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Key Points:

- Climate change related extreme events place pressure on health care systems, however future health care costs are poorly understood
- We calculate future costs related to heatwaves, using ambulance dispatches in Tasmania, Australia as a case study
- Projected costs modeled for a non-adapted population are almost 10× higher than for an adapted population

Supporting Information:

Supporting Information may be found in the online version of this article.

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Methods of Assessing Health Care Costs in a Changing Climate: A Case Study of Heatwaves and Ambulance Dispatches in Tasmania, Australia

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Abstract Anthropogenic climate change is causing a rise in global temperatures, with this trend projected to increase into the future. Rising temperatures result in an increase in the frequency and severity of heatwave events, with an associated increase in poor health outcomes for vulnerable individuals. This places an increasing strain on health care services. However, methods calculating future health care costs associated with this trend are poorly understood. We calculated health care costs attributable to heatwave events in Tasmania 2009–2019, using ambulance dispatches as a case study. We also modeled the expected health and economic burden for projected heatwave frequencies between 2010 and 2089. We developed our models based on two possible approaches to describing population adaptation to heatwaves—an adapted population calculated by determining heatwave episodes using a rolling baseline, and a non-adapted population calculated by determining heatwave episodes using a static baseline. Using a rolling baseline calculation for 2010 to 2089, we estimated additional ambulance costs averaging AUD$57,147 per year and totaling AUD$4,571,788. For the same period using a static baseline, we estimated additional ambulance costs averaging AUD$517,342 per year and totaling AUD$41,387,349. While this method is suitable for estimating the health care costs associated with heatwaves, it could be utilized for estimating health care costs related to other climate-related extreme events. Different methods of estimating heatwaves, modeling an adapted versus non-adapted population, provide substantial differences in projected costs. There is potential for considerable health system cost savings when a population is supported to adapt to extreme heat.

Plain Language Summary Our research describes the projected economic cost of heatwaves on health care services, using ambulance dispatches in Tasmania, Australia as a case study. We find that costs modeled for a population not adapted to heatwaves are almost 10 times higher than for a population adapted to heatwaves.

1. Introduction

Anthropogenic climate change is causing a global increase in the frequency and severity of extreme heat events or heatwaves (Perkins-Kirkpatrick & Lewis, 2020), a trend projected to continue into the future unless substantial limiting of greenhouse gas emissions is undertaken worldwide (Intergovernmental Panel on Climate Change, 2021).

An extensive body of research indicates these events are closely associated with poor health outcomes such as increased mortality and morbidity, as evidenced by increased hospital admissions, emergency department presentations and ambulance dispatches during and immediately after heatwave events (Campbell et al., 2018; Song et al., 2017). While these impacts occur across populations, consistent associations are present for the aged, the young, and for those with existing medical conditions, including cardiovascular, respiratory, psychological and renal conditions across a wide variety of regions, landscapes and climates (Dalip et al., 2015; Gronlund et al., 2016; Trang et al., 2016; Wang et al., 2014).

However, the economic impact of these events on the health care system is poorly understood, with few studies analyzing health care costs by assessing mortality and morbidity impact (Adélaïde et al., 2021; Yan et al., 2022), and a small number of studies analyzing economic impact through labor reduction (García-León et al., 2021; Miller et al., 2021; Zander et al., 2015). The projected impacts and costs to the health care system as heatwaves rise in frequency and severity are even less well understood, with limited and recent studies exploring this association (Ke et al., 2023; Tong et al., 2021).

Here, we use ambulance dispatches in Tasmania, Australia as a specific case study to evaluate the projected cost of heatwaves on health care outcomes. We use data from a previous analysis describing the historic association between ambulance dispatches and heatwave events (Campbell et al., 2021), and use climate projection data to determine the frequency and severity of heatwaves from 2010 to 2089 for this region. We compare and contrast two approaches: (a) using a rolling baseline, which models a population adapted to increasing episodes of extreme heat, and (b) a static baseline, which models a population non-adapted to increasing heat.

1.1. Study Location

Tasmania lies approximately 300 km south of mainland Australia. The majority of the Tasmanian population reside in an area classified as regional or remote (Australian Bureau of Statistics, 2011). The state's estimated population in 2022 was 571,500, with the majority of the population residing in one of three major centers: Hobart in the south east Launceston in the central north, and the combined north-west coastal centers of Burnie and Devonport (Australian Bureau of Statistics, 2022). Remaining residents are scattered across small towns and settlements. The Bureau of Meteorology forecast districts of South East, Central North and North West Coast align with these major population centers (Figure 1).

Although heatwaves are relatively rare in Tasmania compared to other Australian jurisdictions (Campbell et al., 2019), Tasmania has a greater proportion of elderly people, a greater proportion of those living with a chronic health condition, and the highest proportion of those living in disadvantaged regions (Australian Bureau of Statistics, 2018; Department of Health, 2018). This makes the Tasmanian population potentially more vulnerable to heat-related illness when compared to other Australian jurisdictions.

Previous studies located in Tasmania have demonstrated a rise in health care episodes due to heatwaves. These studies show that ambulance dispatches rise by 4% in low-intensity events (OR 1.04, 95% CI 1.02–1.06), by 10% in severe events (OR 1.10, 95% CI 1.05–1.15) and by 34% in extreme events (OR 1.34, 95% CI 1.18–1.52) (Campbell et al., 2021). Furthermore, a rise of 5% in emergency department presentations across the whole population is evident in combined severe and extreme events (OR 1.05, 95% CI 1.01–1.09), increasing to 13% (OR 1.13, 95% CI 1.03–1.24) for children 15 years and under, and to 19% (OR 1.19, 95% CI 1.04–1.36) for children 5 years and under (Campbell et al., 2019). Results from Campbell et al. (2021) were used in this study as the basis for estimating future health care costs.

2. Materials and Data

We used the following steps to estimate projected ambulance costs associated with heatwave events (see Figure 2). At Level 1, we used existing data sets describing health care, health care costs, historical climate and projected future climate (as outlined in Sections 2.1–2.3 below). These were analyzed (Level 2) to create additional multidisciplinary data sets (Level 3), where health care data and health cost data were combined, and health care data and heatwave data were combined. At Level 4, these new data sets were analyzed to generate economic costs of heatwaves. At Level 5, this analysis was combined with projected climate data to create the projected health care costs of heatwave events.

2.1. Previous Analysis

Historical heatwave data (Step 1a) and ambulance data (Step 1b) were previously analyzed (Step 2a) to provide heatwave association data (Step 3a) (Campbell et al., 2021).

2.2. Ambulance Cost

Ambulance cost data (Step 1c) were derived from (a) the *Ambulance Service* (*Fees*) *Regulations Act 2011* (Tasmanian Government, 2022) and (b) the 2021 fee attribution unit as determined by the Tasmanian Department of Treasury and Finance (Tasmanian Government, 2021). Under the Act, the use of an ambulance (for treatment and transport round trip) is costed at 622.04 fee units for the first 15 km (or part of), with a further 5.07 fee units

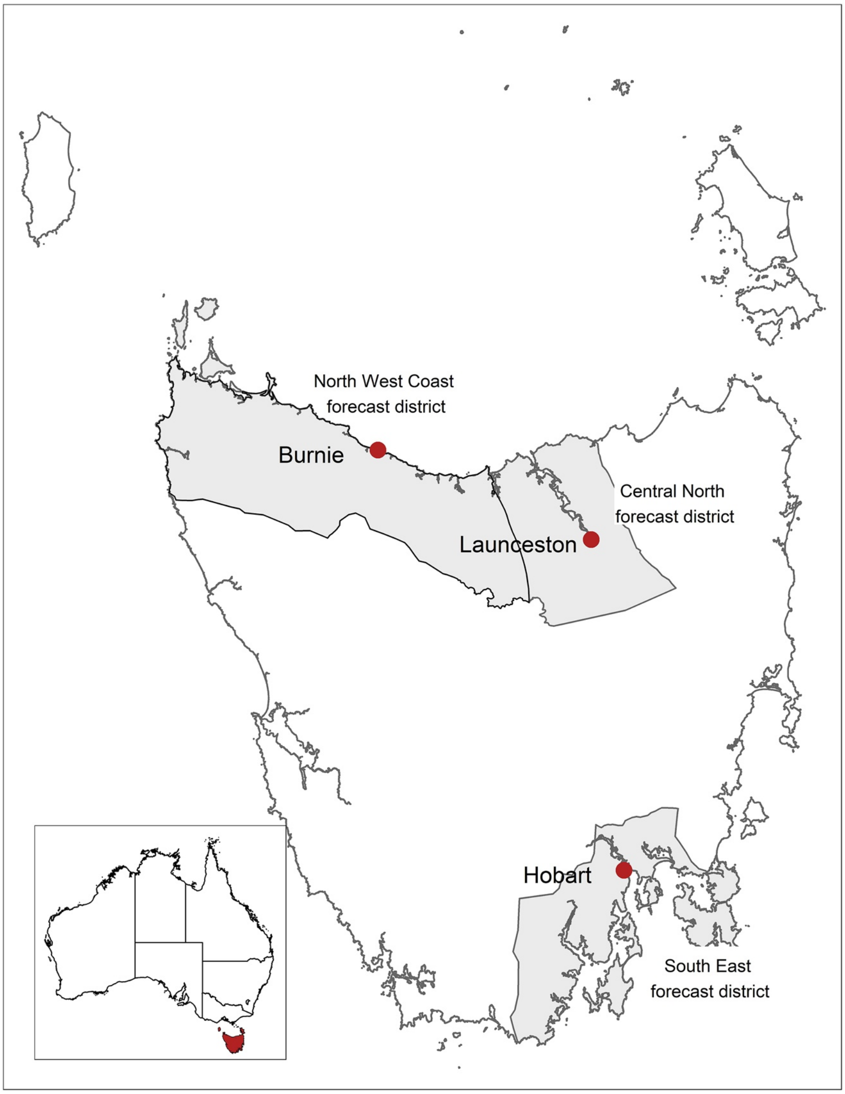

Figure 1. Map of Tasmania, Australia with Bureau of Meteorology forecast districts overlaying major population centers.

for each kilometer thereafter. As distance traveled for each dispatch was not available, we assumed an average flat rate of 15 km per dispatch. Using the 2021 fee unit attribution of $1.65, cost per ambulance dispatch in 2021 terms was calculated (Step 2b) as:

$$\$1.65 * 622.04 = \$1026.37$$

creating costed ambulance data (Step 3b).

2.3. Projected Heatwave Data

Climate projection data were derived using an ensemble of six global climate models (CSIRO-BOM-ACCESS1-0, CNRM-CERFACS-CNRM-CM5, NOAA-GFDL-GFDL-ESM2M, MOHC-HadGEM2-CC, MIROC-MIROC5, and NCC-NorESM1-M) at approximately 100 km spatial resolution and 6-hourly temporal resolution. This was dynamically downscaled using the CCAM model to approximately 10 km spatial resolution and 6-min temporal resolution, stored at 1-hr timesteps. Full details of this process can be found in Thatcher and Hurley (2012). This modeled output was then bias-adjusted using the Australian Gridded Climate Data product (Jones et al., 2009) as the reference data set. From this ensemble, daily maximum temperature was extracted for analysis for the period 1960 to 2089 (Step 1d).

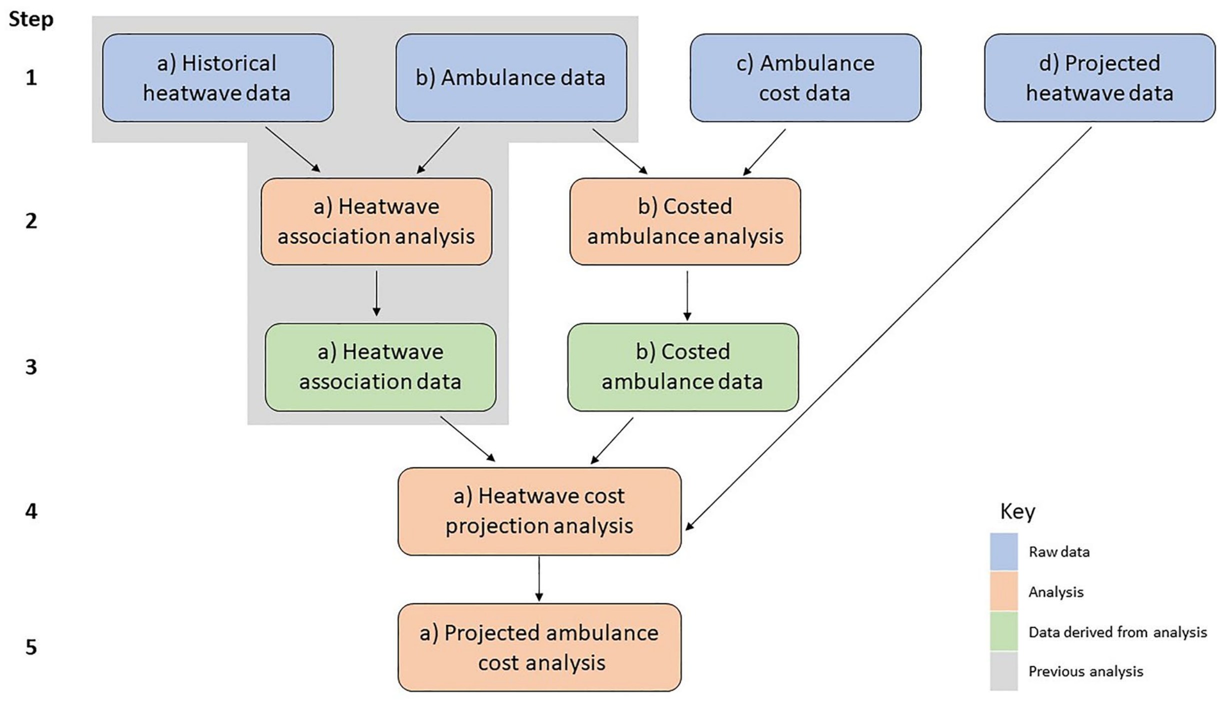

Figure 2. Steps involved in analyzing projected ambulance costs associated with heatwave events.

2.4. Spatial Analysis

The target regions for analysis were defined by the Bureau of Meteorology forecast districts of South East, Central North and North West Coast, corresponding to the major population centers of Hobart, Launceston and Burnie/Devonport respectively (see Figure 1). Model output grid cells that intersected with these polygons were included. For each timestep, the spatial mean was calculated to create a time series for each target region. This time series was used as input to the heatwave assessment.

For each of the three forecast districts, the number of heatwave days by severity (low-intensity, severe and extreme) were calculated for each model, using the Excess Heat Factor method described elsewhere (Nairn & Fawcett, 2015), which notably is also used by the Bureau of Meteorology's Heatwave Service for Australia (Bureau of Meteorology, 2019). For each district and across all severity levels, two methods of EHF calculation were used: (a) a static baseline (over the period 1960–1989); and (b) a rolling baseline (30-year time periods looking at the previous 30 years, stepping forward each year from 1990 to 2089).

The EHF methods described by Nairn and Fawcett (2015) use a single baseline period to calculate the key percentiles and physical thresholds where populations in that location begin to feel heat stress from a heatwave. If only a single baseline period is used, it assumes minimal adaptation of the target population or social system as the climate changes. While this may be true for some species, conditions or situations, for example, where adaptation is not possible, it is unlikely in the context of human exposure to heat, where adaptation is likely (such as the installation of improved cooling systems, public cooled spaces, improved housing structures and increased tree shading). A well-adapted system would have key thresholds that change over time, statistically represented as a rolling baseline. Therefore, methods using a single baseline period are not useful for assessing heatwave risk into the future.

Keeping some consistency with Nairn and Fawcett (2015), we used a rolling baseline defined as the 30-year period prior to the year being assessed. These methods revealed two frequency assessments of heatwaves and their severity, one following an assumption of minimal adaptation and the other assuming near-perfect adaptation.

For each of the three regions and for each model, the number of heatwave days per year were calculated by severity (low-intensity, severe and extreme). The mean number of heatwave days were then calculated per year for each severity level, using the average number of days per year across all models. For optimal visualization, statistical methods described in Mann (2008) were used.

Table 1
Projected Number of Heatwave Days per Year for Tasmania, Australia[a]

	Low-intensity		Severe		Extreme	
Year	Static baseline	Rolling baseline	Static baseline	Rolling baseline	Static baseline	Rolling baseline
1960	10.16	11.21	2.29	2.01	0.14	0.17
1970	9.23	9.12	1.44	1.44	0.14	0.14
1980	8.73	8.68	1.23	1.32	0.11	0.10
1990	10.15	10.31	1.63	1.65	0.08	0.08
2000	12.22	11.86	2.03	1.95	0.10	0.10
2010	13.70	12.07	2.17	1.96	0.14	0.12
2020	15.72	12.09	2.38	1.92	0.20	0.15
2030	19.49	12.97	2.95	2.00	0.28	0.19
2040	23.71	13.78	3.72	2.11	0.35	0.23
2050	27.10	13.63	4.44	2.19	0.42	0.23
2060	31.64	13.57	5.25	2.38	0.55	0.21
2070	39.31	14.47	6.40	2.62	0.80	0.23
2080	47.29	14.85	7.58	2.56	1.00	0.27

[a]Heatwaves days include low-intensity, severe and extreme heatwave categories. Projected days by both static baseline and rolling baseline from a multi-model mean (year samples by decade, 2020–2080).

For a state-wide assessment, values for each forecast district were aggregated. Forecast districts were treated as independent, therefore values were aggregated by summing all heatwave days for each year across all three forecast districts.

2.5. Ambulance Data

Ambulance dispatch data for paramedic assessments for all regions of Tasmania were obtained from Ambulance Tasmania for the period 1 January 2008–31 March 2021. These data are clinical records completed by the attending paramedic at the time of, or immediately following, the incident prompting the ambulance dispatch. Records containing "Standby" and "Transfer" dispatches were excluded as they do not reflect acute clinical cases, as were records with no date, no suburb or those recorded as outside Tasmania.

Using these data, the daily mean of all ambulance dispatches was calculated for the period 1 January 2010–31 December 2019.

2.6. Projected Cost Attribution

Using the daily mean of ambulance dispatches as described above, a baseline daily cost was calculated. For each year, the number of heatwave days over or under this baseline period were calculated. This figure was multiplied by the baseline daily cost and the corresponding heatwave severity odds ratio (increased fraction) obtained from Campbell et al. (2021). These were:

- Low-intensity heatwaves: 0.04
- Severe heatwaves: 0.10
- Extreme heatwaves: 0.34.

This calculation resulted in determining an additional cost over the baseline period, for each year, for each heatwave severity and for each of the static and rolling baseline models.

3. Results

3.1. Descriptive Ambulance Results

From 1 January 2010–31 December 2019, 660,065 ambulance dispatches were recorded across Tasmania. The daily mean was 180.7, with a daily range of 36–258. The gender distribution of cases were 51.73% female and 48.00% male, with 0.26% unknown. Age distribution shows 4.19% aged 5 years and under; 7.73% aged 15 years and under; 45.04% aged 16–64 years, and 46.41% aged 65 and over.

3.2. Heatwave Days

Table 1 and Figure 3 show the annual projected number of heatwave days for Tasmania by severity (low-intensity, severe and extreme) using a multi-model ensemble mean, showing both a static baseline and a rolling baseline. Table 1 shows sample points at decadal intervals only. For annual data, see Table S1 in Supporting Information S1. Charts for South East, Central North and North West Coast regions can be found in Figures S1–S3 in Supporting Information S1.

3.3. Additional Ambulance Dispatch Costs

Table 2 and Figure 4 show the annual additional projected ambulance dispatch costs in Tasmania using both a static baseline and a rolling baseline. Table 2 shows sample points at decadal intervals only for the multi-model mean. For annual data, see Table S2 in Supporting Information S1.

4. Discussion

Our study calculated the projected costs of ambulance dispatches due to heatwaves in Tasmania, Australia using two different methodologies. Using a static baseline, these costs were in excess of AUD$40 million for the period

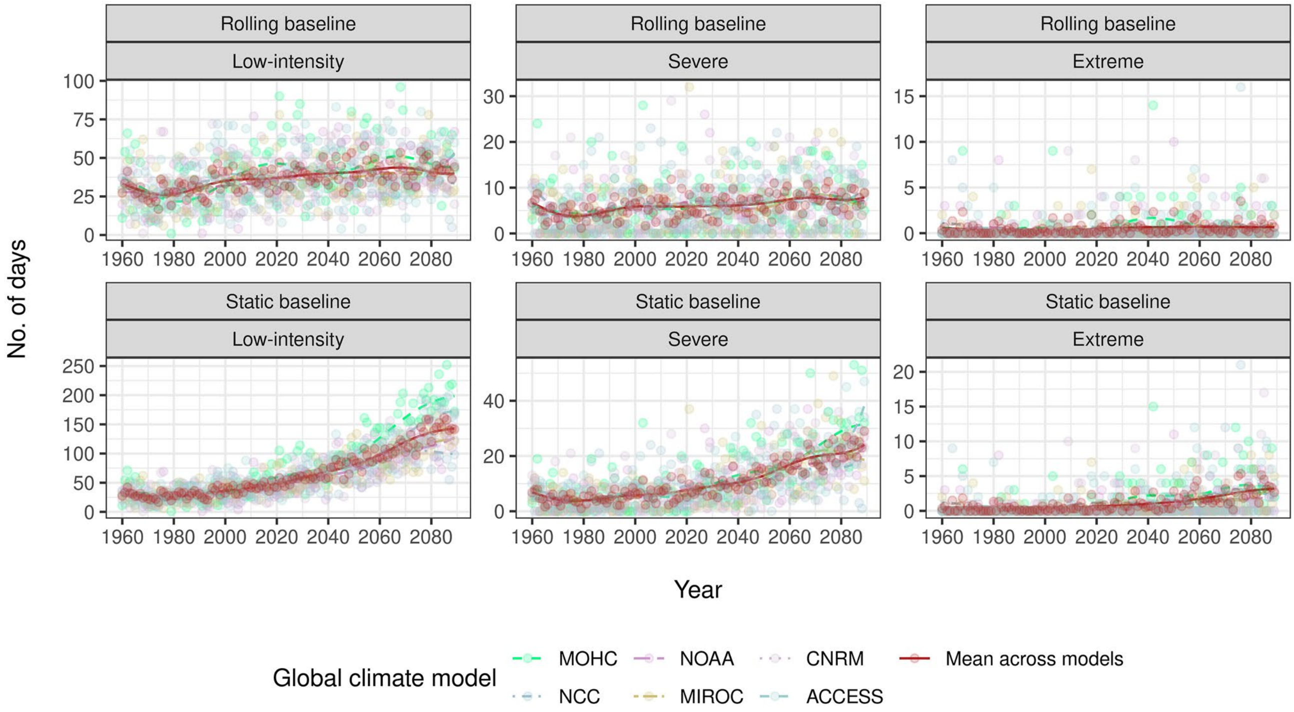

Figure 3. Projected number of days per year across multiple models for low-intensity, severe and extreme heatwaves in Tasmania, using a rolling baseline and a static baseline (1960–2089).

2010–2089. Using a rolling baseline, these costs were in excess of AUD$4.5 million for the same period. Our study highlights the difference between an adaptive approach and a non-adaptive approach when evaluating the health costs of climate-related extreme events.

The main strength of our study is that the methodological steps involved can be adapted and scaled to other jurisdictions, alternative extreme events, climate projection and health outcome data as available. For example, the projected costs of hospital admissions from bushfires and poor air quality in New South Wales, Australia could be calculated, where the association between poor air quality from bushfires and hospital admissions had been previously studied, and the projected frequency and severity of bushfires had been determined through climate projections.

Both a static baseline and a rolling baseline were used to assess the impact of heatwaves with non-adaptive and near perfectly-adaptive scenarios respectively. While we can assume humans can adapt to increasing temperatures (to a limit) through the application of technology, behavior change and physiological changes, we are unable to ascertain with certainty the degree of this adaptation. Providing a methodology to calculate EHF (and therefore heatwave intensity and severity) for both non-adaptive and adaptive scenarios allows an estimate of the range of plausible futures, taking climatic and social drivers into account.

Given substantial uncertainty over the amount and demographic mix of population estimates to 2089, projected population estimates were not taken into consideration in this analysis. Therefore, it can be assumed that these costs are expressed in current dollars, with current population levels, but with projected temperatures. Assuming an increasing population, these costs will be amplified accordingly.

Costs identified by this method only quantify ambulance dispatch and transport costs and do not take other ambulance costs into account, for example, call center and administrative staff costs. Therefore, the costs expressed in

Table 2
Additional Ambulance Costs From Heatwaves Above Baseline (2010–2019) for Tasmania, Australia[a]

Year	Rolling baseline	Static baseline
2020	$7,829.97	$52,203.66
2030	$30,919.35	$168,445.81
2040	$47,035.02	$283,504.45
2050	$63,597.70	$430,867.09
2060	$94,758.24	$662,582.24
2070	$105,665.58	$917,655.74
2080	$76,199.58	$1,095,238.94

[a]Projected costs for both static baseline and rolling baseline from a multi-model mean (year samples by decade, 2020–2080).

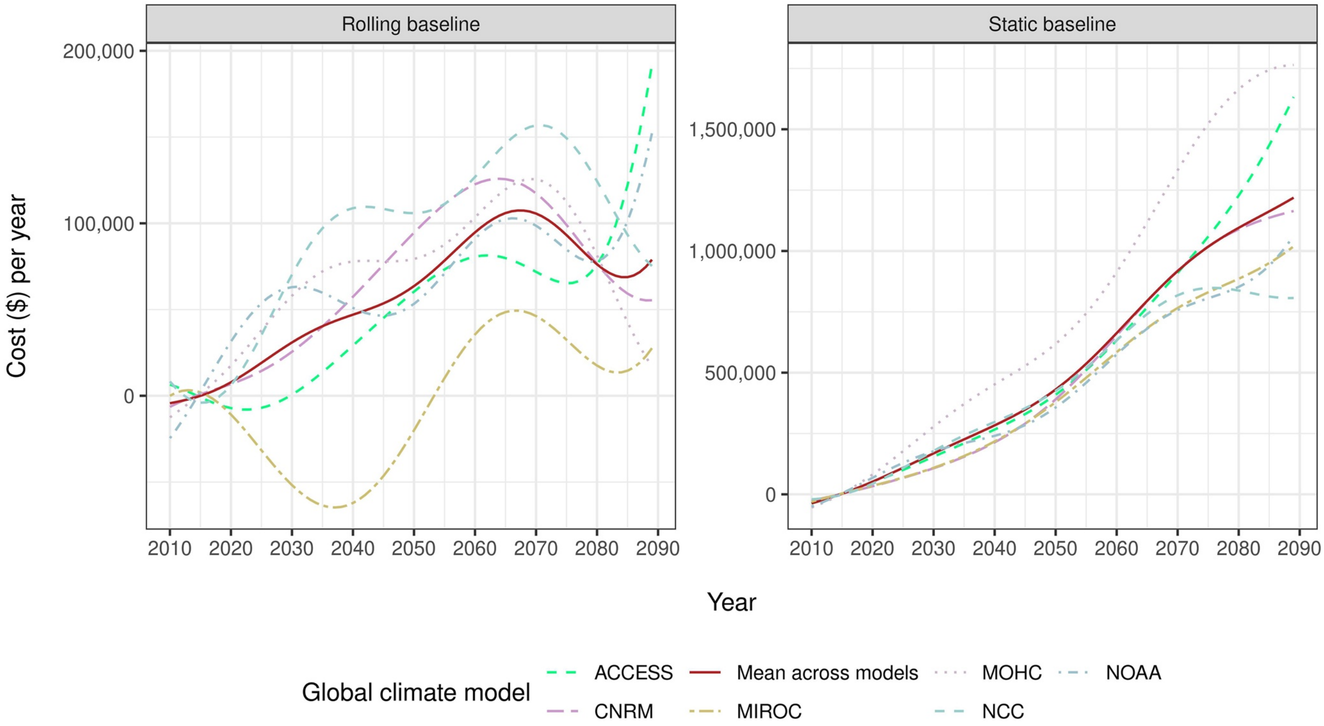

Figure 4. Additional ambulance costs from heatwaves above baseline (2010–2019) for Tasmania, Australia, projected for both a static baseline and rolling baseline across multiple models.

this methodology are the minimum costs applied to the health outcome in question. It is also important to note that this study only reflects costs associated with ambulance dispatches, and does not include the many and varied additional health care costs associated with heatwaves, for example, hospital presentations and admissions, general practice visits and mental health service visits, which provide future research opportunities to evaluate the true cost of heatwaves on the health system.

This proposed methodology potentially provides a robust and scalable method for health policymakers to plan for future health care costs in the face of increasing and more severe extreme events. Using both adaptive and non-adaptive methods highlight the importance of adopting adaptive mechanisms at an early stage to minimize future costs. To make best use of this methodology, an analysis of the impact of a variety of extreme events (e.g., heatwaves and bushfires) across multiple health outcomes (e.g., ambulance dispatches, emergency presentations, admitted episodes and mortality) needs to have been performed for a specific location (e.g., a jurisdiction). These analyses on their own are highly useful to policymakers when developing surge capacity plans for extreme events, and where these analyses have not been previously undertaken for jurisdictions, this first step is highly recommended. Future research can then include these analyses in adapting the proposed methods for other jurisdictions, extreme events and health outcomes as needed.

Finally, it is important to note that the health care system itself is a contributor to total greenhouse gas emissions, estimated at 4.4% of global net emissions (Karliner et al., 2019), and rising to 7% in Australia (Malik et al., 2018). Action taken within the system to reduce emissions will potentially reduce the health care burden of heatwaves for future generations.

5. Conclusion

Heatwaves and other climate-related extreme events will continue to be an increasing financial burden on the health care system. Our study proposes a scalable and flexible methodology for estimating these costs into the future, providing a robust platform for health care planning in a warming climate. Our study also highlights the potential considerable healthcare cost-savings over time when a population is supported to adapt to extreme heat.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Climate model data supporting this research are available via the Federated Climate Data Initiative managed by the University of Tasmania, and is available with approval for qualified researchers through a support request at www.eratos.com. Ambulance dispatch data supporting this research are available from Ambulance Tasmania, and are not accessible to the public or research community without explicit approval. Contact Ambulance Tasmania on performancereporting@ambulance.tas.gov.au to discuss data and access requirements. R software functions used to analyze this research are available through CRAN (CRAN Network, 2023). The mannsmooth function is described in Mann (2008).

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