

https://dspace.org/

On the need to better integrate the social environment in research on climate change and health recommendations and thinking tools

Laurence Mabile; Lola Neufcourt; Matthew Chersich; Valériane Leroy; Cyrille Delpierre ...

https://hdl.handle.net/10539/44334
SCOPUS

Downloaded from a DSpace repository. https://dspace.org/

Check for updates

REVIEW

REVISED On the need to better integrate the social environment in research on climate change and health: recommendations and thinking tools

[version 3; peer review: 3 approved]

Laurence Mabile[1], Lola Neufcourt[1], Matthew Chersich[2], Valériane Leroy[1], Cyrille Delpierre[1], Michelle Kelly-Irving[1]

[1]CERPOP, Inserm, Université Toulouse III Paul Sabatier, Toulouse, 31000, France
[2]Wits RHI, University of the Witwatersrand, Johannesburg, 2000, South Africa

v3 **First published:** 28 May 2024, **4**:105
https://doi.org/10.12688/openreseurope.17528.1
Second version: 25 Oct 2024, **4**:105
https://doi.org/10.12688/openreseurope.17528.2
Third version: 20 Nov 2024, **4**:105
https://doi.org/10.12688/openreseurope.17528.3
Latest published: 14 Jan 2025, **4**:105
https://doi.org/10.12688/openreseurope.17528.4

Abstract

Social inequality impacts health, is aggravated by the consequences of climate change, and may be influenced by inappropriate policy responses. These interdependent effects create a self-perpetuating loop exacerbating the impact of climate dysregulation on health in an uncontrolled and poorly understood way. Holistic approaches to public health such as One Health, EcoHealth or Planetary Health are well suited to tackling the considerable and complex environmental and social issues underlying climate dysregulation. However, the extent to which research using such frameworks investigates social determinants of health is not clear. In this paper we discuss the ways in which the social environment has so far been considered in the literature to problematize and analyze the relationship between climate dysregulation and health within holistic frameworks and provide tools and recommendations to facilitate their apprehension. Social factors are investigated empirically only in a minor fraction of studies addressing the relation between climate and health in holistic frameworks, and not systematically. Barriers to such approaches are discussed. This work also provides two analytical tools (a process diagram and a knowledge framework) and a set of recommendations to help include the social environment more meaningfully in such frameworks. They are meant to facilitate our understanding of the

Open Peer Review

Approval Status ✓ ✓ ✓

	1	2	3
version 4 (revision) 14 Jan 2025			
version 3 (revision) 20 Nov 2024	✓ view	✓ view	✓ view
version 2 (revision) 25 Oct 2024			
version 1 28 May 2024	? view	✗ view	

1. **Sandrah P Eckel**, University of Southern California, Los Angeles, USA
2. **Rosemary Hiscock**, University of Bath, Bath, UK
3. **Roger Few**, University of East Anglia, Norwich, UK

Any reports and responses or comments on the article can be found at the end of the article.

current status of this type of research and to encourage trans-disciplinary and trans-sectorial endeavors towards directions which need to be taken to ensure societal factors and inequalities are placed at the center of research on climate and health and the ensuing policy response.

Keywords
Climate change, Planetary Health, One Health, EcoHealth, Social environment, Social determinants of health, Empirical studies

This article is included in the Earth and Environmental Sciences gateway.

This article is included in the Health Sciences gateway.

This article is included in the Horizon 2020 gateway.

This article is included in the European Research Council (ERC) gateway.

Corresponding author: Laurence Mabile (laurence.mabile@univ-tlse3.fr)

Author roles: Mabile L: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing; **Neufcourt L**: Data Curation, Formal Analysis, Writing – Review & Editing; **Chersich M**: Writing – Review & Editing; **Leroy V**: Writing – Review & Editing; **Delpierre C**: Writing – Review & Editing; **Kelly-Irving M**: Conceptualization, Methodology, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003966 (Enhancing Belmont Research Action to support EU policy making on climate change and health [ENBEL]). This project has also received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 856478). LM received funding from the French National Research Agency (ANR-18-BELM-0002-02) as part of the PARSEC Belmont Forum Collaborative Research Action on Science-Driven e-Infrastructures Innovation (SEI2018). LN is supported by the Healthy Choices project, funded by the Research Council of Norway (grant 289440).
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Copyright: © 2024 Mabile L *et al*. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Mabile L, Neufcourt L, Chersich M *et al.* **On the need to better integrate the social environment in research on climate change and health: recommendations and thinking tools [version 3; peer review: 3 approved]** Open Research Europe 2024, **4**:105 https://doi.org/10.12688/openreseurope.17528.3

First published: 28 May 2024, **4**:105 https://doi.org/10.12688/openreseurope.17528.1

REVISED **Amendments from Version 2**

The following text has been added or clarified as follows (including 14 new references):

In Introduction:

Paragraph 3:

"as for socio-economic factors, the poorest people have the highest levels of morbidity and premature mortality"

"Social position includes social components such as age, gender and ethnicity, and thereby may be associated with poor health outcomes because of its relationship with other determinants of health, such as..."

1 new ref

Paragraph 4 :

"These driving forces ... further widening inequalities (3 new refs)"

"Additionally, climate changes can worsen income or occupation inequality and may even create a feedback loop with it (3 new refs)

"On top of this, ...in emerging economies" (1 new ref)

Paragraph 5:

"As climate change is likely to exacerbate inequality and as poverty... »

"worsening" instead of 'exacerbating"

"the estimated number of people expected to fall into extreme poverty (i.e., income below the international Poverty line)..."

"...it is critical to understand the global picture when to design adequate actions, not to imbalance the system or generate deleterious effects in other places and break the devastating loop (1 new ref)"

Paragraph 6 :

"As well as their own vulnerability ... disproportionately burdened by new policies ...which can have regressive impacts (2 new refs)"

"As such, understanding and ... and of ensuing incentives or deterrent measures are key if we are to avail ourselves of actionable, reliable research and appropriate policy priorities".

Paragraph 7, ahead of the description of holistic models:

"Given the complexity of the climate and health challenges ...3 new refs

... and more recently, Planetary Health..."

In Discussion:

Limitations section:

"Furthermore, we have not included commercial determinants of health in the bibliographic search string related to social components despite their important role in climate change and social inequalities."

Any further responses from the reviewers can be found at the end of the article

Introduction

Climate change is increasing the frequency and intensity of many extreme weather events, resulting in severe damage to the natural and social systems on which health depends[1]. While mitigation strategies clearly need to be actively pursued, it is critical to base adaptation strategies on detailed knowledge of the numerous climate dysregulations, their impact, and their underlying interconnections with other major social and political challenges given the complexity of this global concern.

The devastating health and social consequences of such changes are part of a bigger global picture where the human and economic costs are already high. Climate change has adversely impacted health in many ways: from deaths, injuries, premature births and post-traumatic stress disorders caused by direct effects of extreme weather events, to a myriad of diseases due to indirect effects linked to air, soil, water, food quality and availability and to biodiversity loss (WHO Meeting Report, 2015). Long neglected in climate change discourse, the climate change impact on health is now fully incorporated within the last Intergovernmental Panel on Climate Change (IPCC) assessment[2] which also highlights the interdependence of climate, biodiversity and populations, some of which more vulnerable than others.

Health is determined by our social conditions, resources and environment: as for socio-economic factors, the poorest people have the highest levels of morbidity and premature mortality[3]. Furthermore, across the social spectrum, health follows a social gradient: on average the lower one's socioeconomic position, the worse is one's health[4]. Social position includes components such as age, gender and ethnicity, and thereby may be associated with poor health outcomes because of its relationship with other determinants of health, e.g. access and use of health services, psychosocial support, behavioral factors, education, food, housing, recreational activities and other societal resources, all critical for good health and well-being. These in turn are shaped by political, social, and economic forces that lead to inequity in a systematic way, produced by social norms, policies, and practices that tolerate or promote unfair distribution of and access to power, wealth, and other necessary social resources[5,6].

Climate change also meaningfully affects the social determinants of health which are critical in the construction of health[7]. This happens in different ways, notably described in the WHO Commission on Social Determinants of Health final report and identified formally by Islam & Winkel (UN Department of Economic & Social Affairs working paper, 2017), as affecting exposure, sensitivity and resilience of disadvantaged populations. These include increased exposure of poor populations to extreme heat, pollution and climatic disasters due to their residential hazardous location usually more prone to flooding, erosion, mudslides or close to waste- sites, roads and factories; increased susceptibility of some population groups such as women, due to their typical daily tasks imposed by social norms, or some workers whose occupational location and activities, or populations living in poor quality housing or with comorbidities; and a decreased ability to cope with stressful climatic events or to prevent or recover from physical and material damages (due to systematic resource-constraints such as lack of private resources, of insurance contracts, of access to public resources and services…)[8,9]. These driving forces can lead to property loss, reduced livelihoods, residential relocation, and other climate-related crises (infrastructure damages limiting access to healthcare, food insecurity, forced migration, war…) further widening inequalities[10–12]. Additionnally, climate changes can worsen income or occupation inequality and may even create a feedback loop with it[13–15]. On top of this, social inequalities and per capita greenhouse gas emissions are positively correlated in emerging economies, which implies that inequalities

may even aggravate the climate change process[16] (UN Department of Economic & Social Affairs working paper, 2015).

As climate change is likely to exacerbate inequality and as poverty and social injustice continue to kill people on a grand scale, also gaining ground in high income countries[17], a vicious circle sets in that further amplifies climate change impacts on vulnerable populations, worsening climate impact on health in an uncontrolled vertiginous way that not only affects some populations disproportionately but also adds on the burden on medical services. According to the World Bank, the estimated number of people expected to fall into extreme poverty (i.e., income below the international Poverty line) due to climate change is ranged between 32 million and 132 million in most scenarios by 2030[18]. Therefore, it is critical to understand the global picture to design adequate actions, and break the devastating loop[19].

As well as their own vulnerability to the effects of climate change, the most socially disadvantaged are also disproportionately burdened by new policies which are set in place to foster behavioral or cultural changes and which can have regressive impacts[19–22]. Disadvantage caused by poverty, discrimination or geographical factors has led to the exclusion of some groups from digital technologies, sustainable foods or public transport infrastructures, areas which will be important to develop to deliver carbon neutral targets. For instance, when policy incentives are established to improve housing and facilitate shifts away from polluting vehicles, these must consider the challenges faced by people with low incomes and/or living in isolated rural places[23]. As such, understanding and identifying the social patterning of the human health and wellbeing consequences of climate dysregulation and ecosystem disruption and of ensuing incentives or deterrent measures are key if we are to avail ourselves of actionable, reliable research and appropriate policy priorities[24]. Thus, the climate emergency and social inequalities in health must be addressed simultaneously based on scientific actionable evidence to guide equitable and acceptable policy responses[25].

Given the complexity of the climate and health challenges that span various knowledge disciplines, necessitating multilevel analyses and the involvement of diverse sectoral actors, the importance of systems thinking has emerged. Unlike traditional statistical analysis, which tends to isolate individual components of study, systems thinking views these components as a complex whole made up of interrelated and interdependent parts[26–28]. This shift has led to the rise of holistic health approaches over the past decade, including EcoHealth, One Health, and more recently, Planetary Health. Among public health models, these holistic approaches aim to provide comprehensive frameworks to systematically investigate complex multifactorial relationships between political, social, cultural and environmental factors that underpin climate change impacts on health of humans, living organisms, natural ecosystems and of the planet. Specifically, these frameworks are well suited to tackle inequalities between high and low and middle income countries. Although there are some minor differences[29], all three assume that humans and other animals share the same planet habitats and face the same environmental challenges, infectious agents as well as other aspects of health[30]. The "One Health" (OH) concept was introduced at the beginning of the 21st century, emphasizing that human and animal health are interdependent and connected to the ecosystems in which they exist. OH is also seen as « the collaborative effort of multiple health science professions, mainly medical and veterinary sciences and institutions—working locally, nationally, and globally—to attain optimal health for people, domestic animals, wildlife, plants, and our environment ». EcoHealth (EcoH) is described as being committed to fostering the health of humans, animals, and ecosystems (including microorganisms) and « to conducting research which recognizes the inextricable linkages between the health of all species and their environments ». Emphasis is placed on the threat that a resource-depleted, polluted, and socially unstable planet poses for health on the long run[30]. Planetary health (PH) is the most recent ecological public health model in line with the 1970's environmental and holistic health movements and with the indigenous knowledge of health. Compared to the WHO definition where "health is a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity", the definition of planetary health would be "the achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity and to the Earth's natural systems that define the safe environmental limits within which humanity can flourish"[5].

Scientific papers are increasingly discussing the impacts of climate change on health through the lens of the above holistic frameworks. However, the extent to which social determinants of health have been investigated within such frameworks is not clear. In this paper, we discuss the ways in which the social environment is considered in problematizing and analyzing the relationships between climate dysregulation and health within holistic frameworks as well as the challenges that may be faced in such research works. We further provide some recommendations and tools that may facilitate our understanding of the current status of this research, and help foster research and actions towards directions which need to be taken to ensure that social inequalities and societal factors are placed at the center of research on climate and health and the ensuing policy response.

Discussion

Climate change, social environment & health within holistic frameworks: insights from the literature analysis

The climate change topic has been increasingly infusing research since the 1990s mainly after the first Intergovernmental Panel on Climate Change assessment was reported. In the life sciences and biomedical research literature, this topic represents though a very small proportion of health research in general and is significantly associated with holistic approaches of health (namely OH, EcoH, PH) that increasingly appeared in this literature over the past decade. These holistic models address a broader field of environmental investigation which make them well fitted to tackle environmental and social issues such as those conveyed by climate change. We carried out a literature analysis in PubMed and Web of Science databases for which detailed information is available as supplementary data[31–34]. Among articles which simultaneously

included i) the term “climate change”, ii) one of the holistic above-mentioned frameworks (OH, EcoH or PH) and iii) at least one term related to the broadly-defined social environment - i.e. related to any social organization, process, norm, habits, and characteristics possibly affecting health (directly or indirectly) including lifestyle behaviors -, we first found that a noteworthy though limited number of articles have so far addressed the climate change topic through the lens of holistic approaches of health (Eco H, PH or OH; 595 in Wos, 393 in Pubmed). A fraction of these works further considered simultaneously some aspects of the social environment (57%; n=401) as follows.

The majority of such articles (80%) were not original research articles but theoretical works such as reviews or various types of commentaries, recommendations and method papers. Overall, the theoretical works covered a variety of knowledge and areas that pointed to challenges and problems faced across domains at a global level when working on holistic models of health. These areas were either addressed (i) through a theoretical lens such as syntheses on specific effects of climate change related to health; concepts development within the three holistic frameworks; rationales for their use in the context of environmental changes including climate change and critique of the different approaches; vulnerability rationales to climate and/or diseases (zoonotic mostly) and views on transforming the food system to better protect environment and health; or (ii) as practice papers such as lessons-learned from implemented approaches; public health/clinical practice & training considerations in such approaches; indicators of resilience monitoring; analyses of policies alignment to the Sustainable Development Goals and analyses of political agendas towards risk reduction.

Only a minority were empirical papers (20%), mainly observational, modelling, and assessment ones that globally not only addressed direct or indirect impacts of climate change on health but also tackled climate change and health as independent topics of education, training or risk monitoring. The major topic areas covered were related to public health & healthcare services, health professional practice & training, and nutrition. All aimed to provide new knowledge in domains often challenged at the human/animal or ecosystem interface, sometimes also considering planet resources.

With regard to the social factors studied in the empirical studies, a minority (19%) were treated as the main variable of interest / exposure / outcome, most of them were either treated as covariates (43%), often as descriptive variables or only discussed as having a possible influence (37%). None of the factors related to individual characteristics (gender, ethnicity, education) or to household assets (including occupation tenure and socio-economic items) were addressed as an exposure or outcome. Social determinants were more often analyzed as consequences than as exposures although they influence both[35]. Some examples of such empirical studies are detailed in supplementary material[36].

Social factors are deemed important when working with holistic health frameworks and many see that this is an important area to invest effort across research themes. Though globally few of the research papers analyzed have carried comprehensive analyses of the diverse inter-relations with climate change and health reflecting a still largely incomplete knowledge. Considering the role of social factors in structuring the environmental exposition, people resilience and ability to cope, it is crucial they are considered in a more systematic way and further studied as the main outcome and variable of interest to understand the underlying mechanisms of construction[37]. Only such an approach to the social environment will provide some factual clarification and guide how to possibly reduce the aggravating effects or prevent new social inequalities. A set of methodological recommendations provided by Neufcourt *et al.*[38] can help extend research into this direction. These are meant to be used when designing empirical studies aimed at investigating relations between exposome and health outcomes They highlight questions to ask to make the relationships hypothesized more explicit, especially when testing hypotheses: which approach to use (agnostic / hypothesis driven / mixed); when selecting data, which type of social variables to account for (behavioural / material / psychosocial); how to treat social factors in analyses; what are the corresponding limitations.

Visualizing the challenging entanglement of social components in climate & health

As the social environment is considered to have a potential influence on health in many unclear ways, we endeavored to map the social environment & pathways discussed so far. Process diagrams are visual representations of the way in which interacting factors behave within a complex system; they are useful for summarizing and organizing information from interdisciplinary research and help identify data gaps or links[39]. First, we identified the specific nature of climate and social/societal components discussed in the 80 empirical studies. It resulted in a number of contributive elements that we reported as a process diagram along with the corresponding number of studies they were part of (Figure 1), to facilitate their apprehension. We then inferred the theoretical pathways most likely to relate the social components to health outcomes from the literature in social epidemiology and reported them in the diagram. Potential links were determined and placed between the related social components and their possible pathways as well as between some social components.

The climate elements were overall mainly referred to as the generic concept of ‘climate change’. Among the meteorological parameters studied, temperature was the most frequent component measured, followed by precipitations, greenhouse gas emissions and humidity; wind conditions were addressed in one study, which highlights the lack of research on some climate factors that could also impact health substantially (Figure 1, cloud boxes). It can be noted that ‘pollution’ did not emerge from the analysis.

Regarding social factors, six broad categories (visualized as colored clusters in the diagram, Figure 1) emerged from the analysis: factors related to food (light grey boxes) or health systems (dark grey boxes) and to individual characteristics (i.e., lifestyle behaviors, gender, education, livelihoods – green boxes) were most often reported, followed by factors related to built environment (black boxes) and to sanitation (white box). Their potential relations to health were analyzed and the most obvious theoretical pathways possibly mediating these effects were inferred from the social epidemiology literature. These pathways were integrated into the diagram as hexagons and

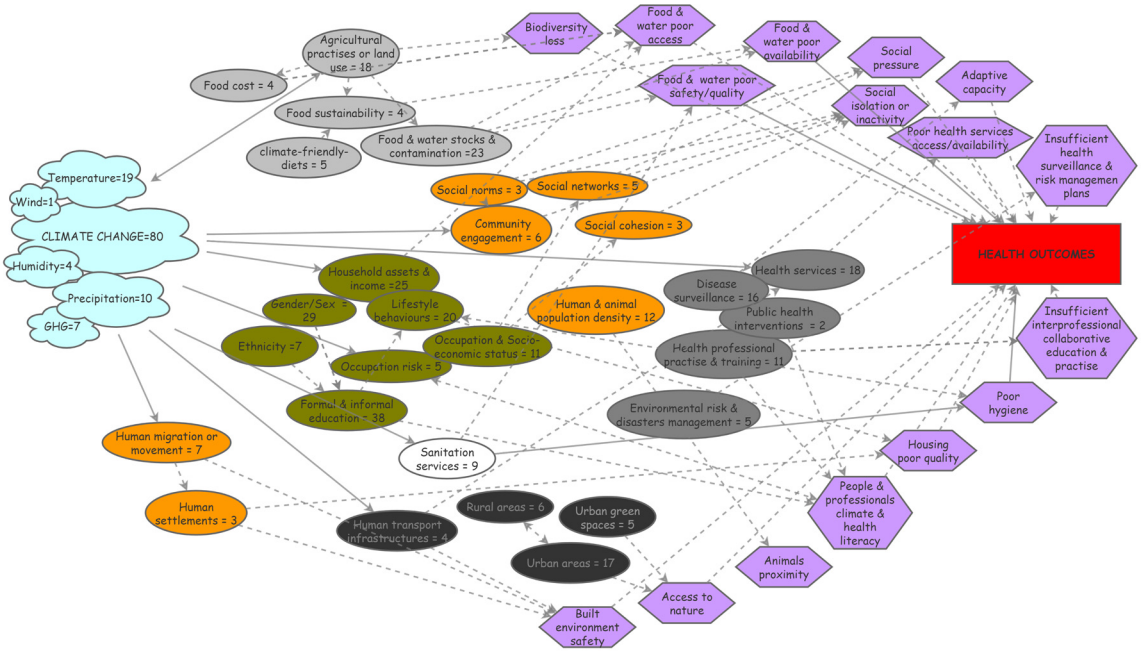

Figure 1. Process diagram figuring climate exposures, social components and their pathways to health. This diagram relies on 80 empirical papers identified in a literature review and individually scrutinized for text elements related to climate change or to social components that were either studied or mentioned; identified elements were reported in the diagram as cloud for climate elements or oval boxes for social ones (food-related in grey; health services-related in dark grey; individual characteristics in green; ...). Theoretical pathways the most likely to link the social components to health outcomes were reported in the diagram as purple hexagon boxes; arrows were placed between the related social components and their possible pathways to health (plain arrows) as well as between possibly inter-linked social components (dashed arrows). GHG: greenhouse gas.

their relationships as arrows (plain arrows for direct effects, dashed arrows for indirect effects; Figure 1). This knowledge thus synthesized can be visualized more easily and may be helpful to inform and guide research in identifying upstream risk factors and eventually providing a way to conceptualize causal processes.

Framing and structuring the complexity

Such inter-relations between climate change, social conditions or organization, and health outcomes remain complex and are a key hurdle in addressing social inequalities. Clarifying the research-based knowledge by further structuring all the information identified as a knowledge framework may help facilitate the analysis and the understanding of underlying structural systems. Figure 2 provides such a framework where the diversity and heterogeneity of the identified social components were categorized and organized as various layers of social characteristics and/or social organization constitutive of distinct levels of the environment (micro/meso/macro-environments), all relating in some way to key pathways of climate change impacts. The micro-level consisted of all individual or household characteristics such as ethnicity, gender, household assets (defined as a broad category including livelihoods, social & socio-economic status, housing & pets, belongings and lifestyle behaviors like eating habits); the meso-level included characteristics or processes at a larger group-level such as people migration & movement, population density, settlements, social & community networks and engagement, professional practice & training for specific groups; the macro-level referred to global organizational systems or activities built by the society such as food systems, sanitation & health services, education, built environment, risks management. Macro-level exposures are especially relevant for inter-country comparisons; micro- and meso-level environments are easier to characterise using national administrative data. Such a framework can be used by researchers and health actors interested in understanding social determinants and consequences of climate change on health, and facilitate a more systematic consideration and integration of social variables in our understanding, mitigation or prevention of the mechanisms underlying the relationship between climate change and health. An example of directed graph integrating levels of social environment in causal pathways to mortality is given as supplementary file[40].

Data challenges

Another key hurdle explaining the difficulty in addressing social factors is the lack of data and lack of data linkage. Social data are either rarely or not measured, or are not reusable or linkable across health, social and climate disciplines. The reuse from multi-sources databases and linkage of individual-level data remains challenging at several levels: difficult discoverability; data heterogeneity between sources; lack of social data collection; frequent impossible linkage between databases; complex legal processes for data access and reuse; unwillingness from some researchers to share data; and considerable work needed for data preparation before sharing, not anticipated nor

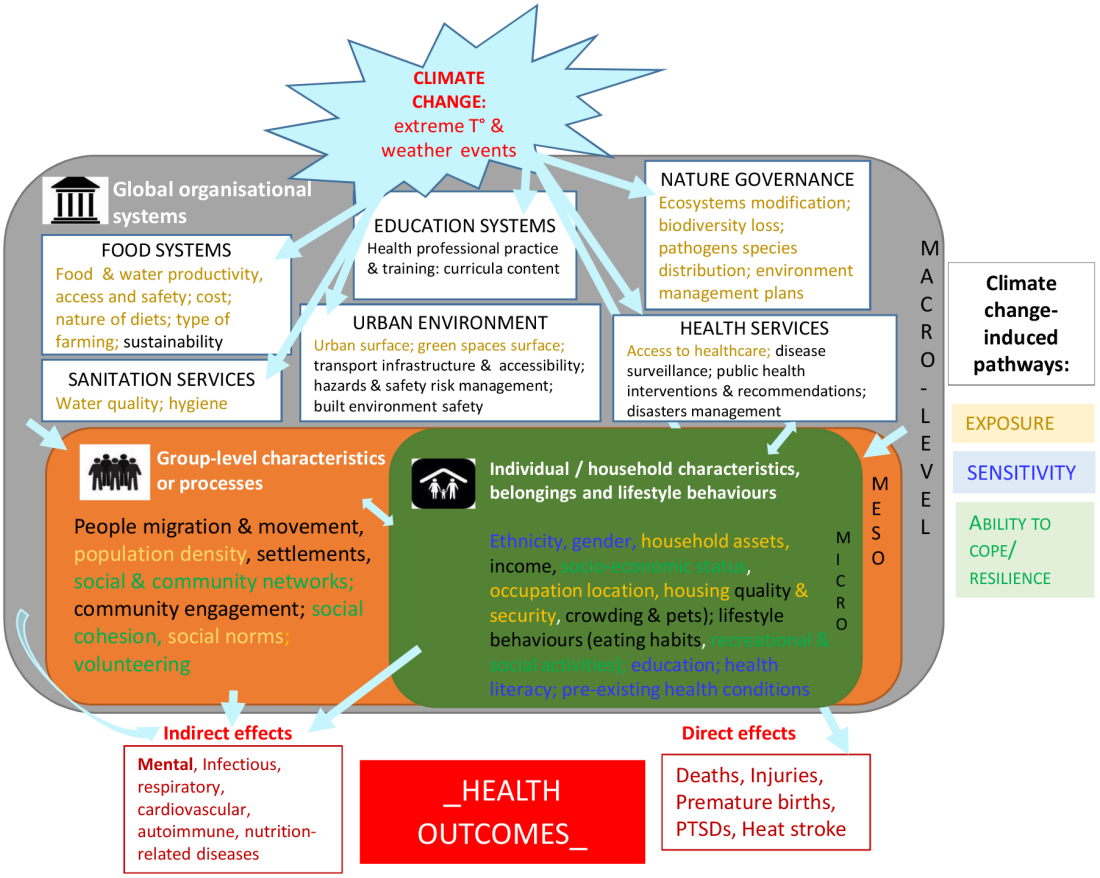

Figure 2. Synthetic knowledge framework for climate change, health outcomes and social determinants of health. This theoretical framework is based on the knowledge generated from the empirical studies describing the inter-dependence between climate change, health outcomes and social determinants of health at three different social organization levels (micro/meso/macro). T°: temperature; PTSD: post-traumatic syndrome disorder.

funded. These challenges, detailed in Box 1, are in our view major issues to be anticipated for further improvement[41].

Box 1. Data challenges for reusing multi-sources databases and linkage of individual-level data

i/ **Difficult discoverability:** Health & social data are quite fragmented and distributed across several information systems (healthcare establishments, research laboratories, public statistical databases, or many different governmental establishments) and in disciplinary siloes which makes it difficult to discover and access them. Climate model data have though been made openly available as part of the World Climate Research Program to researchers from a wide range of communities[42]. There is a need for better data visibility;

ii/ **Increasing heterogeneity** of data from different sources: the information collected is increasingly heterogeneous due to (a) the varied structural and lexical nature of data (i.e. genomics, physiological, biological, clinical, pharmacy, imaging, medico-economic, epidemiological data for health; psychological, social, cultural, geographical for social data; space or surface borne-instrumental, paleoclimatic, satellite, and model-based sources for climate); (b) the heterogenous formats of data which are not always easy to use for research purposes (text, numerical values, signals, 2D and 3D images, genomic sequences, etc.); (c) the heterogenous data quality and their various levels of sensitivity;

iii/ **Data collection gap**: there is a lack of social data collection, e.g. social data characterizing people's living conditions & ethically collected data on race/ethnicity which often do not exist in many countries for historical and cultural reasons, regarding e.g. racial discrimination, thus impeding the monitoring of health inequalities; on the other hand, climate data are well collected but increasing volumes of climate modelling are produced that complexifies their use[42];

iv/ **Inability to link databases**: Quality quantitative social data available at the individual level (i.e. an individual's occupation, education level, income) are often not linked or linkable to quality health data across countries;

v/ **Complex legal processes** for data access and reuse: Due to the sensitivity of health & social data and to legal aspects such as the European General Data Protection Regulation, linking information across multiple data sources requires approvals that are subject to long delays which in turn are difficult to align with project schedules and funding timelines;

vi/ **Data hogging**: Heterogeneous and unclear data management results in a lack of open sharing practices by default, which often happens in the absence of open data mandates from the funder or publisher;

vii/ **Burden of data preparation**: The heavy burden of data preparation needed for open access and reuse and the lack of support for those tasks discourage researchers to carry them out.

How to move forward: global recommendations

New research is crucial in deciphering the pathways involved in order to provide the required knowledge for decision and action either preventive or adaptive. We encourage health researchers and practitioners to adopt a holistic view integrating the social environment when designing their projects and get all relevant partners and stakeholders across disciplines and sectors on board from conception. Our proposed thinking tools may help guide such trans-sectorial research and can also help in planning data collection and analysis, prevention, public health programming, vulnerability and risk assessment. Notably they could be used along with policy-making frameworks such as the Driving Force-Pressure-State-Exposure-Effect-Action (DPSSEA) framework widely used in European and international health assessments.

In an attempt to move those issues forward, we provide in Box 2 a number of recommendations towards various stakeholders in climate, environment and health research. They are meant to help conceptualize and design research as systems where the social environment is assessed and considered as part of any research project or intervention addressing climate change & health. Furthermore, we recommend that national research bodies design plans and set programs to develop cross-disciplinary integrated platforms for secure data access and analysis that provide data spaces where both health data and social data can be accessed, linked, used and analyzed safely by researchers. Some countries have started to develop infrastructures to facilitate the matching of health databases with other sources like cohorts and administrative data such as at the regional level in the Western Cape, South Africa[43]; others start providing complex computer and statistical programs and algorithms to analyze large volumes of information [E.g., https://www.health-data-hub.fr/]. Such initiatives must be supported and developed in a sustainable way.

Box 2. Recommendations to stakeholders in climate & health research to better consider social data into research & intervention

➢ **To Researchers :**

- Leverage holistic frameworks (such as One Health, Planetary Health or EcoHealth) where social determinants are a key feature, to guide the projects design and studies examining health in the context of climate change
- Use a systematic methodology to investigate at best social determinants potentially in relation with health and climate, as an environmental risk. A set of recommendations has been provided by Neufcourt *et al.*[38]
- Use linked datasets across social, administrative, environmental and health sources where possible, thereby limiting selection bias, attrition and loss to follow-up which are difficult to manage in ad-hoc studies and adversely affect the inclusion of disadvantaged or vulnerable populations in analyses over time

➢ **To Health practitioners:**

- Use holistic frameworks such as those described in this paper as part of a global system thinking analysis to help design adapted interventions
- Systematically consider the living conditions of the target populations as part of a social risk assessment ahead of designing interventions

➢ **To Research institutions and funding agencies:**

- Actively promote sustainable health equity as a fundamental ethical principle that guides research policies and funding[44]
- Decrease funding projects that do not prioritize sustainable health equity
- Call for more and strengthen the funding of global multidisciplinary holistic by design projects, in order to facilitate the connection of fields otherwise siloed
- Provide secure spaces to centralise multi-sources & multi-disciplinary data relevant for social epidemiology at relevant levels (local, national, European, regional...)
- Support a better visibility of health & social data: more catalog-like and integrated platforms
- Simplify health & social data access processes (rules & practicalities)
- Make all climate model data, observations, and the software used for processing open, free and easily available to all users, through international agreements

➢ **To publishers, funders, Research institutions:** Promote & facilitate open data

- Provide dedicated human and material support, i.e. steward / managers to help with data access and pre-processing; tools to assist access & use
- Provide training for students and all staff for data vocabulary and format standards/ storage/ legal issues, data science
- Provide recognition mechanisms to foster open science in general (ongoing work, Research Data Alliance - SHARC interest group)
- Require easy access to all data associated with the papers they publish or the work they fund
- Guide authors towards trustworthy repositories where to deposit data
- Guide authors with regards to how to make their data FAIR (Findable, Accessible Interoperable, Reusable)[45]

Limitations

This work was intentionally limited to three main holistic approaches of health because they offer the broadest framework to study environmental changes, including social ones, and as such, provided an overview of research committed to address climate change and the social determinants of health. Nevertheless, we are much aware that a substantial body of research has been carried out on the effects of climate change on health without explicitly referring to holistic approaches, including work on extreme heat in various contexts done by projects such as CHAMNHA, HEATCOST, CLIM-App, EXHAUSTION, and HEAT-SHIELD, and such papers were not included in our review.

The key large international reports from IPCC (2022) and WHO (2008, 2023) which were not present in the source databases (PubMed and Web of Sciences) were not included in the quantitative analysis, although they may have contained useful articles. Nevertheless, we included these sources in the discussion of results. Finally, we did not consider works that were not published in either English or French due to language constraints in the review team. Only a few such papers were identified, although they might be very relevant.

Furthermore, we have not included commercial determinants of health in the bibliographic search string related to social components despite their important role in climate change and social inequalities.

Conclusions

In conclusion, holistic approaches to health such as One Health, EcoHealth or Planetary Health are frameworks well suited to investigate climate change and social determinants of health. However, our literature analysis highlighted that there was limited research using or referring to these approaches to study social determinants as the main variables of interest; individual social determinants were mostly absent or under-represented in these studies. Hence, subsequent decision making and actions cannot adequately consider the social effects that drive climate change impacts on health and exacerbate climate change itself, leading too often to unsustainable or unfair solutions that may maintain the status quo.

We believe the reasons for these gaps are two-fold: first, climate change impacts on health outcomes in a very complex manner, where inter-dependent relations can lead to negative uncontrolled feedback loops. This complexity makes it difficult to design comprehensive studies. Thinking tools can help organize concepts, ideas and relationships to better integrate and comprehensively understand the inter-dependencies at play thereby enabling adequate analysis for appropriate actions. We provide such tools here including a pathway diagram and a knowledge framework where social determinants are embedded in climate change impacts at three different actionable levels (micro, meso and macro levels), themselves driven by specific processes or resulting from different governance systems. Second, social data are difficult to measure, find or obtain, while health data are difficult to share and climate model data harder to reuse. Global effort is urgently needed to collectively organize and solve these hurdles. Transformative solutions to halt the effects of climate dysregulation and preserve the health of our planet and of its inhabitants will fail unless social inequalities are addressed as an integral part of the climate change reversal roadmap[4]. Our findings are by no means exhaustive, but offer an overview of these important challenges for climate science and public health.

Data availability

This article contains supplementary data available on the OSF repository: http://doi.org/10.17605/OSF.IO/NMCVA

Extended data files are:

- PRISMA Flowchart-Scoping Review.pdf
- Table 1_Data sources_search strings_criteria-Scoping review.pdf
- List of Empirical studies_Search 27jul2023.xlsx
- List of theoretical studies_Search 27july2023.xlsx
- Figure A. Methodological treatment of social elements....pdf
- Box A_Examples of empirical studies...pdf
- Graph A. Example of directed graph.pdf

Acknowledgements

LM wishes to acknowledge Alison Specht, Shelley Stall, Solange Santos and Pedro Luiz Pizzigatti Corrêa, for fruitful discussions at the RDA Plenary 20 - PARSEC co-located event that helped feed the data challenges section of this paper, as well as Emmanuelle Rial-Sebbag for her valuable help regarding data ethical and regulatory issues.

References

1. Romanello M, Di Napoli C, Drummond P, *et al.*: **The 2022 report of the *Lancet* countdown on health and climate change: health at the mercy of fossil fuels.** *Lancet.* 2022; **400**(10363): 1619–1654.
PubMed Abstract | Publisher Full Text

2. Pörtner HO, Roberts DC, Tignor MMB, *et al.*: **Climate change 2022: impacts, adaptation and vulnerability**. *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 2022.
Reference Source

3. Marmot M, Bell R: **Social determinants and non-communicable diseases: time for integrated action.** *BMJ.* 2019; **364**: l251.
PubMed Abstract | Publisher Full Text | Free Full Text

4. Marmot M, Friel S, Bell R, *et al.*: **Closing the gap in a generation: health equity through action on the social determinants of health.** *Lancet.* 2008; **372**(9650): 1661–1669.
PubMed Abstract | Publisher Full Text

5. Whitmee S, Haines A, Beyrer C, *et al.*: **Safeguarding human health in the anthropocene epoch: report of the rockefeller foundation-*Lancet* commission on planetary health.** *Lancet.* 2015; **386**(10007): 1973–2028.
PubMed Abstract | Publisher Full Text

6. Solar O, Irwin A: **A conceptual framework for action on the social determinants of health**. Social Determinants of Health Discussion, Paper 2 (Policy and Practice), 2010.
Reference Source

7. Kelly-Irving M, Delpierre C: **Framework for understanding health inequalities over the life course: the embodiment dynamic and biological mechanisms of exogenous and endogenous origin.** *J Epidemiol Community Health.* 2021; **75**(12): 1181–1186.
PubMed Abstract | Publisher Full Text

8. Winsemius HC, Jongman B, Veldkamp TIE, *et al.*: **Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts.** *Environ Dev Econ.* 2018; **23**(3): 328–348.
Publisher Full Text

9. Park J, Bangalore M, Hallegatte S, *et al.*: **Households and heat stress:**

estimating the distributional consequences of climate change. *Environ Dev Econ.* 2018; **23**(3): 349–368.
Publisher Full Text

10. Markova G, *et al.*: **The impact of disasters and crises 2017 on agriculture and food security**. FAO. 2018.
Reference Source

11. Vuong QH, Nguyen MH, La VP: **The overlooked contributors to climate and biodiversity crises: military operations and wars.** *Environ Manage.* 2024; **73**(6): 1089–1093.
PubMed Abstract | Publisher Full Text

12. Ribot J: **Access failure: deep explanation of climate-related crises.** In: Saturnino M. Borras, Jr., and Jennifer C. Franco (eds), *The Oxford Handbook of Land Politics*. (online edn Oxford Academic), 20 October, 2022.
Publisher Full Text

13. Alam MM, Taufique KMR, Sayal A: **Do climate changes lead to income inequality? Empirical Study on the farming community in Malaysia.** *International Journal of Environment and Sustainable Development.* 2017; **16**(1): 43–59.
Publisher Full Text

14. Ogbeide-Osaretin E, Orhewere B, Ebhote O, *et al.*: **Climate change, poverty and income inequality linkage: empirical evidence from Nigeria.** *International Journal of Energy Economics and Policy.* 2022; **12**(5): 332–341.
Publisher Full Text

15. Fitzgerald JB: **Working time, inequality and carbon emissions in the United States: a multi-dividend approach to climate change mitigation.** *Energy Research & Social Science.* 2022; **84**: 102385.
Publisher Full Text

16. Yameogo CEW, Dauda ROS: **The effect of income inequality and economic growth on environmental quality: a comparative analysis between Burkina Faso and Nigeria.** *J Public Aff.* 2020; **7**(2): 148–163.

17. Wickham S, Anwar E, Barr B, *et al.*: **Poverty and child health in the UK: using evidence for action.** *Arch Dis Child.* 2016; **101**(8): 759–766.
PubMed Abstract | Publisher Full Text | Free Full Text

18. Jafino BA, Walsh B, Rozenberg J, *et al.*: **Revised estimates of the impact of climate change on extreme poverty by 2030**. World Bank, 2020.
Reference Source

19. Markkanen S, Anger-Kraavi A: **Social impacts of climate change mitigation policies and their implications for inequality.** *Clim Policy.* 2019; **19**(7): 827–844.
Publisher Full Text

20. Zachmann G, Fredriksson G, Claeys G: **The distributional effects of climate policies**. Bruegel Think Tank; 2018.
Reference Source

21. Nyiwul L: **Climate change adaptation and inequality in Africa: case of water, energy and food insecurity.** *J Clean Prod.* 2021; **278**: 123393.
Publisher Full Text

22. Bae JH: **Impacts of income inequality on CO2 emission under different climate change mitigation policies.** *Korean Econ Rev.* 2018; **34**(2): 187–211.
Reference Source

23. Howell J, Elliott JR: **As disaster costs rise, so does inequality.** *Socius.* 2018; **4**.
Publisher Full Text

24. Atwoli L, Baqui AH, Benfield T, *et al.*: **Call for emergency action to limit global temperature increases, restore biodiversity, and protect health.** *Lancet.* 2021; **398**(10304): 939–941.
PubMed Abstract | Publisher Full Text | Free Full Text

25. Bradshaw CJA, Ehrlich PR, Beattie A, *et al.*: **Underestimating the challenges of avoiding a ghastly future.** *Front Conserv Sci.* 2021; **1**: 615419.
Publisher Full Text

26. Yasobant S, Bruchhausen W, Saxena D: **Applications of systems thinking for health system research: a one health perspective**. In: *Sage Research Methods Cases: Medicine and Health*. SAGE Publications, Ltd, 2019.
Publisher Full Text

27. Rifat A: **Health systems, systems thinking and innovation.** *Health Policy Plan.* 2012; **Suppl 4**: iv4–iv8.
PubMed Abstract | Publisher Full Text

28. Koskinen KU: **Systemic view and systems thinking.** In: *Knowledge Production in Organizations*. Springer, Heidelberg, 2013.
Publisher Full Text

29. Lerner H, Berg C: **A comparison of three holistic approaches to health: one health, ecohealth, and planetary health.** *Front Vet Sci.* 2017; **4**: 163.
PubMed Abstract | Publisher Full Text | Free Full Text

30. Lerner H, Berg C: **The concept of health in One Health and some practical implications for research and education: what is One Health?** *Infect Ecol Epidemiol.* 2015; **5**: 25300.
PubMed Abstract | Publisher Full Text | Free Full Text

31. Mabile L: **PRISMA flowchart -scoping review.** [Dataset]. Published online 2023.
https://osf.io/a2khn

32. Mabile L: **Table 1_Data sources_search strings_criteria-scoping review.** [Dataset]. Published online 2023.
https://osf.io/bjsua

33. Mabile L: **List of empirical studies_search 27jul2023.** [Dataset]. Published online 2023.
https://osf.io/fdx7t

34. Mabile L: **List of theoretical studies_search 27july2023.** [Dataset]. Published online 2023.
https://osf.io/kupj4

35. Mabile L: **Figure A. Methodological treatment of social elements.** [Dataset]. Published online 2023.
https://osf.io/pvs6g

36. Mabile L: **Box A_Examples of empirical studies.** [Dataset]. Published online 2023.
https://osf.io/6t3j7

37. Link BG, Phelan J: **Social conditions as fundamental causes of disease.** *J Health Soc Behav.* 1995; Spec No: 80-94.
PubMed Abstract | Publisher Full Text

38. Neufcourt L, Castagné R, Mabile L, *et al.*: **Assessing how social exposures are integrated in exposome research: a scoping review.** *Environ Health Perspect.* 2022; **130**(11): 116001.
PubMed Abstract | Publisher Full Text | Free Full Text

39. Joffe M, Mindell J: **Complex causal process diagrams for analyzing the health impacts of policy interventions.** *Am J Public Health.* 2006; **96**(3): 473–479.
PubMed Abstract | Publisher Full Text | Free Full Text

40. Mabile L: Graph A. **Example of directed graph.** [Dataset]. Published online 2024.
https://osf.io/5dc8e?view_only=9940481c8b634e23b59ca327ee21e27f

41. Specht A, Minahan B, Lammey R, *et al.*: **Insights into the practicalities of collaboration, data and code sharing across the globe**. Presented at: March 25, 2023; Gothenburg, Sweden, 2023.
Reference Source

42. Overpeck J, Meehl G, Bony S, *et al.*: **Climate data challenges in the 21st century.** *Science.* 2011; **331**(6018): 700–702.
PubMed Abstract | Publisher Full Text

43. Mutemaringa T, Heekes A, Smith M, *et al.*: **Record linkage for routinely collected health data in an African health information exchange.** *Int J Popul Data Sci.* 2023; **8**(1): 1771.
PubMed Abstract | Free Full Text

44. Castro A, Marmot M, Garay J, *et al.*: **Achieving sustainable health equity.** *Bull World Health Organ.* 2022; **100**(1): 81–83.
PubMed Abstract | Publisher Full Text | Free Full Text

45. Wilkinson MD, Dumontier M, Aalbersberg IjJ, *et al.*: **Comment: the FAIR guiding principles for scientific data management and stewardship.** *Sci Data.* 2016; **3**: 160018.
PubMed Abstract | Publisher Full Text | Free Full Text

Open Peer Review

Current Peer Review Status: ✔ ✔ ✔

Version 3

Reviewer Report 16 January 2025

https://doi.org/10.21956/openreseurope.20514.r46928

© **2025 Eckel S.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✔ **Sandrah P Eckel**
University of Southern California, Los Angeles, California, USA

Thank you to the authors for your responses to my comments, I have no further suggestions.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Biostatistics, Environmental Health, Climate and Health

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 07 January 2025

https://doi.org/10.21956/openreseurope.20514.r46927

© **2025 Hiscock R.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✔ **Rosemary Hiscock**
University of Bath, Bath, England, UK

I have no further comments.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 24 December 2024

https://doi.org/10.21956/openreseurope.20514.r47466

© 2024 Few R. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Roger Few
School of International Development, University of East Anglia, Norwich, England, UK

This paper has been reviewed previously by two peer reviewers, and a report on the responses to their comments provided. I have reviewed both the paper itself and I am satisfied that the author has responded positively and sufficiently to the comments. In light of this, I am happy to endorse the paper for publication as a positive contribution to the field, helping to shed light on the complexities of considering social dimensions within ecologically-framed analyses of the linkages between climate change and health.

I have no substantial further comments, other than two things I would like to see addressed in the Introduction (which is key because it sets the orientation of the piece):

1) Define/introduce the term 'dysregulation' more informatively, and also any critiques of the term. To me, it is not a well-known term as used in the context of climate change.

2) Please be careful in the phrasing of this sentence in the second paragraph, starting 'Climate change has adversely impacted....'. because I feel the wording gives the impression that climate change is solely responsible for these environmental risk-related impacts on health. Of course, it is not - e.g. as noted in the opening sentence, extreme weather events will exist regardless of climate change's exacerbating effect on their frequency, magnitude or distribution. The authors know this, but referring again to the contributory or amplifying effect of CC in this sentence would be wise, I feel.

Is the topic of the review discussed comprehensively in the context of the current literature?
Yes

Are all factual statements correct and adequately supported by citations?
Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate change, disaster risk, health, vulnerability and adaptation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 08 Jan 2025

Laurence Mabile

Many thanks for your encouraging remarks and relevant suggestions that help us to be more accurate.

From Reviewer 3:
I have no substantial further comments, other than two things I would like to see addressed in the Introduction (which is key because it sets the orientation of the piece):
1) Define/introduce the term 'dysregulation' more informatively, and also any critiques of the term. To me, it is not a well-known term as used in the context of climate change.
Author Response: Climate dysregulations are meant as climate changes induced by human activity that per se disturb the natural phenomena and amplify extreme responses. This is now specified in the corresponding sentence (Introduction, paragraph 1, line 4).

2) Please be careful in the phrasing of this sentence in the second paragraph, starting 'Climate change has adversely impacted....'. because I feel the wording gives the impression that climate change is solely responsible for these environmental risk-related impacts on health. Of course, it is not - e.g. as noted in the opening sentence, extreme weather events will exist regardless of climate change's exacerbating effect on their frequency, magnitude or distribution. The authors know this, but referring again to the contributory or amplifying effect of CC in this sentence would be wise, I feel.
Author Response: The phrasing has been modified as follows: "Climate change has contributed to adversely impact health in many ways..." (Introduction, paragraph 2, line 3).

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 29 August 2024

https://doi.org/10.21956/openreseurope.18943.r43192

© 2024 Hiscock R. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Rosemary Hiscock

University of Bath, Bath, England, UK

This paper looks at how previous research using holistic models has linked worsening socioeconomic inequalities in health to climate change.
The article is a big overview but at times is too non specific
Box2 the list of problems with getting data was useful.
The paper needs to talk more about holistic theories and introduce systems theory – concepts from which explain why holistic theories are important. The paper could make more of negative feedback loop of climate change leading to more inequality which then leads to more climate change
The paper needs to conceptualies socioeconomic position more precisely. Socioeconomic position is income and wealth, occupation, education. Ethnicity and gender are not socioeconomic position. They are demographic characteristics which can predispose towards lower socioeconomic position. Then there are conditions associated with low socioeconomic position eg poor condition insecure housing, fewer consumer goods including cars. SOMETIMES low socioeconomic position is associated with poor access to healthy food, transport, internet, education however in other cases poor people live in central cities with good access.
People who can't afford to eat won't be able to afford more climate friendly options or alternatively are more environmentally friendly because they can't afford as much meat or air-freighted vegetables flown in from great distance. Then there are cultural attitudes where low socioeconomic position might not see being climate aware as for them or they can't socialise with their peers if they refuse to eat fast food McDonalds etc – peer support may be more important for low socioeconomic position in order to get by.
In figure 1 and 2 there appear to be wider social determinants than just socioeconomic or sociodemographic inequality eg pets
Also inequalities between high income and low and middle income countries globally could be emphasised for a global approach.

There also appeared to be confusion between climate change, climate change adaption, climate change mitigation and collateral damage from climate change policies

I think the paper could do with a box with examples of empirical studies which showed

1. Climate change leads to worse inequality
2. Climate change mitigation/adapaption policies lead to worse inequality
3. Inequality leads to worse climate change

For each of these the main concepts of climate change inequality and linking concepts (eg health professional expertise) should be detailed

Intro para 3 "Social position also affects" might be better as "social position may be associated with poor health outcomes because it is linked to"

Intro para 4
"mudslides or close to waste sites, roads and factories" why is this linked to climate change?
"typical daily tasks imposed by social norms, or some workers whose occupational location and activities, or populations living in poor quality housing or with comorbidities; and a decreased ability to cope with stressful events or to prevent or recover from physical and material damages

(due to systematic resource-constraints such as lack of private resources, of insurance contracts, of access to public resources and services…)" Again these are not themselves linked to climate change.
"susceptibility of some population groups such as women" you are conflating socioeconomics with demographics here. You need to say some demographic groups are overrepresented in proportion in low socioeconomic position such as women and some ethnicities in the previous paragraph to set this up.
"These driving forces can lead to property loss, reduced livelihoods, residential relocation, and other climate-related crises (infrastructure damages limiting access to healthcare, food insecurity, forced migration, war…)" I think you need a section on what climate related crises are before you link to low social position
"some economic contexts" what contexts – are they common, are they likely to persist?
" As poverty and social injustice" I think this is a new paragraph which needs to be started with "Climate change is likely to exacerbate inequality"

"falling" change to "expected to fall". Define extreme poverty

"Therefore, it is critical to understand the global picture when to design adequate actions, not to imbalance the system or generate deleterious effects in other places."
This conclusion does not follow from what you have written. You would need to add info about poverty being in many different places globally and a bit about systems theory in order to understand why an action in one place might affect somewhere else and why they might not also be positive.
Intro para 5 "As well as their own vulnerability to the effects of climate change, the most socially disadvantaged are also disproportionately burdened by new and often regressive policies which are set in place to foster behavioral or cultural changes" you need to reword to say that some climate change policies to foster behavioral or cultural changes can have regressive impacts
"As such, understanding and identifying the social patterning of the human health and wellbeing consequences of climate dysregulation and ecosystem disruption are key if we are to avail ourselves of actionable, reliable research and policy priorities14. " This sentence does not follow from the previous sentence– this sentence is about the impact of climate change whereas the previous sentences were about impacts of policies to combat climate change.

Intro 1 para 6 Can you say what the differences between the 3 approaches are

Climate change, social environment & health within holistic frameworks: insights from the literature analysis
Para 1 'infiltrating' sounds like an enemy invading.
Might be good to include here if you searched databases eg pubmed
I would say this paragraph is a methods not a discussion section – the following paragraphs are results not a discussion
Figure 1 gender and ethnicity are not themselves socioeconomic status – they are demographic behavours where some subgroups are overrepresented in low socioeconomic position.

Figure 2 appears to have lost sight of the concept of socioeconomic status. It appears to confuse being low socioeconomic status and behaviours that go with it (eating habits) and living conditions (housing) and values (education)

Limitations
You need to set up better in the introduction what holistic approaches are and why you think they are most useful.

You also need to include in the limitations that you have not included commercial determinants of health which impact climate change and social inequalities and government power to reduce inequalities and climate change eg https://gh.bmj.com/content/8/11/e013698
https://gh.bmj.com/content/8/11/e013698.abstract
https://blogs.bath.ac.uk/tcrg/2023/04/06/why-cdoh-matters/

Is the topic of the review discussed comprehensively in the context of the current literature?
Partly

Are all factual statements correct and adequately supported by citations?
Partly

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: health inequalities, commercial determinants of health, climate change, tobacco supply chain

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 14 Nov 2024

Laurence Mabile

Authors point-by-point responses to Reviewer 2:
First, many thanks for your scrutiny and all your valuable comments. Please find our point by point responses below. Accordingly, we have integrated in the revised version 2 as many relevant changes as possible given the wordcount constraint.

Reviewer comments: This paper looks at how previous research using holistic models has linked worsening socioeconomic inequalities in health to climate change. The article is a big overview but at times is too non specific
Authors Response: As this first statement has generated a number of comments, we would like to clarify from the start that our work did not focus specifically on socio-economic inequalities but more broadly on the social environment that affects health, as stated in the

title of our manuscript and specified in the first paragraph of our Discussion section, i.e. “Among articles which simultaneously included i) the term “climate change”, ii) one of the holistic above-mentioned frameworks (OH, EcoH or PH) and iii) at least one term related to the broadly-defined social environment - i.e. related to any social organization, process, norm, habits, and characteristics possibly affecting health (directly or indirectly) including lifestyle behaviors -, we first found… ». Accordingly the keywords string we used for the bibliographic database search included socio-economic components such as income, occupation and education but also age, gender, ethnicity, living conditions, nutrition and others at the macro level. The complete string is available at [https://osf.io/bjsua]. We have now clarified this information in the Data availability section.

Reviewer comments: Box2 the list of problems with getting data was useful.
Authors Response: Thank you for your encouragements.

Reviewer comments: The paper needs to talk more about holistic theories and introduce systems theory – concepts from which explain why holistic theories are important.
Authors Response: The following sentences have been added in Introduction, ahead of the description of holistic models (paragraph 6): “Given the complexity of the climate and health challenges that span various knowledge disciplines, necessitating multi-level analyses and the involvement of diverse sectoral actors, the importance of systems thinking has emerged. Unlike traditional statistical analysis, which tends to isolate individual components of study, systems thinking views these components as a complex whole made up of interrelated and interdependent parts (ref URLs: https://dx.doi.org/10.4135/9781529730739; https://doi.org/10.1093/heapol/czs088; https://doi.org/10.1007/978-3-319-00104-3_3). This shift has led to the rise of holistic health approaches over the past decade, including EcoHealth, One Health, and more recently, Planetary Health…”

Reviewer comments: The paper could make more of negative feedback loop of climate change leading to more inequality which then leads to more climate change.
Authors Response: We tackled those points in Introduction. However, results from the scoping review did not bring about such feedback elements driving us to discuss other aspects.

Reviewer comments: The paper needs to conceptualies socioeconomic position more precisely. Socioeconomic position is income and wealth, occupation, education. Ethnicity and gender are not socioeconomic position. They are demographic characteristics which can predispose towards lower socioeconomic position. Then there are conditions associated with low socioeconomic position eg poor condition insecure housing, fewer consumer goods including cars. SOMETIMES low socioeconomic position is associated with poor access to healthy food, transport, internet, education however in other cases poor people live in central cities with good access.
People who can’t afford to eat won’t be able to afford more climate friendly options or alternatively are more environmentally friendly because they can’t afford as much meat or air-freighted vegetables flown in from great distance. Then there are cultural attitudes where low socioeconomic position might not see being climate aware as for them or they can’t socialize with their peers if they refuse to eat fast food McDonalds etc. – peer support

may be more important for low socioeconomic position in order to get by.
In figure 1 and 2 there appear to be wider social determinants than just socioeconomic or sociodemographic inequality eg pets
Authors Response: Although the perspective of our work was not to focus specifically on socio-economic factors, we agree that some parts of the text might have been confusing. This has been clarified in paragraph 3 by adding the following text: “as for socio-economic factors, the poorest people have the highest levels of morbidity and premature mortality” “Social position includes social components such as age, gender and ethnicity, and thereby thereby may be associated with poor health outcomes because of its relationship with other determinants of health,...” The WHO conceptual Framework for Action on the Social Determinants of Health has been added as a reference at the end of the paragraph: Solar et al. 2010 - https://iris.who.int/bitstream/handle/10665/44489/9789241500852_eng.pdf?sequence=1

Reviewer comments: Also inequalities between high income and low and middle income countries globally could be emphasized for a global approach.
Authors Response: The following sentence has been added to the section related to systems thinking, paragraph 7 of introduction: “Specifically, these frameworks are well suited to tackle inequalities between high and low and middle income countries”

Reviewer comments: There also appeared to be confusion between climate change, climate change adaption, climate change mitigation and collateral damage from climate change policies
Authors Response: In our work, the term climate change referred to meteorological factors and sometimes to related extreme events. When referring to adaptation or mitigation, this was specified.

Reviewer comments: I think the paper could do with a box with examples of empirical studies which showed

1. Climate change leads to worse inequality
2. Climate change mitigation/adaptation policies lead to worse inequality
3. Inequality leads to worse climate change

For each of these the main concepts of climate change inequality and linking concepts (eg health professional expertise) should be detailed
Authors Response: As highlighted by our work, social factors are investigated empirically only in a minor fraction of studies addressing the relation between climate and health in holistic frameworks. None of the factors related to individual characteristics (gender, ethnicity, education) or to household assets (including occupation tenure and socio-economic items) were addressed as an exposure or outcome which makes it impossible to provide the requested table. Some examples of empirical studies are detailed in supplementary material (https://osf.io/6t3j7). However, we agree that your three suggested points would gain from being more emphasized in introduction. Accordingly, we have added the following references (& text) in the indicated sections of Introduction :

1. Climate change leads to worse inequality:

Text added in paragraph 4 : « Additionally, climate changes can worsen income or occupation inequality and may even create a feedback loop with it « (Malam et al. 2017:

https://doi.org/10.1504/IJESD.2017.080848; Ogbeide-Osaretin et al; 2022: https://doi.org/10.32479/ijeep.13556; Fitzgerald et al. 2022: https://doi.org/10.1016/j.erss.2021.102385) »
2.Climate change mitigation/adaptation policies lead to worse inequality: References added in paragraph 6 : Niiwul et al. 2021: https://doi.org/10.1016/j.jclepro.2020.123393; Bae et al. 2018: http://keapaper.kea.ne.kr/RePEc/kea/keappr/KER-20180701-34-2-04.pdf
3. Inequality leads to worse climate change: References added in paragraph 4: Ogbeide-Osaretin et al; 2022: https://doi.org/10.32479/ijeep.13556; Yameogo et al. (2020), The effect of income inequality and economic growth on environmental quality: A comparative analysis between Burkina Faso and Nigeria. Journal of Public Affairs, 7(2), 148-163.

Reviewer comments: Intro para 3 “Social position also affects” might be better as “social position may be associated with poor health outcomes because it is linked to”
Authors Response: Changes have been made in the text, the sentence is now as follows: “Social position includes social components such as age, gender and ethnicity, and thereby may be associated with poor health outcomes because of its relationship with other determinants of health, such as…”

Reviewer comments: Intro para 4:
“mudslides or close to waste sites, roads and factories” why is this linked to climate change?
Authors Response: These are indirect consequences of climate change. Mudslides are more likely to occur following flooding events which are part of the extreme events triggered by climate change; Proximity to waste sites increases risk of contamination in case of flooding for instance.

Reviewer comments: “typical daily tasks imposed by social norms, or some workers whose occupational location and activities, or populations living in poor quality housing or with comorbidities; and a decreased ability to cope with stressful events or to prevent or recover from physical and material damages (due to systematic resource-constraints such as lack of private resources, of insurance contracts, of access to public resources and services…)” Again these are not themselves linked to climate change.
Authors Response: Climate extreme events are more stressful and impactful to poor populations who have been shown to be less resilient, i.e. have a decreased ability to cope with, prevent or recover from such events. In other words, as external stressors, climate events mean disadvantaged populations are exposed to physiological stress responses, and degraded material conditions, both of which are mechanisms driving health inequalities. The word climatic has been added as follows: “decreased ability to cope with stressful climatic events

Reviewer comments: “susceptibility of some population groups such as women” you are conflating socioeconomics with demographics here. You need to say some demographic groups are overrepresented in proportion in low socioeconomic position such as women and some ethnicities in the previous paragraph to set this up.
Authors Response: Gender & ethnicity may be related to socio-economic status, however they are structural systems that are connected to and interact with socio-economic factors. They systematically assign roles in society such as for example outdoors daily tasks for African women or road works for male immigrants.

Reviewer comments: "These driving forces can lead to property loss, reduced livelihoods, residential relocation, and other climate-related crises (infrastructure damages limiting access to healthcare, food insecurity, forced migration, war…)" I think you need a section on what climate related crises are before you link to low social position
Authors Response: We have provided additional references to climate related crises in the following sentence: "These driving forces can lead to property loss, reduced livelihoods, residential relocation, and other climate-related crises (infrastructure damages limiting access to healthcare, food insecurity, forced migration, war…) further widening inequalities (URLs: Markova et al., 2018 -http://www.fao.org/3/I8656EN/i8656en.pdf; Vuong et al. 2024 - https://doi.org/10.1007/s00267-024-01976-4; Ribot et al, 2023 - https://doi.org/10.1093/oxfordhb/9780197618646.013.20, accessed 26 Oct. 2024)".

Reviewer comments: "some economic contexts" what contexts – are they common, are they likely to persist?
Authors Response: This has been clarified as follows: "On top of this, social inequalities and per capita greenhouse gas emissions are positively correlated in emerging economies…"

Reviewer comments: " As poverty and social injustice" I think this is a new paragraph which needs to be started with "Climate change is likely to exacerbate inequality"
Authors Response: We have modified the paragraph accordingly.

Reviewer comments: "falling" change to "expected to fall". Define extreme poverty
Authors Response: This has been changed and clarified in the text as follows: "According to the World Bank, the estimated number of people expected to fall into extreme poverty (i.e., income below the international Poverty line) due to climate change is ranged between 32 million and 132 million in most scenarios by 2030".

Reviewer comments: "Therefore, it is critical to understand the global picture when to design adequate actions, not to imbalance the system or generate deleterious effects in other places."
This conclusion does not follow from what you have written. You would need to add info about poverty being in many different places globally and a bit about systems theory in order to understand why an action in one place might affect somewhere else and why they might not also be positive.
Authors Response: The sentence has been modified as follows for more clarification: "Therefore, it is critical to understand the global picture to design adequate actions and break the devastating loop."

Reviewer comments: Intro para 5 "As well as their own vulnerability to the effects of climate change, the most socially disadvantaged are also disproportionately burdened by new and often regressive policies which are set in place to foster behavioral or cultural changes" you need to reword to say that some climate change policies to foster behavioral or cultural changes can have regressive impacts
Authors Response: Changes have been made in the text accordingly. The sentence is now: "As well as their own vulnerability to the effects of climate change, the most socially disadvantaged are also disproportionately burdened by new policies which are set in place

to foster behavioral or cultural changes and which can have regressive impacts". Following, two references have been added: Nyiwul 2021: https://doi.org/10.1016/j.jclepro.2020.123393_Bae et al. 2018: Impacts of income inequality on CO2 emission under different climate change mitigation policies. Korean Econ Rev, 34(2), 187-211 (2018).

Reviewer comments: "As such, understanding and identifying the social patterning of the human health and wellbeing consequences of climate dysregulation and ecosystem disruption are key if we are to avail ourselves of actionable, reliable research and policy priorities[14]. "This sentence does not follow from the previous sentence– this sentence is about the impact of climate change whereas the previous sentences were about impacts of policies to combat climate change.
Authors Response: We have clarified the meaning as follows: "As such, understanding and identifying the social patterning of the human health and wellbeing consequences of climate dysregulation and ecosystem disruption and of ensuing incentives or deterrent measures are key if we are to avail ourselves of actionable, reliable research and appropriate policy priorities".

Reviewer comments: Intro 1 para 6 Can you say what the differences between the 3 approaches are
Authors Response: The overall differences between the three holistic approaches lie in which environmental aspects they most emphasise when framing human health: interactions of human with all species within ecosystems as for EcoHealth; interactions between animals & human as for One Health; limited resources of the planet as for Planetary Health. These differences are already highlighted in paragraph 7 (previously 6).

Reviewer comments: Climate change, social environment & health within holistic frameworks: insights from the literature analysis Para 1 'infiltrating' sounds like an enemy invading.
Authors Response: "Infiltrating" has been changed by "infusing".

Reviewer comments: Might be good to include here if you searched databases eg pubmed
Authors Response: This is now specified in the text and detailed in supplementary data as mentioned.

Reviewer comments: I would say this paragraph is a methods not a discussion section – the following paragraphs are results not a discussion
Authors Response: We are constrained by the editorial structure of ORE reviews which do not include the usual Method and Results section. We have thus detailed the methodology as supplementary data on OSF and discussed results and beyond in the Discussion section.

Reviewer comments: Figure 1 gender and ethnicity are not themselves socioeconomic status – they are demographic behaviors where some subgroups are overrepresented in low socioeconomic position.
Authors Response: We fully agree. As mentioned earlier, our perspective was to study social components in a broad sense (as defined in the text) that includes gender and ethnicity as they are structuring factors in building social patterns of health.

Reviewer comments: Figure 2 appears to have lost sight of the concept of socioeconomic status. It appears to confuse being low socioeconomic status and behaviors that go with it (eating habits) and living conditions (housing) and values (education)
Authors Response: We have intentionally identified all the social elements (in the broad sense defined in our text) that resulted from the scoping review to provide a synthetic scheme helping view in one shot all involved elements. This scheme only attempts to organise these elements as meaningful levels (micro/meso/macro) of influence and interactions with climate change and health but not in a causal way. Socio-economic status is related to behaviours, living conditions and education (at the micro-level). This framework does not distinguish structuring factors of social inequalities of health such as socio-economic ones or education from more distal factors like living conditions or behaviors as described by Solar O, Irwin A.[A conceptual framework for action on the social determinants of health. WHO Social Determinants of Health Discussion Paper 2 (Policy and Practice). 2010]

Reviewer comments: Limitations
You need to set up better in the introduction what holistic approaches are and why you think they are most useful.
Authors Response: We have clarified this at the beginning of paragraph 7 while adding the section on systems thinking above mentioned. The text is now: “Given the complexity of the climate and health challenges that span various knowledge disciplines, necessitating multi-level analyses and the involvement of diverse sectoral actors, the importance of systems thinking has emerged. Unlike traditional statistical analysis, which tends to isolate individual components of study, systems thinking views these components as a complex whole made up of interrelated and interdependent parts (Yasobant et al. 2020; Atun, 2012; Koskinen, 2013 = new refs 27-29. This shift has led to the rise of holistic health approaches over the past decade, including EcoHealth, One Health, and more recently, Planetary Health…”

Reviewer comments: You also need to include in the limitations that you have not included commercial determinants of health which impact climate change and social inequalities and government power to reduce inequalities and climate change eg
https://gh.bmj.com/content/8/11/e013698
https://gh.bmj.com/content/8/11/e013698.abstract
https://blogs.bath.ac.uk/tcrg/2023/04/06/why-cdoh-matters/
Authors Response: We fully agree that commercial determinants are key components of the climate change/social inequality/health landscape but we did consider them as economic factors rather than social ones. The following sentence was added in the Limitations paragraph. “Furthermore, we have not included commercial determinants of health in the bibliographic search string related to social components despite their important role in climate change and social inequalities.”

Competing Interests: No competing interests were disclosed.

Reviewer Report 27 August 2024

https://doi.org/10.21956/openreseurope.18943.r42200

© **2024 Eckel S.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

Sandrah P Eckel
University of Southern California, Los Angeles, California, USA

Thank you for the opportunity to provide comments on this review article which is a call to action on better integrating the social inequities and societal factors into climate change and health research & policy response. The authors conducted a review of the literature at the intersection of climate change, holistic frameworks of health and the social environment, summarizing trends (and identifying gaps?) with the process diagram in Figure 1. The authors then structure this information in the synthetic knowledge framework in Figure 2, and provide a summary of barriers to progress in terms of data-related challenges (Box 1) and recommendations for various stakeholders (Box 2). The authors are to be commended for tackling such a large and tricky problem of how to advance the study of climate and health by integrating the social environment. This review will help drive progress, though I do have several comments which may help strengthen the contribution.

Major comments:

- It is challenging to operationalize a holistic approach in empirical studies, as shown by only 20% of the reviewed articles being empirical. The general recommendations for researchers in Box 2 are helpful. But it might drive the field forward more quickly to highlight several empirical research case studies (e.g., drawn from the 20%), perhaps sharing strengths/limitations.
- The recommendations of Neufcourt et al are mentioned twice, but not described. Please add a more context here for the reader.
- Epidemiological studies are increasingly using causal thinking and directed acyclic graphs (DAGs), can the authors provide an example of how to operationalize Fig 1&2 in an epi study DAG?
- As described meso-level processes seem well-suited to ecological analysis of administrative data, might be worthwhile to describe this more?
- Fig 1 – I was surprised to not see wildfires or air pollution in the climate clouds.

Minor comments:

Introduction, Paragraph 6, Sentence 1: consider citing a review that compares the 3 holistic frameworks of health mentioned, perhaps: Lerner H, Berg C, 2017 [Ref-1]
Discussion paragraph 1. Reconsider use of the word “significant” since readers may think this refers to statistical significance of a hypothesis test
Fig 1/text – English language - consider using “precipitation” rather than “precipitations”
Fig 2 – note: with current color choice some words become illegible when printed in black and white.

References

1. Lerner H, Berg C: A Comparison of Three Holistic Approaches to Health: One Health, EcoHealth, and Planetary Health.*Front Vet Sci*. 2017; **4**: 163 PubMed Abstract | Publisher Full Text

Is the topic of the review discussed comprehensively in the context of the current

literature?
Yes

Are all factual statements correct and adequately supported by citations?
Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Biostatistics, Environmental Statistics, Air pollution Epidemiology, Climate and Health

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 17 Oct 2024

Laurence Mabile

Reviewer Comments:
Thank you for the opportunity to provide comments on this review article which is a call to action on better integrating the social inequities and societal factors into climate change and health research & policy response. The authors conducted a review of the literature at the intersection of climate change, holistic frameworks of health and the social environment, summarizing trends (and identifying gaps?) with the process diagram in Figure 1.

The authors then structure this information in the synthetic knowledge framework in Figure 2, and provide a summary of barriers to progress in terms of data-related challenges (Box 1) and recommendations for various stakeholders (Box 2).

The authors are to be commended for tackling such a large and tricky problem of how to advance the study of climate and health by integrating the social environment. This review will help drive progress, though I do have several comments which may help strengthen the contribution.
Author Response: Many thanks for your attentive reading and for your constructive comments and suggestions.

Reviewer Comments:
Major comments: It is challenging to operationalize a holistic approach in empirical studies, as shown by only 20% of the reviewed articles being empirical. The general

recommendations for researchers in Box 2 are helpful. But it might drive the field forward more quickly to highlight several empirical research case studies (e.g., drawn from the 20%), perhaps sharing strengths/limitations.
Author Response: We have provided, as a supplementary box, three examples of empirical studies that illustrate how integrating social conditions as part of the a holistic view can help better understanding complex human-environmental risks leading to health issues.

This box (Box A) is now added to the supplementary material of the manuscript at the OSF repository [https://osf.io/6t3j7] and is referred to in the main text at the end of third paragraph of the discussion section.
Further comment: Generally speaking with regards to many infectious disease models, data used in such models imply that all people face and pose uniform risks of infection. Knowledge about socially differentiated exposure could be more integrated into disease modelling efforts to improve the understanding of the heterogeneous dynamics of transmission.

Social data could also convey more specific and quantitative information if treated as fundamental causes in statistical analyses (i.e. contributive part for each social exposure in a causal inference model leading to health issues through contamination or directly).

Reviewer Comments:
The recommendations of Neufcourt et al are mentioned twice, but not described. Please add a more context here for the reader.
Author Response: We have now added the following sentence at the end of the Discussion section headed 'Climate change, social environment & health within holistic frameworks: insights from the literature analysis': « A set of methodological recommendations provided by Neufcourt et al.[18] can help extend research in this direction.

These are meant to be used when designing empirical studies aimed at investigating relations between exposome and health outcomes. They highlight questions to ask to make the hypothesised relationships more explicit, especially when testing hypotheses: which approach to use (agnostic / hypothesis driven / mixed) ; when selecting data, which type of social variables to account for (behavioural / material / psychosocial) ; how to treat social factors in analyses ; what are the corresponding limitations. »

Reviewer Comments:
Epidemiological studies are increasingly using causal thinking and directed acyclic graphs (DAGs), can the authors provide an example of how to operationalize Fig 1&2 in an epi study DAG?
Author Response: Directed acyclic graphs are causal diagrams where statistical interactions between exposures cannot be represented such as the interaction between climate and social conditions. The climate/social/health pattern can however be illustrated conceptually specifying the exposures, the various variable effects and their direction, and interactions. Where we provide a specific example (see Graph A at : https://osf.io/5dc8e] On one side, global urban policies (macro-level of environment) determine people 's housing conditions. Housing (micro-level) in turn can increase mortality through the quality of the building which may lead to indoor air pollution or mould spore exposure.

On the other side, nature macro-governance such as human activities impacting GHG emission (e.g. deforestation) contributes to increasing global temperatures. High temperature in turn triggers mortality through hyperthermia.

Meanwhile, housing can be affected by high temperature depending on various characteristics (insulating capacities, surrounding vegetal cover…). Interaction between both exposures (high temperature x housing) modifies the effect of temperature on increasing mortality.

Further, human migration (meso-level) affects conditions of housing and worsens mortality. Graph A is referred to, as a supplementary file, in the main text at the end of the Discussion section named *Framing and structuring the complexity.*

Reviewer Comments:
As described meso-level processes seem well-suited to ecological analysis of administrative data, might be worthwhile to describe this more?
Author Response: Many thanks for pointing this out. Indeed, while working with administrative data we are more likely to have access to meso and micro data. Analysing macro exposures is rather relevant for inter-country comparisons. We have now specified this in the text (at the end of the paragraph named *Framing and structuring the complexity)*.

Reviewer Comments:
Fig 1 – I was surprised to not see wildfires or air pollution in the climate clouds.
Author Response: Figure 1 provides a synthesis of the 80 empirical papers identified from our literature review on the basis of the keywords string that did not specifically include the term 'wildfires' as they were considered as consequences of climate change.

Further, each box of Figure 1 (all except purple ones) specifies the number of articles mentioning the social element identified. Wildfires and pollution did not come out from the analysis in any of the 80 articles.

However, as part of the theoretical pathways that were specified as purple hexagon boxes in Fig.1 -the most likely to link the social components to health outcomes (based on the literature)-, pollution was implicitly considered as 'food & water safety/quality'.

The following sentence has now been added in the discussion section of the manuscript : 'It can be noted that 'pollution' did not emerge from the analysis. (at the end of second paragraph of section named *Visualizing the challenging entanglement of social components in climate & health*

Reviewer Comments:
Minor comments:
Introduction, Paragraph 6, Sentence 1: consider citing a review that compares the 3 holistic frameworks of health mentioned, perhaps: Lerner H, Berg C, 2017 [Ref-1]
Author Response: We agree this reference describes well the commonalities and differences between the three approaches. It has now been added where mentioned.

Reviewer Comments:
Discussion paragraph 1. Reconsider use of the word “significant” since readers may think this refers to statistical significance of a hypothesis test
Author Response: The word «significant » has now been replaced by « noteworthy».

Reviewer Comments:
Fig 1/text – English language - consider using “precipitation” rather than “precipitations”
Author Response: The ‘s’ has now been removed in Figure 1.

Reviewer Comments:
Fig 2 – note: with current color choice some words become illegible when printed in black and white.
Author Response: We are aware and sorry for this. We have not found any other ways to integrate all dimensions than using many colors...

Competing Interests: No competing interests were disclosed.