



STUDY PROTOCOL

**REVISED** **Quantifying the effectiveness and health co-benefits of climate change mitigation actions across sectors: a protocol for an umbrella review [version 2; peer review: 3 approved, 2 approved with reservations]**

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**v2** First published: 18 Mar 2022, 7:98  
<https://doi.org/10.12688/wellcomeopenres.17498.1>

Latest published: 25 Aug 2022, 7:98  
<https://doi.org/10.12688/wellcomeopenres.17498.2>

### Abstract

Background: Effective and rapid actions are required to achieve global goals for climate change mitigation, and there is an opportunity to ensure that the actions taken are also positive for human health. However, little is known about the relative magnitude of the health co-benefits that can be achieved from mitigation actions, so robust and comprehensive syntheses of the evidence on the nature and effects of relevant actions are required. This paper presents a protocol for an interdisciplinary and cross-sectoral umbrella review of systematic reviews, synthesising modelled and empirical evidence on such actions.

Methods: Nine bibliographic databases will be searched, capturing literature across a wide range of disciplines and sectors. Unique records retrieved by the searches will be screened by two independent reviewers. The quality of all the included systematic reviews will be assessed using A Measurement Tool to Assess Systematic Reviews (AMSTAR) 2 critical appraisal tool. Data will be extracted on methodological and thematic characteristics of the reviews, nature of the actions, and their effects on greenhouse gas emission reduction, health, and its determinants, as well as any other reported effects and interactions across different actions.

Results: Narrative and quantitative synthesis methods will be used to

### Open Peer Review

Approval Status

	1	2	3	4	5
<b>version 2</b> (revision) 25 Aug 2022	 <a href="#">view</a>		 <a href="#">view</a>	 <a href="#">view</a>	 <a href="#">view</a>
<b>version 1</b> 18 Mar 2022	 <a href="#">view</a>	 <a href="#">view</a>			

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create a typology of relevant actions, map pathways to their impacts on health, compare the magnitude of health and greenhouse gas (GHG) emission reduction impacts by selected characteristics of the actions and the nature of the evidence, as well as to identify gaps in evidence syntheses.

Conclusion: This review will identify the most effective actions for global climate change mitigation and health based on the best available scientific evidence.

This protocol has been registered in PROSPERO, Reg No.: CRD42021239292.

### Keywords

climate change, mitigation, climate action, actions, planetary health, health, systematic review, evidence synthesis, umbrella review

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**Competing interests:** No competing interests were disclosed.

**Grant information:** This work was supported by Wellcome [221284 <https://doi.org/10.35802/221284>] through an Our Planet, Our Health programme grant for the Pathfinder Initiative with support from the Oak Foundation (grant number OFIL-20-093). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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**How to cite this article:** Belesova K, Green R, Clercq-Roques R *et al.* **Quantifying the effectiveness and health co-benefits of climate change mitigation actions across sectors: a protocol for an umbrella review [version 2; peer review: 3 approved, 2 approved with reservations]** Wellcome Open Research 2022, 7:98 <https://doi.org/10.12688/wellcomeopenres.17498.2>

**First published:** 18 Mar 2022, 7:98 <https://doi.org/10.12688/wellcomeopenres.17498.1>

**REVISED Amendments from Version 1**

This revised version of the article is updated in response to the reviewers' comments on its previous version. In this version, we have clarified the meaning of the umbrella review, our approach to data extraction from both the included systematic reviews and their primary studies, methodological description of data extraction on synergies and trade-offs, and the proposed synthesis methods. We have also clarified the inclusion criteria by editing the list of eligible health outcomes and elaborating the sectors of potential intervention. Further clarifications were added on the scope of the Pathfinder Initiative, the process of screening of abstracts in foreign languages, and to discussion of the potential geographical bias of this review.

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

**Introduction**

The Paris Agreement's goal to limit global average temperature increase to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels requires reaching net zero greenhouse gas emissions globally by 2050 if not earlier ([United Nations Environment Programme, 2019](#)). Our society is, therefore, facing the responsibility to identify and implement actions capable of triggering and sustaining system-wide transitions from the current greenhouse gas (GHG) emission trajectory onto a pathway for timely achievement of the net zero target. To meet all three dimensions of sustainable development – social, economic, and environmental – such a trajectory should allow everyone to thrive within the planetary boundaries ([Steffen et al., 2015](#); [Whitmee et al., 2015](#)). It has been estimated that millions of premature deaths could be averted by reducing air pollution through fossil fuel phase out, transitioning to healthy and sustainable diets and housing, developing net zero health care systems, increasing the proportion of active travel and use of active transport, and implementing nature-based solutions, including reforestation and reducing deforestation ([Aleksandrowicz et al., 2016](#); [IUCN, 2016](#); [Lelieveld et al., 2019](#); [Lenzen et al., 2020](#); [Pencheon & Wight, 2020](#); [Seddou et al., 2021](#); [Wilkinson et al., 2009](#); [Willett et al., 2019](#)). Therefore, priority must be given to identifying and implementing actions that not only offer the greatest climate change mitigation potential, but also have significant potential to positively contribute to health worldwide and avoid adversely affecting health outcomes (e.g., through regressive policies).

To accelerate the necessary system-wide transitions and implementation of the most promising actions, there is an urgent need for a comprehensive interdisciplinary and cross-sectoral synthesis of evidence on the range of actions available and their effectiveness in mitigating climate change and improving human health and wellbeing. The synthesis should also account for any evidence of unintended consequences and spillover effects (i.e., positive or negative effects of one actor's mitigation actions on another actor's ability to achieve mitigation or other sustainable development objectives), synergies and trade-offs, as well as implications for health equity. To date, many published systematic reviews have focussed on a single

sector, discipline, and/or category of impact; for example, only climate change mitigation impact or health impact and vice versa (e.g., [Cantler et al., 2020](#); [Court & Sorrell, 2020](#); [Hertwich et al., 2019](#); [Javaid et al., 2020](#); [Sethi et al., 2020](#)). Such focussed reviews often offer limited opportunities to understand the cross-sectoral, cross-disciplinary, and system-wide implications of climate change mitigation actions, reducing our capacity to draw balanced conclusions on the most effective actions and their synergistic combinations. Furthermore, most systematic reviews do not attempt quantitative synthesis of the impact of actions on greenhouse gas emissions and health, as the actions and designs of the original studies that quantify their impact are highly heterogeneous.

The Pathfinder Initiative aims to identify and synthesise evidence on actions that accelerate progress towards a zero-carbon economy and simultaneously help to improve health locally and globally. Although the focus of the initiative is on climate change mitigation, the adaptation actions are in scope of our work as long as they also have a significant mitigation component. The Pathfinder Initiative will provide evidence on the important gaps in knowledge on which actions can help achieving the greatest benefits with minimal trade-offs for the climate and health in different contexts and how these actions can be effectively scaled-up ([Hassan et al., 2021](#)).

Here we report a protocol for an umbrella review – a review of systematic reviews or meta-analyses, undertaken as a part of the Pathfinder Initiative, to synthesise the existing syntheses of findings on the range and effectiveness of actions – both potential and already implemented in practice – for climate change mitigation and health across all sectors and disciplines that can help triggering and sustaining the necessary system-wide transitions. We focus not only on the short-term health benefits of climate change mitigation actions but also on the health benefits that would occur as a result of climate change mitigation in the long term by reducing the anticipated future health impacts of climate change. The umbrella review will compare results across sectors and disciplines and provide synthesis of any inter-sectoral and inter-scalar effects (i.e., the effects of actions implemented in one sector or scale on other sectors or scales), including synergies and trade-offs. Modelled or observed evidence on unintended consequences, spillover effects, and distributional effects with implications for health equity will also be synthesised where available. We will assess the nature and quality of the existing systematic evidence syntheses and map the 'absolute gaps' in evidence that require new primary studies, 'synthesis gaps' that require new focussed systematic reviews and syntheses, and 'synthesis update gaps' where existing reviews are based on outdated searches and updates of the existing focussed reviews are necessary.

**Aim and research questions**

The aim of the umbrella review is to assess and synthesise the nature, quality, and strength of the systematically reviewed evidence on climate change mitigation actions (and their health co-effects, which largely are co-benefits but may involve certain

trade-offs) for a range of system wide transitions and their corresponding sectors including but not limited to, energy supply, transport, buildings, industry, agriculture, forestry, and other land use (AFOLU), human settlements/infrastructure, and nature-based actions. We will focus on addressing the following research questions:

1. What types of climate change mitigation actions with defined short-term and long-term health co-benefits have been reported in systematic reviews and what are their pathways of impact on health?
2. How does the magnitude of change in health outcome or exposure and GHG emissions differ within and between the identified types of actions, based on the modelled as compared to the observational evidence (provided there is sufficient observational information of implemented actions), and across different contexts?
3. How do syntheses differ in their coverage, quality, and strength of evidence across sectors, disciplines, action types, and their implementation or modelling contexts? Are there any sectors where no syntheses exist?

## Protocol

### Inclusion criteria

The scope of our umbrella review is defined by the following inclusion criteria of existing systematic reviews.

**Population:** studies with exposures and impacts of relevance to human population without geographical restrictions

**Intervention:** actions primarily targeting climate change mitigation or known to have an impact on climate change mitigation alongside other primary targets, e.g., improving health and climate change adaptation. We will include interventions undertaken in any sector, broadly: Energy systems; Agriculture, Forest and Other Land Use (AFOLU); Transport; Buildings; Industry; and Land, Coastal and Ocean Sinks, and Engineered Sinks. These could be single solutions carried out within single sectors, multiple actions carried out in single sectors (e.g., system transitions), or multiple actions carried out across multiple sectors. Several classification systems exist and could be used to group and present our findings, for example, the classification system used in the IPCC AR6 WG3 report (Figure SPM.8) (IPCC, 2022), or the Drawdown Framework for Climate Solutions (Project Drawdown, 2022). We will use and if necessary, adapt the classification system to which our data fits best.

### Outcome:

(1) any form of documented changes in health outcomes (e.g., all-cause or cause-specific mortality, years of life lost, morbidity from respiratory, cardiovascular and other diseases) or its well-established determinants whether positive or negative, short-term or

long-term (i.e., as a result of reducing potential future health impacts of climate change), including changes in those exposures that are known to increase the risk of adverse health outcomes, e.g., environmental risk factors included in the Global Burden of Disease Assessment (Abbafati *et al.*, 2020). The preliminary list of eligible outcomes, exposures, and risk factors is available in the [Table 1](#)

(2) change in emissions or atmospheric concentrations of major greenhouse gases: Carbon dioxide (CO<sub>2</sub>), Nitrous oxide (N<sub>2</sub>O), Methane (CH<sub>4</sub>), or short-lived climate pollutants such as black carbon

**Study design:** systematic review, defined as a study that identifies explicitly as a systematic review and meets the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) criteria, including an explicit systematic search strategy and clear criteria for the inclusion of original studies that report the impact of actions on both outcomes outlined above, synthesised using meta-analysis or narrative synthesis approaches

**Year of publication:** from 2000 until present to capture reviews published after the introduction of the Millennium Development Goals (MDGs), wider acceptance of the concept of health co-benefits, and the establishment of international bodies coordinating high quality reviews on social and environmental topics (e.g., Campbell Collaboration founded in 2000, Collaboration for Environmental Evidence founded in 2006)

**Language:** studies published in English, Spanish, French, Portuguese, Chinese, Russian, German, Dutch, Italian, Arabic

To develop our methodology, we reviewed some of the relevant systematic reviews (that would be included in our analyses) and concluded that the data reported in the systematic reviews often falls short from the level of detail required to address the objectives of our umbrella review. For example, many systematic reviews are narrative and do not attempt any quantitative synthesis even when such synthesis would be feasible. Furthermore, systematic reviews without a quantitative synthesis often do not report sufficient data from the primary studies that they reviewed, e.g., only reporting either the health or GHG impact of the actions but not both or lacking information on the baseline or scale of the impact, which are necessary to allow comparing the impact of actions across studies and settings. However, these data are often available from the text of the primary studies. Therefore, we adapted the umbrella review methodology to expand our data extraction procedure beyond the (often limited) text of the systematic reviews to the text of primary studies that were included in these systematic reviews. We propose to extract data from relevant primary studies included in eligible systematic reviews to capture the data on action health and GHG emission impact estimates and their characteristics that are not reported in the systematic reviews.

**Table 1. The preliminary list of health outcomes and exposures/risk factors\* that will be used to guide inclusion and exclusion as well as assist the extraction of data on health outcome/exposure types.** Adapted from Table 5 from [Hassan et al. \(2021\)](#), available under a CC-BY-4 license.

Health outcomes
Disease manifestations of poor diets (vitamin and mineral deficiencies)
Disease manifestations of air pollution (chronic lung and cardiovascular diseases)
Disease manifestations of increased climate sensitive pathogens (malaria, Lyme disease, West Nile virus, enteric diseases)
Weather-related morbidity and mortality with implications for productivity
Transport related morbidity/mortality (road traffic accidents)
Mental health conditions arising from climate-related exposures
Morbidity and mortality related to the urban heat island effect
Risk factors for ill health (based on the risk factors used in the Global Burden of Disease project ( <a href="#">Abbaftati et al., 2020</a> ))
Childhood underweight and overweight
Diet low in fruits, vegetables, legumes, nuts and seeds, seafood and omega-3 fatty acids
Diet high in red meats
Overweight and obesity (BMI)
Physical inactivity
Ambient particulate matter and ozone pollution
Household air pollution exposure
Noise pollution
Chemical pollution
Poor housing insulation leading to cold indoor conditions
Crowding / physical proximity
Exposures to climate change impacts
Disruptions to water supply and quality
Disruptions to energy
Disruptions to healthcare access
Disruptions to food supply
Displacement
Increase in climate sensitive pathogens and vectors (ticks, mosquitoes, sand flies)
Socio-economic determinants of health
Poverty
Homelessness
Unemployment
Female education and female participation in the workforce
Governance and decision-making processes

\*We include both short-term health co-benefits of climate change mitigation as well as long-term impacts of climate change on health that can be avoided through climate change mitigation.

We will use the following criteria to select eligible primary studies:

**Study designs:** any experimental or observational (including natural experimental) empirical study or a modelling study that reports quantitative estimates using the following methods:

- (1) randomised controlled trials (RCTs) using random assignment of units to groups with and

without the mitigation action, and quasi-RCTs using prospective methods of assignment of units such as alternation

- (2) studies with non-random assignment of units to mitigation actions and comparison with pre-test and post-test data collection (controlled before vs after), or studies with post-test data collection only (cross-sectional and case-control studies)

- (3) studies with single group data and sufficient observations to establish trends before and after a mitigation action, i.e., interrupted time series (ITS), and ITS incorporating a control group (controlled-ITS)
- (4) non-randomised studies with assignment to a mitigation action based on a threshold on an ordinal or continuous assignment variable (regression discontinuity design), or a geographical or administrative boundary (geographical discontinuity design), comparing outcomes for groups around the threshold
- (5) non-randomised studies, sometimes called natural experiments, using statistical approaches to account for unobservable confounding (e.g., difference-in-differences, instrumental variables)
- (6) modelling studies are eligible where they compare a scenario with a mitigation action against a business as usual or another scenario without a mitigation action, and have modelled GHG emissions and health impacts (including impacts on exposures and health determinants) of the scenarios

**Comparisons:** eligible comparisons include ‘no mitigation action’, a ‘wait-list’ where subjects/places that have not yet been exposed to the mitigation action are used as controls, ‘business as usual’ or another strategy that does not lead to reductions in GHG emission or atmospheric concentrations. Studies with active controls, i.e., a comparison of two mitigation action scenarios (without a scenario where there are no mitigation actions), are excluded.

This protocol has been registered in PROSPERO, Reg No.: CRD42021239292 (Belesova *et al.*, 2021b).

### Literature search

Our searches will be performed in the following nine databases: Medline ALL, Embase, Global Health and Econlit on the OvidSP platform; Africa-Wide Information and GreenFILE on the Ebsco platform and Web of Science Core Collection, BIOSIS Citation Index and SciELO on the Clarivate Analytics Web of Science platform. The structure of our search consists of two search blocks combined as follows: (climate change mitigation terms) AND (systematic review terms). The search strategy was developed by a librarian experienced in systematic review borrowing climate change and climate change mitigation search terms from the search strategy developed by Belesova *et al.* (2021a) and Falconer (2014) and terms for reviews from Lee *et al.* (2012). The search terms were reviewed by members of the Pathfinder Initiative, implementing their recommendations where appropriate. The search syntax was adapted for each of the bibliographic databases. The full search strategy for each database is available through the LSHTM Data Compass depository (Belesova *et al.*, 2022). In addition, to ensure coverage of peer-reviewed systematic reviews

that remain outside of academic databases, we will hand search the libraries of the Campbell Collaboration, Collaboration for Environmental Evidence, and the EPPI-centre.

### Screening for inclusion

Screening for inclusion will follow a two-stage approach. In the first stage, the titles and abstracts will be screened against the inclusion criteria and in the second – full texts. The unique records identified from our searches will be first downloaded into the Rayyan open access software where the title and abstract screening will be performed (Ouzzani *et al.*, 2016). All records eligible for the full text review will be then imported into EPPI-Reviewer software where the full text screening, quality assessment, and data extraction will be performed (Thomas *et al.*, 2010). We will use the PRISMA statement and flow diagram to record the search and screening results. We will record all reasons for exclusion at the full text review level. In all stages, screening will be performed by pairs of independent reviewers, who will reconcile any differences, consulting a third reviewer where necessary. The same screening process will be applied to the abstracts and full texts that are only available in other languages than English that are eligible for inclusion (Spanish, French, Portuguese, Chinese, Russian, German, Dutch, Italian, and Arabic). In our team of individual reviewers at least one (but often two) reviewer(s) speaks each of these languages. When only one team member speaks the necessary language, we will invite and train additional independent reviewers from our wide pool of collaborators and colleagues.

### Quality assessment

The quality will be assessed for each of the review papers included after the full text review stage using A MeaSurement Tool to Assess Systematic Reviews (AMSTAR) 2 critical appraisal tool for systematic reviews (Shea *et al.*, 2007). AMSTAR 2 is based on 16 assessment questions focussed on methodological quality of systematic reviews. It has been recognised as suitable for assessing the quality of systematic reviews of studies evaluating health care interventions, including randomised and non-randomised trials (Shea *et al.*, 2017). Therefore, AMSTAR 2 is particularly suitable for our proposed umbrella review on climate change mitigation actions, which will include (although will not be limited to) studies with designs similar to those evaluating public health interventions. In addition to the AMSTAR 2 assessment criteria, we will extract information on the last search data in each review and incorporate that into the critical appraisal to identify “synthesis update gaps”, i.e., the topics and reviews that need updating based on the currency of the search dates as well as the likelihood of additional primary study evidence being available. The critical appraisal will be performed by an expert reviewer. A second reviewer will independently assess quality of a random sample of the papers. Any differences will be reviewed and reconciled, consulting a third reviewer where necessary.

For primary studies, we will extract the risk of bias rating that the study was assigned by the relevant systematic review, where the reviews report results of such appraisal. In addition,

we will appraise the primary studies by classifying the directness and nature of their evidence: modelled evidence only *vs* evidence observed at the health exposure or determinant level and modelled at the human health outcome level *vs* evidence observed at the health exposure or determinant level *vs* evidence observed at the health outcome level. Studies providing observed evidence will be further classified by whether they attempted to apply an appropriate type of control for confounding for the study design. Modelling studies will be classified into studies with and without a quantitative analysis of uncertainty, as an important for element of modelled study critical appraisal (Hess *et al.*, 2020; Remais *et al.*, 2014).

### Data extraction

The data extraction process will be first piloted on a subset of studies to ensure coherence. All data extraction will be performed by one reviewer. A second reviewer will independently extract data for a random sample of 10% of the reviews to verify accuracy of the data extraction. Should there be substantial differences in the judgement of the two reviewers, further comparisons and reconciliation will be undertaken to achieve an acceptable agreement on the extracted data and accuracy of the extracts.

Our preliminary examination of relevant systematic reviews demonstrated that data on the impact of the actions on health and GHG emissions are often not presented in the systematic reviews but are available in the primary studies included in such reviews. Important details of the impact measures and action characteristics that are required to draw comparisons of the impact across different actions (e.g., the scale at which the action was implemented and specific GHGs that were considered in the impact estimates) are also often lacking in the systematic reviews but are available in the primary studies. To capture these data, we will extend our data extraction process beyond the data reported in our examined systematic reviews to include the data reported in those primary studies that are included in these systematic reviews which meet our primary study inclusion criteria (see the section on inclusion criteria above). Where systematic reviews present a quantitative synthesis but insufficient detail on the results of individual primary studies to allow us to re-produce their synthesis, we will contact the review authors to request the data they extracted from the primary studies.

Hence, the data extraction process will be conducted at two levels. First, data will be extracted from the included systematic reviews in EPPI-Reviewer:

- (1) Citation
- (2) Type of review (systematic with or without meta-analysis)
- (3) Number of bibliographic databases searched
- (4) Final search date (month, year)
- (5) The range of publication dates of the studies included in the review

- (6) Number of studies included in the review
- (7) Number of study participants covered by the review (where applicable)
- (8) Types of studies included in the review (modelling, experimental, and observational with or without a comparison)
- (9) Counterfactual (used in modelling studies) or comparison group (in empirical studies)
- (10) Level of geographical coverage of the review (global, regional, national, city, another level – specified in the review)
- (11) Setting (high-, middle-, low-income, all)
- (12) Type of study quality appraisal method (i.e., the risk of bias assessment tool) used by the review
- (13) Overall rating of the quality of studies included in the review (overall quality, % of studies assessed as good quality)
- (14) Pooled estimates of GHG reductions together with 95% confidence intervals and heterogeneity statistics (I-squared and tau-squared) (where applicable)
- (15) Pooled estimates of health impacts together with 95% confidence intervals and heterogeneity statistics (I-squared and tau-squared) (where available)
- (16) Any synergies and trade-offs suggested by the review authors

Second, data from the individual studies included within each review will be extracted into an MS Excel-based data extraction tool, whose preliminary structure is illustrated in [Table 2](#).

### Synthesis

To determine what types of climate change mitigation actions with defined health co-benefits have been reported in systematic reviews (research question 1), we will use narrative/thematic synthesis developing a typology of the reported actions. We will further use Sankey diagrams to map the pathways (i.e., routes of exposure and health determinants) through which the health impact of the identified actions in each sector and sub-sector is estimated. The pathway maps will demonstrate what exposure routes and GHG and health outcomes have been linked in existing research and how. We will also narratively synthesise any other effects of our identified actions, e.g., any synergies (i.e., effects of actions that apart from their own impact on GHG emissions and health co-benefits also enhance the effectiveness of other climate change mitigation actions of the capacity to implement the other actions) and trade-offs (i.e., effects of a climate mitigation action that preclude implementation of other climate mitigation actions or minimise the effectiveness of the other actions) suggested by the review authors, potential for unintended consequences, spillover effects, and distributional effects with implications for health equity.

**Table 2. Variables for data extraction from individual (primary) studies.** Acronyms: AFOLU: agriculture, forestry, and other land use; CH<sub>4</sub>: methane; CI: confidence interval; CO<sub>2</sub>: carbon dioxide; DALY: disability-adjusted life years; GHG: greenhouse gas emissions; ITS: interrupted time series; RCT: randomised controlled trial; N<sub>2</sub>O: nitrous oxide.

Data extraction variable	Notes
Authors	Of the review
Title	Of the review
Number of included studies	In the review
Number of studies relevant for the umbrella review	How many studies in the review report GHG and health impact measurements
Relevant study citation	Primary study citation
Studies appear in multiple systematic reviews of the umbrella review	Flags primary studies included in the umbrella review from more than one systematic review
Sector	Energy, transport, AFOLU, buildings, oceans, industry, human settlements, health care, education
Sub-sector	No pre-determined list—elaborate on the sector selected above
Country(-ies)	Country of study
Action	Briefly describes the mitigation action
Pathfinder categories of action	The most relevant of the following pre-defined categories: energy-efficient transportation, alternatives to private cars: public transport, active transport, cross-sectoral actions and policy instruments, lower emission energy sources, energy efficiency of buildings and appliances, improved agricultural processes (increased efficiency and reduced input use), dietary shift towards low-emission land-based products, improved industrial processes, low-emission fuels
Description	Describe the mitigation action, including any data relevant to the timeframe, methods, and treatments
Experiment	Flags a 'new' mitigation action, potential new way of doing things
Baseline	Specifies the type of comparison without the mitigation action
Modelled or implemented action	Was the action modelled or implemented in practice
Study design	E.g., RCT, ITS, cross-sectional and case-control studies, controlled before vs after
Uncertainty estimation	If this is a modelling study, does it report any quantitative analysis of uncertainty
Model/action scale	Scale of the model or mitigation action
Impact scale	E.g., farm, local, city, country-wide
Timeframe of action	Timeframe over which the action has been implemented or modelled
Timeframe of impact	Specify if different from the timeframe of action
GHG indicator	CH <sub>4</sub> , CO <sub>2</sub> , N <sub>2</sub> O (black carbon, ozone)
GHG unit	E.g., kgCO <sub>2</sub>
GHG measure (action)	GHG measure for the estimate with the action
Modelled or empirical GHG estimate	Was the estimate modelled or empirical
GHG lower CI	Lower CI (if available) for the action estimate
GHG higher CI	Higher CI (if available) for the action estimate
Absolute value for baseline GHGs	GHG measure for the baseline estimate
GHG lower CI	Lower CI (if available) for the baseline estimate
GHG higher CI	Higher CI (if available) for the baseline estimate
Health indicator	Particulate matter (PM), NO <sub>x</sub> , deaths, respiratory disease incidence, etc.
Health unit	E.g., DALYs
Health measure	Health measure for the estimate with the action
Health lower CI	Lower CI (if available) for the action estimate



Data extraction variable	Notes
Health higher CI	Higher CI (if available) for the action estimate
Modelled or empirical health estimate	Was the estimate modelled or empirical
Impact pathway	If the health measure is a health outcome, what route(-s) of exposure or health determinants were considered when estimating or modelling the health impact
Absolute value for baseline health measure	Health measure for the baseline estimate
Health lower CI	Lower CI (if available) for the baseline estimate
Health higher CI	Higher CI (if available) for the baseline estimate
Synergies / trade-offs	Effects that enhance or reduce the effectiveness of or the capacity to implement other actions
Units of change for spillover 1	E.g., DALYs
Amount of spillover	The estimate of the spillover effect
Lower CI for spillover	Lower CI (if available) for the spillover effect estimate
Upper CI for spillover	Upper CI (if available) for the spillover effect estimate
Quality	Rating of primary study by review authors
Comment	Any definitions, important notes, abbreviations, elaborations of standard practice, etc.

Particular attention will be paid to the timeframe over which actions are shown to exert effects on health and GHG emissions/concentrations and location where the health effects are experienced (e.g., locally, regionally, globally).

To compare how the magnitude of change in health outcomes or exposures and GHG emissions or concentrations impact differ within the identified types of actions, based on the modelled as compared to the observational evidence and across different modelling and implementation contexts (research question 2), we will perform quantitative syntheses of the impact of the reviewed actions on health outcomes and GHG emissions, where possible, provided sufficient homogeneity across the individual effect estimates. If pooling of findings across studies is feasible for any particular outcome, inverse-variance weighted random effects meta-analysis will be used. Meta-regression models may also be estimated to explore heterogeneity across outcomes by types of actions or exposures or contextual factors. We propose to use the standard methods of synthesis to pool findings across studies should enough data be available. This might incorporate inverse-variance random effects meta-analysis for particular mitigation strategies and outcome constructs, where measures of the variance (or variables closely relating to it, such as sample size) are presented and appropriate. Another option is to conduct meta-regression analysis (MRA), which enables pooling of effects across mitigation strategies and outcome constructs in a larger model. Where this is possible, we will use appropriate methods of weighting depending on the underlying literature (empirical literature might use inverse-variance, modelling literature might use population measures). In producing any quantitative syntheses, we will take account of any studies that are overlapping, i.e., captured by multiple included systematic reviews, by only including one estimate per primary

study for each outcome synthesised. Where quantitative syntheses are not appropriate, evidence of effects on health, its well-established determinants, and GHG emissions will be synthesised narratively. Our synthesis of the effects and quality of the evidence will be stratified by sector, action and health outcome type, modelled *vs* observational evidence, different geographical modelling and implementation contexts, and, where possible, any evidence of implications for health equity. The direction and strength of effect and quality of evidence (including effect heterogeneity across the reviews) will be reported and illustrated graphically for each stratum, with relevant graphs and figures presented where possible, for example using forest plots.

To determine how syntheses differ in their coverage, quality, and strength of evidence across sectors, disciplines, action types, and their implementation or modelling contexts (research question 3), we will use the EPPI Mapper tool to produce visual maps that present the evidence as a matrix classifying the evidence by the characteristics of interest. The maps will help identifying the key gaps in the available evidence syntheses, particularly in relation to different geographies, contexts, sectors, and types of actions. We will map the ‘absolute gaps’ in evidence that require new primary studies, ‘synthesis gaps’ that require new focussed systematic reviews and syntheses, and ‘update gaps’ where existing reviews are based on outdated searches and updates of the existing focussed reviews are necessary.

## Discussion

This paper presented the protocol for an umbrella review of the systematically synthesised evidence on climate change mitigation actions of benefit for health. To our knowledge, this will be the first attempt at an integrated synthesis of actions examined in

systematic reviews across all sectors and disciplines that can help lead to system wide transitions that are necessary for the net zero carbon future.

We acknowledge that our proposed review is subject to a number of potential sources of bias:

1. **Inconsistent definitions** may be used across systematic reviews, particularly when those pertain to different sectors or originate from different disciplines or research communities. To minimise this bias, we will set our own broad definitions for key terms accounting for different disciplinary and sectoral perspectives and follow those in a consistent manner throughout our evidence synthesis, reporting, and communication of our results. Feedback will be sought from the multi-disciplinary panel of commissioners and partners of the Pathfinder Initiative, where necessary.
2. **Risk of bias in the effect size calculations** can arise as different primary papers and systematic reviews may use different formulas to calculate their examined effect sizes for the health and GHG emission impact of the actions. To address this, we will translate between the different effect size types, where possible, using established methods such as on converting between standardised mean difference and odds ratios (Deeks *et al.*, 2021). Suggestions for specialised translation methods will be sought from the panel of commissioners and partners of the Pathfinder Initiative, where necessary.
3. **Reviewer bias** can arise when evaluating records retrieved from the searches for inclusion and exclusion as a result of differences in the way reviewers interpret the inclusion and exclusion criteria. To minimise the risk of such bias, we will train all reviewers to apply the inclusion/exclusion criteria in a consistent manner. The training will be done on an initial sample of studies that all reviewers will first individually assess for inclusion and then collectively reconcile in consultation engaging in an in-depth critical discussion of any differences in their judgement. For the rest of the screening process, each record will be reviewed by a pair of reviewers and any differences in judgement will be reconciled, referring to a third reviewer, where necessary. Reviewer bias can also be introduced in data extraction. To minimise the risk of such bias, data extraction will be first piloted for a small sample of studies with extracts reviewed and their accuracy agreed with other team members before the rest of the data extraction process takes place. A sample of all data extracts will be reviewed by a second reviewer with any differences reconciled involving a third reviewer, where necessary, and expanding the sample, if required.
4. **Publication bias** may arise for four reasons: (1) more original studies of climate change mitigation actions are conducted and subsequently synthesised in systematic reviews in high income settings than low-income settings,

which would introduce an unavoidable geographical location bias; however, higher income countries also have higher per capita GHG emissions and mitigation is therefore a priority for these countries. (2) more systematic reviews may have a focus on developed and high-income countries (or vice versa) and their searches may therefore be restricted to high income countries (or vice versa) (3) Studies published in English – as the “prima lingua” of the modern science – are more likely to be included in systematic reviews than studies published in other languages, which introduces a language bias; although we include systematic reviews published in other languages, and the critical appraisal done under AMSTAR 2 assesses whether systematic reviews published in English are themselves limited to English language studies only. (4) Studies demonstrating evidence for an effect of an action on the outcome of interest are more likely to be published than studies that are not able to demonstrate evidence of effect (such as due to insufficient statistical power), subsequently introducing bias towards capturing actions with demonstrated impacts as opposed to without; we attempt to address this by incorporating primary studies in synthesis regardless of publication status, and the critical appraisal under AMSTAR 2 also assesses whether formal publication bias tests have been done in the review. (5) Systematic reviews are more prevalent in the disciplines with a strong tradition of this approach to evidence synthesis, e.g., medicine, public health, and criminology, than others, e.g., global environmental change and development studies, where evidence derivation and synthesis tradition is rooted in differently, and often less rigorously, structured assessment and summary reports (Minx *et al.*, 2019; Tusting *et al.*, 2021; Waddington *et al.*, 2012). Our umbrella review focuses on actions with documented impact on health and its well-established determinants, and incorporates evidence from two fields where concerted efforts are being made to improve the quality of primary studies and evidence synthesis (environmental science and development studies).

As with all umbrella reviews, our proposed review can only synthesise what other researchers have investigated, published, and systematically reviewed (Fusar-Poli & Radua, 2018). We foresee that the systematic reviews that our umbrella review will cover will likely lack quantitative syntheses, as we have seen in our preliminary examination of relevant systematic reviews. To address this challenge, we will extend our data extraction to primary studies to produce our own quantitative syntheses and meet our research objectives. This leads to another potential source of bias, as our umbrella review will not be covering any primary studies that are not captured by the identified systematic reviews. Hence, we will not capture primary studies that are not included by these syntheses, e.g., because they were published after the date when the literature searches for the reviews were conducted, and primary studies in areas where systematic reviews have not been conducted. To account

for these gaps in our syntheses, we will record the date of the last search date of each review and use it with other characteristics of the evidence to examine the ‘synthesis gaps’ and ‘synthesis update gaps’, as explained earlier.

Another foreseeable challenge is the likely heterogeneity across the primary studies, which may limit the extent to which we will be able to perform quantitative syntheses of their results for some of the actions. For example, [Hess \*et al.\* \(2020\)](#) reported that studies of health and GHG impacts of climate change mitigation actions often use different metrics of success and timescales, and often have limited reporting of baseline health outcome or exposure and GHG emission levels. We will endeavour to examine the sources of heterogeneity and account for uncertainty in any quantitative syntheses that we will perform.

This umbrella review is intended to provide a robust synthesis of the nature and quality of the published and systematically synthesised evidence on actions for climate change mitigation and health. It will complement other research components of the Pathfinder Initiative, which will synthesise evidence from cases where climate change mitigation actions have been implemented in different contexts in practice. In the future, this umbrella review could be turned into a living review to help speed up the incorporation of the latest evidence into climate change mitigation policy and practice in a manner that allows simultaneously achieving the greatest health benefits ([Sethi \*et al.\*, 2020](#)).

## Conclusion

This protocol presents our approach to the development of an umbrella review of actions for climate change mitigation and health. It will provide a robust and transparent assessment of the quality of the available evidence for the actions and their effects reported in published systematic reviews across a wide range of disciplines and sectors. The review will help identifying the most effective actions, as indicated by the published evidence syntheses, and gaps in the evidence syntheses.

## Ethics, outputs, and dissemination

As a project entirely comprised of synthesis of existing evidence and not involving any individual participants or patients, the study does not require ethical approval. However, the study protocol has undergone consultation with the Observational Ethics Committee of the London School of Hygiene & Tropical Medicine.

Results of the umbrella review will be presented in a peer-reviewed academic paper. Furthermore, key messages from the review will be communicated through the Lancet Pathfinder Commission report which will be published in late 2022, at relevant international meetings, and through Pathfinder Initiative partner organisations (OECD, SDSN, C40 Cities, CDP and the Alliance for Health Policy and Systems Research), using targeted policy briefs appropriate to each partner’s network.

## Study status

The literature searches and screening for inclusion have been completed. Data extraction is in progress.

## Data availability

### Underlying data

No underlying data are associated with this article.

### Extended data

LSHTM Data Compass: Search strategy for the umbrella review “Quantifying the effectiveness and health co-benefits of climate change mitigation actions across sectors: a protocol for an umbrella review”. <https://doi.org/10.17037/DATA.00002761> ([Belesova \*et al.\*, 2022](#))

Data are available under the terms of the [Creative Commons Attribution 3.0 Unported](#) (CC-BY 3.0).

## Acknowledgments

We would like to thank Dr Roberto Picetti for commenting on the proposed data extraction fields from the systematic reviews.

**Author roles:** Belesova K: Conceptualization, Data Curation, Investigation, Methodology, Supervision, Validation, Writing – Original Draft Preparation; Green R: Conceptualization, Data Curation, Funding Acquisition, Methodology, Supervision, Writing – Review & Editing; Clercq-Roques R: Data Curation, Investigation, Validation, Writing – Review & Editing; Falconer J: Data Curation, Investigation, Writing – Review & Editing; Whitmee S: Conceptualization, Methodology, Writing – Review & Editing; Haines A: Conceptualization, Funding Acquisition, Methodology, Supervision, Writing – Review & Editing; Sharma Waddington H: Methodology, Writing – Review & Editing; Reynolds T: Data Curation, Investigation, Writing – Review & Editing; Hassan S: Writing – Review & Editing.

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# Open Peer Review

Current Peer Review Status:     

## Version 2

Reviewer Report 13 July 2023

<https://doi.org/10.21956/wellcomeopenres.20134.r58589>

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**Jesse E Bell**

University of Nebraska-Lincoln, Lincoln, Nebraska, USA

**Kelli Gribben**

University of Nebraska Medical Center, Omaha, NE, USA

The reviewer thinks this is an important effort and thank the authors and the journal for the opportunity to review this protocol. I've provided my comments and decision below.

### Summary

Publication describes a protocol for conducting an umbrella review on climate change mitigation actions inclusive of multiple sectors (Energy systems, agriculture, forest, and other land use, transport, buildings, industry, and land coastal and ocean sinks, and engineered sinks), environmental indicators, health measures, and geography (local to global). The study aligns with the goal of the Pathfinder Initiative by applying a broad inclusion criteria to capture all available evidence from peer-reviewed systematic reviews to comprehensively evaluate and estimate the impacts of climate change mitigation activities on health and identify gaps.

### Introduction

Rationale and research questions – clearly stated on page 3. The proposed umbrella review will expand on previous evidence from individual systematic reviews and meta-analyses by considering cross-sectoral, cross disciplinary, and system-wide implications of climate change mitigation actions on health. This will be the most comprehensive review and meta-analysis of climate change mitigation and health to direct future activities by diverse stakeholders.

### Protocol

#### Inclusion criteria

Population – I wonder if the authors can be more specific here? page 4 under Protocol inclusion criteria. Suggested change/example:

Populations: Published systematic reviews, meta-analyses, narratives on climate change mitigation interventions or predictive analyses related to climate indicators and human health measured on any geographical scale (local to global) year 2000-[date].

## Discussion

There is a need to clarify the stratification of evidence plan on page 9. From the text: "Our synthesis of the effects and quality of the evidence will be stratified by sector, action and health outcome type, modelled vs observational evidence, different geographical modelling and implementation contexts, and, where possible, any evidence of implications for health equity. The direction and strength of effect and quality of evidence (including effect heterogeneity across the reviews) will be reported and illustrated graphically for each stratum, with relevant graphs and figures presented where possible, for example using forest plots."

Do the authors intend to grade the evidence for each stated stratum based on the quality of evidence? If so, what will the criteria be for each level of evidence?

What software will be used for the meta-analyses?

Can the authors provide more detail on any potential sensitivity analyses?

Is there a plan to describe limitations of the umbrella review in detail? This can provide much needed context for the results.

### **Is the rationale for, and objectives of, the study clearly described?**

Yes

### **Is the study design appropriate for the research question?**

Yes

### **Are sufficient details of the methods provided to allow replication by others?**

Partly

### **Are the datasets clearly presented in a useable and accessible format?**

Not applicable

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** climate and respiratory health

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

Reviewer Report 10 July 2023

<https://doi.org/10.21956/wellcomeopenres.20134.r58584>

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**Mirko S Winkler** 

University of Basel, Basel, Switzerland

Congratulations to the authors for this well-developed high-quality study protocol.

Here my few observations:

A) Is my understanding correct that, in a simplified manner, you will follow the following steps for conducting your umbrella review: 1) You will, through your literature search, identify “systematic reviews or meta-analyses”. 2) You will then extract primary studies from the identified systematic reviews or meta-analyses based on your criteria. 3) Those primary studies will then be characterized and synthesized. If my understanding is wrong, I am inviting the authors to further clarify the overall process. E.g. An overview of the main steps could be provided early in the methods chapter. In any case, it would be nice to have a simple graphic illustrating the overall process of the umbrella review.

B) The authors state that they will map gaps in existing evidence that require new primary studies. Will this assessment of gaps only be done based on the primary papers identified in the systematic reviews/meta-analyses or does it also reflect on health co-benefits that have not yet been studied/been included in systematic reviews/meta-analyses? This should be clarified, including methodological aspects.

Minor observations:

1. Search term: will you apply the search term in different languages? Seems not yet clear to me.
2. The following sentence is hard to read (a dash seems missing): “Here we report a protocol for an umbrella review – a review of systematic reviews or meta-analyses, undertaken as a part of the Pathfinder Initiative, to synthesize the existing syntheses of findings on the range and effectiveness of actions – both potential and already implemented in practice – for climate change mitigation and health across all sectors and disciplines that can help triggering and sustaining the necessary system-wide transitions.”
3. Suggesting to also include “well-being” as a health outcome, as mental health does not fully capture the well-being dimension.
4. Suggesting to also include antimicrobial resistance as a risk factor, as it is linked to health and climate change (e.g. increased temperatures increase both the rate of bacterial growth and the rate of the spread of antibiotic-resistant genes between microorganisms).
5. Since your review is about “health co-benefits”, shouldn’t you also include health promoters (e.g. spending more time outdoors, increased physical activity, fewer cold days (in the north, etc.) in addition to health risks?

**Is the rationale for, and objectives of, the study clearly described?**

Yes

**Is the study design appropriate for the research question?**

Yes

**Are sufficient details of the methods provided to allow replication by others?**

Yes

**Are the datasets clearly presented in a useable and accessible format?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Urban public health, health impact assessment, epidemiology

**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 10 July 2023

<https://doi.org/10.21956/wellcomeopenres.20134.r58590>

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**Martin W Bloem** 

Johns Hopkins University, Baltimore, Maryland, USA

The proposal by Belesova et al. presents a comprehensive "umbrella review" that systematically examines quantitative studies on the health co-benefits of climate change mitigation policies. The primary objective of this research is to advance our understanding of the magnitude and significance of the health impacts associated with actions taken to address climate change. By synthesizing the existing literature, this analysis aims to provide valuable insights and inform policy discussions in the context of the global climate crisis.

The authors have already acknowledged the concern raised by Belle Workman and Kathryn Bowen regarding the potential bias towards developed economy countries in the published systematic literature base. Although the authors have taken steps to address this issue through adjusted methodology, it is important to highlight two additional points:

Firstly, the observation that a greater number of original studies on climate change mitigation actions are conducted and synthesized in high-income settings compared to low-income settings highlights an important aspect of the current research landscape. While it is true that higher-income countries have higher per capita greenhouse gas (GHG) emissions, and thus mitigation is



a crucial focus for these countries, it is equally important to recognize the transboundary nature of GHG emissions and their impacts. Research conducted by organizations such as Oxfam has demonstrated the disproportionate impact of climate change on low- and middle-income countries (LMICs) (OXFAM, 2022)<sup>1</sup>. Despite contributing a minimal percentage of global carbon emissions, these countries have experienced escalating hunger crises, heat waves, and other extreme weather events in climate hotspots. Therefore, it is imperative to acknowledge and address the geographical bias in climate change mitigation studies. By doing so, we can address the interconnected and unequal distribution of climate change impacts and gain insights into the unique challenges faced by LMICs.

Secondly, it is important to note that the study utilizes modeling studies, which have inherent limitations, particularly when it comes to capturing the complexities and unique health challenges of LMICs. Global modeling studies that examine the consequences of climate action on health rely on data and assumptions that may not fully capture the nuances of LMICs. Consequently, there is a risk of underestimating the impact of climate action on morbidity, mortality, and nutritional requirements in LMICs.

For instance, the EAT-Lancet diet, developed through global modeling, presents differential impacts for LMICs. While this diet aligns with GHG targets in line with the Paris Agreement and has the potential to reduce emissions by up to 80%, a study by Semba et al. demonstrated that in predominantly LMICs, agricultural GHG emissions would increase by 12-283%. This is due to the nutritional requirements in LMICs, where animal-source foods are still essential to ensure dietary adequacy (Semba et al., 2020; Willett et al., 2019)<sup>2,3</sup>.

This finding is also reflected in the critique of Low- and Middle-Income Countries (LMICs) at COP meetings revolving around their challenge of balancing economic development priorities with the disproportionate impacts of climate change, despite their minimal contribution to global greenhouse gas emissions. Important research like these types of studies should include these facts in their discussion.

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## Is the rationale for, and objectives of, the study clearly described?

Yes

## Is the study design appropriate for the research question?

Yes

## Are sufficient details of the methods provided to allow replication by others?

Yes

**Are the datasets clearly presented in a useable and accessible format?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Nutrition, Public Health, NCDs, Climate Change, Policies, Micronutrients, Humanitarian, Emergencies, HIV/AIDS, Infectious diseases.

**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 13 October 2022

<https://doi.org/10.21956/wellcomeopenres.20134.r52171>

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**Jonathan A. Patz** 

Department of Population Health Sciences, University of Wisconsin-Madison, Madison, WI, USA

I've read through the responses and the revised manuscript, and I approve since the article is scientifically valid in its revised form.

**Is the rationale for, and objectives of, the study clearly described?**

Yes

**Is the study design appropriate for the research question?**

Yes

**Are sufficient details of the methods provided to allow replication by others?**

Yes

**Are the datasets clearly presented in a useable and accessible format?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental public health, climate change 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.**

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**Version 1**

Reviewer Report 30 May 2022

<https://doi.org/10.21956/wellcomeopenres.19348.r49304>

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**Belle Workman**

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This paper is a helpful step to better understand mitigation actions and their health effects. However, a large caveat is that this is based on the published systematic literature base, which has a bias towards developed economy countries. Suggestions are provided to strengthen the paper, including clarity on the health outcomes of interest, and a stronger focus on determinants of health (e.g. governance). Detailed comments can be found in the following annotated manuscript pdf: [https://s3-eu-west-1.amazonaws.com/wellcomeopenresearch/linked/266422.Belesova\\_et\\_al\\_AW%2BKBreview.pdf](https://s3-eu-west-1.amazonaws.com/wellcomeopenresearch/linked/266422.Belesova_et_al_AW%2BKBreview.pdf)

**Is the rationale for, and objectives of, the study clearly described?**

Yes

**Is the study design appropriate for the research question?**

Yes

**Are sufficient details of the methods provided to allow replication by others?**

Yes

**Are the datasets clearly presented in a useable and accessible format?**

Not applicable

**Competing Interests:** No competing interests were disclosed.

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

Author Response 31 Jul 2022

**Kristine Belesova**

1. *A large caveat is that this is based on the published systematic literature base, which has a bias towards developed economy countries*

This indeed is a potential bias and we have now further elaborated on it in the discussion section of the protocol on page 17. However, having by now completed screening and classification of the included systematic reviews, we are finding a good balance in systematic review focus on developing and developed economies. Most of the geographical bias would be originating from the higher proportion of original studies focussing on developed economies. Our evidence mapping will be illustrating the geographical balance of both systematic reviews and original studies.

2. *To expand the last sentence of the first introductory paragraph by adding “and avoid adversely affecting health outcomes (e.g., through regressive policies)”*

We expanded the sentence as suggested on page 4.

3. *To briefly contextualise the scope of the initiative here by addressing why adaptation is out of scope, given that adaptation policy is often where health is incorporated*

We have added the suggested edits on page 4.

4. *The IPCC uses four slightly different system transitions - would be good to adapt this for consistency, unless there is a good reason not to.*

To our knowledge, the IPCC has two different categorisations of system transitions: one in AR6 WG3 focussed on mitigation (<https://www.ipcc.ch/report/ar6/wg3/figures/summary-for-policymakers/figure-spm-8/>) and another in the AR6 WG2 focussed on Impacts, Vulnerability, and Adaptation (<https://www.ipcc.ch/report/ar6/wg2/figures/summary-for-policymakers/figure-spm-4/>).

The system transitions we illustrated in Table 1 were mainly focussed on the IPCC AR6 WG3 classification, as it was more closely aligned with the focus of our umbrella review on mitigation. However, although the categories used in the IPCC AR6 WG3 report summarised the IPCC evidence-base well, we are finding that this framework is not encapsulating the results that we are obtaining from the umbrella review. As such, we are considering other classifications, such as the classification used in Project Drawdown. Currently, the Drawdown Framework for Climate Solutions seems to be better suited to our data as it includes specific solutions, which are grouped into broader areas of action within the different sectors. This framework offers clearer boundaries on where individual actions can be placed. However, any classification we use will be inevitably adapted in view of our results. Therefore, we are also considering ways in which to adapt the Drawdown Framework to also reflect system transitions and cross-cutting actions. As such, we have removed the table from the manuscript, and instead, we have now elaborated (on page 6) that we are considering several classification systems and will choose and adapt the one that best fits our data to present our findings.

5. *To explain the meaning of the shaded cells in Table 1.*

The shading had no meaning, it must have been introduced by accident while formatting the table. We have removed the table from the manuscript, as explained above.

6. *Edit the Table 5 in response following the specific suggestions made on selected lines of the table*

We have made the suggested specific edits on pages 7 and 8. We would like to refrain from broader revisions of the list of risk factors, as it is taken directly from the Global Burden of Disease (GBD) project. We have now added a reference to the GBD for clarity.

7. *To elaborate how the abstracts and full texts identified in other languages will be screened.*

We have now elaborated on this on page 10.

**Competing Interests:** No competing interests were disclosed.

Reviewer Report 04 April 2022

<https://doi.org/10.21956/wellcomeopenres.19348.r49305>

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**Jonathan A. Patz** 

Department of Population Health Sciences, University of Wisconsin-Madison, Madison, WI, USA

This manuscript describes a cross-sectoral “umbrella review” of quantitative studies on the health co-benefits of climate change mitigation policies. Such information is critical in advancing our understanding of the magnitude of health benefits (or disbenefits) of actions taken to avert climate change. This analysis, therefore, will be important and timely in the policy discourse around the global climate crisis.

The methods are appropriate and thorough. The approach to the review, however, can be clarified especially related to systematic reviews versus primary studies. For example, while the authors stipulate that they intend to provide a comprehensive synthesis across published systematic reviews, in their preliminary analysis, they already state that key information (that may exist within a primary study) does not appear in the systematic review in which that study appears. So the

authors state, "...we will extend our data extraction to primary studies to produce our own quantitative synthesis." How this selection of primary studies needs to be clarified, and it also calls to question why the team's approach limits its efforts to only include studies that have been captured within the (relatively few) systematic reviews, knowing the deficiencies already discovered.

Also, additional methodological description of "synergies and trade-offs" would be useful. Mapping pathways of benefits across sectors is important and the authors specify an "inverse-variance weighted random effects meta-analysis". I think an example and further explaining this approach is warranted. Further, I'd like to know how this approach is similar or different from optimization modelling.

**Is the rationale for, and objectives of, the study clearly described?**

Yes

**Is the study design appropriate for the research question?**

Yes

**Are sufficient details of the methods provided to allow replication by others?**

Yes

**Are the datasets clearly presented in a useable and accessible format?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental public health, climate change 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 31 Jul 2022

**Kristine Belesova**

- 1. The approach to the review, however, can be clarified especially related to systematic reviews versus primary studies. For example, while the authors stipulate that they intend to provide a comprehensive synthesis across published systematic reviews, in their preliminary analysis, they already state that key information (that may exist within a primary study) does not appear in the systematic review in which that study appears. So the authors state, "...we will extend our data extraction to primary studies to produce our own quantitative synthesis." How this selection of primary studies needs to be clarified, and it also calls to question why the team's approach limits its efforts to only include studies that have been captured within the (relatively few) systematic reviews, knowing the deficiencies already discovered.*

Our ambition is to undertake an umbrella review and produce a comprehensive comparative meta-synthesis of the evidence that has been captured by existing systematic reviews. However, after reviewing some of the systematic reviews that were eligible for inclusion in our analysis, we concluded that the data that is reported in the systematic reviews often falls short from the level of detail that is required for our analyses. For example, many systematic reviews are narrative and do not attempt any quantitative synthesis even when such synthesis would be feasible. In some cases, this coincides with poor quality of the review; in others with their focus on research and synthesis questions that do not necessarily require a quantitative synthesis. Furthermore, systematic reviews without a quantitative synthesis often do not report sufficient data from the primary studies that they reviewed, e.g., only reporting either the health or GHG impact of actions but not both or lacking information on the baseline or scale of the impact, which are necessary to allow comparing the impact of actions across studies and settings. However, these data are often available from the text of the primary studies. Therefore, we adapted the umbrella review methodology to expand our data extraction procedure beyond the (often limited) text of the systematic reviews to the text of primary studies that were synthesised in the systematic reviews that met our inclusion criteria. In other words, we are referring to the primary studies to overcome the limited (and sometimes poor quality) of reporting by the systematic reviews.

Primary studies that have not been captured in existing systematic reviews were beyond the scope of our synthesis. Their inclusion would not be justifiable as a part of the umbrella review methodology and would require a fundamentally different approach to literature identification at the outset targeting primary studies instead of systematic reviews. Such an approach is beyond the scope of our project and resources. Hence, our choice of the umbrella review methodology was largely pragmatic – aiming to produce a meta-synthesis of the evidence that has been captured in existing systematic reviews. Through our umbrella review, we also aim to map the gaps in existing systematic reviews, indicating areas and topics where systematic reviews are lacking or have not been recently updated. We will be highlighting these gaps in our results making recommendations for future systematic reviews and updates of existing systematic reviews.

We have now elaborated these points in the text of our protocol on page 8. We also have now defined the term “umbrella review” on pages 4-5.

## *2. Additional methodological description of “synergies and trade-offs” would be useful*

We will extract any information on synergies and trade-offs from the systematic reviews, as it is presented by the authors of the systematic reviews. As synergies we consider the effects of actions that, apart from their own impact on GHG emissions and health co-benefits, also enhance the effectiveness of other climate change mitigations actions or the capacity for other actions to be implemented. As trade-offs we consider the effects of a climate mitigation action that precludes the implementation of other climate mitigation actions or minimises their effectiveness.

We have now elaborated these methodological aspects on page 15 of the protocol.

3. *Mapping pathways of benefits across sectors is important and the authors specify an “inverse-variance weighted random effects meta-analysis”. I think an example and further explaining this approach is warranted. Further, I’d like to know how this approach is similar or different from optimization modelling.*

The purpose of the mapping pathways is to demonstrate what exposure routes and GHG and health outcomes have been linked in existing research and how. This will be done using Sankey diagrams.

A separate issue is how the evidence is synthesised. We propose to use the standard methods of synthesis to pool findings across studies should enough data be available. This might incorporate inverse-variance random effects meta-analysis for particular mitigation strategies and outcome constructs, where measures of the variance (or variables closely relating to it, such as sample size) are presented and appropriate. Another option is to conduct meta-regression analysis (MRA), which enables pooling of effects across mitigation strategies and outcome constructs in a larger model. Where this is possible, we will use appropriate methods of weighting depending on the underlying literature (empirical literature might use inverse-variance, modelling literature might use population measures).

We have elaborated these points on pages 15-16.

**Competing Interests:** No competing interests were disclosed.