected risks of heating, the types of adaptation options available, their feasibility and effectiveness, and the possible resulting synergies and trade-offs allows for more robust assessments of whether system changes are needed and how these might look under different scenarios. Understanding and evaluating the mix and sequence of options for the most effective responses under multiple possible futures is therefore crucial.

In some contexts, incremental changes to existing practices are needed; for example, adding some measures to further enhance the system already in place. In other contexts, the existing set of options does not result in acceptable or tolerable levels of residual risks, therefore requiring systemic changes. Narratives and pathways of change can provide avenues to assess, design, and evaluate a range of opportunities and desired futures, thereby taking a solution space perspective.[18,57]

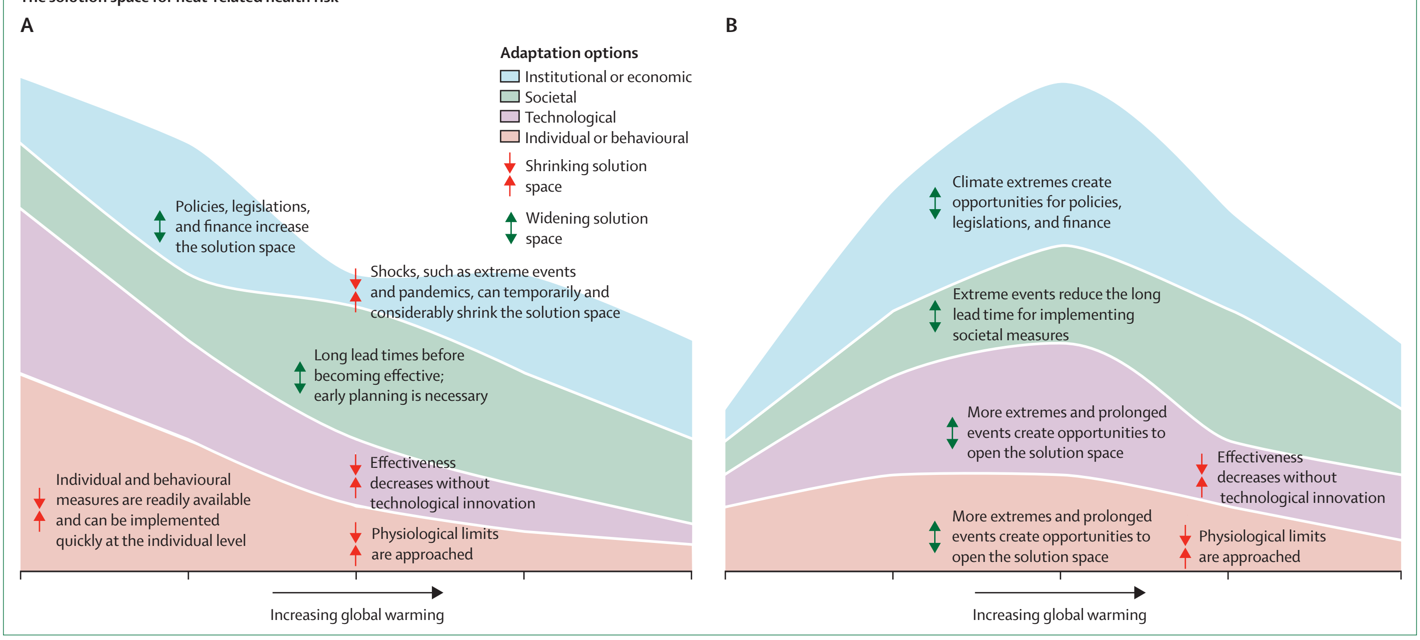

Figure 2: **Two archetypes of stylised solution space showing how solution space (ie, the total coloured area) changes with increasing global warming**
(A) The solution space decreases with further warming. This archetype is for locations where warming will only lead to further shrinking of the solution space for health adaptation to heat because a lot of adaptation and risk reduction has already happened in the form of technological (eg, air-conditioning or cooling) and behavioural (eg, in cities in southern Europe and southeast Asia) measures. The overall solution space decreases with increasing warming, and shocks in the form of climatic extremes or pandemics can suddenly lead to further and temporal shrinking of the solution space. Some measures that require positive disruptive changes and innovations have long lead times (eg, urban planning or urban redesign). (B) The solution space is a bell-shaped curve. This archetype is for locations where extreme heat events are new and the solution space is small to start with due to lack of awareness and finance. An increased frequency of extreme events can raise awareness and create opportunities through finance and societal support. For example, the 2003 heatwave in Europe led to numerous countries in northern and central Europe establishing health-related heat action plans. With increasing warming, the effectiveness of adaptation measures decreases, and physiological limits can be approached, ultimately reducing the solution space overall.

We show these avenues by means of solution space diagrams (figure 2). The solution space in figure 2 A depicts how, as global warming increases, the space for behavioural measures will shrink. Although technological measures, such as air-conditioning, help to mitigate the effect of heating in the short term, more transformative and sustainable measures at the level of urban planning and green infrastructure (alongside an enabling societal and policy environment) will be needed to keep the solution space open. This pattern is usually the case for locations that already have a long history of dealing with extreme heat and instances in which behavioural and technological measures are already constrained. The second solution space (figure 2B) characterises a location archetype where new, more frequent, and intense heat extremes lead to an increase in heat awareness that opens the solution space. Examples include northern and central European regions, which, during the past few decades, have started developing and implementing health action plans in response to deadly heatwaves.[58,59] However, increasing warming constrains how much the solution space can expand and, ultimately, this space will also contract and offer comparatively fewer options or combinations of options for reducing health risks. Feasible and effective adaptation pathways can be derived within these spaces and constitute a dynamic process to guide future decisions and action[57] in their respective contexts. Assessing the solution space requires an understanding of the hard and soft limits to adaptation under different levels of warming and the current and future policies and actions needed to make particular options accessible.[57]

The approach of adaptation pathways is particularly useful for supporting decision making under uncertainty and breaking adaptation into manageable steps over time. Exploring pathways as part of the solution space allows us to identify both low-regret, near-term actions and long-term options to further adapt, if needed. Adaptation pathways can illuminate path-dependency—when further adaptation due to lock-ins is difficult and costly.[57] The adaptation pathway and solution space narratives form an integral part of the anticipatory and forward-looking decision making needed to tackle increasingly “wicked” problems.[60]

Way forward: towards (more) integrated heat research and policy

Heat is already impacting human health worldwide and has become a crucially important topic in research and policy.[33] Despite recent advancements,[61,62] current research on climate change-induced heat extremes, their consequences, and their solutions is fragmented;

important topics are underdeveloped; and we therefore call for more cross-disciplinary research to develop the field further and support policy and practice more effectively.[14] Our ability to better assess future health risks depends on our ability to link model projections with adaptation and the broader context in which adaptation is taking place. Similarly, implementation of adaptation is severely constrained if adaptation research is not considerate of future risks, limits, and the drivers of limits.[63]

Taking a systems perspective that considers both the extent of the problem and ways to equitably address it allows for the identification of specific knowledge gaps. Important next steps therefore include developing and financing integrated projects that combine the different building blocks and take a truly integrated perspective. Disciplines need to come together more directly and promote integrative research and methods, which address seemingly contradictory results or unexpected outcomes. This work also requires the acknowledgment that understanding the problem better (eg, with impact modelling) does not mean implementing solutions is easy. Rather, identifying many solutions and pathways needs to be connected to the projected risks and current and future solution space more explicitly and acknowledge the complex nature of such risks.[64]

Operationalising this framework requires combining qualitative and quantitative assessment methods; for example, a combination of scientific insights from empirical studies and the knowledge and expertise of policy makers, planners, and other practitioners can be used to make an inventory of adaptation measures.[14,19] The effectiveness of adaptation measures is also found through modelling studies, policy experiments, and evidence from case studies.[65] Having both empirical and modelling studies can reveal the existence of residual risks. How to address residual risks from empirical and modelling knowledge can provide new knowledge, for example, on the limits of particular options and when or how insurance instruments might be needed.[66]

The integrated approach proposed in this Personal View also helps to direct learning across different contexts, recognise differences in health systems, and tailor specific research efforts to where they are most needed. There are many opportunities to combine the six building blocks into a new research framework for health adaptation to heat. The urgency of accelerating risks (often beyond human tolerance) should strengthen our efforts in this direction.

Contributors
VM and RB developed the narrative and structure of this Personal View. VM contributed to most of the sections of this Personal View and, in particular, to the introduction, and sections on current and projected heat-related health risks, adaptation options, and adaptation limits and residual risks. RB contributed, in particular, to the sections on feasibility and effectiveness, and synergies and trade-offs. All authors contributed to the abstract, the section on pathways of adaptation and the final section on the way forward. SH and MH reviewed several versions of the manuscript and contributed revised text and additional references. VM and SH co-developed figure 1 and all authors contributed to further improvements. VM and MH co-developed figure 2 and all authors contributed to further improvements. RB and SH addressed most of the revision comments and supported VM in the preparation of the response letter and revised version of this Personal View.

Declaration of interests
We declare no competing interests.

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