Systematic Mapping Review of Australian Research on Climate Change and Health Interventions

National Health and Climate Strategy | Action 7.2

© Commonwealth of Australia as represented by the Australian Centre for Disease Control

Title: Summary Report: Systematic Mapping Review and Gap Analysis of Australian Research on Climate and Health Interventions

ISBN: 978-1-76007-310-7

Acknowledgement of Country

The Australian Government acknowledges the Traditional Owners of Country throughout Australia, and their continuing connection to land, sea and community. We pay our respects to them and their cultures, and to Elders both past and present.

Citation

Department of Health and Aged Care (2024) ‘Systematic Mapping Review of Australian Research on Climate Change and Health Interventions’, Australian Centre for Disease Control, Australian Government.

Contributors

Vardoulakis S, Kazda L,Haddock R, Barratt A, McGain F, Wangdi K, Okokon E, Espinoza Oyarce D, Indu G, Goodman N, Matthews V, Spurrier P, McGushin A, Behrens G, Skellern M

Creative Commons Licence

This publication is licensed under the Creative Commons Attribution 4.0 International Public License available from https://creativecommons.org/licenses/by/4.0/legalcode (“Licence”). You must read and understand the Licence before using any material from this publication.

Restrictions

The Licence may not give you all the permissions necessary for your intended use. For example, other rights (such as publicity, privacy and moral rights) may limit how you use the material found in this publication.

The Licence does not cover, and there is no permission given for, use of any of the following material found in this publication:

* the Commonwealth Coat of Arms. (by way of information, the terms under which the Coat of Arms may be used can be found on the Department of Prime Minister and Cabinet website
* any logos and trademarks;
* any photographs and images;
* any signatures; and
* any material belonging to third parties. The third party elements must be included here or have a footnote reference throughout the document showing where they are

Attribution

Without limiting your obligations under the Licence, the Department of Health and Aged Care requests that you attribute this publication in your work. Any reasonable form of words may be used provided that you:

* include a reference to this publication and where, practicable, the relevant page numbers;
* make it clear that you have permission to use the material under the Creative Commons Attribution 4.0 International Public License;
* make it clear whether or not you have changed the material used from this publication;
* include a copyright notice in relation to the material used. In the case of no change to the material, the words “© Commonwealth of Australia (Australian Centre for Disease Control) 20XX” may be used. In the case where the material has been changed or adapted, the words: “Based on Commonwealth of Australia (Australian Centre for Disease Control) material” may be used; and
* do not suggest that the Australian Centre for Disease Control endorses you or your use of the material.

Enquiries

Enquiries regarding any other use of this publication should be addressed to the Branch Manager, Communication Branch, Australian Centre for Disease Control, GPO Box 9848, Canberra ACT 2601, or via e-mail to [copyright@health.gov.au](mailto:copyright@health.gov.au)

# Table of contents

[Table of contents 3](#_Toc181092247)

[Figures and Tables 4](#_Toc181092248)

[List of Figures 4](#_Toc181092249)

[List of Tables 4](#_Toc181092250)

[Version control 5](#_Toc181092251)

[Executive summary 6](#_Toc181092252)

[1 Introduction 7](#_Toc181092253)

[1.1 Policy context and aim 7](#_Toc181092254)

[1.2 The climate and health research landscape 7](#_Toc181092255)

[2 Methods 8](#_Toc181092256)

[2.1 Overview 8](#_Toc181092257)

[2.2 Objectives and research questions 8](#_Toc181092258)

[2.3 Research themes 8](#_Toc181092259)

[3 Overall summary of the research 9](#_Toc181092260)

[4 Summary of the research by theme 11](#_Toc181092261)

[4.1 Theme 1: Health system decarbonisation 11](#_Toc181092262)

[4.2 Theme 2: Health system adaptation, vulnerability and resilience 15](#_Toc181092263)

[4.3 Theme 3: Health co-benefits of climate change mitigation outside the health system 19](#_Toc181092264)

[4.4 Theme 4: Adaptation to protect health outside the health system 22](#_Toc181092265)

[5 Advancing Australian climate and health research 26](#_Toc181092266)

[5.1 Discussion 26](#_Toc181092267)

[5.2 Limitations 28](#_Toc181092268)

[5.3 Recommendations 28](#_Toc181092269)

[5.4 Conclusion 29](#_Toc181092270)

[References 30](#_Toc181092271)

Figures and Tables

## List of Figures

[Figure 1. Annual distribution of publications included between 2008 to March 2024 10](#_Toc181092281)

## List of Tables

[Table 1. Summary of included studies by theme 9](#_Toc181092272)

[Table 2. Summary of overall Quality Assessment results for primary studies by theme 10](#_Toc181092273)

[Table 3. Theme 1 primary studies grouped by type of health system decarbonisation intervention 12](#_Toc181092274)

[Table 4. Theme 1 primary studies grouped by category of health and aged care services 13](#_Toc181092275)

[Table 5. Theme 2 primary studies grouped by climate impact 17](#_Toc181092276)

[Table 6. Theme 2 primary studies grouped by areas of health and aged care services 17](#_Toc181092277)

[Table 7. Theme 3 primary studies grouped by economic sector 20](#_Toc181092278)

[Table 8. Theme 4 primary studies grouped by climate impact 24](#_Toc181092279)

[Table 9. Theme 4 primary studies grouped by economic sector 24](#_Toc181092280)

# Version control

This document was prepared in October 2024 by the National Health, Sustainability and Climate (NHSC) Unit, Environmental Health and Climate Change Branch, Health Protection Policy and Surveillance Division, interim Australian Centre for Disease Control, Australian Government Department of Health and Aged Care.

This document highlights the key findings from a systematic mapping review written collaboratively between the NHSC Unit and the Healthy Environment and Lives (HEAL) Network. Changes to this document will be reflected in the below table when required.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| # | Revision description | Section | Date | Approved by |
| 1.0 | New document | All | October 2024 | First Assistant Secretary |

# Executive summary

Action 7.2 of the National Health and Climate Strategy commits the Australian Government to publishing a scan of research activities in Australia on climate change and health. In fulfilment of this action, and in partnership with the Healthy Environment and Lives (HEAL) Network, a systematic mapping review of the Australian peer-reviewed literature on climate and health interventions was undertaken to inform the prioritisation of future research and funding. The systematic mapping review (the review) identified, described, and catalogued the Australian evidence on climate and health interventions, and included published peer-reviewed studies and literature reviews that proposed or implemented climate-health interventions. This document summarises key findings.

Included research studies (n=81) were categorised under four themes: (Theme 1) Health system decarbonisation (n=18); (Theme 2) Health system adaptation, vulnerability and resilience (n=24); (Theme 3) Health co-benefits of climate change mitigation outside the health system (n=7); and (Theme 4) Adaptation to protect health in sectors outside the health system (n=26). Six additional research studies spanned several of these themes.

Overall, the review found only limited local, high-quality evidence across all four themes. Most health system decarbonisation studies (Theme 1) focused on hospital-based clinical care. In comparison, most of the health system adaptation, vulnerability and resilience studies (Theme 2) focused on interventions in non-clinical settings. Of all climate hazards, interventions to address the health impacts of heat were the most studied across the two adaptation-related themes (Themes 2 and 4). The interventions in these two themes also largely focused on addressing the direct, physical health impacts of climate change, with fewer studies on interventions to ameliorate the psychosocial or mental health impacts of climate change. There were few studies on the health co-benefits of climate change mitigation outside the health system (Theme 3). Across all themes, a limited number of studies had a focus on priority populations, including First Nations people.

Most of the included studies used qualitative or semi-quantitative survey methods, with fewer studies employing methods such as randomised controlled trials, comparative life cycle assessments, or other observational or modelling study designs. Many primary studies demonstrated limited stakeholder engagement and co-design in the design, implementation and evaluation of interventions.

To support the policy agenda outlined in the National Health and Climate Strategy, there is a need for a sustained increase in interdisciplinary research on climate and health interventions. Evidence from local contexts, using robust methods and stakeholder engagement, will support effective action on climate change and health in Australia’s health system and communities.

# 1 Introduction

## 1.1 Policy context and aim

Australia’s first National Health and Climate Strategy (the Strategy) was published in December 2023. The Strategy sets out a whole-of-government plan for achieving ‘healthy, climate-resilient communities, and a sustainable, resilient, high-quality, net zero health system’. The Strategy identifies the importance of coordinated climate and health research to realise this vision, and includes ‘Research and Innovation’ as one of four Enablers that will help achieve its core objectives.

Action 7.2 of the Strategy commits the Australian Government to commissioning and publishing a scan of Australian research activities pertaining to climate change and health, with a view to informing the prioritisation of future research funding and policy decisions for health adaptation and mitigation. In fulfilment of Action 7.2, a systematic mapping review was undertaken in partnership with the Healthy Environment and Lives (HEAL) Network. The review aimed to map and thematically understand the existing research on policies and interventions related to health and climate change adaptation and mitigation in Australia. This report summarises the main findings of the systematic mapping review.

## 1.2 The climate and health research landscape

Climate change is undermining the environmental and social determinants of health by disrupting Earth’s natural systems, and is one of the greatest threats to human health and wellbeing in Australia and worldwide (AAHMS 2022). Since 2012, the number of scientific papers researching climate change and human health globally has increased three-fold (Romanello et al. 2023). However, most of the extant climate change and health literature focuses on estimating the health impacts of exposure to climate hazards (Romanello et al. 2023). Moving forward, it is important that academic research explores and evaluates potential solutions to reduce the impacts of climate change on population health and on the Australian health system to improve health and wellbeing.

# 2 Methods

## 2.1 Overview

A systematic mapping review methodology (James et al. 2016) was employed to collate, describe and catalogue the relevant Australian published evidence. Research published between 1 January 2008 and 1 March 2024 was collected by searching and screening the peer-reviewed literature in three bibliographic databases (Medline, Scopus, and Google Scholar). This process was complemented with manual searches of the literature cited in the Medical Journal of Australia-Lancet Countdown reports on health and climate change in Australia (2018-2023) and other published reviews. Relevant data was then extracted and collated about all included studies.

Primary research studies were critically appraised using the Quality Assessment with Diverse Studies (QuADS) tool (Harrison et al. 2021) to highlight the strengths and weakness of the evidence base. As this review thematically outlines the content of the evidence base, the results of individual studies were not analysed. For further information, please refer to the full methodology outlined in Appendix 1.

## 2.2 Objectives and research questions

The objectives and research questions of the review were:

1. **Map the existing research on climate and health policies and interventions in Australia**. What evidence is available on policies and interventions related to health and climate change in Australia, in the areas of health adaptation and resilience, health system decarbonisation, and health co-benefits of climate change mitigation outside the health system?
2. **Highlight strengths and weaknesses in the evidence base**. What are the strengths and weaknesses of the current research field on health and climate change policies and interventions in Australia?
3. **Identify research and evidence gaps**. What are the main research gaps in relation to health adaptation and resilience, health system decarbonisation, and the health co-benefits of climate change mitigation outside the health system?

## 2.3 Research themes

Articles were grouped under four themes: 1) health system decarbonisation; 2) health system adaptation, vulnerability and resilience; 3) health co-benefits of climate change mitigation outside the health system; and 4) adaptation to protect health outside the health system.

# 3 Overall summary of the research

7303 titles were identified through bibliographic database searches with 25 additional articles added through manual searches. After removing duplicates, 6833 titles and abstracts were screened, and 256 full-text articles were obtained and assessed for eligibility. From these 256 articles, 81 articles were ultimately included in the review.

Of the 81 articles included in the synthesis, 48 were original research studies and 33 were evidence reviews. Table 1 shows the allocation of these articles to the four themes. For a complete list of each article’s study characteristics grouped by theme, please refer to Appendix 9 (primary studies) and Appendix 10 (reviews) in the Appendices document.

Table 1. Summary of included studies by theme

| Theme | Primary studies (total, n=48) | Reviews (total, n=33\*) | Total studies |
| --- | --- | --- | --- |
| 1. Health system decarbonisation | 13 | 5 | 18 |
| 1. Health system adaptation, vulnerability and resilience | 14 | 10 | 24 |
| 1. Health co-benefits of climate change mitigation outside the health system | 4 | 3 | 7 |
| 1. Adaptation to protect health outside the health system | 17 | 9 | 26 |

\* Includes the six MJA-Lancet Countdown Reports on Health and Climate Change, which were not assigned to a specific theme due to the diverse topics included.

A majority of included studies (27 primary studies and 20 reviews) were published in the last five complete years (2019-2023), and seven more studies (three primary studies and four reviews) were published in the first two months of 2024 (Figure 2). Of the 33 eligible reviews, only seven were systematic reviews.

Figure 1. Annual distribution of publications included between 2008 to March 2024

Seven studies covered populations or health services from across all of Australia. There were 14 studies focused on New South Wales (NSW), 11 on Victora (VIC), five on Queensland (QLD), six on South Australia (SA), one on Western Australia (WA), two on Tasmania (TAS), and five on the Northern Territory (NT). Of these articles, three covered two jurisdictions each (NSW and VIC, SA and VIC, and WA and NT). There were no eligible studies from the Australian Capital Territory (ACT).

The Quality Assessment found that most of the primary studies (n=35) were of moderate quality, with fewer studies of low quality (n=8) or high quality (n=5) (Table 2). No studies were found to be of very low quality.

Table 2. Summary of overall Quality Assessment results for primary studies by theme

|  |  | Score\* | |  |
| --- | --- | --- | --- | --- |
| Theme | Very low (0) | Low (1) | Moderate (2) | High (3) |
| 1. Health system decarbonisation | 0 | 3 | 9 | 1 |
| 1. Health system adaptation, vulnerability and resilience | 0 | 2 | 10 | 2 |
| 1. Health co-benefits of climate change mitigation outside the health system | 0 | 0 | 3 | 1 |
| 1. Adaptation to protect health outside the health system | 0 | 3 | 13 | 1 |

\*Scores corresponding to QuADS quality assessment tool

# 4 Summary of the research by theme

## 4.1 Theme 1: Health system decarbonisation

**Health system decarbonisation:** this theme includes studies that explore emissions reduction and sustainability interventions within the Australian health system. It includes:

● Life Cycle Assessment studies, which report on the greenhouse gas emissions footprint of equipment and supplies used in healthcare settings.

● Studies that assess behaviour- and system-change interventions to reduce greenhouse gas emissions in healthcare settings.

### 4.1.1 Results

There were 13 primary research studies and five reviews included in this theme (total n=18). Of the 13 primary studies, only two studies evaluated interventions that were implemented in a healthcare setting. The first of these two studies was a quality improvement study to reduce volatile anaesthetic gases in operating theatres of a Brisbane hospital (Wyssusek et al. 2022). The second was an evaluation of an intervention to reduce the frequency of ordering of non-urgent blood tests in a Sydney hospital (McAlister et al. 2023).

There were three other studies in healthcare settings that used a variety of methods. The first study outlined a variety of interventions suggested by health leaders (Charlesworth and Jamieson 2019). The second examined the potential impacts of more environmentally sustainable practices within dialysis units (Talbot et al. 2022). The third study examined the predicted carbon emission savings from use of telehealth in rural Australia (Ellis et al. 2013).

There were seven Life Cycle Assessment (LCA) studies. Four of these studies compared CO2e emissions associated with reusable and single-use medical equipment. These four studies compared, respectively: reusable plastic trays with single-use plastic anaesthetic drug trays (McGain et al. 2010); reusable and single-use central venous catheter insertion kits (McGain et al. 2012); reusable and single-use anaesthetic equipment, including anaesthetic circuits, face masks, laryngeal mask airways, and direct and videolaryngoscope blades and handles (McGain et al. 2017); and reusable and single‐use ureteroscopes (Davis et al. 2018).

The other three LCA studies estimated the emissions footprint of pathology tests (including full blood examination, urea and electrolyte levels, coagulation profile, C-reactive protein concentration, and arterial blood gases) (McAlister et al. 2020); hospital diagnostic imaging (including computerised tomography, magnetic resonance imaging, ultrasound, chest X-ray, and mobile chest X-ray) (McAlister et al. 2022); and oral versus intravenous perioperative paracetamol use (Davies et al. 2024).

One study in this theme reported on anaesthetists’ perspectives on the emissions footprint of anaesthesia and identified future opportunities and challenges for reducing the impact of anaesthesia on the environment (Breth-Petersen et al. 2024).

Of the 13 primary research studies, nine were conducted in metropolitan areas (McAlister et al. 2023; Wyssusek et al. 2022; Breth-Petersen et al. 2024; McGain et al. 2010; McGain et al. 2012; McGain et al. 2017; Davis et al. 2018; McAlister et al. 2020; McAlister et al. 2022). Only one primary study was conducted in rural Australia (Ellis et al. 2013). Three studies did not have a specific geographical focus (Charlesworth and Jamieson 2019; Talbot et al. 2022; Davies et al. 2024).

The five reviews in this theme covered topics including energy sources, water use, waste management, and travel/transport, in healthcare services outside (Duindam 2022) and within hospitals (Pencheon et al. 2009); opportunities to green operating theatres (Wyssusek et al. 2019); reducing greenhouse gas emissions from nitrous oxide use (Liu et al. 2023); and improving environmental sustainability in hospitals (McGain and Naylor 2014).

### 4.1.2 Thematic mapping

The 13 primary studies have been thematically grouped by type of health system decarbonisation intervention (Table 3) and category of health and aged care services (Table 4) to provide a framework for understanding the types of interventions included in Theme 1. Some studies may appear in more than one category.

Table 3. Theme 1 primary studies grouped by type of health system decarbonisation intervention

| Type of health system decarbonisation intervention | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Built environment, energy and water | Changing models of care | Preventing ill health | Reducing low-value care | Medicines and gases | Food and catering | Supply chains and procurement | Travel and transport | Waste and resource use |
| (Talbot et al. 2022) | (Charlesworth and Jamieson 2019) |  | (McAlister et al. 2020)  (McAlister et al. 2022)  (McAlister et al. 2023) | (Breth-Petersen et al. 2023)  (Davies et al. 2024)  (Wyssusek et al. 2022) |  | (Talbot et al. 2022) | (Ellis et al. 2013)  (Talbot et al. 2022) | (Davis et al. 2018)  (McGain et al. 2010)  (McGain et al. 2012)  (McGain et al. 2017)  (Talbot et al. 2022) |
| 1 | 1 | 0 | 3 | 3 | 0 | 1 | 2 | 5 |

Table 4. Theme 1 primary studies grouped by category of health and aged care services

| Category of health and aged care services | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Healthcare (general) | Hospitals (excl. psychiatric) | Psychiatric hospitals | General practice | Specialist medical services | Pathology and diagnostic imaging | Allied health | Ambulance | Aged Care |
| (Charlesworth and Jamieson 2019)  (Ellis et al. 2013) | (Davies et al. 2024) |  |  | (Breth-Petersen et al. 2023)  (Davis et al. 2018)  (McGain et al. 2010)  (McGain et al. 2012)  (McGain et al. 2017)  (Talbot et al. 2022)  (Wyssusek et al. 2022) | (McAlister et al. 2020)  (McAlister et al. 2022)  (McAlister et al. 2023) |  |  |  |
| 2 | 1 | 0 | 0 | 7 | 3 | 0 | 0 | 0 |

### 4.1.3 Research gaps

Overall, the evidence base on health system decarbonisation is sparse in Australia, indicative of an emerging research field. The studies covered a limited set of health services, notably anaesthesia/analgesia services, which use volatile anaesthetic gases such as desflurane, sevoflurane and nitrous oxide (four primary studies and one review). These and the remaining studies predominantly reflect the work of a small number of sustainable healthcare leaders in anaesthesia, renal medicine, hospital management, and hospital building energy and waste management.

There is emerging research in other areas of clinical practice such as pathology testing and diagnostic imaging (McAlister et al. 2020; McAlister et al. 2022), which can inform the implementation of interventions. However, there is an absence of interventional research about decarbonising other areas of clinical practice, especially in non-hospital settings. There is a need for more studies conducted in a wider range of healthcare settings, such as in primary care and allied health contexts, as well as in aged care settings. Future research should also consider evaluating interventions conducted in rural, regional, and remote health service areas of Australia.

The studies identified sought to improve sustainability and reduce emissions through initiatives such as reducing the consumption of anaesthetic gases or restricting blood tests within a specific hospital department. There is a notable gap around the potential for environmental co-benefits of health system reform to reduce medical overuse and low-value care, shift healthcare delivery towards primary care, and increase primordial and primary prevention interventions (Barratt et al. 2022). Future studies are needed to assess opportunities for broader health system reform to reduce demand for emissions-intensive, hospital-based care.

Studies that measure the environmental impact of healthcare products and procedures can help clinicians to make informed decisions to decarbonise the health system. Future LCAs on a broader range of healthcare products and procedures could help to inform clinical interventions that support transitioning to low carbon high-value care, and to inform procurement and reimbursement decisions.

## 4.2 Theme 2: Health system adaptation, vulnerability and resilience

**Health system adaptation, vulnerability and resilience**: this theme includes studies of interventions to support the health system to adapt to climate change. It includes:

● Studies of educational interventions to improve awareness about the health risks of climate change.

● Studies of strategies to deliver physical and mental health services in response to climate change.

Adaptation and resilience interventions that are primarily delivered outside the health system are captured in theme 4.

### 4.2.1 Results

There were 14 primary research studies and 10 reviews included in this theme (total n=24). There was a cluster (n=4) of primary studies from SA that investigated the effects of heat-health warning systems on healthcare cost or utilisation (Williams et al. 2022; Nitschke et al. 2016), mortality (Nitschke et al. 2016), and health-related behaviours, knowledge, and awareness (Nitschke et al. 2017; Williams et al. 2019). Only one other study explored an adaptation intervention in response to heat: De Souza et al. (2023) examined the use of biophilic landscape design to reduce urban heat at Royal Darwin Hospital, in the NT.

There were six primary studies that considered health system adaptation interventions to climate change in general (van Beurden et al. 2011; Patrick and Capetola 2011; Patrick and Kingsley 2019; McLean et al. 2022; Walker 2009; Mohtady Ali et al. 2022) rather than exploring an intervention tailored to a specific climate hazard. Two of these studies looked at health promotion and sustainability interventions implemented in health service organisations across Australia (Patrick and Capetola 2011; Patrick and Kingsley 2019). One study conducted in rural Australia investigated how health promotion teams can establish organisational collaborations to mitigate and adapt to climate change (van Beurden et al. 2011). One study articulated a framework to support decisions about primary health care agencies’ responses to climate change (Walker 2009). There were two studies examining education and training interventions. McLean et al. (2022) focused on the integration of planetary health into a five-year medical curriculum and Mohtady Ali et al. (2022) evaluated a resilience toolkit for disaster management and climate change adaptation for healthcare workers in QLD.

The remaining three primary studies investigated interventions related to floods and bushfires. Kildea et al. (2018) compared midwifery group practice care to standard care in reducing the mental health impacts of flooding events in QLD before, during and after pregnancy. Marfori et al. (2020) looked at the impact of public health messaging related to smoke from bushfires on health-related knowledge, awareness and attitudes in TAS. One study reported on interventions related to floods and bushfires. Knezevic et al. (2023) examined a psychological program to support healthcare staff in the aftermath of bushfires and floods.

Across the primary studies, seven out of 13 studies were conducted in urban areas (Williams et al. 2022; Nitschke et al. 2017; Nitschke et al. 2016; Kildea et al. 2018; de Souza et al. 2023; McLean et al. 2022; Mohtady Ali et al. 2022). There were only four studies conducted in regional and remote areas (Marfori et al. 2020; Knezevic et al. 2023; van Beurden et al. 2011; Williams et al. 2019).

No studies in the scope of the review specifically considered interventions for First Nations health services or for First Nations healthcare workers and patients. However, the landscape design study at Royal Darwin Hospital did feature a strong focus on Aboriginal culture and community input when designing and implementing landscaping interventions to create climate-resilient, culturally safe spaces for staff and patients (de Souza et al. 2023).

The topics of the 10 reviews were generally broader than the primary studies. Seven reviews investigated responses to a wide range of climate hazards (Crandon et al. 2022; Palinkas et al. 2020; Walter et al. 2024; Xu et al. 2023; Blashki et al. 2011; Zurynski et al. 2024; Lokmic-Tomkins et al. 2023). Two reviews focused on heat interventions (Vu et al. 2019; Walker et al. 2011), and one review on interventions in relation to air pollution and temperature variability (Hu et al. 2022).

In terms of the health outcomes examined in the included studies, one review reported on asthma-related emergency department and hospital admissions amongst children during heat, dust storms and bushfires (Hu et al. 2022). Vu et al. (2019) summarised measures to ameliorate adverse effects of extreme heat in older people. Crandon et al. (2022) assessed clinical interventions to respond to the mental health impacts of climate change. Blashki et al. (2011) described a wide range of climate related health outcomes, including mental health. One review specifically focused on health and safety outcomes for the health workforce (Zurynski et al. 2024). Health outcomes were not specified but broadly discussed in five of the included reviews (Lokmic-Tomkins et al. 2023; Palinkas et al. 2020; Walter et al. 2024; Walker et al. 2011; Xu et al. 2023).

### 4.2.2 Thematic mapping

The 14 primary studies have been thematically grouped by climate impact (Table 5) and category of health and aged care services (Table 6) to provide a framework for understanding the types of interventions included in Theme 2. Some studies may appear in more than one category.

Table 5. Theme 2 primary studies grouped by climate impact

| Climate impact | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Air pollution (excl. bushfire smoke) | Bushfire (incl. bushfire smoke) | Drought | Heat | Flood | Storm | Communicable diseases | Sea level rise | General climate impacts or hazards |
|  | (Knezevic et al. 2023)  (Marfori et al. 2020) |  | (de Souza et al. 2023)  (Nitschke et al. 2017)  (Nitschke et al. 2016)  (Williams et al. 2019)  (Williams et al. 2022) | (Kildea et al. 2018)  (Knezevic et al. 2023) |  |  |  | (McLean et al. 2022)  (Mohtady Ali et al. 2022)  (Patrick and Capetola 2011)  (Patrick and Kingsley 2019)  (van Beurden et al. 2011)  (Walker 2009) |
| 0 | 2 | 0 | 5 | 2 | 0 | 0 | 0 | 6 |

Table 6. Theme 2 primary studies grouped by areas of health and aged care services

| Areas of health and aged care services | | | | | | | | | |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Healthcare (general, including non-clinical settings ) | Hospitals (excl. psychiatric) | Psychiatric hospitals | General practice | Specialist medical services | Pathology and diagnostic imaging | | Allied health | | Ambulance | Aged Care |
| (Knezevic et al. 2023)  (Marfori et al. 2020)  (McLean et al. 2022)  (Nitschke et al. 2017)  (Patrick and Capetola 2011)  (Patrick and Kingsley 2019)  (van Beurden et al. 2011)  (Williams et al. 2019)  (Williams et al. 2022) | (de Souza et al. 2023)  (Mohtady Ali et al. 2022)  (Nitschke et al. 2016) |  | (Walker 2009) |  |  | (Kildea et al. 2018)  (Walker 2009) | | (Nitschke et al. 2016) | |  |
| 9 | 3 | 0 | 0 | 0 | 0 | 2 | | 1 | | 0 |

### 4.2.3 Research gaps

Overall, the evidence base in this theme is still emerging in Australia. Primary studies to date have focused on a narrow range of interventions, and health outcomes are often not clearly specified. A large proportion of existing studies focused on a single intervention, namely a heat-health warning system in SA (n=4).

Most of the included studies reported on interventions in non-clinical settings, so evidence is limited to specific components of the health system. Most interventions examined were limited to health promotion, community health, public health communication and early warning systems. Very few studies focused on actions to strengthen the resilience of health services and adapt clinical care delivery to better address the health impacts of climate change. Health system adaptation, vulnerability and resilience studies in a wide range of clinical settings would be particularly useful. This should include various speciality areas across primary, secondary and tertiary levels of care and should be geographically diverse across a range of urban and rural, regional and remote health services.

There is also a notable deficit of studies in this theme that report accurate and reliable measures of health or health system outcomes. These outcomes may include reliable measures of mortality, morbidity and health system utilisation. Future research should include these to better design adaptation interventions in the health system. In addition, there is a lack of research investigating interventions to improve the resilience and adaptive capacity of health services and a lack of consideration of the potential environmental co-benefits of such interventions. Studies investigating whole-of-system adaptation and resilience and the co-benefits of interventions within the health system are important and should be prioritised.

There are significant research gaps around health system interventions designed for priority populations, such as culturally and linguistically diverse groups, First Nations people, the elderly or young, people living with a disability, and people who are socioeconomically disadvantaged. Within this synthesis there was a lack of studies on potential environmental co-benefits (such as reductions in greenhouse gas emissions, waste, or resource use) of adaptation interventions in health system settings.

Future research should consider co-designing adaptation interventions in the health system with at-risk priority populations, particularly First Nations people to better incorporate lived experiences and preferences. Likewise, when considering health system adaptation, vulnerability and resilience, there is a need for interventional research to consider a diverse range of healthcare workers, including allied healthcare workers, to address the impact of climate change on their ability to provide high quality care.

Finally, there were several studies evaluating the implementation of a heat-health warning intervention in SA. If similar interventions are employed across the country, future research should consider the impact on local health system adaptation and resilience. Similarly, future research could evaluate the potential of integrated health warning systems, such as weather and air pollution forecasts and modelling of climate-sensitive communicable diseases, that are not yet used in Australia.

## 4.3 Theme 3: Health co-benefits of climate change mitigation outside the health system

**Health co-benefits of climate change mitigation outside the health system**: this theme includes studies which identify, assess and evaluate the ancillary health outcomes of climate change mitigation interventions in all sectors outside the health system, including agriculture and food, land and water management, energy generation and energy efficiency, the built environment including housing, transport, and education and training. This includes studies that:

● Evaluate the health benefits of Indigenous land management activities.

● Identify the health benefits of improving energy efficiency in the built environment.

● Review the health benefits of sustainable agriculture and food consumption.

### 4.3.1 Results

There were four primary research studies and three reviews included in this theme (total n=7). There were two primary studies on Indigenous land management, exploring the health co-benefits for First Nations people who engage in ‘Caring for Country’ activities. The first study investigated the associations between participation in six caring for Country activities (spending time on Country, burning of annual grasses, gathering of food and medicinal resource, participating in cultural ceremonies, protection of sacred sites, and creating artwork) and health outcomes relevant to excess First Nations morbidity and mortality in the NT (Burgess et al. 2009). The second study similarly explored Indigenous land management programs as a primary health care intervention in remote communities in WA and the NT (Schultz et al. 2018).

One primary study explored the health co-benefits of interventions to reduce urban heat in Darwin (Haddad et al. 2020). The study estimated changes in heat-related mortality associated with urban greening and cool materials to reduce urban heat and air-conditioning demand for electricity and associated greenhouse gas emissions. The final study assessed the health outcomes of various diets with different greenhouse gas emissions footprints to identify potential health co-benefits from environmentally sustainable dietary choices (Ridoutt et al. 2021).

There were three non-systematic reviews, two of which featured only a small number of Australian studies (Giles-Corti et al. 2010; Willand et al. 2015). The third review included policy documents from the Australian Government and from state and territory governments (Delany-Crowe et al. 2019). There were no eligible systematic reviews. The topics covered by the three reviews were investment into active transport (Giles-Corti et al. 2010), residential energy efficiency interventions (Willand et al. 2015), and implementation of water management policies to improve health and wellbeing (Delany-Crowe et al. 2019).

### 4.3.2 Thematic mapping

The four primary studies have been thematically grouped by economic sector (Table 7) to provide a framework for understanding the types of interventions included in Theme 3.

Table 7. Theme 3 primary studies grouped by economic sector

| Sector | | | | | |
| --- | --- | --- | --- | --- | --- |
| Agriculture and food | Built environment (incl. housing and urban planning) | Education, training and communication | Energy and electricity | Land and water environmental management | Travel and transport |
| (Ridoutt et al. 2021) | (Haddad et al. 2020) |  |  | (Burgess et al. 2009)  (Schultz et al. 2018) |  |
| 1 | 1 | 0 | 0 | 2 | 0 |

### 4.3.3 Research gaps

The very limited number of primary research studies identified highlights a lack of Australian health co-benefits interventional research, which may limit the ability of policymakers and decision-makers to fully consider potential health co-benefits of emissions reduction policies (Workman et al. 2016). The lack of Australian studies on the health co-benefits of interventions is consistent with findings of the ‘Pathways to a healthy net-zero future’ report of the Lancet Pathfinder Commission which found substantial modelled evidence on health co-benefits of climate change mitigation, but globally very limited evidence on the health co-benefits from implemented mitigation actions (Whitmee et al. 2024).

There were limited studies included in this review which examine the health co-benefits of mitigation across several sectors in Australia. For instance, international studies have shown that housing interventions improve the thermal properties and ventilation of residential buildings (Howden-Chapman and Chapman 2012) and can have the greatest potential health benefit for occupants (Milner et al. 2023). Local research is needed to better understand the co-benefits of housing interventions on health and decarbonisation in the Australian context. Future co-benefit studies should also consider exploring the health co-benefits of interventions for First Nations people living in remote housing. This may include studies addressing high indoor air temperature, overcrowding, food safety, and energy security.

In the travel and transport sector, the co-benefits of active travel (e.g. cycling and walking) and public transport interventions have not been sufficiently studied in Australia. Similarly, there are no high-quality Australian studies on the health co-benefits of sustainable food production and consumption. Australian research that evaluates local interventions from a health co-benefit lens may support implementation of sustainable, health-promoting transport and agriculture in the future.

As Australia transitions to a net-zero emissions future, research could consider the health co-benefits of local energy transition policies and interventions. Future research may consider evaluating the health co-benefits of interventions that reduce greenhouse gas emissions from energy generation in an Australian context. For example, transitioning away from coal-fired power stations and coal mines may have health co-benefits for local communities due to a reduction in local air pollution (Henneman et al. 2023). Likewise, research could consider evaluating the health co-benefits of Australian policies and interventions to transition away from widespread use of wood heaters or indoor gas appliances that exacerbate indoor and outdoor air pollution.

Future Australian research on the health co-benefits across a wide range of sectors should also consider research on priority populations. Although it is widely recognised that land management programs for First Nations communities yield positive health benefits, more co-benefit studies are required to assess the specific health outcomes for First Nations communities in other sectors.

Similarly, research should consider other priority populations that could experience health co-benefits of mitigation interventions, such as people living in social housing or experiencing homelessness, the elderly or young, workers in industries involved in the energy transition, and people of low socioeconomic status. Co-benefit interventional studies that focus on priority populations could further be completed by quantitative geospatial studies that explore the distribution, spatial patterns and relationships of climate change and health outcomes. Such studies help inform the implementation of interventions in areas where there are significant environmental and population health benefits to be realised.

## 4.4 Theme 4: Adaptation to protect health outside the health system

Adaptation to protect health outside the health system: this theme includes studies that identify and evaluate interventions that seek to improve health outcomes, but which are primarily implemented in sectors outside of the health system. This includes studies that:

● Examine interventions in the urban environment to build resilience to heat, such as urban greening and cooling materials.

● Explore the role of housing in protecting health from the impacts of climate change. This includes interventions such as insulation, air conditioning and indoor ventilation.

● Implement interventions in the workplace (excluding health system workplaces) to address the impact of climate change on occupational health.

● Assess the use of personal protective behaviours or equipment (e.g. facemasks) in different populations.

● Implement nature-based approaches to restore ecosystems with the aim to protect health from climate hazards like floods and drought.

● Review interventions that promote community connectedness to foster social cohesion, climate resilience, and improve community mental health and wellbeing.

### 4.4.1 Results

There were 17 primary research studies and nine reviews included in this theme (total n=26). Heat was the most researched climate hazard in this theme (primary studies n=8). Of these primary studies, four explored interventions to reduce urban heat, including

the role of urban vegetation (Chen et al. 2014; Sadeghi et al. 2022), cooling materials and greenery (Qi et al. 2021), and mix-use landscaping of vegetation, cooling materials and irrigation to enhance evapotranspiration (Santamouris et al. 2020).

Of the four remaining heat-focused primary studies, one presented a case study on public heat refuges for populations at risk (Dufty 2022). Hansen et al. (2011) assessed the effectiveness of heat-health warnings and the use of heat protective behaviours for older persons. Similarly, Varghese et al. (2020) investigated the role of personal protection behaviours, as well as education and training, and administrative and engineering controls for indoor and outdoor workers in relation to heat-related injuries. Only one study considered adaptation to heat for First Nations peoples by comparing non-Indigenous and Indigenous communities in the NT to discuss physiological, sociocultural, technological and infrastructure interventions to adapt to heat (Quilty et al. 2023).

Several primary studies explored adaptation interventions to support mental health. Two studies investigated the efficacy and delivery of the trauma-informed Skills for Life Adjustment and Resilience (SOLAR) program in communities affected by disasters such as bushfires and droughts (Cowlishaw et al. 2023 and O'Donnell et al. 2020). Hart et al. (2011) described the introduction of the NSW Government funded Rural Adversity Mental Health Program (RAMHP) in drought impacted rural communities. Rigby et al. (2011) also evaluated the RAMHP, but with a specific focus on rural First Nations communities in NSW and the impact of drought on their social and emotional wellbeing. One study, also conducted in rural NSW, researched community activities that build resilience to the mental health and wellbeing impacts of climate change (Longman et al. 2023). Finally, one study explored psychological interventions to support children’s wellbeing and resilience after a bushfire (McGill et al. 2024). Two studies explored adaptation interventions in response to bushfire smoke. Seale et al. (2023) examined the factors influencing people to use facemasks during bushfire events and Wheeler et al. (2021) evaluated the potential for a public building (a library) to be a clean air shelter during extreme smoke events. This study also evaluated the efficacy of portable HEPA filters within the clean air shelter. Only one study explored an adaptation intervention for a communicable disease. Tomerini et al. (2011) compared different mosquito management strategies and the incidence of Ross River virus across different climatic regions in QLD.

There were no primary studies examining adaptation interventions outside the health system specifically in relation to floods, although a primary study on the mental health impacts of extreme events (Longman et al. 2023), and a systematic review on green infrastructure interventions (Pitman et al. 2015) referred to floods in the context of climate change. The RAMHP intervention can also be used for other climate impacts beyond droughts, including for floods (Hart et al. 2011).

The nine reviews covered an array of adaptation interventions in relation to a diverse range of climate hazards. Two systematic reviews (Adnan et al. 2022; Pitman et al. 2015) and one narrative review (Jay et al. 2021) focused on adaption interventions to heat, including urban greening, shading, water-sensitive urban design, cooling materials, ventilation and thermal insulation of buildings, heat-heat warning systems, and personal cooling strategies. Communication techniques and materials to disseminate information and influence adaptive behaviour change in response to bushfire smoke was the focus of two reviews (Heaney et al. 2021; Vien et al. 2024). One discussed adaptation interventions in response to the future impact of climate change on respiratory, diarrheal, and vector-borne diseases in Australia (Harley et al. 2011). One assessed the interventions available to support community mental health (Charlson et al. 2021). Finally, two studies explored the implementation of adaptation plans and strategies (Desai and Zhang 2021;Zhao et al. 2022). The impact of climate change on women’s adaptation was a particular focus of Desai and Zhang's (2021) review.4.4.2 Thematic mapping

The 17 primary studies have been thematically grouped by climate impact (Table 8) and sector (Table 9) to provide a framework for understanding the types of interventions included in Theme 4. Some studies may appear in more than one category.

Table 8. Theme 4 primary studies grouped by climate impact

| Climate impact | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Air pollution (excl. bushfire smoke) | Bushfire (incl. bushfire smoke) | Drought | Heat | Flood | Storm | Communicable diseases | Sea level rise | General climate impacts or hazards |
| (Wheeler et al. 2021) | (Cowlishaw et al. 2023)  (Longman et al. 2023)  (McGill et al. 2024)  (O'Donnell et al. 2020)  (Seale et al. 2023)  (Wheeler et al. 2021) | (Cowlishaw et al. 2023)  (Hart et al. 2011)  (Longman et al. 2023)  (Rigby et al. 2011) | (Chen et al. 2014)  (Dufty 2022)  (Hansen et al. 2011)  (Qi et al. 2021)  (Quilty et al. 2023)  (Sadeghi et al. 2022)  (Santamouris et al. 2020)  (Varghese et al. 2020) | (Longman et al. 2023) |  | (Tomerini et al. 2011) |  | (Hart et al. 2011) |
| 1 | 6 | 4 | 8 | 1 | 0 | 1 | 0 | 1 |

Table 9. Theme 4 primary studies grouped by economic sector

| Sector | | | | | |
| --- | --- | --- | --- | --- | --- |
| Agriculture and food | Built environment (incl. housing and urban planning) | Education, training and communication | Energy and electricity | Land and water environmental management | Travel and transport |
|  | (Chen et al. 2014)  (Dufty 2022)  (Qi et al. 2021)  (Quilty et al. 2023)  (Sadeghi et al. 2022)  (Santamouris et al. 2020)  (Wheeler et al. 2021) | (Cowlishaw et al. 2023)  (Hansen et al. 2011)  (Longman et al. 2023)  (Hart et al. 2011)  (McGill et al. 2024)  (O'Donnell et al. 2020)  (Rigby et al. 2011)  (Seale et al. 2023)  (Varghese et al. 2020) |  | (Tomerini et al. 2011) |  |
| 0 | 7 | 9 | 0 | 1 | 0 |

### 4.4.3 Research gaps

The research evidence base for health adaptation interventions outside of the health system is growing. This includes a small number of studies that consider interventions specifically for priority populations, such as First Nations people, the elderly and women. Several of the included studies focused on communities in regional and remote areas, indicating a balanced split between urban and rural interventions. Of these studies, NSW was the most represented study location, indicating future opportunities to assess interventions in other climatic and geographic areas.

Most studies focused on interventions responding to the health impacts of heat and were largely within the built environment sector. However, there is a lack of studies on interventions to build community resilience to the health impacts of heat, building on the existing studies which explored the role of communication and education to promote personal protection behaviours (Hansen et al. 2011; Varghese et al. 2020). Future research could consider the evaluation of local heat-health action plans, including further studies on public cooling and resilience centres. These interventions can provide a coordinated response to protecting community health and reducing harm by setting out the actions and systems necessary to support priority populations during extreme heat.

Few studies included in the review explored local interventions to protect health from climate-related air pollution. Only two studies examined interventions in relation to the health impacts of bushfire smoke, and no included studies examined interventions to address the potential health impacts of climate-related changes in aeroallergens, such as pollen, and related adaptation measures for allergic diseases. Future research could consider assessing interventions in relation to climate sensitive air-pollutants, including fine particulate matter (PM2.5), ground-level ozone, and aeroallergens like pollen.

There is a significant lack of Australian studies of interventions aiming to strengthen long-term resilience to the physical and mental health impacts of floods, particularly in socioeconomically disadvantaged communities and for people living with a disability. In the studies included in this review, there is limited Australian evidence on interventions to address the health impacts of floods. It is important that future research includes floods adaptation and resilience interventions.

Studies about surveillance and early warning systems with a specific focus on climate-sensitive communicable diseases are underrepresented in the Australian evidence base. There is a need for interventional research that can strengthen adaptation to climate-sensitive communicable diseases in a diverse range of Australian contexts.

For all hazard-specific interventions, it is important that future research specifically considers priority populations that may have reduced adaptative capacity. Research evidence is needed to better design interventions for priority populations, including the development of effective communications tools suitable for diverse audiences, for all potential climate and health impacts.

# 5 Advancing Australian climate and health research

## 5.1 Discussion

In Australia, most climate change and health literature has focused on health impacts, rather than mitigation or adaptation solutions (Beggs et al. 2024), which is consistent with global research trends (Romanello et al. 2023). Overall, the systematic mapping review demonstrated there is a small yet growing body of interventional literature that focuses on mitigation or adaptation solutions across the four themes. This includes 48 primary research studies and 33 reviews published since 2008.

The existing evidence base on climate and health interventions in Australia is small. More research is needed across all four themes to evaluate the efficacy, acceptability and scalability of health-related adaptation and mitigation interventions both within and outside of the health system. Theme 3 had the smallest number of relevant primary studies and reviews. This indicates that while research is needed across all four themes, there is a particular need for more health co-benefit studies of mitigation interventions outside the health system. This requires more interdisciplinary research on interventions across a variety of sectors where it is expected there may be environmental and health co-benefits of mitigation. Health co-benefit research can also inform cross-sectoral policy solutions and help to break down policy silos, which will support the implementation of health-promoting adaptation and mitigation policies.

The research base of certain climate hazards was greater than others across multiple themes. There was a larger number of studies and reviews that discussed interventions addressing extreme heat (n=20) than in relation to any other hazard. This may be because extreme heat causes more injuries and deaths than other extreme weather events and is therefore a considerable health risk (AIHW 2023). However, it is still important that interventions for a diverse range of climate hazards are assessed in the academic literature. This review found a lack of studies of interventions aiming to build long-term resilience to floods. Bushfire smoke was the focus of air quality-related interventions in studies included in this review. There was an absence of studies of climate adaptation interventions to address the health impacts of a wider range of air pollutants potentially exacerbated by climate change, including PM2.5, ground-level ozone, and aeroallergens like pollen.

Similarly, it is important that interventions are designed to address a diverse range of health outcomes. Most of the primary studies focused on the direct and physical health impacts of climate change. A limited number of adaptation studies considered interventions to improve community resilience and mental health outcomes. As climate change continues to influence the spread of infectious diseases, there is a need for research which considers interventions to support communities to adapt to new and unfamiliar infectious diseases. Future research also needs to consider indirect and mental health outcomes, and should account for variations in health outcomes across the country, population groups and over time.

There is a need for more studies with a clear focus on priority populations at the greatest risk of experiencing the health impacts of climate change. Effective engagement and co-design with priority populations can harness communities’ knowledge to design and deliver effective adaptation and mitigation interventions. Some studies in Themes 2 and 4 addressed relevant priority populations in the study design, and considered First Nations people, the elderly, children, and pregnant women. However, gaps persist regarding adaptation and resilience interventions for culturally and linguistically diverse groups, people living with a disability or chronic health condition, socioeconomically disadvantaged communities, healthcare workers, and workers exposed to climate hazards. It is also important that mitigation co-benefit studies consider priority populations, as emissions reductions interventions may have environmental and health benefits for priority populations that could reduce health inequities.

Of note, there is little Australian research that could underpin decarbonisation of Australian health systems, despite the sector’s significant greenhouse gas emissions. There is a need for a larger body of Life Cycle Assessment studies and intervention studies to support Australia’s transition to high-value, low carbon healthcare.

Most of the included studies used qualitative or semi-quantitative survey methods, with fewer studies employing methods such as randomised control trials, comparative life cycle assessments, or other observational or modelling study designs. In future, a more diverse array of study designs would be useful to assess the efficacy of implemented interventions across all four themes. Further, there is a need for future interventional research to assess well-developed and well-defined interventions with strong theoretical foundations, pilot testing, and co-designed methods. Interventions to change behaviour require a strong theoretical basis and pilot testing (Michie et al. 2011). Multicomponent and environmental (system change) interventions are likely to be more effective than single-component (e.g. educational or behavioural) interventions (Michie et al. 2011; Hollands et al. 2017).

As the research evidence base grows, it is important that the literature includes reviews to summarise, catalogue and synthesise the health and environmental benefits of adaptation and mitigation interventions. More reviews are needed, particularly systematic reviews. The results of the systematic mapping review show that most of the relevant reviews published since 2008 are either scoping or narrative.

Finally, across all four themes, studies should be conducted in a wider array of settings. Mitigation studies within the health system should consider interventions in a wider variety of clinical settings, including in primary care and allied health services. Adaption studies need to be conducted in both urban and rural, regional and remote areas. This is to ensure that interventions are not maladaptive and are effective in a diverse range of geographic, socioeconomic and climatic environments.

## 5.2 Limitations

This review only included research studies from the three chosen databases, which were selected given their large collections of health research. Studies only available on other research databases may not have been captured and included, although further manual searches were conducted. Similarly, the inclusion and exclusion criteria used may have inadvertently excluded relevant studies. Furthermore, systematic mapping reviews are at risk of bias due to the inherent nature of categorising the evidence base. To address this limitation, the authorship agreed on the research themes and two reviewers independently categorised them accordingly, with a third reviewer resolving any disagreements. This review seeks to thematically outline the content of the evidence base. It does not synthesise the results of individual studies. Finally, this review only included peer-reviewed literature and did not consider the grey literature. It is important to acknowledge that any screening of the published scientific evidence may not capture the knowledge about adaptation and mitigation interventions by communities or sectors who are not connected with formal academia.

## 5.3 Recommendations

Recommendations for future research identified in the systematic mapping review are summarised below:

### Theme 1: Health system decarbonisation

* **Studies in a diverse range of healthcare settings:** To support health system decarbonisation, interventional research is needed in a variety of clinical settings, including in primary care and allied health services, as well as in aged care. Life Cycle Assessment studies in different health care settings can pinpoint the leverage points for effective decarbonisation intervention. This research can support a transition to low-carbon, high-value care, and can inform procurement and reimbursement decisions.
* **Health-system reform studies:** Studies that explore innovative ideas to reform the health system through interventions to reduce medical overuse and low-value care and prioritise preventative health are needed to reduce the demand for emissions-intensive, hospital-based care.

### Theme 2: Health system adaptation, vulnerability and resilience

* **Studies in a diverse range of healthcare settings to support adaptation for priority populations:** Studies need to be conducted in a wider range of healthcare settings within various speciality areas throughout primary, secondary and tertiary levels of care and should identify the relevant and benefiting priority populations.
* **Whole-of system interventions to promote health system adaptation and resilience:** Research that considers multi-component system level interventions (e.g. focusing on both health workforce resilience as well as service delivery) is needed. This research can support the health system to develop and evaluate comprehensive adaptation interventions for both patients and healthcare workers.

### Theme 3: Health co-benefits of climate change mitigation outside the health system

* **Health co-benefits as a priority theme for climate change and health interventional research:** As the most underrepresented theme, research about the health co-benefits of mitigation outside the health system is a priority. Examining the barriers and enablers of effective implementation and scale-up of interventions that may have health co-benefits is also important. Research needs to be focused in sectors likely to have a significant impact on health, such as housing (including First Nations housing), renewable energy, active transport, and sustainable food production and consumption.

### Theme 4: Adaptation to protect health outside the health system

* **Studies responding to a diverse range of climate impacts:** Adaptation interventions are required on a wider array of climate change and health impacts, including specifically (but not limited to) floods, air pollutants and climate-sensitive communicable diseases. This research should also consider climate impacts in relation to key priority population groups and assess the role of interventions in building long-term community resilience and adaptive capacity.

## 5.4 Conclusion

To advance the Australian climate and health research agenda, there is a need for more research on interventions across all four themes identified in the systematic mapping review. Overall, health co-benefit studies are underrepresented in the Australian literature and should be prioritised. Adaptation and mitigation studies need to be conducted in a broader range of clinical settings to help build a sustainable and resilient health system. Adaptation interventions need to consider a greater diversity of climate hazards, including floods. Across all themes, a clearer focus on priority populations, including First Nations people, is necessary to support health equity in the face of climate change. Methodologically robust, innovative and creative research that proposes, implements and evaluates adaptation and mitigation interventions within and outside the health system will support evidence-based policy and decision-making.

# References

AAHMS (Australian Academy of Health and Medical Sciences) (2022) [*Climate change: an urgent health priority*](https://aahms.org/wp-content/uploads/2022/03/AAHMS_Health-impacts-of-climate-change.pdf), AAHMS.

AIHW (Australian Institute of Health and Welfare) (2023) [*Let’s talk about the weather: injuries related to extreme weather*](https://www.aihw.gov.au/reports/injury/extreme-weather-injuries/contents/about), AIHW, Australian Government.

Adnan MSG, Dewan A, Botje D, Shahid S, Hassan QK (2022) ‘Vulnerability of Australia to heatwaves: A systematic review on influencing factors, impacts, and mitigation options’, Environmental Research, 213(113703), doi:10.1016/j.envres.2022.113703.

Barratt AL, Bell KJL, Charlesworth K, McGain F (2022) ‘High value health care is low carbon health care’, The Medical Journal of Australia, 216(2):67-68, doi:10.5694/mja2.51331.

Beggs PJ, Trueck S, Linnenluecke MK, Bambrick H, Capon AG, Hanigan IC, Arriagada NB, Cross TJ, Friel S, Green D, Heenan M, Jay O, Kennard H, Malik A, McMichael C, Stevenson M, Vardoulakis S, Dang TN, Garvey G, Lovett R, Matthews V, Phung D, Woodward AJ, Romanello MB, Zhang Y (2024) ‘The 2023 report of the MJA–Lancet Countdown on health and climate change: Sustainability needed in Australia's health care sector’, The Medical Journal of Australia, 220(6):282-303, doi:10.5694/mja2.52245.

Blashki G, Armstrong G, Berry HL, Weaver HJ, Hanna EG, Bi P, Harley D, Spickett JT (2011) ‘Preparing health services for climate change in Australia’, Asia-Pacific journal of public health, 23(2 SUPPL.):133A-143S, doi:10.1177/1010539510395121.

Breth-Petersen M, Barratt AL, McGain F, Skowno JJ, Zhong G, Weatherall AD, Bell KJL, Pickles KM (2024) ‘‘Exploring anaesthetists’ views on the carbon footprint of anaesthesia and identifying opportunities and challenges for reducing its impact on the environment’, Anaesthesia and Intensive Care, 52(2):91-103, doi:10.1177/0310057X231212211.

Burgess CP, Johnston FH, Berry HL, McDonnell J, Yibarbuk D, Gunabarra C, Mileran A, Bailie RS (2009) ‘Healthy country, healthy people: the relationship between Indigenous health status and “caring for country”’, The Medical Journal of Australia, 190(10):567-572, doi:10.5694/j.1326-5377.2009.tb02566.x.

Charlesworth KE, Jamieson M (2019) ‘Healthcare in a carbon-constrained world’, Australian Health Review, 43(3):241-245, doi:10.1071/AH17184.

Charlson F, Ali S, Benmarhnia T, Pearl M, Massazza A, Augustinavicius J, Scott JG (2021) ‘Climate change and mental health: A scoping review’, International Journal of Environmental Research and Public Health, 18(9):4486, doi:10.3390/ijerph18094486.

Chen D, Wang X, Thatcher M, Barnett G, Kachenko A, Prince R (2014) ‘Urban vegetation for reducing heat related mortality’, Environmental Pollution, 192:275-284, doi: 10.1016/j.envpol.2014.05.002.

Cowlishaw S, Gibson K, Alexander S, Howard A, Agathos J, Strauven S, Chisholm K, Fredrickson J, Pham L, Lau W, O'Donnell ML (2023) ‘Improving mental health following multiple disasters in Australia: a randomized controlled trial of the Skills for Life Adjustment and Resilience (SOLAR) programme’, European Journal of Psychotraumatology, 14(2):2284032, doi:10.1080/20008066.2023.2284032.

Crandon TJ, Dey C, Scott JG, Thomas HJ, Ali S, Charlson FJ (2022) ‘The clinical implications of climate change for mental health’, Nature Human Behaviour, 6(11):1474-1481, doi:10.1038/s41562-022-01477-6.

Davies JF, McAlister S, Eckelman MJ, McGain F, Seglenieks R, Gutman EN, Groome J, Palipane N, Latoff K, Nielsen D, Sherman JD, TRA2SH, GASP, WAAREN (2024) ‘Environmental and financial impacts of perioperative paracetamol use: a multicentre international life-cycle analysis’, British Journal of Anaesthesia, doi:10.1016/j.bja.2023.11.053.

Davis NF, McGrath S, Quinlan M, Jack G, Lawrentschuk N, Bolton DM (2018) ‘Carbon footprint in flexible ureteroscopy: A comparative study on the environmental impact of reusable and single-use ureteroscopes’, Journal of Endourology, 32(3):214-217, doi:10.1089/end.2018.0001.

de Souza M, Lee AB, Cook S (2023) ‘Healthy patients, workforce and environment: Coupling climate adaptation and mitigation to wellbeing in healthcare’, International Journal of Environmental Research and Public Health, 20(22):7059, doi:10.3390/ijerph20227059.

Delany-Crowe T, Marinova D, Fisher M, McGreevy M, Baum F (2019) ‘Australian policies on water management and climate change: are they supporting the sustainable development goals and improved health and well-being?’, Globalization and health, 15(1):68, doi:10.1186/s12992-019-0509-3.

Desai Z, Zhang Y (2021) ‘Climate change and women's health: A scoping review’, GeoHealth, 5(9): e2021GH000386, doi:10.1029/2021GH000386.

Dufty N (2022) ‘Using heat refuges in heatwave emergencies’, Australian Journal of Emergency Management, 37(2):38-44.

Duindam D (2022) ‘Transitioning to sustainable healthcare: Decarbonising healthcare clinics, a literature review’, Challenges, 13(2):68, doi:10.3390/challe13020068.

Ellis I, Cheek C, Jaffray L, Skinner T (2013) ‘Making a case for telehealth: measuring the carbon cost of health-related travel’, Rural and Remote Health, 13(4):2723.

Giles-Corti B, Foster S, Shilton T, Falconer R (2010) ‘The co-benefits for health of investing in active transportation’, New South Wales Public Health Bulletin, 21(5-6):122-127, doi:10.1071/NB10027.

Haddad S, Paolini R, Ulpiani G, Synnefa A, Hatvani-Kovacs G, Garshasbi S, Fox J, Vasilakopoulou K, Nield L, Santamouris M (2020) ‘Holistic approach to assess co-benefits of local climate mitigation in a hot humid region of Australia’, Scientific Reports, 10(1):14216, doi:10.1038/s41598-020-71148-x.

Hansen A, Bi P, Nitschke M, Pisaniello D, Newbury J, Kitson A (2011) ‘Perceptions of heat-susceptibility in older persons: barriers to adaptation’, International Journal of Environmental Research and Public Health, 8(12)4714-4728, doi:10.3390/ijerph8124714.

Harley D, Bi P, Hall G, Swaminathan A, Tong S, Williams C (2011) ‘Climate change and infectious diseases in Australia: future prospects, adaptation options, and research priorities’, Asia-Pacific Journal of Public Health, 23(2Suppl):54S-66, doi:10.1177/1010539510391660.

Harrison R, Jones B, Gardner P, Lawton R (2021) ‘Quality assessment with diverse studies (QuADS): an appraisal tool for methodological and reporting quality in systematic reviews of mixed- or multi-method studies’, BMC health services research, 21(1):144, doi:10.1186/s12913-021-06122-y.

Hart CR, Berry HL, Tonna AM (2011) ‘Improving the mental health of rural New South Wales communities facing drought and other adversities’, The Australian Journal of Rural Health, 19(5):231-238, doi:10.1111/j.1440-1584.2011.01225.x.

Heaney E, Hunter L, Clulow A, Bowles D, Vardoulakis S (2021) ‘Efficacy of communication techniques and health outcomes of bushfire smoke exposure: A scoping review’, International Journal of Environmental Research and Public Health, 18(20):10889, doi:10.3390/ijerph182010889.

Henneman L, Choirate C, Dedoussi I, Dominici F, Roberts J, Corwin Z (2023) ‘Mortality risk from United States coal electricity generation’, Science, 382(6673):941-946, doi:10.1126/science.adf4915.

Hollands GJ, Bignardi G, Johnston M, Kelly MP, Ogilvie D, Petticrew M, Prestwich A, Shemilt I, Sutton S, Marteau TM (2017) ‘The TIPPME intervention typology for changing environments to change behaviour’, Nature Human Behaviour, 1(0140):1-9, doi:10.1038/s41562-017-0140.

Howden-Chapman P, Chapman R (2012) ‘Health co-benefits from housing-related policies’, Current Opinion in Environmental Sustainability, 4(4):414-419, doi:10.1016/j.cosust.2012.08.010.

Hu Y, Cheng J, Liu S, Tan J, Yan C, Yu G, Yin Y, Tong S (2022) ‘Evaluation of climate change adaptation measures for childhood asthma: A systematic review of epidemiological evidence’, The Science of the Total Environment, 15(839):156291, doi: 10.1016/j.scitotenv.2022.156291.

James KL, Randall NP, Haddaway NR (2016) ‘A methodology for systematic mapping in environmental sciences’, Environmental Evidence, 5(7):1-13, doi:10.1186/s13750-016-0059-6.

Jay O, Capon A, Berry P, Broderick C, de Dear R, Havenith G, Honda Y, Kovats RS, Ma W, Malik A, Morris NB, Nybo L, Seneviratne SI, Vanos J, Ebi KL (2021) ‘Reducing the health effects of hot weather and heat extremes: From personal cooling strategies to green cities’, The Lancet, 398(10301):709-724, doi:10.1016/s0140-6736(21)01209-5.

Kildea S, Simcock G, Liu A, Elgbeili G, Laplante DP, Kahler A, Austin M-P, Tracy S, Kruske S, Tracy M, O'Hara MW, King S (2018) ‘Continuity of midwifery carer moderates the effects of prenatal maternal stress on postnatal maternal wellbeing: The Queensland flood study’, Archives of Women's Mental Health, 21(2):203-214, doi:10.1007/s00737-017-0781-2

Knezevic A, Olcoń K, Smith L, Allan J, Pai P (2023) ‘Wellness Warriors: A qualitative exploration of healthcare staff learning to support their colleagues in the aftermath of the Australian bushfires’, International Journal of Qualitative Studies on Health and Well-being, 18(1):2167298-2167298, doi:10.1080/17482631.2023.2167298.

Liu Y, Lee-Archer P, Sheridan NM, Seglenieks R, McGain F, Eley VA (2023) ‘Nitrous oxide use in Australian health care: Strategies to reduce the climate impact’, Anesthesia and Analgesia, 137(4):819-829, doi:10.1213/ane.0000000000006620

Lokmic-Tomkins Z, Bhandari D, Bain C, Borda A, Kariotis TC, Reser D (2023) ‘Lessons learned from natural disasters around digital health technologies and delivering quality healthcare, International Journal of Environmental Research and Public Health, 20(5):4552, doi:10.3390%2Fijerph20054542.

Longman J, Braddon M, Verlie B, Schlosberg D, Hampshire L, Hawke C, Noonan A, Saurman E (2023) ‘Building resilience to the mental health impacts of climate change in rural Australia’, The Journal of Climate Change and Health, 12:100240, doi:10.1016/j.joclim.2023.100240.

Marfori MT, Campbell SL, Garvey K, McKeown S, Veitch M, Wheeler AJ, Borchers-Arriagada N, Johnston FH (2020) ‘Public health messaging during extreme smoke events: Are we hitting the mark?’, Frontiers in Public Health, 8:465, doi:10.3389/fpubh.2020.00465.

McAlister S, Barratt AL, Bell KJL, McGain F (2020) ‘The carbon footprint of pathology testing’, Medical Journal of Australia, 212(8):377-382, doi:10.5694/mja2.50583.

McAlister S, McGain F, Breth-Petersen M, Story D, Charlesworth K, Ison G, Barratt A (2022) ‘The carbon footprint of hospital diagnostic imaging in Australia’, The Lancet Regional Health – Western Pacific, 24:100459, doi:10.1016/j.lanwpc.2022.100459.

McAlister S, Smyth B, Koprivic I, Luca Di Tanna G, McGain F, Charlesworth K, Brown MA, Konecny P (2023) ‘Carbon emissions and hospital pathology stewardship: A retrospective cohort analysis’, Internal Medicine Journal, 53(4):584-589, doi:10.1111/imj.15622.

McGain F, McAlister S, McGavin A, Story D (2010) ‘The financial and environmental costs of reusable and single-use plastic anaesthetic drug trays’, Anaesthesia and Intensive Care, 38(3):538-544, doi:10.1177/0310057x1003800320.

McGain F, McAlister S, McGavin A, Story D (2012) ‘A Life Cycle Assessment of reusable and single-use central venous catheter insertion kits’. Anesthesia and Analgesia, 114(5):1073-1080, doi:10.1213/ane.0b013e31824e9b69.

McGain F, Naylor C (2014) ‘Environmental sustainability in hospitals – a systematic review and research agenda’, Journal of Health Services Research and Policy, 19(4):245-252, doi:10.1177/1355819614534836.

McGain F, Story D, Lim T, McAlister S (2017) ‘Financial and environmental costs of reusable and single-use anaesthetic equipment’, British Journal of Anaesthesia, 118(6):862-869, doi: 10.1093/bja/aex098.

McGill N, Curtin M, Hodgins G, Parnell T, Verdon S, Crockett J, Davison WR (2024) ‘Supporting children's recovery from bushfires: Stakeholders' views about the impact of a community-based intervention program on children’, The Australian Journal of Rural Health, 32(1):42-52, doi:10.1111/ajr.13060.

McLean M, Phelps C, Smith J, Maheshwari N, Veer V, Bushell D, Matthews R, Craig B, Moro C (2022) ‘An authentic learner-centered planetary health assignment: A five-year evaluation of student choices to address Sustainable Development Goal 13 (Climate Action)’, Frontiers in Public Health, 10:1049932, doi:10.3389/fpubh.2022.1049932.

Michie S, van Stralen MM, West R (2011) ‘The behaviour change wheel: A new method for characterising and designing behaviour change interventions’, Implementation Science, 6:42, doi:10.1186/1748-5908-6-42.

Milner J, Turner G, Ibbetson A, Eustachio Colombo P, Green R, D Dangour A, Haines A, Wilkinson P (2023) ‘Impact on mortality of pathways to net zero greenhouse gas emissions in England and Wales: a multisectoral modelling study’, The Lancet Planetary Health, 7(2), e128-e136, doi:10.1016/s2542-5196(22)00310-2.

Mohtady Ali H, Ranse J, Roiko A, Desha C (2022) ‘’Healthcare Workers’ Resilience Toolkit for Disaster Management and Climate Change Adaptation’, International Journal of Environmental Research and Public Health, 19(19):12440, doi:10.3390/ijerph191912440.

Nitschke M, Krackowizer A, Hansen AL, Bi P, Tucker GR (2017) ‘Heat health messages: A randomized controlled trial of a preventative messages tool in the older population of South Australia’, International Journal of Environmental Research and Public Health, 14(19):992, doi:10.3390/ijerph14090992.

Nitschke M, Tucker G, Hansen A, Williams S, Zhang Y, Bi P (2016) ‘Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis’, BMJ Open, 6(7):e012125, doi:10.1136/bmjopen-2016-012125.

O'Donnell ML, Lau W, Fredrickson J, Gibson K, Bryant RA, Bisson J, Burke S, Busuttil W, Coghlan A, Creamer M, Gray D, Greenberg N, McDermott B, McFarlane AC, Monson CM, Phelps A, Ruzek JI, Schnurr PP, Ugsang J, Watson P, Whitton S, Williams R, Cowlishaw S, Forbes D (2020) ‘An open label pilot study of a brief psychosocial intervention for disaster and trauma survivors’, Frontiers in Psychiatry, 11:483, doi:10.3389/fpsyt.2020.00483.

Palinkas LA, O'Donnell ML, Lau W, Wong M (2020) ‘Strategies for delivering mental health services in response to global climate change: A narrative review’, International Journal of Environmental Research and Public Health, 17(22):8562, doi:10.3390/ijerph17228562.

Patrick R, Capetola T (2011) ‘It's here! Are we ready? Five case studies of health promotion practices that address climate change from within Victorian health care settings’, Health Promotion Journal of Australia, 22:S61-S67, doi:10.1071/he11461.

Patrick R, Kingsley J (2019) ‘Health promotion and sustainability programmes in Australia: barriers and enablers to evaluation’, Global Health Promotion, 26(2):82-92, doi:10.1177/1757975917715038.

Pencheon D, Rissel CE, Hadfield G, Madden DL (2009) ‘Health sector leadership in mitigating climate change: experience from the UK and NSW’, New South Wales Public Health Bulletin, 20(11-12):173-176, doi:10.1071/NB09044.

Pitman SD, Daniels CB, Ely ME (2015) ‘Green infrastructure as life support: Urban nature and climate change’, Transactions of the Royal Society of South Australia, 139(1):97-112, doi:10.1080/03721426.2015.1035219.

Qi J, Ding L, Lim S (2021) ‘Toward cool cities and communities: A sensitivity analysis method to identify the key planning and design variables for urban heat mitigation techniques’, Sustainable Cities and Society, 75:103377, doi:10.1016/j.scs.2021.103377.

Quilty S, Jupurrurla NF, Lal A, Matthews V, Gasparrini A, Hope P, Brearley M, Ebi KL (2023) ‘The relative value of sociocultural and infrastructural adaptations to heat in a very hot climate in northern Australia: a case time series of heat-associated mortality’, The Lancet Planetary Health, 7(8):e684-e693, doi:10.1016/S2542-5196(23)00138-9.

Ridoutt B, Baird D, Hendrie GA (2021) ‘Diets within environmental limits: The climate impact of current and recommended Australian diets’, Nutrients, 13(4):1122, doi:10.3390/nu13041122.

Rigby CW, Rosen A, Berry HL, Hart CR (2011) ‘If the land's sick, we're sick:\* the impact of prolonged drought on the social and emotional well-being of Aboriginal communities in rural New South Wales’, The Australian Journal of Rural Health, 19(5):249-254, doi:10.1111/j.1440-1584.2011.01223.x.

Romanello M, Napoli Cd, Green C, Kennard H, Lampard P, Scamman D, Walawender M, Ali Z, Ameli N, Ayeb-Karlsson S, Beggs PJ, Belesova K, Berrang Ford L, Bowen K, Cai W, Callaghan M, Campbell-Lendrum D, Chambers J, Cross TJ, van Daalen KR, Dalin C, Dasandi N, Dasgupta S, Davies M, Dominguez-Salas P, Dubrow R, Ebi KL, Eckelman M, Ekins P, Freyberg C, Gasparyan O, Gordon-Strachan G, Graham H, Gunther SH, Hamilton I, Hang Y, Hänninen R, Hartinger S, He K, Heidecke J, Hess JJ, Hsu S-C, Jamart L, Jankin S, Jay O, Kelman I, Kiesewetter G, Kinney P, Kniveton D, Kouznetsov R, Larosa F, Lee JKW, Lemke B, Liu Y, Liu Z, Lott M, Lotto Batista M, Lowe R, Odhiambo Sewe M, Martinez-Urtaza J, Maslin M, McAllister L, McMichael C, Mi Z, Milner J, Minor K, Minx JC, Mohajeri N, Momen NC, Moradi-Lakeh M, Morrissey K, Munzert S, Murray KA, Neville T, Nilsson M, Obradovich N, O'Hare MB, Oliveira C, Oreszczyn T, Otto M, Owfi F, Pearman O, Pega F, Pershing A, Rabbaniha M, Rickman J, Robinson EJZ, Rocklöv J, Salas RN, Semenza JC, Sherman JD, Shumake-Guillemot J, Silbert G, Sofiev M, Springmann M, Stowell JD, Tabatabaei M, Taylor J, Thompson R, Tonne C, et al. (2023) ‘The 2023 report of the Lancet Countdown on health and climate change: The imperative for a health-centred response in a world facing irreversible harms’, The Lancet, 402(10419):2346-2394, doi:0.1016/S0140-6736(23)01859-7.

Sadeghi M, Chaston T, Hanigan I, de Dear R, Santamouris M, Jalaludin B, Morgan GG (2022) ‘The health benefits of greening strategies to cool urban environments – A heat health impact method’, Building and Environment, 207:108546, doi: 10.1016/j.buildenv.2021.108546.

Santamouris M, Paolini R, Haddad S, Synnefa A, Garshasbi S, Hatvani-Kovacs G, Gobakis K, Yenneti K, Vasilakopoulou K, Feng J, Gao K, Papangelis G, Dandou A, Methymaki G, Portalakis P, Tombrou M (2020) ‘Heat mitigation technologies can improve sustainability in cities. An holistic experimental and numerical impact assessment of urban overheating and related heat mitigation strategies on energy consumption, indoor comfort, vulnerability and heat-related mortality and morbidity in cities’, Energy and Buildings, 217:110002, doi:10.1016/j.enbuild.2020.110002.

Seale H, Trent M, Marks GB, Shah S, Chughtai AA, MacIntyre CR (2023) ‘Exploring the use of masks for protection against the effects of wildfire smoke among people with preexisting respiratory conditions’, BMC Public Health, 23(1):2330, doi:10.1186/s12889-023-17274-3.

Schultz R, Abbott T, Yamaguchi J, Cairney S (2018) ‘Indigenous land management as primary health care: qualitative analysis from the Interplay research project in remote Australia’, BMC Health Services Research, 18(1):960, doi:10.1186/s12913-018-3764-8.

Talbot B, Barraclough K, Sypek M, Gois P, Arnold L, McDonald S, Knight J (2022) ‘A survey of environmental sustainability practices in dialysis facilities in Australia and New Zealand’, Clinical Journal of the American Society of Nephrology, 17(12):1792-1799, doi:10.2215/CJN.08090722.

Tomerini DM, Dale PE, Sipe N (2011) ‘Does mosquito control have an effect on mosquito-borne disease? The case of Ross River virus disease and mosquito management in Queensland, Australia’, Journal of the American Mosquito Control Association, 27(1):39-44, doi:10.2987/10-6038.1.

Walker R, Hassall J, Chaplin S, Congues J, Bajayo R, Mason W (2011) ‘Health promotion interventions to address climate change using a primary health care approach: a literature review’, Health Promotion Journal of Australia, 22:S6-S12, doi:10.1071/he11406.

Walker R, South East Healthy Communities P (2009) ‘Climate change and primary health care intervention framework’, Australian Journal of Primary Health, 15(4):276-284, doi:10.1071/PY09041.

Walter TG, Bricknell LK, Preston RG, Crawford EGC (2024) ‘Climate change adaptation methods for public health prevention in Australia: an integrative review’, Current Environmental Health Reports, 11(1):71-87, doi:10.1007/s40572-023-00422-7.

Wheeler AJ, Allen RW, Lawrence K, Roulston CT, Powell J, Williamson GJ, Jones PJ, Reisen F, Morgan GG, Johnston FH (2021) ‘Can public spaces effectively be used as cleaner indoor air shelters during extreme smoke events?’, International Journal of Environmental Research and Public Health, 18(8):4085, doi:10.3390/ijerph18084085.

Whitmee S, Green R, Belesova K, Hassan S, Cuevas S, Murage P, Picetti R, Clercq-Roques R, Murray K, Falconer J, Anton B, Reynolds T, Sharma Waddington H, Hughes RC, Spadaro J, Aguilar Jaber A, Saheb Y, Campbell-Lendrum D, Cortés-Puch M, Ebi K, Huxley R, Mazzucato M, Oni T, de Paula N, Peng G, Revi A, Rockström J, Srivastava L, Whitmarsh L, Zougmoré R, Phumaphi J, Clark H, Haines A (2024) ‘Pathways to a healthy net-zero future: report of the Lancet Pathfinder Commission’, The Lancet, 403(10421):67-110, doi:10.1016/S0140-6736(23)02466-2.

Willand N, Ridley I, Maller C (2015) ‘Towards explaining the health impacts of residential energy efficiency interventions - A realist review. Part 1: Pathways’, Social Science and Medicine, 133:191-201, doi:10.1016/j.socscimed.2015.02.005.

Williams S, Hanson-Easey S, Nitschke M, Howell S, Nairn J, Beattie C, Wynwood G, Bi P (2019) ‘Heat-health warnings in regional Australia: Examining public perceptions and responses’, Environmental Hazards, 18(4):287-310, doi:10.1080/17477891.2018.1538867.

Williams S, Nitschke M, Wondmagegn BY, Tong M, Xiang J, Hansen A, Nairn J, Karnon J, Bi P (2022) ‘Evaluating cost benefits from a heat health warning system in Adelaide, South Australia’, Australian and New Zealand Journal of Public Health, 46(2):149-154, doi:10.1111/1753-6405.13194.

Workman A, Blashki G, Karoly D, Wiseman J. (2016) ‘The role of health co-benefits in the development of Australian climate change mitigation policies’, International Journal of Environmental Research and Public Health, 13(9):927, doi:10.3390/ijerph13090927.

Wyssusek K, Chan KL, Eames G, Whately Y (2022) ‘Greenhouse gas reduction in anaesthesia practice: a departmental environmental strategy’, BMJ Open Quality, 11(3):e001867, doi:10.1136/bmjoq-2022-001867.

Wyssusek KH, Keys MT, van Zundert AAJ (2019) ‘Operating room greening initiatives - the old, the new, and the way forward: A narrative review’, Waste Management and Research, 37(1):3-19, doi:10.1177/0734242X18793937.

van Beurden EK, Kia AM, Hughes D, Fuller JD, Dietrich U, Howton K, Kavooru S (2011) ‘Networked resilience in rural Australia--a role for health promotion in regional responses to climate change’, Health Promotion Journal of Australia, 22:S54-S60, doi:10.1071/he11454.

Varghese BM, Hansen AL, Williams S, Bi P, Hanson-Easey S, Barnett AG, Heyworth JS, Sim MR, Rowett S, Nitschke M, Di Corleto R, Pisaniello DL (2020) ‘Heat-related injuries in Australian workplaces: Perspectives from health and safety representatives’, Safety Science, 126:104651, 10.1016/j.ssci.2020.104651.

Vien MH, Ivey SL, Boyden H, Holm S, Neuhauser L (2024) ‘A scoping review of wildfire smoke risk communications: issues, gaps, and recommendations’, BMC Public Health, 24(1):312, doi:10.1186/s12889-024-17681-0.

Vu A, Rutherford S, Phung D (2019) ‘Heat health prevention measures and adaptation in older populations - A systematic review’ International Journal of Environmental Research and Public Health, 16(22):4370, doi:10.3390/ijerph16224370.

Xu R, Yu P, Liu Y, Chen G, Yang Z, Zhang Y, Wu Y, Beggs PJ, Zhang Y, Boocock J, Ji F, Hanigan I, Jay O, Bi P, Vargas N, Leder K, Green D, Quail K, Huxley R, Jalaludin B, Hu W, Dennekamp M, Vardoulakis S, Bone A, Abrahams J, Johnston FH, Broome R, Capon T, Li S, Guo Y (2023) ‘Climate change, environmental extremes, and human health in Australia: Challenges, adaptation strategies, and policy gaps’, The Lancet Regional Health. Western Pacific, 40:100936, doi:10.1016/j.lanwpc.2023.100936.

Zhao Q, Yu P, Mahendran R, Huang W, Gao Y, Yang Z, Ye T, Wen B, Wu Y, Li S, Guo Y (2022) ‘Global climate change and human health: Pathways and possible solutions’, Eco-Environment & Health (Online), 1(2):53-62, doi:10.1016/j.eehl.2022.04.004.

Zurynski Y, Fisher G, Wijekulasuriya S, Leask E, Dharmayani PNA, Ellis LA, Smith CL, Braithwaite J (2024) ‘Bolstering health systems to cope with the impacts of climate change events: A review of the evidence on workforce planning, upskilling, and capacity building’,The International Journal of Health Planning and Management, 39(3):781-805, doi:10.1002/hpm.3769.

