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HEAL

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

National Health and Climate Strategy | Action 7.2



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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.

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Table of contents

Table of contents	3
Figures and Tables	4
List of Figures	4
List of Tables.....	4
Version control.....	5
Executive summary	6
1 Introduction.....	7
1.1 Policy context and aim	7
1.2 The climate and health research landscape	7
2 Methods	8
2.1 Overview.....	8
2.2 Objectives and research questions	8
2.3 Research themes.....	8
3 Overall summary of the research	9
4 Summary of the research by theme	11
4.1 Theme 1: Health system decarbonisation	11
4.2 Theme 2: Health system adaptation, vulnerability and resilience	15
4.3 Theme 3: Health co-benefits of climate change mitigation outside the health system	19
4.4 Theme 4: Adaptation to protect health outside the health system.....	22
5 Advancing Australian climate and health research	26
5.1 Discussion	26
5.2 Limitations	28
5.3 Recommendations.....	28
5.4 Conclusion.....	29
References	30

Figures and Tables

List of Figures

Figure 1. Annual distribution of publications included between 2008 to March 202410

List of Tables

Table 1. Summary of included studies by theme.....9

Table 2. Summary of overall Quality Assessment results for primary studies by theme ..10

Table 3. Theme 1 primary studies grouped by type of health system decarbonisation intervention12

Table 4. Theme 1 primary studies grouped by category of health and aged care services13

Table 5. Theme 2 primary studies grouped by climate impact17

Table 6. Theme 2 primary studies grouped by areas of health and aged care services ..17

Table 7. Theme 3 primary studies grouped by economic sector20

Table 8. Theme 4 primary studies grouped by climate impact24

Table 9. Theme 4 primary studies grouped by economic sector24

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
(2) Health system adaptation, vulnerability and resilience	14	10	24
(3) Health co-benefits of climate change mitigation outside the health system	4	3	7
(4) 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.

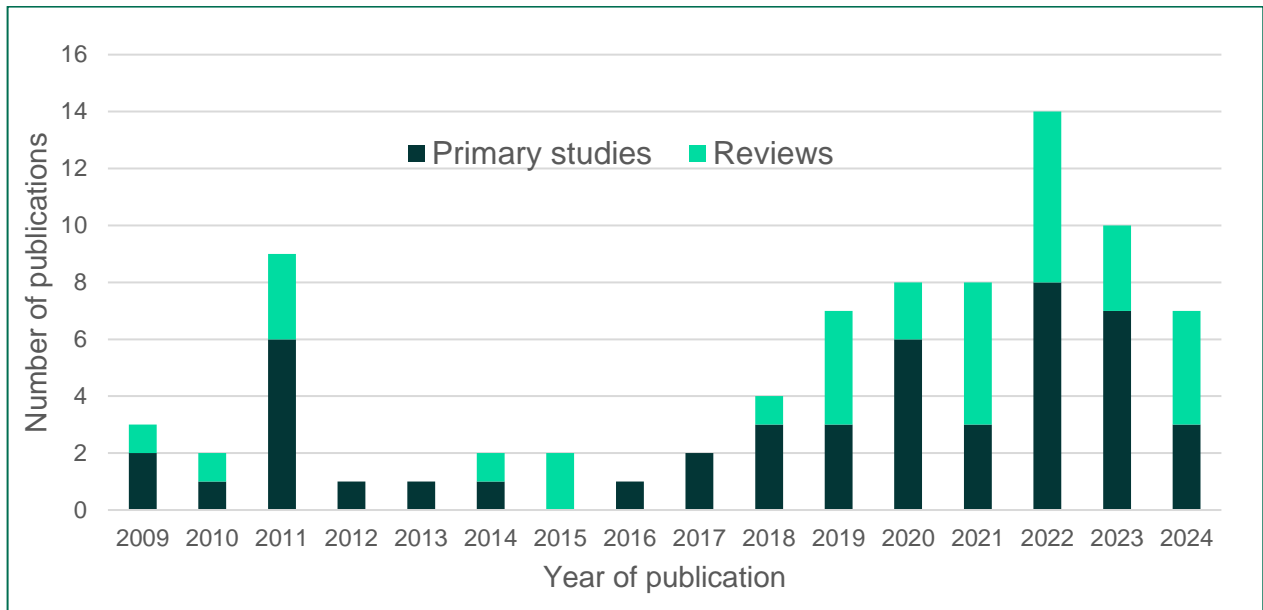


Figure 1. Annual distribution of publications included between 2008 to March 2024

Seven studies covered populations or health services from across all of Australia. There were 14 studies focused on New South Wales (NSW), 11 on Victoria (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

Theme	Score*			
	Very low (0)	Low (1)	Moderate (2)	High (3)
(1) Health system decarbonisation	0	3	9	1
(2) Health system adaptation, vulnerability and resilience	0	2	10	2
(3) Health co-benefits of climate change mitigation outside the health system	0	0	3	1
(4) 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 (Cowlshaw 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)	(Cowlshaw et al. 2023) (Longman et al. 2023) (McGill et al. 2024) (O'Donnell et al. 2020) (Seale et al. 2023) (Wheeler et al. 2021)	(Cowlshaw 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)	(Cowlshaw 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 (PM_{2.5}), 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 adaptive 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 PM_{2.5}, 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.

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