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Review

Health impact studies of climate change adaptation and mitigation measures – A scoping review

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ABSTRACT

Climate change affects both mental and physical health. Besides limiting the extent and consequences of climate change, mitigation and adaptation measures can have additional and potentially unintended health impacts. This scoping review outlines how health effects of climate mitigation and adaptation measures have been studied in the scientific literature. We conducted a systematic literature search in the databases PubMed, Scopus and Web of Science without time restriction. All peer-reviewed articles reporting quantified health impacts linked to specific climate change adaptation and mitigation measures were included. Overall, the 89 included articles considered only a narrow range of health determinants and health outcomes. Adaptation- and mitigation-related articles most frequently investigated the environmental health determinants air temperature and air pollution, respectively. Non-communicable diseases were predominantly studied while other relevant health outcome categories, such as mental health, food- and nutrition-related issues, and communicable diseases were rarely reported. The scarcity of studies focusing on the social health determinants and providing stratified health impacts among vulnerable population groups in assessments points to an inadequate consideration of health equity aspects. Increased efforts to quantify health impacts more comprehensively and to identify underlying vulnerability factors among specific population groups seem needed. This information could provide policymakers with more accurate evidence to address health equity aspects, limit adverse health impacts and promote health co-benefits of climate change adaptation and mitigation measures.

1. Introduction

Climate change is one of the major environmental and human health challenges of the 21st century and adversely impacts both physical and mental health [1]. Action to respond to climate change, in the form of mitigation and adaptation measures, is urgently needed as the impacts of climate change are increasingly felt [2–4]. Climate change mitigation measures aim to lower greenhouse gas (GHG) emissions to the atmosphere, or remove them from the atmosphere, to curb future climate change [5]. Analogously, climate change adaptation measures aim to adjust to current and future climate change and limit its adverse effects [1]. Adaptation and mitigation measures can have intended and unintended health impacts [2,6–10], both positive and negative [11–14].

Mitigation measures often have co-benefits on health. For example, measures targeting the transport sector, like vehicle emission standards [15], improved urban mass transport systems [16–18], or segregation of bicycle lanes from the road [19] can result in substantial health benefits mediated through changes in physical activity, noise, traffic and air pollution levels. Similarly, replacing coal-powered electricity production with renewable energy technologies has been shown to lower the disease burden from air pollution [20–24]. Acting through a different pathway, mitigation measures aimed at reducing dietary GHG emissions by replacing animal protein sources with plant-based proteins can reduce cancer and heart disease cases [25,26]. However, some mitigation measures can also have unintended negative health consequences. For example, while an increase in the share of electric vehicles might result in a reduction of direct greenhouse gas emissions from road transport, the necessary increase in energy production might come with an increase in air pollution, depending on the energy source [13].

Similarly, adaptation measures can affect health through various pathways. For instance, adaptation measures such as increasing

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urban tree cover [27–31], increasing surface reflectivity by increasing building roof albedo [29,32,33], implementation of air conditioning [14,34] and early warning systems [35–37] all aim to reduce negative health effects of heat exposure. Furthermore, the provision of temporary shelters to flood victims and forecast-triggered cash grants to flood-prone communities, can help to alleviate the adverse health impacts from floods [38,39]. Some adaptation measures can have unintended adverse health impacts, e.g. the use of air conditioning for heat adaptation can increase the emission of air pollutants potentially causing respiratory disease [14,40].

More knowledge about the health effects of climate action is urgently needed, as it can provide additional motivation to implement more stringent climate action, help to uncover underlying health inequities and support policymakers to limit adverse health impacts and promote health co-benefits [41–43]. A recent review by WHO found an increasing number of articles on the topic of climate change and health but concluded that knowledge on health impacts of climate measures is lacking, especially regarding impacts on vulnerable communities [44]. It remains unclear which specific health determinants and outcomes are considered in the scientific literature on health impacts of climate measures. Therefore, the purpose of this review was to address this knowledge gap by mapping the existing scientific body of literature, a task for which the scoping review methodology is well-suited [45]. The objective of this scoping review is to investigate which health determinants and health outcomes are considered by scientific articles that quantify the health impacts of climate measures and whether the investigated health impacts are reported in a specific or stratified manner.

2. Methods

As the overarching methodological framework, we followed the scoping review methodology outlined in the frameworks of Arksey and O'Malley and Levac and colleagues [45,46]. This scoping review follows the reporting guidelines set out in the "Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation" [47].

2.1. Search terms and strategy

With the aim of providing policymakers with a decision basis that is specific as possible, we limited our search to articles that report quantified health impacts, since they can provide comparable metrics for decision making between climate adaptation and mitigation measures. The search string used for the literature search was adapted from the work of Ammann and colleagues [48], who conducted a scoping review on health impact assessment and climate change. The search strategy (Table A1) was developed jointly by the author team and consists of three search blocks related to: (i) climate change; (ii) adaptation and mitigation; and (iii) health. The final search strategy was checked and approved by the authors. The electronic literature databases PubMed, Scopus and Web of Science were searched for relevant articles, without applying language, spatial or time restrictions. While the search string was not translated into other languages, identified articles written in English, French or German were included, in line with the reading comprehension of A.L. and D.D. The search string was adapted to the specific technical requirements of each database and document type filters were applied (Table A1), except for the PubMed database, where the available filters were deemed too restrictive. The online literature search was conducted on March 9, 2022. Articles unavailable online by that date were not considered in this scoping review.

2.2. Literature screening

The following definitions for adaptation and mitigation measures were applied throughout the screening stages: (1) climate change mitigation measures aim to lower greenhouse gas (GHG) emissions to the atmosphere, or remove them from the atmosphere, to curb future climate change [5]; (2) climate change adaptation measures aim to adjust to current and future climate change and limit its adverse effects [1]. After the literature search, duplicates were removed using the reference manager Zotero version 5.0.96.3 (RRCHNM, George Mason University, Fairfax, VA, USA). The titles and abstracts of the obtained articles were screened independently by A. L. and D.D. by applying a set of pre-defined inclusion criteria (Table 1). For this step, the web-based application "Rayyan" [49] was used. Conflicts regarding in-/exclusion of articles were discussed between A.L. and D.D. until consensus was reached. During the full text screening A.L. applied a set of pre-defined inclusion criteria (Table 1) and D. D. provided assistance in case of uncertainties. Consensus regarding in-/exclusion was reached in all cases.

2.3. Data analysis

The data extraction spreadsheet was designed by A.L. and D.D, using MS Excel version 2021 (Microsoft Office 365, Microsoft Corporation, Redmond, WA, USA). Data from the first five to ten included articles was extracted independently by A.L. and D.D to cross-validate the approach to data extraction, as outlined in the work of Levac and colleagues [45]. Data extraction from the remaining articles was extracted by A.L. and D.D. was consulted in cases of uncertainty. Article information on the following variables was extracted: (i) article characteristics; (ii) investigated climate change adaptation and mitigation measure(s); (iii) investigated health determinants and health outcomes (see

Table A2 for more detail on the variables and Table A6 for the full data extraction spreadsheet). Health determinants and health outcomes were categorized based on the typology developed by Dietler and colleagues [50]. Countries were categorized according to the World Bank's income level classifications [51]. Categorization of the climate change measures was based on the adapted typology from the United Nations Intergovernmental Panel on Climate Change (IPCC) (Tables A3 and A4) [1,52].

3. Results

3.1. Overview

In total, 8477 articles were identified through the literature search (Fig. 1). After removing 3862 duplicates, 4535 articles were included for the title and abstract screening. Based on this first screening step

Table 1
Inclusion criteria applied during the title and abstract screening and the full-text screening of the articles identified through the literature search.

Screening stage	Inclusion criteria
T&A screening	• Focus on climate change adaptation or mitigation measure(s) • Discussion of health impacts
Full text screening	• Peer-reviewed research article • Full-text accessible and written in English, French or German • Focus on at least one specific climate change adaption or mitigation measure embedded in a policy or strategy • Quantification health impact(s) associated with the climate change adaptation or mitigation measure(s) in non-monetary terms

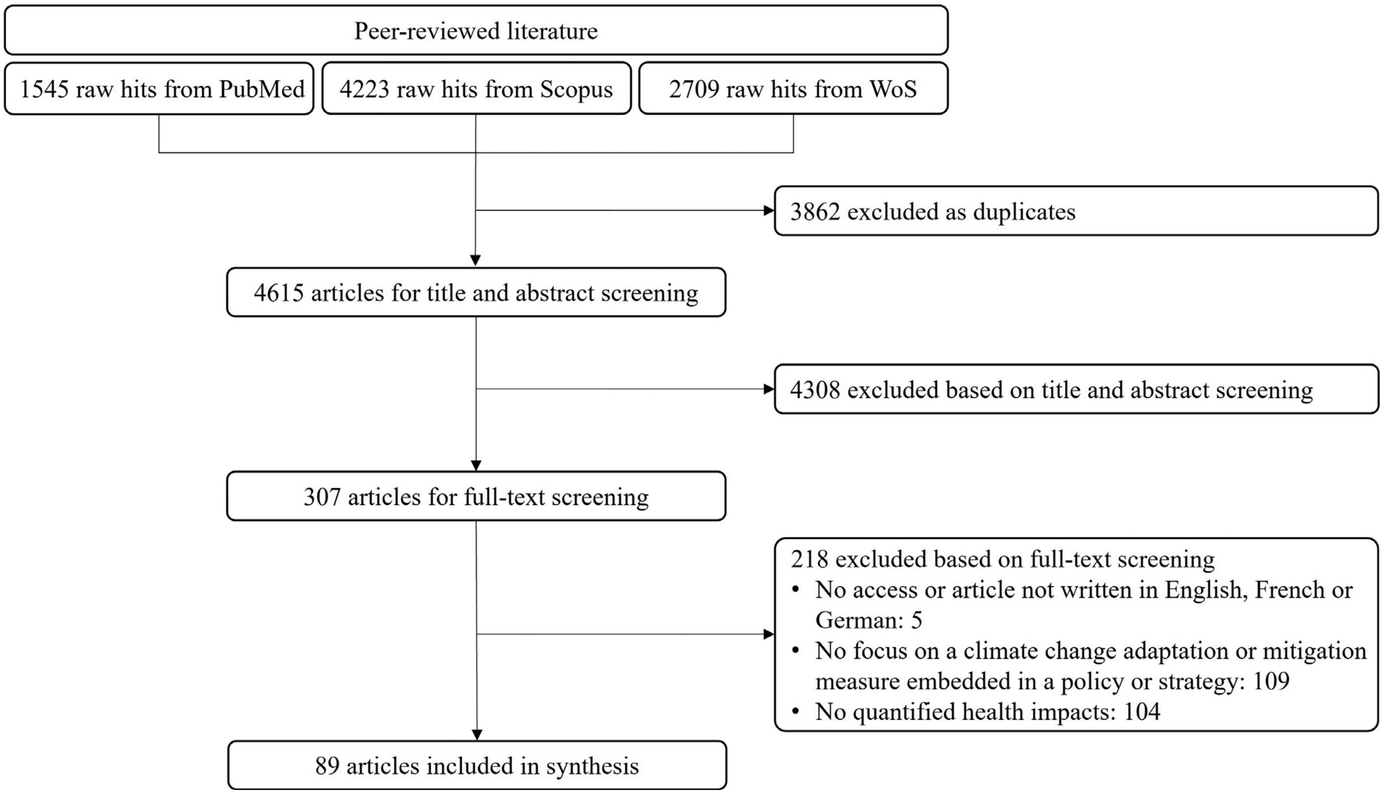

Fig. 1. PRISMA flow chart of the literature search and subsequent screening process. WoS = Web of Science.

4615 articles were excluded while 307 articles remained for the full-text screening. At this stage, 218 articles were excluded, ultimately leaving 89 articles for data synthesis. While systematic reviews were not excluded a priori, no systematic review was included in the study sample. All included articles are listed in Table A5.

3.2. Article characteristics

In total, 56 (63%) and 33 (37%) articles focused on mitigation and adaptation measures, respectively. The first mitigation- and adaptation-related articles were published in 2001 and 2012, respectively (Fig. 2). Most articles (n = 77, 87%) were published from 2014 onwards.

A small share of articles (n = 6, 7%) only provided aggregated estimates of health impacts covering multiple countries [25,53–57], while the vast majority (n = 83, 93%) provided quantified estimates of health impacts for at least one specific country, covering a total of 35 different countries (Fig. 3 Panel A). In 9 (10%) articles, country-specific health impact estimates were provided for two or more specific countries. There was a clear pattern in the geographic distribution of

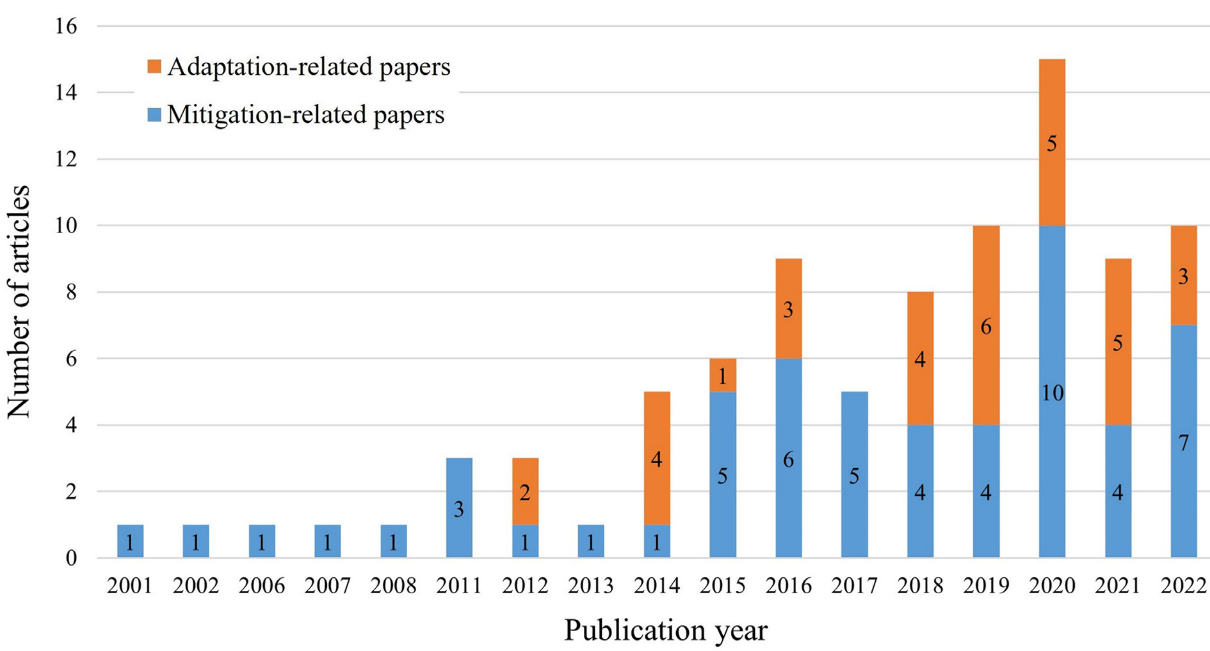

Fig. 2. Included articles (n = 89) published over time since publication of the first included article. Years during which no articles were published are not shown in the figure.

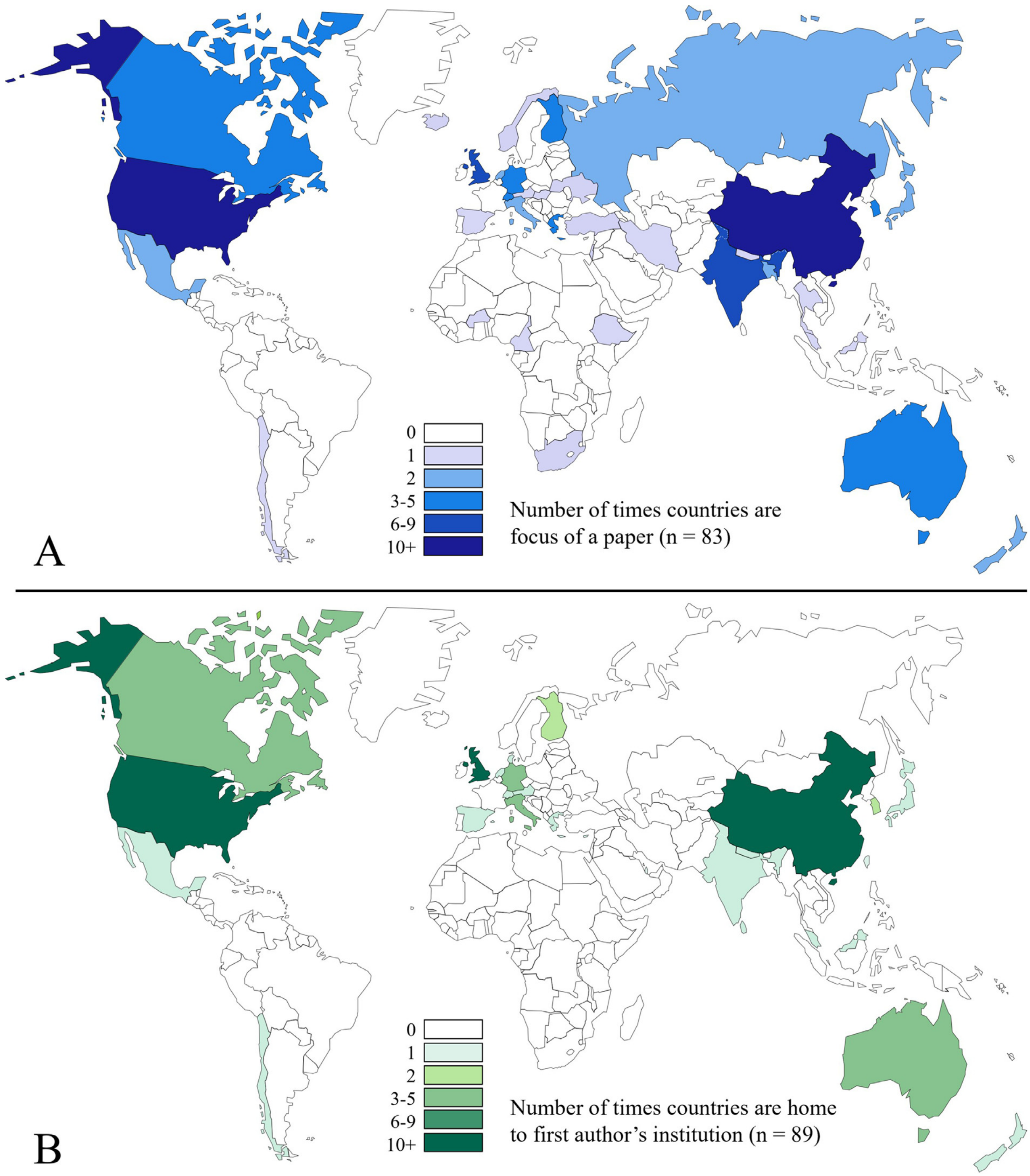

Fig. 3. World map showing the geographic distribution of (A) study countries of articles reporting at least one country-specific quantified health impact and (B) first authors' main institution countries.

study countries and first authors' institutions. The majority of articles focused on and were written by researchers based in high-income countries (HICs). Of the 83 articles included in Fig. 3 panel A, 56 (63%) focused on at least one HIC, 22 (25%) on one or more upper-middle income country (UMIC), 12 (15%) on one or more lower-middle income country (LMIC) and 1 (1%) article on a low-income country (LIC).

Panel B in Fig. 3 shows the geographic distribution of the first author's main institution. The first authors' main institutions are located in 26 different countries. Notably, 82% (n = 73) of all first authors were based in HICs, while only 13% (n = 13) and 3% (n = 3) authors were from institutions based in UMICs and LMICs, respectively, while none of the first authors were based in a LIC. The United States of America, China and the United Kingdom were not only the countries most frequently studied (24, 16 and 8 times, respectively), but also accounted for most of first authors (31, 10 and 12, respectively).

3.3. Investigated mitigation and adaptation measures

The 56 mitigation-related articles quantified the health impacts of a total of 181 mitigation measures from 32 different measure categories (Fig. 4). The measures targeted the energy (n = 60, 33%), transport (n = 58, 32%) and buildings (n = 27, 15%) sectors most, while the

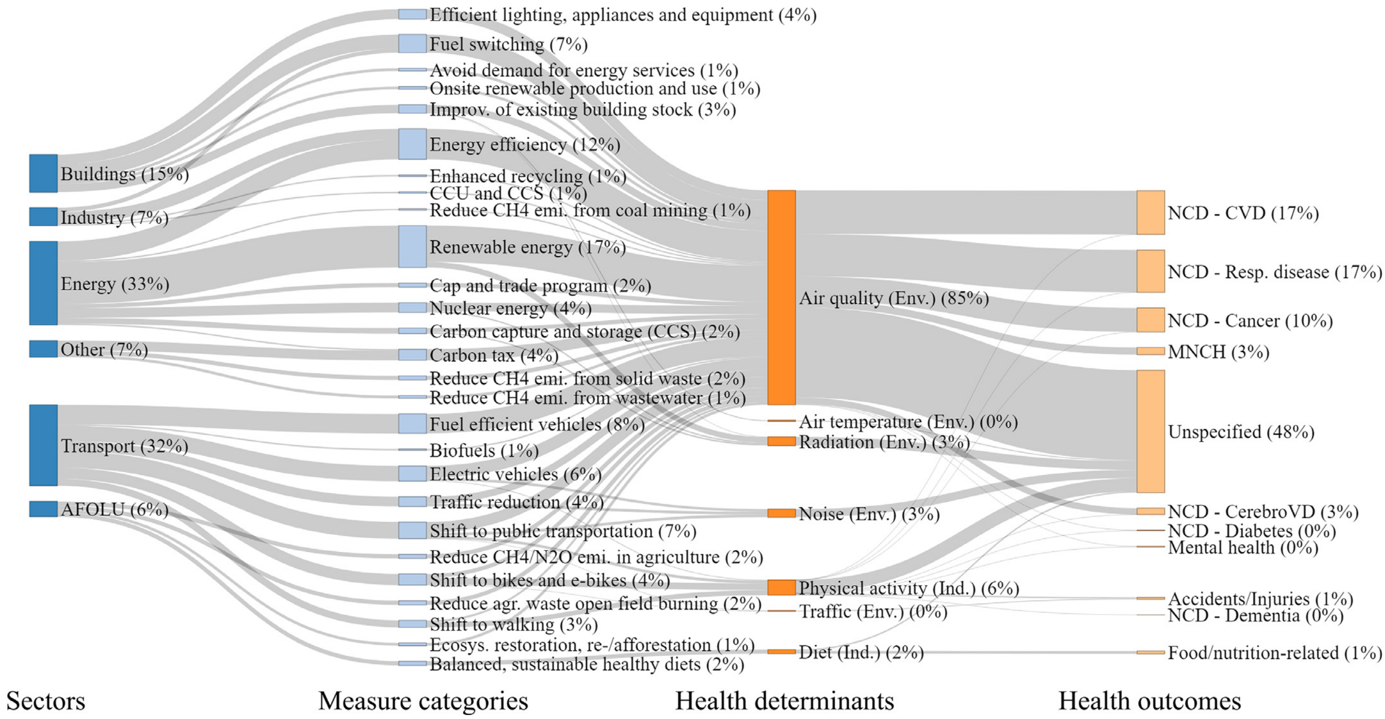

Fig. 4. Sankey diagram of mitigation measures and related health determinants and health outcomes. In the first two columns, the measures are categorized according to sector and measure types based on the adapted IPCC typology (Table A3). In the last two columns, health determinants and outcomes are based on the typology from [50]. The percentages refer to the share of the total number of measures (note that due to rounding a percentage can be zero, although the corresponding width of the bar is merely close to zero). The width of the bars in the columns "Health determinants" and "Health outcomes" is weighted by the number of total health determinant/outcome categories considered for each measure. For example, if a study assessed impacts of a specific measure on two health outcomes, the width of each bar is divided by two. AFOLU = agriculture, forestry and other land use; agr. = agricultural; CCS = carbon capture and storage; CCU = carbon capture with utilization; CerebroVD = cerebrovascular disease; ecosys. = ecosystem; emi. = emissions; env. = environmental; improv. = improvement; ind. = individual; inst. = institutional; MNCH = maternal, neonatal and child health; NCD = non-communicable disease; resp. = respiratory.

remaining sectors industry (13, 7%), other (12, 7%) and agriculture, forestry and other land use (AFOLU) (n = 11, 6%) are each targeted by less than one in ten measures. The most frequently investigated measures (sector in brackets) are renewable energy (energy, n = 30, 17%), fuel efficient vehicles (transport, n = 14, 8%), electric vehicles (energy, n = 11, 6%), and fuel switching (buildings, n = 10, 6%).

Taken together, the 33 adaptation-related articles quantified the health impacts of a total of 43 adaptation measures from 11 different measure categories (Fig. 5). The most frequently investigated measures (system in brackets) are green infrastructure and services (n = 10, 23%), albedo increase, incl. cool roofs (n = 8, 19%) and climate services, including early warning systems (n = 5, 12%).

3.4. Studied health determinants and outcomes

Regarding health impacts, 65 (73%) articles found only positive and 5 (6%) articles only negative health impacts, while 14 (16%) articles found both positive and negative health impacts of the investigated climate change measures (Table A6). Health impacts were categorized based on the nature of the health outcome, meaning that for example a decrease in deaths is considered positive health impact while an increase in disease cases is considered a negative impact. In the remaining 5 (6%) articles, there was uncertainty concerning the direction and magnitude of health impacts associated with the investigated climate measures.

Regarding the nature of the reported health impacts, around half (n = 44, 49%) of articles reported only mortality-related quantified health impacts, e.g. avoided or excess premature deaths. Over a fifth of articles (n = 19, 21%) reported only morbidity related impacts, which were quantified using a plethora of indicators such as disability-adjusted life years, disease cases, number of hospitalizations, number of intensive care unit admissions and scores on standardized scales. The remaining 26 articles (30%) reported both mortality and morbidity quantified health impact estimates.

3.4.1. Health determinants

Overall, most (n = 79, 89%) articles reported environmental health determinants in connection with health impacts, while individual, institutional and social health determinants were reported 9 (10%), 5 (6%), 6 (7%) times, respectively (Table A6). A minority of articles (n = 10, 11%) reported multiple health determinants responsible for health impacts.

Health impacts resulting from the investigated mitigation measures were most frequently associated with the environmental health determinant air quality (n = 154, 85%), followed by the individual health determinant physical activity (n = 11, 6%) (Fig. 4). Frequently encountered mitigation measures impacting air quality included for example replacement of energy from coal by renewable energy sources or implementation of a carbon tax. A typical measure that impacted physical activity levels was the shift from individual motorized vehicles to bicycles.

Health impacts resulting from the investigated adaptation measures (n = 43) were most frequently associated with the environmental health determinant air temperature (n = 24, 55%), followed by the institutional health determinant capacity of health care system (n = 6, 14%). Encountered adaptation measures impacting air temperature included, among others, urban greening and reflective cool roofs, while for measures targeting the capacity of health care system early warning systems for heat were typical.

3.4.2. Health outcomes

While just over half of articles (n = 46, 52%) reported specific health outcomes responsible for the reported health effects, the

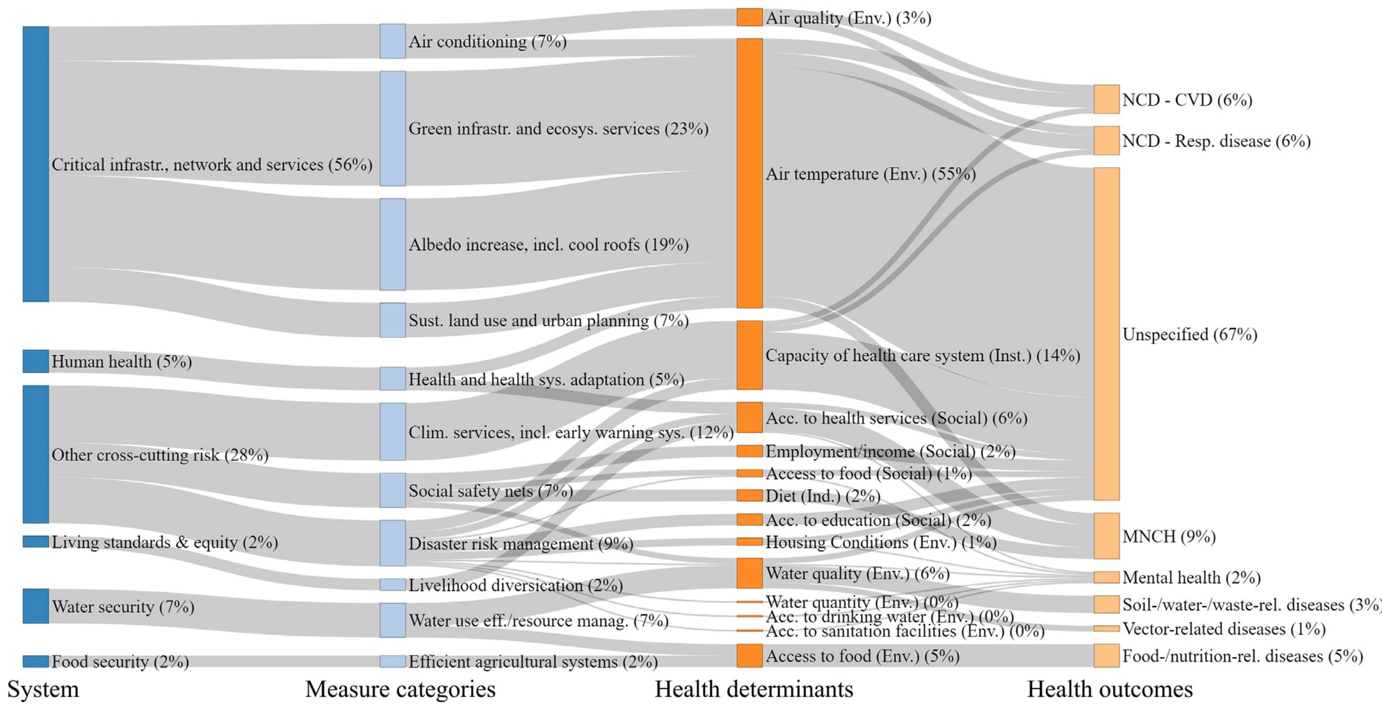

Fig. 5. Sankey diagram of adaptation measures and related health determinants and outcomes. In the first two columns, the measures are categorized according to system and measure types based on the adapted IPCC typology (Table A4). In the last two columns, health determinants and outcomes are based on the typology from [50]. The percentages refer to the share of the total number of measures (note that due to rounding a percentage can be zero, although the corresponding width of the bar is merely close to zero). The width of the bars in the columns "Health determinants" and "Health outcomes" is weighted by the number of total health determinant/outcome categories considered for each measure. For example, if a study assessed impacts of a specific measure on two health outcomes, the width of each bar is divided by two. acc. = access; ecosys. = ecosystem; eff. = efficiency; env. = environmental; incl. = including; ind. = individual; infrastr. = infrastructure; inst. = institutional; manag. = management; MNCH = maternal, neonatal and child health; rel. = related; resp. = respiratory sys. = systems.

remaining articles (n = 43, 48%) provided more general health impacts in the form of mortality or morbidity estimates without specifying the associated health outcomes (Fig. A1). Among the articles reporting specific health outcomes, 72% (n = 33) and 28% (n = 13) were mitigation- and adaptation-related articles, respectively.

Fig. 4 shows that collectively, non-communicable diseases (NCDs) were by far reported most often in connection with the investigated mitigation measures, followed by maternal, neonatal and child health health outcomes. Fig. 5 shows that NCDs also were most frequently reported in connection with adaptation measures, followed by maternal, neonatal and child health outcomes. Other health outcomes were rarely found by both adaptation- and mitigation-related articles. Among the NCDs, respiratory tract-related health outcomes and cardiovascular diseases were found most frequently (Fig. A1).

Around a sixth of articles (n = 15, 17%) reported at least one quantified health outcome in a stratified way, i.e. providing a health outcome for at least two distinct sub-populations. Health outcomes were most frequently stratified according to age (n = 13, 15%). A small minority of articles (n = 5, 6%) provided quantified health outcomes stratified according to a different variable, e.g. socio-economic status (n = 3), education (n = 2), marital status (n = 2), occupation (n = 2), sex (n = 2), or health (n = 1, i.e. presence/absence of disease).

4. Discussion

In this scoping review 89 articles reporting quantified health impacts of specific climate change adaptation and mitigation measures were identified and subsequently analyzed. The environmental health determinants air quality and air temperature were most frequently investigated, while reported health outcomes were mostly related to NCDs. Other relevant health determinants and outcomes were underrepresented in our sample. Only around half of articles reported specific health outcomes, which were mostly mortality-related, whereas morbidity-related impacts were assessed less frequently. Stratification of health impacts to sub-populations was done by a minority of articles. We identified an underrepresentation of LMICs and LICs among the study countries.

4.1. Focus on environmental health determinants and NCDs

The environmental health determinants air temperature and air quality were reported most by adaptation- and mitigation-related articles, respectively. This pattern was also found by other studies in the field of climate change and health [48,58]. This finding may also reflect the health burden associated with these factors, given that air pollution is the environmental health determinant associated with the highest mortality burden [59,60] and considering the increasing frequency and intensity of heat waves [3]. The relevance of these health determinants is expected to further increase with ongoing urbanization [61], which will likely result in increased air pollution and a stronger urban heat island effect [62,63]. Furthermore, air pollution and heat cause a variety of NCDs, such as cardiovascular and respiratory diseases [64–66]. In light of the global epidemiological transition towards NCDs [59], the increased recognition of NCD-related health co-benefits from climate action is promising to promote the implementation of stringent climate measures.

4.2. Narrow scope of considered health outcomes

Other health outcomes besides NCDs, such as mental health, food- and nutrition-related issues and communicable diseases, are underrepresented, which could be partly due to the observed scarcity of measures aiming at the AFOLU sector and water and food security systems. However, these health issues are strongly affected by climate change and related measures. For instance, climate change might pose the greatest risk to mental health in this century [67], particularly for vulnerable groups such as children and the elderly [1,44]. Nonetheless, mental health outcomes are rarely considered in the literature on climate change measures and health [44,68]. Moreover, food- and nutrition-related issues are linked to lower food production and access [1], for example due to slow adoption of climate resilient farming practices [69]. In addition, replacing animal proteins with plant-sourced proteins in the diet can reduce GHG emissions and have positive effects on health [70–72]. Lastly, climate change is influencing the prevalence of communicable diseases, including water-related diseases [1,73], vector-borne diseases [74,75] and zoonoses [1,76]. Consequently, a more comprehensive consideration of potential health outcomes in impact assessments of climate measures would reflect the associated health effects more accurately. In addition, reporting impacts on both mortality and morbidity of specific health outcomes would reveal the full potential co-benefits and risks relevant for policymaking.

4.3. Underrepresentation of lower income groups

As a consequence of the identified underrepresentation of LMICs and LICs among study countries, the investigated health outcomes are strongly oriented towards higher income countries. This underrepresentation has been observed in other recent studies [44,48]. Lower income countries generally have weaker public systems than higher income countries, resulting in a high vulnerability to the impacts of climate change [1,77]. Projected rapid population growth and continuing urbanization will put additional strain on these public systems, such as water and food systems and exacerbate existing vulnerabilities [1,78,79]. Examples include an increased heat burden, due to the heat island effect [80], and increased air pollution [81], resulting from increased urban traffic. Therefore, the implementation of adaptation and mitigation measures and the evaluation of their impacts on health is particularly pertinent to support climate-resilient sustainable development in the underrepresented lower income areas [1,52]. An increased understanding of the health impacts of climate action in these contexts could provide policymakers with urgently needed evidence to foster their health co-benefits and to promote global health equity.

4.4. Lack of consideration of underlying vulnerability factors

On a smaller scale, the observed underrepresentation of social health determinants and lack of health impact stratification have further implications for health equity and climate justice [82]. Social health determinants, such as employment/income [83], access to health services [39,84] and education [85], can influence the vulnerability level of individuals and communities to the impacts of climate change [52]. Therefore, consistent inclusion of social health determinants in assessments would increase our understanding of the underlying drivers of climate justice. To promote health equity among affected populations, the most vulnerable groups must be identified [1]. This could be accomplished by stratification of health impacts according to relevant factors, such as socio-economic (e.g. income) and demographic parameters (e.g. age) [86]. For example, by stratifying the health impacts Vargo and colleagues showed that both the oldest and the poorest population groups profit most from an intervention aimed at lowering summer temperature by increasing the amount of vegetation [87]. Taken together, a better understanding of the effects of the social health determinants among vulnerable populations would allow policymakers to design climate change adaptation and mitigation measures that promote health equity and climate justice.

4.5. Strengths and limitations

The focus of this scoping review on climate change adaptation and mitigation measures with quantified health impacts allowed for novel insights, thereby adding to the scientific literature on the climate change and health topic. Considering the broad search terminology applied and the variety of literature databases searched it is likely that a large share of the relevant peer-reviewed literature was identified. Nonetheless, this article has several limitations that must be considered. Firstly, the search strategy is likely to have missed relevant articles that do not specifically refer to adaptation or mitigation measures in the title and abstract. However, given the wide range of possible adaptation and mitigation measures, specifying all potential measures was out of scope for this scoping review and would certainly have proved challenging, as new climate measures are designed constantly. Secondly, as the search terms were not translated to other languages it is likely that we missed some relevant literature, especially literature studying the underrepresented regions Latin America and the Caribbean, the Middle East, North Africa and sub-Saharan Africa, where scientific literature might be mainly published in Arabic, French or Spanish. Thirdly, grey literature was not considered in this review. Therefore, some relevant literature was likely not identified. Lastly, a quality appraisal of the included articles was not conducted, which is typical for scoping reviews [45,46]. As our aim was to determine if and to what extent health impacts were assessed we feel it would have added little merit to the present scoping review.

5. Conclusion

In our sample of 89 articles studying health impacts of climate measures, we observed a scarcity of publications from or focusing on LMICs and LICs. Overall, the included articles had a narrow scope of considered health determinants and health outcomes with a strong focus on environmental health determinants, such as air quality and air temperature, and NCDs, respectively. The lack of social health determinants and stratified health impacts in assessments point to an inadequate consideration of health equity aspects. In order to provide a solid evidence base for policymaking, increased efforts to quantify health impacts more comprehensively and to identify potentially vulnerable populations seem needed. Such information would be critical for policymakers to adequately address health equity aspects, limit adverse health impacts and promote health co-benefits of climate change adaptation and mitigation measures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Axel Luyten: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. **Mirko S. Winkler:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Priska Ammann:** Writing – review & editing. **Dominik Dietler:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision.

Appendix A

Fig. A1.

Table A1
Search strings used for each database searched.

Database	Search string	Result filters employed
PubMed	(("climate change"[Title/Abstract]) OR ("global warming"[Title/Abstract]) OR ("climate"[Title/Abstract] AND "change"[Title/Abstract]) OR ("climate"[Title/Abstract] AND "changing"[Title/Abstract]) OR ("climate"[Title/Abstract] AND "warming"[Title/Abstract]) OR ("Climate Change" [Mesh]) OR ("Global Warming" [Mesh]) OR ("climate crisis"[Title/Abstract])) AND (("adaption"[Title/Abstract]) OR ("mitigation"[Title/Abstract]) OR ("adaptation"[Title/Abstract])) AND (("health"[Title/Abstract]))	–
Scopus	(("climate change" OR "global warming" OR ("climate" AND "change") OR ("climate" AND "changing") OR ("climate" AND "warming") OR "climate crisis") AND ("adaption" OR "mitigation" OR "adaptation") AND ("health"))	Document type filters: • Article • Review
Web of Science	(TI = ("climate change" OR "global warming" OR ("climate" AND "change") OR ("climate" AND "changing") OR ("climate" AND "warming") OR "climate crisis") AND (TI = ("health")) AND (TI = ("adaption" OR "mitigation" OR "adaptation"))) OR (AB = ("climate change" OR "global warming" OR ("climate" AND "change") OR ("climate" AND "changing") OR ("climate" AND "warming") OR "climate crisis") AND (AB = ("health")) AND (AB = ("adaption" OR "mitigation" OR "adaptation"))) OR (AK = ("climate change" OR "global warming" OR ("climate" AND "change") OR ("climate" AND "changing") OR ("climate" AND "warming") OR "climate crisis") AND (AK = ("health")) AND (AK = ("adaption" OR "mitigation" OR "adaptation")))	Document types filters: • Articles • Review Articles

Table A2
Data extraction categories.

Data extraction categories	Options
Article characteristics	
Main author	-
Article title	-
Year of publication	-
Country of first author's main institution	-
Study country/ies	-
Climate change adaptation and mitigation measures	See Tables A3 and A4
Measure focus	Adaptation or mitigation
Health determinants and Health Impacts	
Nature of health impacts	Positive, negative or no impact
Health impacts reported	Morbidity or mortality
Health determinants responsible for health impacts (main categories)	Environmental; Individual; Social; Institutional
Health determinants responsible for health impacts (sub-categories)	Access to health services; Access to traditional health services; Access to education; Access to food, Employment/income; Air quality; Water quality; Water quantity; Access to drinking water; Access to sanitation facilities; Soil quality; Noise; Traffic; Housing conditions; Waste management; Migration; Capacity of health care system; Capacity of maternal and child health services; Capacity of education facilities
Health outcomes (main categories)	Accidents/Injuries; Communicable diseases related to housing and overcrowding; Food- and nutrition-related issues; Maternal, neonatal and child health; Mental health; Non-communicable diseases; Sexual and reproductive health; Soil-, water- and waste-related diseases; Vector-related diseases; Zoonoses
NCD health outcomes (sub-categories)	Cancer; CVD; Dementia; Diabetes; Respiratory tract-related
Stratification of health outcome	Yes/no
- If yes: stratified indicator	-

Table A3
United Nations Intergovernmental Panel on Climate Change Assessment Report 6 mitigation measures typology (adapted). Sectors are in bold and italic and added/adapted measures are in italic font. The numbers in the right column "Articles" refer to the list of peer-reviewed articles included in the scoping review (Table A5) and indicate which articles investigated the corresponding measure in the first column.

Measures (per sector) Energy	Articles
Renewable energy (created by merging the existing categories "Wind energy", "Solar energy", "Bioelectricity", "Hydropower" and "Geothermal energy")	4, 13, 14, 15, 19, 27, 30, 34, 35, 43, 51, 52, 53, 56, 58, 63, 77, 78, 88
Nuclear energy	32, 34, 43, 57, 58, 77, 84
Carbon capture and storage (CCS)	7, 34, 41, 78
Bioelectricity with CCS	-
Reduce CH4 emission from coal mining	3
Reduce CH4 emission from oil and gas	-
Energy efficiency*	16, 27, 30, 35, 40, 53, 54, 57, 59, 62, 63, 78, 81, 88
Cap and trade program*	41, 55, 62
Agriculture, forestry and other land use (AFOLU)	
Carbon sequestration in agriculture	-
Reduce CH4 and N2O emission in agriculture	3, 35, 51
Reduced conversion of forests and other ecosystems	-
Ecosystem restoration, afforestation, reforestation	51, 77
Improved sustainable forest management	-
Reduce food loss and food waste	-
Shift to balanced, sustainable healthy diets	29, 60, 72
Reduce open field burning of agricultural waste*	3, 35, 51
Buildings	
Avoid demand for energy services	29, 30
Efficient lighting, appliances and equipment	3, 6, 16, 30, 35

(*continued*)

Table A3 (*Continued*)

Measures (per sector) Energy	Articles
New buildings with high energy performance	-
Onsite renewable production and use	30, 77
Improvement of existing building stock	4, 29, 30, 63, 77, 82
Enhanced use of wood products	-
Fuel switching*	4, 15, 29, 30, 35, 37, 54, 61, 63, 82
Transport	
Fuel efficient vehicles (created by merging the existing categories “Fuel efficient light duty vehicles” and “Fuel efficient heavy duty vehicles)	3, 4, 15, 16, 21, 27, 29, 30, 35, 47, 51, 54, 63, 67
Electric vehicles (created by merging the existing categories “Electric light duty vehicles” and “Electric heavy duty vehicles, incl. buses”)	11, 15, 30, 51. 56, 63, 66, 77, 80, 85, 87
Shift to public transportation	11, 16, 18, 21, 30, 36, 51, 66, 70, 77, 85, 88
Shift to bikes and e-bikes	21, 29, 30, 45, 63, 70, 77, 85
Shipping – efficiency and optimization	-
Aviation – energy efficiency	-
Biofuels	15
Traffic reduction (including car fleet size reduction)*	11, 21, 27, 30, 63, 80, 87
Shift to walking*	29, 30, 63, 77, 85
Industry	
Energy efficiency	3, 16, 20, 35, 38, 51, 54, 88
Material efficiency	-
Enhanced recycling	77
Fuel switching (electr., nat. gas, bio-energy, H2)	16, 43, 51
Feedstock decarbonization, process change	-
Carbon capture with utilisation (CCU) and CCS	78
Cementitious material substitution	-
Reduction of non-CO2 emissions	-
Other	
Reduce emission of fluorinated gas	-
Reduce CH4 emissions from solid waste	3, 15, 51
Reduce CH4 emissions from wastewater	3, 51
Carbon tax*	5, 13, 14, 19, 22, 43, 58, 59

* added measures

Table A4
United Nations Intergovernmental Panel on Climate Change Assessment Report 6 adaptation measures typology (adapted). Main categories (called “System transitions”) are in bold and italic and sub-categories (called “Representative key risks”) in italic font. Measures are listed in the middle column. The numbers in the right column “Articles” refer to the list of peer-reviewed articles included in the scoping review (Table A5) and indicate which articles investigated the corresponding measure in the middle column.

Categories Land and ocean ecosystems	Measures	Articles
Coastal socio-ecological systems	Coastal defence and hardening	-
	Integrated coastal zone management	-
Terrestrial and ocean ecosystem services	Forest-based adaptation	-
	Sustainable aquaculture and fisheries	-
	Agroforestry	-
	Biodiversity management and ecosystem connectivity	-
Water security	Water use efficiency and water resource management	9, 71, 75
Food security	Improved cropland management	-
	Efficient livestock systems	-
	Efficient agricultural systems*	75
Urban infrastructure systems		
Critical infrastructure, network and services	Green infrastructure and ecosystem services	10, 24, 46, 64, 65, 68, 69, 73, 74, 83
	Sustainable land use and urban planning	73, 79. 83
	Sustainable urban water management	-
	Air conditioning*	1, 12, 33
	Albedo increase (including cool roofs)*	24, 26, 28, 44, 65, 73, 74, 76
Energy systems		
Water security	Improve water use efficiency	-
Critical infrastructure, networks and services	Resilient power systems	-
	Energy reliability	-
Cross-sectoral		
Human health	Health and health systems adaptation	8, 31
Living standards and equity	Livelihood diversification	8
Peace and human mobility	Planned relocation and resettlement	-
	Human migration	-
Other cross-cutting risks	Disaster risk management	17, 48, 86, 89
	Climate services, including early warning systems	17, 25, 42, 49, 50
	Social safety nets	2, 23, 42
	Risk spreading and sharing	-

* Added measures.

Table A5
List of included peer-reviewed articles (n = 89).

	Refs.
1	Abel DW, Holloway T, Harkey M, Meier P, Ahl D, Limaye VS, et al. Air-quality-related health impacts from climate change and from adaptation of cooling demand for buildings in the eastern United States: An interdisciplinary modeling study. Thomson M, editor. PLoS Med. 2018;15(7):e1002599. 10.1371/journal.pmed.1002599.
2	Aguilar A, Vicarelli M. El Niño and children: Medium-term effects of early-life weather shocks on cognitive and health outcomes. World Dev. 2022;150:105690. 10.1016/j.worlddev.2021.105690.
3	Anenberg SC, Schwartz J, Shindell D, Amann M, Faluvegi G, Klimont Z, et al. Global air quality and health co-benefits of mitigating near-term climate change through methane and black carbon emission controls. Environ Health Persp. 2012;120(6):831–9. 10.1289/ehp.1104301.
4	Asikainen A, Pärjälä E, Jantunen M, Tuomisto JT, Sabel and CE. Effects of local greenhouse gas abatement strategies on air pollutant emissions and on health in Kuopio, Finland. Climate. 2017;5(2):43. 10.3390/cli5020043.
5	Bahn O, Leach A. The secondary benefits of climate change mitigation: an overlapping generations approach. Comput Manag Sci. 2008;5(3):233–57. 10.1007/s10287-007-0048-x.
6	Bailey J, Gerasopoulos E, Rojas-Rueda D, Benmarhnia T. Potential health and equity co-benefits related to the mitigation policies reducing air pollution from residential wood burning in Athens, Greece. J Environ Sci Heal A. 2019;54(11):1144–51. 10.1080/10934529.2019.1629211.
7	Banacloche S, Lechon Y, Rodríguez-Martínez A. Carbon capture penetration in Mexico's 2050 horizon: A sustainability assessment of Mexican CCS policy. Int J Greenh Gas Con. 2022;115:103603. 10.1016/j.ijggc.2022.103603.
8	Banerjee R, Maharaj R. Heat, infant mortality, and adaptation: Evidence from India. J Dev Econ. 2020;143:102378. 10.1016/j.jdeveco.2019.102378.
9	Boelee E, Yohannes M, Poda JN, McCartney M, Cecchi P, Kibret S, et al. Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. Reg Environ Change. 2013;13(3):509–19. 10.1007/s10113-012-0287-4.
10	Boumans RJM, Phillips DL, Victery W, Fontaine TD. Developing a model for effects of climate change on human health and health–environment interactions: Heat stress in Austin, Texas. Urban Climate. 2014;8:78–99. 10.1016/j.uclim.2014.03.001.
11	Braubach M, Tobollik M, Mudu P, Hiscock R, Chapizanis D, Sarigiannis D, et al. Development of a quantitative methodology to assess the impacts of urban transport interventions and related noise on well-being. IJERPH. 2015;12(6):5792–814. 10.3390/ijerph120605792.
12	Buchin O, Hoelscher MT, Meier F, Nehls T, Ziegler F. Evaluation of the health-risk reduction potential of countermeasures to urban heat islands. Energ Buildings. 2016;114:27–37. 10.1016/j.enbuild.2015.06.038.
13	Buonocore JJ, Levy JI, Guinto RR, Bernstein AS. Climate, air quality, and health benefits of a carbon fee-and-rebate bill in Massachusetts, USA. Environ Res Lett. 2018;13(11):114014. 10.1088/1748-9326/aae62c.
14	Buonocore JJ, Luckow P, Fisher J, Kempton W, Levy JI. Health and climate benefits of offshore wind facilities in the Mid-Atlantic United States. Environ Res Lett. 2016;11(7):074019. 10.1088/1748-9326/11/7/074019.
15	Chae Y, Park J. Quantifying costs and benefits of integrated environmental strategies of air quality management and greenhouse gas reduction in the Seoul Metropolitan Area. Energ Policy. 2011;39(9):5296–308. 10.1016/j.enpol.2011.05.034.
16	Cifuentes L, Borja-Aburto VH, Gouveia N, Thurston G, Davis DL. Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000-2020): Santiago, São Paulo, México City, and New York City. Environ Health Persp. 2001;109:7. 10.1289/ehp.01109s3419.
17	de'Donato F, Scortichini M, De Sario M, de Martino A, Michelozzi P. Temporal variation in the effect of heat and the role of the Italian heat prevention plan. Public Health. 2018;161:154–62. 10.1016/j.puhe.2018.03.030.
18	Diallo T, Cantoreggi N, Simos J. Co-bénéfices pour la santé des politiques urbaines relatives au changement climatique à l'échelon local : l'exemple de Genève. Environ Risque Sante. 2016;15:9. 10.1684/ers.2016.0890.
19	Dimanchev EG, Paltsev S, Yuan M, Rothenberg D, Tessum CW, Marshall JD, et al. Health co-benefits of sub-national renewable energy policy in the US. Environ Res Lett. 2019;14(8):085012. 10.1088/1748-9326/ab31d9.
20	Fang J, Li G, Aunan K, Vennemo H, Seip HM, Oye KA, et al. A proposed industrial-boiler efficiency program in Shanxi: potential CO2-mitigation, health benefits and associated costs. Appl Energ. 2002;71(4):275–85. 10.1016/S0306-2619(02)00013-2.
21	Farzaneh H, de Oliveira JAP, McLellan B, Ohgaki H. Towards a low emission transport system: Evaluating the public health and environmental benefits. Energies. 2019;12(19):3747. 10.3390/en12193747.
22	Garcia-Menendez F, Saari RK, Monier E, Selin NE. U.S. air quality and health benefits from avoided climate change under greenhouse gas mitigation. Environ Sci Technol. 2015;49(13):7580–8. 10.1021/acs.est.5b01324.
23	Gros C, Bailey M, Schwager S, Hassan A, Zingg R, Uddin MM, et al. Household-level effects of providing forecast-based cash in anticipation of extreme weather events: Quasi-experimental evidence from humanitarian interventions in the 2017 floods in Bangladesh. Int J Disast Risk Re. 2019;41:101275. 10.1016/j.ijdrr.2019.101275.
24	Haddad S, Paolini R, Ulpiani G, Synnefa A, Hatvani-Kovacs G, Garshasbi S, et al. Holistic approach to assess co-benefits of local climate mitigation in a hot humid region of Australia. Sci Rep-UK. 2020;10(1):14216. 10.1038/s41598-020-71148-x.
25	Heo S, Nori-Sarma A, Lee K, Benmarhnia T, Dominici F, Bell ML. The use of a quasi-experimental study on the mortality effect of a heat wave warning system in Korean. IJERPH. 2019;16(12):2245. 10.3390/ijerph16122245.
26	Hondula DM, Georgescu M, Balling RC. Challenges associated with projecting urbanization-induced heat-related mortality. Sci Total Environ. 2014;490:538–44. 10.1016/j.scitotenv.2014.04.130.
27	Hsieh I-YL, Chossière GP, Gençer E, Chen H, Barrett S, Green WH. An integrated assessment of emissions, air quality, and public health impacts of China's transition to electric vehicles. Environ Sci Technol 2022;56:6836–46. 10.1021/acs.est.1c06148.
28	Jandaghian Z, Akbari H. Increasing urban albedo to reduce heat-related mortality in Toronto and Montreal, Canada. Energ Buildings. 2021;237:110697. 10.1016/j.enbuild.2020.110697.
29	Jensen HT, Keogh-Brown MR, Smith RD, Chalabi Z, Dangour AD, Davies M, et al. The importance of health co-benefits in macroeconomic assessments of UK Greenhouse Gas emission reduction strategies. Climatic Change. 2013;121(2):223–37. 10.1007/s10584-013-0881-6.
30	Johnson S, Haney J, Cairone L, Huskey C, Kheirbek I. Assessing air quality and public health benefits of New York City's climate action plans. Environ Sci Technol. 2020;54(16):9804–13. 10.1021/acs.est.0c00694.
31	Kakkad K, Barzaga ML, Wallenstein S, Azhar GS, Sheffield PE. Neonates in Ahmedabad, India, during the 2010 Heat Wave: A Climate Change Adaptation Study. Journal of Environmental and Public Health. 2014;2014:1–8. 10.1155/2014/946875.
32	Kharecha PA, Sato M. Implications of energy and CO2 emission changes in Japan and Germany after the Fukushima accident. Energ Policy. 2019;132:647–53. 10.1016/j.enpol.2019.05.057.
33	Kouis P, Psistaki K, Giallouros G, Michanikou A, Kakkoura MG, Stylianou KS, et al. Heat-related mortality under climate change and the impact of adaptation through air conditioning: A case study from Thessaloniki, Greece. Environ Res. 2021;199:111285. 10.1016/j.envres.2021.111285.
34	Kouloumpis V, Stamford L, Azapagic A. Decarbonising electricity supply: Is climate change mitigation going to be carried out at the expense of other environmental impacts? Sustainable Production and Consumption. 2015;1:1–21. 10.1016/j.spc.2015.04.001.
35	Kuylenstierna JCI, Heaps CG, Ahmed T, Vallack HW, Hicks WK, Ashmore MR, et al. Development of the Low Emissions Analysis Platform – Integrated Benefits Calculator (LEAP-IBC) tool to assess air quality and climate co-benefits: Application for Bangladesh. Environ Int. 2020;145:106155. 10.1016/j.envint.2020.106155.
36	Kwan SC, Tainio M, Woodcock J, Hashim JH. Health co-benefits in mortality avoidance from implementation of the mass rapid transit (MRT) system in Kuala Lumpur, Malaysia. Rev Environ Health. 2016;31(1):179–83. 10.1515/reveh-2015-0038.
37	Kypridemos C, Puzzolo E, Aamaas B, Hyseni L, Shupler M, Aunan K, et al. Health and climate impacts of scaling adoption of liquefied petroleum gas (LPG) for clean household cooking in Cameroon: A modeling study. Environ Health Persp. 2020;128(4):047001. 10.1289/EHP4899.

(*continued*)

Table A5 (*Continued*)

	Refs.
38	Li BS, Chen Y, Zhang S, Wu Z, Cofala J, Dai H. Climate and health benefits of phasing out iron & steel production capacity in China Findings from the IMED model. Climate Change Economics. 2020;11(03):2041008. 10.1142/S2010007820410080.
39	Li JC. A multi-period analysis of a carbon tax including local health feedback: an application to Thailand. Environ Dev Econ. 2006;11(3):317–42. 10.1017/S1355770 × 06002841.
40	Li J, Cai W, Li H, Zheng X, Zhang S, Cui X, et al. Incorporating health cobenefits in decision-making for the decommissioning of coal-fired power plants in China. Environ Sci Technol. 2020;54(21):13935–43. 10.1021/acs.est.0c03310.
41	Li Y, Yang C, Li Y, Kumar A, Kleeman MJ. Future emissions of particles and gases that cause regional air pollution in California under different greenhouse gas mitigation strategies. Atmos Environ. 2022;273:118960. 10.1016/j.atmosenv.2022.118960.
42	Liu X, Tian Z, Sun L, Liu J, Wu W, Xu H, et al. Mitigating heat-related mortality risk in Shanghai, China: system dynamics modeling simulations. Environ Geochem Hlth. 2020;42(10):3171–84. 10.1007/s10653-020-00556-9.
43	Liu Y, Tong D, Cheng J, Davis SJ, Yu S, Yarlagadda B, et al. Role of climate goals and clean-air policies on reducing future air pollution deaths in China: a modelling study. The Lancet Planetary Health. 2022;6(2):e92–9. 10.1016/S2542-5196(21)00326-0.
44	Macintyre HL, Heaviside C, Cai X, Phalkey R. Comparing temperature-related mortality impacts of cool roofs in winter and summer in a highly urbanized European region for present and future climate. Environ Int. 2021;154:106606. 10.1016/j.envint.2021.106606.
45	Macmillan A, Connor J, Witten K, Kearns R, Rees D, Woodward A. The societal costs and benefits of commuter bicycling: Simulating the effects of specific policies using system dynamics modeling. Environ Health Persp. 2014;122(4):335–44. 10.1289/ehp.1307250.
46	Marvuglia A, Koppelaar R, Rugani B. The effect of green roofs on the reduction of mortality due to heatwaves: Results from the application of a spatial microsimulation model to four European cities. Ecol Model. 2020;438:109351. 10.1016/j.ecolmodel.2020.109351.
47	Mazzi EA, Dowlatabadi H. Air quality impacts of climate mitigation: UK policy and passenger vehicle choice. Environ Sci Technol. 2007;41(2):387–92. 10.1021/es060517w.
48	McCarthy RB, Shofer FS, Green-McKenzie J. Outcomes of a heat stress awareness program on heat-related illness in municipal outdoor workers. J Occup Environ Med. 2019;61(9):5. 10.1097/JOM.0000000000001639.
49	Mehiriz K, Gosselin P. Evaluation of the impacts of a phone warning and advising system for individuals vulnerable to smog. Evidence from a randomized controlled trial study in Canada. IJERPH. 2019;16(10):1817. 10.3390/ijerph16101817.
50	Mehiriz K, Gosselin P, Tardif I, Lemieux MA. The effect of an automated phone warning and health advisory system on adaptation to high heat episodes and health services use in vulnerable groups—Evidence from a randomized controlled study. IJERPH. 2018;15(8):1581. 10.3390/ijerph15081581.
51	Nakarmi AM, Sharma B, Rajbhandari US, Prajapati A, Malley CS, Kuylenstierna JCI, et al. Mitigating the impacts of air pollutants in Nepal and climate co-benefits: a scenario-based approach. Air Qual Atmos Hlth. 2020;13(3):361–70. 10.1007/s11869-020-00799-6.
52	Partridge I, Gamkhar S. A methodology for estimating health benefits of electricity generation using renewable technologies. Environ Int. 2012;39(1):103–10. 10.1016/j.envint.2011.10.003.
53	Peng W, Dai H, Guo H, Purohit P, Urpelainen J, Wagner F, et al. The critical role of policy enforcement in achieving health, air quality, and climate benefits from India's clean electricity transition. Environ Sci Technol. 2020;54(19):11720–31. 10.1021/acs.est.0c01622.
54	Peng W, Yang J, Wagner F, Mauzerall DL. Substantial air quality and climate co-benefits achievable now with sectoral mitigation strategies in China. Sci Total Environ. 2017;598:1076–84. 10.1016/j.scitotenv.2017.03.287.
55	Perera F, Cooley D, Berberian A, Mills D, Kinney P. Co-benefits to children's health of the U.S. regional greenhouse gas initiative. Environ Health Persp. 2020;128(7):077006. 10.1289/EHP6706.
56	Peters DR, Schnell JL, Kinney PL, Naik V, Horton DE. Public health and climate benefits and trade−offs of U.S. vehicle electrification. GeoHealth. 2020;4(10). 10.1029/2020GH000275.
57	Phillips D, Jung TY. An alternative co-benefit framework prioritizing health impacts: Potential air pollution and climate change mitigation pathways through energy sector fuel substitution in South Korea. Climate. 2021;9(6):101. 10.1289/EHP6706.
58	Rauner S, Bauer N, Dirnaichner A, Dingenen RV, Mutel C, Luderer G. Coal-exit health and environmental damage reductions outweigh economic impacts. Nat Clim Change. 2020;10(4):308–12. 10.1038/s41558-020-0728-x.
59	Reis LA, Drouet L, Tavoni M. Internalising health-economic impacts of air pollution into climate policy: a global modelling study. The Lancet Planetary Health. 2022;6(1):e40–8. 10.1016/S2542-5196(21)00259-X.
60	Ritchie H, Reay DS, Higgins P. Potential of meat substitutes for climate change mitigation and improved human health in high-income markets. 2018;2:16. 10.3389/fsufs.2018.00016.
61	Rosenthal J, Quinn A, Grieshop AP, Pillarisetti A, Glass RI. Clean cooking and the SDGs: Integrated analytical approaches to guide energy interventions for health and environment goals. Energy Sustain Dev. 2018;42:152–9. 10.1016/j.esd.2017.11.003.
62	Saari RK, Selin NE, Rausch S, Thompson TM. A self-consistent method to assess air quality co-benefits from U.S. climate policies. J Air Waste Manage. 2015;65(1):74−89. 10.1080/10962247.2014.959139.
63	Sabel CE, Hiscock R, Asikainen A, Bi J, Depledge M, van den Elshout S, et al. Public health impacts of city policies to reduce climate change: findings from the URGENCHE EU-China project. Environ Health. 2016;15(S1):S25. 10.1186/s12940-016-0097-0.
64	Sadeghi M, Chaston T, Hanigan I, de Dear R, Santamouris M, Jalaludin B, et al. The health benefits of greening strategies to cool urban environments – A heat health impact method. Build Environ. 2022;207:108546. 10.1016/j.buildenv.2021.108546.
65	Sailor D, Shepherd M, Sheridan S, Stone B, Kalkstein L, Russell A, et al. Improving Heat-Related Health Outcomes in an Urban Environment with Science-Based Policy. Sustainability. 2016;8(10):1015. 10.3390/su8101015.
66	Sarigiannis DA, Kontoroupis P, Nikolaki S, Gotti A, Chapizanis D, Karakitsios S. Benefits on public health from transport-related greenhouse gas mitigation policies in Southeastern European cities. Sci Total Environ. 2017;579:1427–38. 10.1016/j.scitotenv.2016.11.142.
67	Shindell D, Faluvegi G, Walsh M, Anenberg SC, Van Dingenen R, Muller NZ, et al. Climate, health, agricultural and economic impacts of tighter vehicle-emission standards. Nat Clim Change. 2011;1(1):59–66. 10.1038/nclimate1066.
68	Sinha P, Coville RC, Hirabayashi S, Lim B, Endreny TA, Nowak DJ. Modeling lives saved from extreme heat by urban tree cover☆. Ecol Model. 2021;449:109553. 10.1016/j.ecolmodel.2021.109553.
69	Sinha P, Coville RC, Hirabayashi S, Lim B, Endreny TA, Nowak DJ. Variation in estimates of heat-related mortality reduction due to tree cover in U.S. cities. J Environ Manage. 2022;301:113751. 10.1016/j.jenvman.2021.113751.
70	Smith AC, Holland M, Korkeala O, Warmington J, Forster D, ApSimon H, et al. Health and environmental co-benefits and conflicts of actions to meet UK carbon targets. Clim Policy. 2016;16(3):253–83. 10.1080/14693062.2014.980212.
71	Smith BA, Ruthman T, Sparling E, Auld H, Comer N, Young I, et al. A risk modeling framework to evaluate the impacts of climate change and adaptation on food and water safety. Food Res Int. 2015;68:78–85. 10.1016/j.foodres.2014.07.006.
72	Springmann M, Mason-D'Croz D, Robinson S, Wiebe K, Godfray HCJ, Rayner M, et al. Mitigation potential and global health impacts from emissions pricing of food commodities. Nat Clim Change. 2017;7(1):69–74. 10.1038/nclimate3155.
73	Stone B, Lanza K, Mallen E, Vargo J, Russell A. Urban Heat Management in Louisville, Kentucky: A Framework for Climate Adaptation Planning. J Plan Educ Res. 2019;0739456 × 1987921. 10.1177/0739456 × 19879214.
74	Stone Jr B. Avoided Heat-Related Mortality through Climate Adaptation Strategies in Three US Cities. PLOS ONE. 2014. 10.1371/journal.pone.0100852.
75	Sulser TB, Beach RH, Wiebe KD, Dunston S, Fukagawa NK. Disability-adjusted life years due to chronic and hidden hunger under food system evolution with climate change and adaptation to 2050. The American Journal of Clinical Nutrition. 2021;114(2):550–63. 10.1093/ajcn/nqab101.

(*continued*)

Table A5 (*Continued*)

	Refs.
76	Susca T. Multiscale approach to life cycle assessment: Evaluation of the effect of an increase in New York City's rooftop albedo on human health. J Ind Ecol. 2012;16 (6):951–62. 10.1111/j.1530-9290.2012.00560.x.
77	Symonds P, Milner J, Mohajeri N, Aplin J, Hale J, J Lloyd S, et al. A tool for assessing the climate change mitigation and health impacts of environmental policies: the Cities Rapid Assessment Framework for 1. Symonds P, Milner J, Mohajeri N, Aplin J, Hale J, J Lloyd S, et al. A tool for assessing the climate change mitigation and health impacts of environmental policies: the Cities Rapid Assessment Framework for Transformation (CRAFT). Wellcome Open Research. 2020;5:269. 10.12688/wellcomeopenres.16345.1.
78	Tang R, Zhao J, Liu Y, Huang X, Zhang Y, Zhou D, et al. Air quality and health co-benefits of China's carbon dioxide emissions peaking before 2030. Nat Commun. 2022;13:1008. 10.1038/s41467-022-28672-3.
79	Taylor J, Wilkinson P, Picetti R, Symonds P, Heaviside C, Macintyre HL, et al. Comparison of built environment adaptations to heat exposure and mortality during hot weather, West Midlands region, UK. Environ Int. 2018;111:287–94. 10.1016/j.envint.2017.11.005.
80	Tobollik M, Keuken M, Sabel C, Cowie H, Tuomisto J, Sarigiannis D, et al. Health impact assessment of transport policies in Rotterdam: Decrease of total traffic and increase of electric car use. Environ Res. 2016;146:350–8. 10.1016/j.envres.2016.01.014.
81	Tong D, Geng G, Zhang Q, Cheng J, Qin X, Hong C, et al. Health co-benefits of climate change mitigation depend on strategic power plant retirements and pollution controls. Nat Clim Change. 2021;11(12):1077–83. 10.1038/s41558-021-01216-1.
82	Tuomisto JT, Niittynen M, Pärjälä E, Asikainen A, Perez L, Trüeb S, et al. Building-related health impacts in European and Chinese cities: a scalable assessment method. Environ Health. 2015;14(1):93. 10.1186/s12940-015-0082-z.
83	Vargo J, Stone B, Habeeb D, Liu P, Russell A. The social and spatial distribution of temperature-related health impacts from urban heat island reduction policies. Environ Sci Policy. 2016;66:366–74. 10.1016/j.envsci.2016.08.012.
84	Williams ML, Lott MC, Kitwiroon N, Dajnak D, Walton H, Holland M, et al. The Lancet Countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain. The Lancet Planetary Health. 2018;2(5):e202–13. 10.1016/S2542-5196(18)30067-6.
85	Wolkinger B, Haas W, Bachner G, Weisz U, Steininger K, Hutter HP, et al. Evaluating health co-benefits of climate change mitigation in urban mobility. IJERPH. 2018;15 (5):880. 10.3390/ijerph15050880.
86	Wong-Parodi G. When climate change adaptation becomes a "looming threat" to society: Exploring views and responses to California wildfires and public safety power shutoffs. Energy Research & Social Science. 2020;70:101757. 10.1016/j.erss.2020.101757.
87	Yang X, Lin W, Gong R, Zhu M, Springer C. Transport decarbonization in big cities: An integrated environmental co-benefit analysis of vehicles purchases quota-limit and new energy vehicles promotion policy in Beijing. Sustain Cities Soc. 2021;71:102976. 10.1016/j.scs.2021.102976.
88	Zhang J, Liu M, Bi J. Urban greenhouse gas emission peaking paths and embedded health co-benefits: A multicases comparison study in China. Appl Energ. 2022;311:118740. 10.1016/j.apenergy.2022.118740.
89	Zhong S, Pang M, Ho HC, Jegasothy E, Clayton S, Wang Z, et al. Assessing the effectiveness and pathways of planned shelters in protecting mental health of flood victims in China. Environ Res Lett. 2020;15(12):125006. 10.1088/1748-9326/abc446.

Table A6
Data extraction table. The article numbering in the first column is corresponds to the numbering in the list of articles included in the sample in Table A5. A. = adaptation; CVD = cardiovascular disease; cerebroVD = cerebrovascular disease; env. = environmental; ind. = individual; inst. = institutional; HDs = health determinants; NCD = non-communicable disease; MNCH = maternal, neonatal and child health; M. = mitigation.

Nr.	Author	Year of publication	First author's institution country	Study country/ies	Measure focus	Nature of health impacts	Mortality/ morbidity reported	HDs (main categories)	HDs (sub-categories) connected to health impacts	Categorization of health outcomes	Health outcome stratification
1	Abel	2018	USA	USA	A.	Negative	Both	Env.	Air quality	NCD (CVD, respiratory)	-
2	Aguilar	2022	Mexico	Mexico	A.	Neutral	Morbidity	Ind.	Diet	MNCH	-
3	Anenberg	2012	USA	Global	M.	Negative, Positive	Mortality	Env.	Air quality	NCD (cancer, CVD, respiratory)	-
4	Asikainen	2017	Finland	Finland	M.	Neutral	Both	Env.	Air quality	NCD (CVD, respiratory)	-
5	Bahn	2008	Canada	Global	M.	Positive	Both	Env.	Air quality	MNCH	-
6	Bailey	2019	USA	Greece	M.	Positive	Mortality	Env.	Air quality	Unspecified	Socio-economic status
7	Banacloche	2022	Spain	Mexico	M.	Negative	Morbidity	Env.	Air quality	NCD (cancer)	-
8	Banerjee	2019	United Kingdom	India	A.	Positive	Mortality	Social	Access to health services	MNCH	-
9	Boelee	2012	Sri Lanka	Burkina Faso, Ethiopia	A.	Negative	Morbidity	Env.	Water quality	Soil-, water- and waste-related diseases; Vector-related diseases	-
10	Boumans	2014	USA	USA	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
11	Braubach	2015	Germany	Germany	M.	Positive	Morbidity	Env.	Noise	Unspecified	-
12	Buchin	2016	Germany	Germany	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
13	Buonocore	2018	USA	USA	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
14	Buonocore	2016	USA	USA	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
15	Chae	2011	South Korea	South Korea	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
16	Cifuentes	2001	Chile	Chile	M.	Positive	Both	Env.	Air quality	MNCH; NCD (CVD, respiratory)	Age
17	de'Donato	2018	Italy	Italy	A.	Positive	Mortality	Inst.	Capacity of health care system	Unspecified	-
18	Diallo	2016	Switzerland	Switzerland	M.	Positive	Morbidity	Env.	Noise	Unspecified	-
19	Dimanchev	2019	USA	USA	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
20	Fang	2002	China	China	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
21	Farzaneh	2019	Japan	Iran	M.	Positive	Mortality	Env.	Air quality	NCD (CVD, respiratory)	Age
22	Garcia-Menendez	2015	USA	USA	M.	Positive	Both	Env.	Air quality	Unspecified	-
23	Gros	2019	Netherlands	Bangladesh	A.	Positive	Morbidity	Env.; Social	Access to food; Water quality	Mental health; Soil-, water- and waste related diseases	-
24	Haddad	2020	Australia	Australia	A.	Positive	Both	Env.	Air temperature	Unspecified	Age
25	Heo	2019	USA	South Korea	A.	Positive	Both	Inst.	Capacity of health care system	NCD (CVD, respiratory)	Age; Education; Marital status; Occupation; Sex
26	Hondula	2014	USA	USA	A.	Negative, Positive	Mortality	Env.	Air temperature	Unspecified	-
27	Hsieh	2022	Taiwan	China	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
28	Jandaghian	2021	Canada	Canada	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
29	Jensen	2013	Denmark	United Kingdom	M.	Positive	Both	Env.; Ind.	Air quality; Diet; Physical activity	Unspecified	Age

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Nr.	Author	Year of publication	First author's institution country	Study country/ies	Measure focus	Nature of health impacts	Mortality/morbidity reported	HDs (main categories)	HDs (sub-categories) connected to health impacts	Categorization of health outcomes	Health outcome stratification
30	Johnson	2020	USA	USA	M.	Positive	Both	Env.	Air quality	NCD (CVD, respiratory)	Age
31	Kakkad	2014	India	India	A.	Positive	Morbidity	Env.	Air temperature	MNCH	-
32	Kharecha	2019	USA	Germany, Japan, USA	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
33	Kouis	2021	Cyprus	Greece	A.	Negative, Positive	Mortality	Env.	Air quality; Air temperature	NCD (CVD, respiratory)	-
34	Kouloumpis	2015	United Kingdom	United Kingdom	M.	Negative, Positive	Both	Env.	Radiation	Unspecified	-
35	Kuylenstierna	2020	United Kingdom	Bangladesh	M.	Negative, Positive	Mortality	Env.	Air quality	NCD (cancer, CVD, cerebroVD, respiratory)	Age
36	Kwan	2016	Malaysia	Malaysia	M.	Positive	Mortality	Env.; Ind.	Air quality; Traffic; Physical activity	Accidents/Injuries; Mental health; NCD (cancer, CVD, CerebroVD, dementia, diabetes, respiratory)	-
37	Kypridemos	2020	United Kingdom	Cameroon	M.	Positive	Both	Env.	Air quality	NCD (cancer, CVD, cerebroVD, respiratory)	-
38	Li	2020	China	China	M.	Positive	Both	Env.	Air quality	NCD (CVD, cerebroVD, respiratory)	-
39	Li	2006	USA	Thailand	M.	Positive	Both	Env.	Air quality	NCD (CVD, respiratory)	-
40	Li	2020	China	China	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
41	Li	2022	USA	USA	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
42	Liu	2020	China	China	A.	Positive	Mortality	Inst.; Social	Capacity of health care system; Employment/income	Unspecified	-
43	Liu	2022	China	China	M.	Positive	Mortality	Env.	Air quality	NCD (cancer, CVD, respiratory)	Age
44	Macintyre	2021	United Kingdom	United Kingdom	A.	Neutral	Mortality	Env.	Air temperature	NCD (CVD, respiratory)	-
45	Macmillan	2014	New Zealand	New Zealand	M.	Negative, Positive	Both	Env.; Ind.	Air quality; Traffic; Physical activity	Accidents/Injuries; NCD (respiratory)	-
46	Marvuglia	2020	Luxembourg	Hungary, Spain, Italy, Turkey	A.	Negative, Positive	Mortality	Env.	Air temperature	Unspecified	-
47	Mazzi	2007	Canada	United Kingdom	M.	Negative	Both	Env.	Air quality	NCD (CVD, respiratory)	-
48	McCarthy	2019	USA	USA	A.	Positive	Morbidity	Social	Acc. to education	Unspecified	-
49	Mehiriz	2019	Qatar	Canada	A.	Neutral	Morbidity	Inst.	Capacity of health care system	Unspecified	-
50	Mehiriz	2018	Qatar	Canada	A.	Positive	Morbidity	Inst.	Capacity of health care system	Unspecified	-
51	Nakarmi	2020	Nepal	Nepal	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
52	Partridge	2011	USA	China	M.	Positive	Both	Env.	Air quality	NCD (respiratory)	-
53	Peng	2020	USA	India	M.	Positive	Mortality	Env.	Air quality		-

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Table A6 (*Continued*)

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										NCD (cancer, CVD, cerebroVD, diabetes, respiratory)	
54	Peng	2017	USA	China	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
55	Perera	2020	USA	USA	M.	Positive	Morbidity	Env.	Air quality	MNCH; Mental health; NCD (respiratory)	-
56	Peters	2020	USA	USA	M.	Negative, Positive	Mortality	Env.	Air quality	NCD (CVD, respiratory)	-
57	Phillips	2021	South Korea	South Korea	M.	Positive	Both	Env.	Air quality	NCD (cancer, CVD, cerebroVD, respiratory)	Age
58	Rauner	2020	Germany	China, India	M.	Positive	Morbidity	Env.	Air quality	NCD (cancer, CVD, cerebroVD, respiratory)	-
59	Reis	2022	Italy	Global	M.	Positive	Mortality	Env.	Air quality	Unspecified	-
60	Ritchie	2018	United Kingdom	Australia, Canada, Israel, Japan, New Zealand, Russian Federation, South Africa, United States of America, Norway, Switzerland, Iceland, Ukraine	M.	Positive	Mortality	Ind.	Diet	Food- and nutrition-related issues	-
61	Rosenthal	2017	USA	Global	M.	Positive	Morbidity	Env.	Air quality	Unspecified	-
62	Saari	2015	USA	USA	M.	Positive	Mortality	Env.	Air quality	NCD (CVD, respiratory)	-
63	Sabel	2016	United Kingdom	Finland, Germany, Greece, Netherlands, Switzerland, China	M.	Negative, Positive	Both	Env.; Ind.	Air quality; Air temperature; Noise; Physical activity	MNCH; NCD (cancer, CVD, respiratory)	Health
64	Sadeghi	2022	Australia	Australia	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
65	Sailor	2016	USA	USA	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
66	Sarigiannis	2017	Greece	Greece	M.	Positive	Both	Env.	Air quality	NCD (cancer)	-
67	Shindell	2011	USA	China, India	M.	Positive	Mortality	Env.	Air quality	NCD (cancer, CVD, respiratory)	-
68	Sinha	2021	USA	USA	A.	Positive	Mortality	Env.	Air temperature	NCD (CVD, respiratory)	Age
69	Sinha	2022	USA	USA	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
70	Smith	2016	United Kingdom	United Kingdom	M.	Negative, Positive	Morbidity	Env.; Ind.	Air quality; Noise; Traffic; Physical activity	Accidents/Injuries; Food- and nutrition-related issues	-
71	Smith	2015	Canada	Canada	A.	Positive	Morbidity	Env.	Water quality	Soil-, water- and waste-related diseases	-
72	Springmann	2017	United Kingdom	Global	M.	Negative, Positive	Mortality	Ind.	Diet	Food- and nutrition-related issues	-
73	Stone	2019	USA	USA	A.	Positive	Mortality	Env.	Air temperature	Unspecified	-
74	Stone Jr	2014	USA	USA	A.		Mortality	Env.	Air temperature	Unspecified	-

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Nr.	Author	Year of publication	First author's institution country	Study country/ies	Measure focus	Nature of health impacts	Mortality/ morbidity reported	HDs (main categories)	HDs (sub-categories) connected to health impacts	Categorization of health outcomes	Health outcome stratification
						Negative, Positive					
75	Sulser	2021	USA	Global	A.	Positive	Morbidity	Env.	Access to food	Food- and nutrition-related issues	-
76	Susca	2012	Italy	USA	A.	Positive	Both	Env.	Air temperature	Unspecified	-
77	Symonds	2021	United Kingdom	United Kingdom	M.	Negative, Positive	Mortality	Env.; Ind.	Air quality; Air temperature; Physical activity; Radiation	Unspecified	-
78	Tang	2022	China	China	M.	Neutral	Mortality	Env.	Air quality	Unspecified	Age
79	Taylor	2018	United Kingdom	United Kingdom	A.	Negative, Positive	Mortality	Env.	Air temperature	Unspecified	-
80	Tobollik	2016	Germany	The Netherlands	M.	Negative, Positive	Both	Env.	Air quality; Noise	NCD (cancer, CVD)	-
81	Tong	2021	China	China, India, Russia, USA	M.	Positive	Both	Env.	Air quality	Unspecified	-
82	Tuomisto	2015	Finland	Finland, Switzerland	M.	Positive	Both	Env.	Air quality	NCD (CVD, respiratory)	-
83	Vargo	2016	USA	USA	A.	Positive	Mortality	Env.	Air temperature	Unspecified	Age; Majority race; Socio-economic status
84	Williams	2018	United Kingdom	United Kingdom	M.	Negative, Positive	Morbidity	Env.	Air quality	Unspecified	-
85	Wolkinger	2018	Austria	Austria	M.	Positive	Both	Env.	Air quality; Physical activity	NCD (cancer, CVD, respiratory)	-
86	Wong-Parodi	2020	USA	USA	A.	Negative	Morbidity	Env.; Social	Access to health services; Housing Conditions	Unspecified	-
87	Yang	2021	China	China	M.	Positive	Both	Env.	Air quality	NCD (cancer, CVD, respiratory)	-
88	Zhang	2022	China	China	M.	Positive	Both	Env.	Air quality	NCD (cancer, CVD)	-
89	Zhong	2020	China	China	A.	Positive	Morbidity	Env.; Social	Access to health services; Access to food; Access to drinking water; Access to sanitation facilities; Housing conditions; Water quality; Water quantity	Mental health	Age; Education; Marital status; Occupation; Sex; Socio-economic status

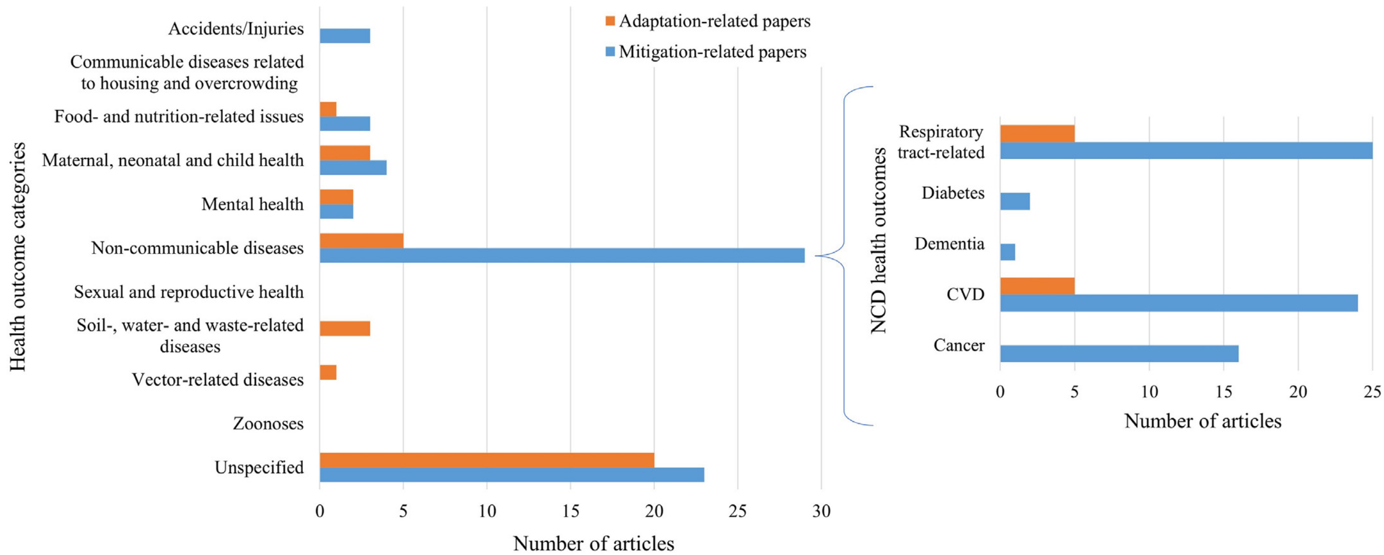

Fig. A1. Main health outcome categories and NCD specific health outcomes reported by articles, disaggregated for adaptation-related and mitigation related-articles. Note that one paper can report multiple health outcomes. NCD = non-communicable disease. CVD = cardio-vascular disease.

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