ARTICLE IN PRESS

Climate Services xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Climate and weather service provision: Economic appraisal of adaptation to health impacts

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ARTICLE INFO

Article history:
Received 6 May 2016
Received in revised form 16 September 2016
Accepted 4 October 2016
Available online xxxx

ABSTRACT

This paper seeks to demonstrate that the value of climate projection information can be used to derive quantitative estimates of both the costs and benefits of information-based measures introduced to reduce climate-related risks. Specifically, information relating to both longer term climate change and weather variability are combined to identify potential resource implications for health service planning when faced with higher frequencies of heatwaves. A range of climate projection-city combinations are explored in order to test the robustness of the economic justification for heatwave warning systems (HWWS) in Europe – London, Madrid and Prague. Our results demonstrate that in most cases the HWWS option can be justified in the current climate – it is therefore a "no/low regret" option. Our results also show that whilst costs increase slightly under climate change scenarios, benefits of HWWS are likely to increase more steeply in European contexts. However, whilst the majority of cost-benefit analysis (CBA) outcomes are found to be positive, (i.e. economic benefits are greater than economic costs), across alternative climate projection-city combinations, in sensitivity analyses it is possible to generate negative results in certain geographical contexts. Indeed, with respect to this climate change risk, this analysis has identified that the analysis of key uncertainties, such as effectiveness of HWWSs and the valuation of health improvements, is critical in strengthening the case for HWWS implementation.

Practical Implications

The paper undertakes a quantitative analysis of both the costs and benefits of heatwave warning systems, (HWWSs), in the cities of London, Madrid and Prague from the present day to 2050 – the mid-point in the period, 2035–2064, for which the climate projections exist. These HWWSs currently exist and rely on the local meteorological institutes to provide advance warning of heatwave conditions. We compare the discounted benefits and costs of the HWWSs to derive net present value (NPV) and benefit-cost (B-C) ratio estimates under a baseline (no climate change) and three climate change scenarios. Unlike previous assessments this analysis uses real-world data, combined with current climate scenario and population projections to provide results that can inform strategies to respond to heat-wave conditions. The central results are presented in Table 1. These results show that under the core assumptions adopted the existing HWWSs pass the economic criterion – known as economic efficiency – since they have positive NPV and B-C ratios greater than one.

However, the paper also shows that the effectiveness of the HWWS is not well-established and may vary depending on location. Thus, in sensitivity analysis it is demonstrated that when a low rate of effectiveness is assumed for the London HWWS economic efficiency is no longer guaranteed. One implication for policy makers – at least in London – is therefore to ensure that effectiveness is likely to be reasonably high; this may entail monitoring the performance of HWWS in the near future, as well as ensuring that lessons are learnt from the experience of other cities,

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http://dx.doi.org/10.1016/j.cliser.2016.10.004
2405-8807/© 2016 The Authors. Published by Elsevier B.V.

Please cite this article in press as: Hunt, A., et al. Climate and weather service provision: Economic appraisal of adaptation to health impacts. clim. Ser. (2016), http://dx.doi.org/10.1016/j.cliser.2016.10.004

Table 1
Cost benefit analysis of heatwave warning systems under baseline and climate change scenarios for the 2035–2064 time period.

Scenario	London		Madrid		Prague	
	NPV	B-C Ratio	NPV	B-C Ratio	NPV	B-C Ratio
Baseline	54,600,000	11	2,097,700,000	913	398,700,000	308
Cool	114,400,000	21	3,297,600,000	1375	498,700,000	385
Median	124,300,000	23	3,297,600,000	1375	498,700,000	385
Hot	154,200,000	28	4,697,500,000	1880	598,700,000	462

particularly those like Paris and New York who are of a similar size to London and who face similar summer weather patterns. Complementary to such monitoring is the impetus that this finding gives to the exploration of other options – such as those presented in Table 6 – that help to reduce the health risks of heatwaves. These include cross-sectoral options that incorporate spatial planning.

A second important finding from a policy perspective is that the preventative resource costs – as well as the resource health treatment costs avoided – implied by the operation of the HWWS rise as the frequency of heatwaves in the three cities increases under future climate change. However, the three climate scenarios indicate that the uncertainty surrounding these estimates is significant. A policy implication of this is that in order to better inform health service resource planning, it would make sense to continue to invest in climate services that were able to reduce the range of uncertainty over time.

1. Introduction

An increase of heat-related mortality and morbidity is identified as being a potentially significant consequence of climate change in Europe (Menne and Ebi, 2006; Confalonieri et al., 2007; Smith et al., 2014). This is of particular concern to people living in large urban areas because the high population density in these areas – combined with the fact that heat exposure may be exacerbated by the urban heat island effect – is likely to result in sizeable public health challenges (Patz et al., 2005). The need to respond to such climate change risks has highlighted the essential role of information provision (Fankhauser et al., 1999). Specifically, knowledge about expected timing and extent of risks, derived from climate projections, can be used to inform design and implementation of adaptation actions that reduce the impact of heat on human health.

This paper identifies the roles that climate and weather services play in responding to risks resulting from climate variability and change before undertaking an economic appraisal of heat warning systems based on weather service provision. The appraisal is of existing heat warning systems in three major European cities under climate change projections for the period 2035–2064. The paper therefore builds upon the literature on the economic appraisal of heat warning systems (Ebi et al., 2004) which is limited to considering current climate risks, and the growing literature of ex-post evaluation of the effectiveness of such warning systems (Toloo et al., 2013). Bringing these together in a future-orientated economic appraisal allows us to make initial estimates of the resource implications of adaptation to climate change, as well as the economic justification for committing these resources in budgetary planning.

The public health context is chosen since private individuals are likely to have imperfect knowledge of the health risks of high ambient temperatures, indicating that this is an area where there is a role for public policy intervention. The paper investigates mortality and morbidity associated with high temperatures. Regarding morbidity, the study focused on respiratory hospital admissions in the elderly population. The rationale for this choice is that the elderly have consistently been shown to be particularly vulnerable to high temperatures, and demographic projections have identified that this segment of the population is going to grow significantly in Europe throughout this century. Respiratory illness is understood to be the dominant risk associated with high temperatures for this age group.

Section 2 describes the steps that constitute the method adopted in this paper. Section 3 then presents the results of the economic appraisal of the heat warning system, before concluding thoughts are given in Section 4.

2. Methods

The methodology consisted in several steps. First, we estimated the impact of heat on mortality and morbidity in three European cities with large populations, selected as representative of three geographic/climatological sub-regions, defined as Mediterranean Europe, North-Western Europe and Eastern Europe. Respectively, these cities are Madrid, Spain (6.5 million population in 2014), London, UK (8.6 m) and Prague, Czech Republic (1.2 m). We then identified potential adaptation options that could be implemented to reduce these impacts. In order to demonstrate the potential for economic appraisal of adaptation options, we focused on a specific option – heat-health warning systems – whose existing features are described in the relevant geographical locations. This option is then evaluated against an economic efficiency criterion across alternative locations. The heat health warning system in each of the three selected cities was evaluated separately.

The analysis was undertaken over the fifty-year period to 2064, matching the lifetime assumed for adaptation options considered. This time period coincides with the period – 2035–2064, which has been assessed as the period when 2 °C of warming globally, relative to pre-industrial, will occur under the RCP4.5 stabilization scenario (Vautard et al., 2014) based on a multi-model ensemble analysis. Beyond this period, climate projections diverge significantly between scenarios, depending on the underlying assumptions regarding the variables such as socio-economics, population, technology, etc. that drive future emissions and radiative forcing.

(1) Identification of heat-health climate risks

A principal health risk from climate change identified in Europe is the risk of mortality and morbidity associated with higher ambient temperature. The epidemiological literature, (e.g. Hajat et al., 2005; Johnson et al., 2005; Carson et al., 2006; Kovats et al., 2004; Hajat et al., 2007; Kovats and Hajat 2008), reports a strong correlation between current temperature and mortality, with the temperature-mortality relationship characterized by a U, V or J shaped curve, the bottom of which indicates the level of temperature where the mortality incidence is minimum (threshold).

In the literature, this temperature-mortality curve is frequently described by two key parameters: the threshold value and the slope above the threshold, usually expressed in terms of change

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in mortality associated with each 1 °C change of temperature above the threshold value. Heat-related mortality is understood to occur when mean daily temperature exceeds the country and/or city-specific threshold (Baccini et al., 2008).

Table 2 summarizes the estimated heat-mortality relationships, or functions, for Mediterranean Europe, North-Western Europe and Eastern Europe, derived from three meta-analyses conducted on the city-specific heat-mortality functions reported in Baccini et al. (2008). In order to capture the risk resulting from combined heat and high humidity, daily mean temperature was used as a measure of exposure. The estimated thresholds were 29.4 °C, 23.9 °C and 22.6 °C for Mediterranean, North-Western, and Eastern Europe, respectively. The estimated increase in mortality associated with 1 °C increase in mean temperature above the city-specific threshold was 3.12% in the Mediterranean region and 1.84% in the North-Western and Eastern European regions. The heat-mortality curve was estimated separately by sub-region in order to account for the heterogeneity of climate and projected climate health risks across Europe (Baccini et al., 2008).

In order to estimate the impact of heat on mortality during the future time slice 2035–2064, the estimates reported in Table 2 were combined with meteorological projections arising from three different regional climate model simulations reflecting the range of uncertainty from a full multi-model ensemble (Vautard et al., 2014). These projections spanned a 25 km × 25 km grid over the European domain and consisted in daily time series (one for each grid cell) of several meteorological indicators. We considered projected mean temperatures and relative humidities, and for each cell and day, we calculated mean apparent temperature (AT) according to the following formula:

$$AT = c_1 + c_2 * T + c_3 * RH + c_4 * T * RH + c_5 * T^2 + c_6 * RH^2 + c_7 * T^2 * RH + c_8 * T * RH^2 + c_9 * T^2 * RH^2$$

where T and RH are daily mean temperature (°C) and relative humidity (%), respectively, and c_i, $i = 1\ldots9$ are fixed coefficients ($c_1 = -42.38$, $c_2 = 2.04901523$, $c_3 = 10.14333127$, $c_4 = -0.22475541$, $c_5 = -0.00683783$, $c_6 = -0.05481717$, $c_7 = 0.00122874$, $c_8 = 0.00085282$, $c_9 = -0.00000199$). Apparent temperatures were set to T if T < 27 °C and RH <40%, following Rothfusz (1990) and Anderson et al. (2013).

Then, for each cell and day, we calculated the daily attributable fraction (AF), i.e. the fraction of deaths attributable to mean apparent temperatures (AT) above the threshold:

$$\begin{aligned} &\mathrm{AF} = 1 - 1/\exp(\mathrm{b}(\mathrm{AT} - \mathrm{h})) \quad \mathrm{ifAT} > h \\ &\mathrm{AF} = 0 \quad \mathrm{ifAT} \geqslant \mathrm{h} \end{aligned} \tag{1}$$

where b is the estimated slope above the threshold assuming a V shape for the heat-mortality curve on a log scale, and h is the estimated threshold. The average AF during each warm season (April 1st-September 30th) in the period 2035–2064 was thus estimated for Spain, UK and Czech Republic by averaging AFs over days and cells by country. Finally, indicating with $\mathrm{AF}_{c,m,t}$ the average AF for country *c*, regional climate model *m* and warm season *t*, we calculated the number of attributable deaths per year (AD) according to this formula:

$$\mathrm{AD}_{c,m,t} = \mathrm{AF}_{c,m,t} * \mathrm{pop}_c * \mathrm{r}_{c,t} * \mathrm{p},$$

where pop_c is the average population of the country *c* or of the city *c* in the time slice of interest; $\mathrm{r}_{c,t}$ is the average annual crude mortality rate for *c* during the time slice; *p* is the average proportion of deaths observed during the warm season over the total number of deaths observed during the year. The population was assumed to change over time according to the scenario SSP2 scenario constructed by OECD (Chateau and Dellink (2012).[1] The crude mortality rate was projected under the assumption of constant fertility.

Table 2
Heat-mortality functions – EU regions.

	Threshold mean temperature	Heat-mortality function (% increase in mortality per 1 C increase in temperature)
Mediterranean EU	25.7	3.12
North-western EU	21.1	1.84
Eastern EU	19.3	1.84

Note: in Baccini et al. (2008) the city-specific thresholds are expressed in terms of daily maximum temperatures. We applied an ad hoc correction to transform daily maximum to daily mean temperatures

Table 3 summarizes the results for the three EU countries. The results are presented for the three regional climate models: SMHI RCA4 (hottest), LSC REMO (coolest) and KMNI RACMO22E (median). In the second column block, the average attributable fractions for each region during the time slice are given. The estimated attributable deaths per year are reported in the third column block. In the last column, the estimated numbers of attributable deaths per year under the assumption of no climate change are reported. For example, we expect that in Spain during the future period 2035–2064, under the hot scenario, around 2.13% of deaths during summer will be due to temperatures exceeding the threshold of 25.7 °C estimated for the Mediterranean region. This percentage corresponds to 6721 attributable deaths per year.

Table 4 then shows the average number of attributable deaths per year for the three cities: London, Madrid and Prague, in the 2035–2064 time-slice, under the three climate models as well as under the assumption of no climate change.

2.1. Morbidity

It is likely that there exist morbidity-based health impacts in addition to mortality impacts, although these are less clearly defined in the underlying health studies. Heatwaves (i.e. continuous days of exceptional heat) have been shown to increase respiratory and cardiovascular illnesses (Patz et al., 2005). Exposure to high temperatures during heatwaves may cause dehydration partly attributable to certain side-effects of drugs (e.g. impaired thermoregulation and suppressed thirst) (Stoellberger et al., 2009), heat cramps caused by fluid and electrolyte imbalances often caused by exertion, heat exhaustion, and heat stroke which can result in organ failure, brain damage or death. Despite variation in findings relating to the different morbidity impacts of high temperatures, there is clear evidence of increased overall morbidity associated with historical heatwaves. For example, there were 35 % more hospital admissions of the elderly (aged 65 or older) during the 1995 heatwave in Chicago, compared with the typical average number of admissions (Semenza et al., 1999). Similarly, a total of 3% excess emergency department visits and 1% excess hospitalizations in California were identified during the 2006 heatwave (Knowlton et al., 2009), and an excess of 1% total emergency hospital admissions in England were found during the 2003 heatwave (Johnson et al., 2005).

There are a number of reasons why the morbidity results are more disparate and less conclusive, including a lack of convergence in the metrics used in different locations as well as the lack of reporting of many more minor health conditions. Moreover, due to the number of available hospital beds is usually decided based also on logistic and administrative issues, the number of hospital admissions might in some case poorly reflect the actual population demand for health assistance. However, it can be concluded that

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[1] Data downloaded from https://secure.iiasa.ac.at/web-apps/ene/SspDb.

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Table 3
Heat Mortality Impacts for 3 EU countries in 2035–2064, for three climate models (hot, median and cool models) for 2 °C of warming globally, and assuming no climate change (no CC).

Location/Time slice/Heat – mortality impacts	Daily attributable fraction			Attributable deaths (AD)			AD
	Hot	Median	Cool	Hot	Median	Cool	No CC
Mediterranean EU – Spain	2.13	1.27	1.26	6721	3987	3978	1474
North-western EU – UK	0.07	0.05	0.04	248	189	160	46
Eastern EU – Czech Republic	1.21	0.94	0.9	862	669	643	312

Table 4
Expected annual attributable deaths in the three cities for the period 2035–2064 under the three climate models (hot, median and cool models) for 2 °C warming globally, and assuming no climate change (No CC).

Location	Attributable deaths in the cities			AD No CC
Climate model	Hot	No CC	Cool	
Madrid	928	550	549	203
London	33	25	21	6
Prague	102	79	76	37

generally hotter climatic conditions and more frequent and intense heatwaves are likely to cause an increase in patient-days per year in hospital in the EU due to heat-related illness (i.e. hospital admissions attributable to high temperatures but not necessarily diagnosed as hyperthermia, heat stroke, etc.). The rate of change is more uncertain than that of heat-related mortality. However, Donaldson et al. (2002) indicates a linear relationship between heat related mortality and heat related patient-days which they estimated as 102 patient days in hospital for every one death. Although this figure can be considered uncertain due to the very limited published evidence, it can be used as an indication of a suitable function for this metric. Heat related morbidity is therefore tentatively determined by multiplying the heat related mortality deaths by 102. The resulting morbidity cases per year in the three cities are presented in Table 5.

The results presented in Tables 3–5 are generated under the assumptions that currently heat-health warning systems do not exist and that acclimatization mechanisms do not occur. As outlined in the Discussion section below these mechanisms are not yet well understood and so we are not yet able to make allowances for them under future climate projections with confidence; it is therefore more transparent to hold temperature-health relationships constant at current levels. The next step – 2 – is to identify what options are open to reduce the size of these risks.

(2) Identify adaptation responses

Across Europe, there are generally understood to be a large number of potential adaptation options available to address many of the identified climate risks. Adaptation options may take a number of forms including, but not limited to: infrastructure investments; financial incentives: autonomous and regulated price adjustments; voluntary behavioral change, and; undertaking management decision-making processes that incorporate climate change risks. These options also vary widely between aggregation levels and governance and according to different socio-economic futures. In the context of heat-health risks, a range of options can be identified that may either be introduced immediately or over a longer passage of time. Examples of these are presented in Table 6.

The options identified in Table 6 clearly have degrees of both substitutability and complementarity with each other. Indeed, recent adaptation frameworks have moved away from thinking about single time-bound solutions for adaptation and instead advance iterative risk management and the use of adaptation pathways (Downing, 2012). These recognize the evolving nature of future risks under increasing levels of climate change – as well as the high uncertainty involved. The response is to advance adaptive management approaches that include complementary portfolios which allow for learning and updated responses.

In this paper we select the Heat-Health Watch system for economic appraisal. We focus on this option because experience to date in its implementation can shed light on the quantitative needs of this appraisal. It also has the merit of being flexible with respect to the degree of climate variability and change that occurs over the lifetime of the system.

The Heat-Health Watch system that currently operates in London is incorporated in the Heat Wave Plan for England. This is outlined below.

The Heat Wave plan for England, 2015

The heat-wave plan (NHS England, 2015) and supporting documents describe the responsibilities of a number of implementing organizations, including Primary Care Trusts (PCTs), Local Authorities (LAs), Strategic Health Authorities (SHAs) and NHS Trusts. The core elements of the plan are:

- ‘Heat-Health watch’ over the summer months which triggers levels of response (Levels 1–4);
- Advice and information direct to the public and health and social care professionals;
- Guidelines for the identification of individuals at risk and local advice for assisting these individuals;
- Extra assistance from the voluntary sector, families and others to care for those most at risk;
- The use of the media to get the information disseminated both before and during a heatwave;
- Long term multi-agency planning to adapt to and reduce the impact of climate change, including ‘greening the built environment’, increasing shading around and insulation of buildings, increasing energy efficiency and reducing carbon emissions.

Table 5
Expected annual number of attributable patient-days in the three cities for the period 2035–2064 under the three climate models (hot, median and cool models) for 2 °C warming globally and assuming no climate change.

Location	Attributable Patient-Days per year			
Climate model	Hot	Median	Cool	No climate change
Madrid	94,605	56,120	55,988	20,706
London	3386	2581	2183	612
Prague	10,373	8048	7742	3774

Please cite this article in press as: Hunt, A., et al. Climate and weather service provision: Economic appraisal of adaptation to health impacts. clim. Ser. (2016), http://dx.doi.org/10.1016/j.cliser.2016.10.004

Table 6
Possible options to limit the adverse effects of extreme heat in Europe.

Measures	Examples	Advantages	Disadvantages
Short-term measures	Advice on behavior Awareness-raising, including heat alert systems. Access to cool spaces Mobile evaporative coolers Air conditioners	Immediate benefit Can be implemented by individuals, community groups or local authorities	May be of limited public health benefit if advice/awareness not well targeted. Potential adverse health impacts of room air conditioners, e.g. airborne infections May be inequitable, depending how allocated. Increase in energy use and greenhouse gas emissions from use of air conditioners.
Medium-term	Increased albedo of building envelope External shading Insulation Decreasing internal heat load. Passive cooling technologies Efficient active cooling	Can be designed without increase in energy consumption and implemented at building or city scales. Synergistic effects throughout the year	Advance planning needed. Selection of measures at the building scale needs to consider local circumstances. Moderately expensive Potential risk to “design buildings for the heatwave” forgetting the rest of the year
Long-term	Building regulations Urban planning Land-use changes Mitigation of climate change	Reduced energy consumption and greenhouse gas emissions. Can be combined with active mobility and air pollution reductions Inherently equitable, with major potential health benefits	Very Costly Long lead times. Requires political will.

Source: Adapted from Chalabi and Kovats (2014) and Menne and Matthies (2008)

The first five elements listed above are incorporated in the UK Heat Health Watch System (HWWS). In the HWWS, the UK Meteorological Office issues heat-wave weather warnings when there is an expectation of significantly higher than average temperatures in one or more regions of England. The HHWS comprises four levels of response based upon threshold maximum daytime and minimum night-time temperatures. These thresholds vary by English region, though an average threshold temperature is 30 °C by day and 15 °C overnight.

The HWWS operates in England from 1 June to 15 September each year. The four levels of response are:

Level 1 – Awareness — the minimum state of vigilance during the summer.

Level 2 – Alert — triggered as soon as the risk is 60% or above for threshold temperatures being reached on at least two consecutive days to have significant effects on health. This will normally occur 2–3 days before the event is expected.

Level 3 – Heatwave — triggered as soon as the Meteorological Office confirms threshold temperatures will be reached in one or more regions.

Level 4 – Emergency — reached when a heatwave is so severe and/or prolonged that its effects extend outside the health and social care system.

This HWWS has a common four level structure with the equivalent systems in the Czech Republic and Spain.

(3) Estimate the costs and benefits of heat-health warning systems

2.2. Resource costs

Step 2 demonstrates that the heat-health warning systems currently implemented in the three countries have very similar structures and component actions. We therefore assume that the medical labour time resource requirements associated with the four component actions – i.e. the levels of alarm – are equivalent in the three cities. Table 7 documents the roles of these health professionals and the associated resource implications of these roles that we assume in this analysis.

The three warning systems are formulated principally as requiring action by health professionals, notably local Health Visitors and District Nurses, who are primarily involved in the care of the local population in their homes, rather than in hospitals. We assume that the co-ordinating action of nurse and health visitor team leaders is included in the time that is allocated to nurses/health visitors.

The warning systems are evaluated on the basis of the costs and benefits associated with their implementation. The HWWS is considered over a 50-year time period, from 2015 to 2064. The current and future costs of the warning systems are calculated according to a series of stages:

(a) The total number, (full-time equivalents), of Health Visitors (HVs) and District Nurses (DNs) currently working in each city, allocated to “acute, elderly and general” populations, are calculated.[2] As of July 2010 these totals are 743 and 733, for HVs and DNs, respectively in London. For Madrid and Prague, these are scaled on the basis of total population – 37% and 15%, respectively. The sum of these HVs and DNs are the total Health Professionals (HPs) assumed to be employed and engaged in the demographic group most vulnerable to heat-waves.

(b) The employment totals are projected over the 50 year time period under the IIASA SSP2 population scenario. It is assumed that the population-HP ratio is kept constant at today’s levels over this time period.

(c) The annual cost of employing an HP is calculated from cost information identified for the three cities. Cost information includes: salary, on-costs, non-capital overheads, capital overheads. These are converted to Euro 2010 prices and divided by 220 (annual working days) to give costs of €202/day (London),[3] €97/day (Madrid)[4] and €71/day (Prague).[5]

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[2] Department of Health – NHS staff by occupation code staff groups 1997–2004.

[3] Curtis (2010) Unit Costs of Health and Social Care 2010. At: http://www.pssru.ac.uk/pdf/uc/uc2010/uc2010.pdf.

[4] www.ine.es/dyngs/INEbase/en/categoria.htm?c=Estadistica_P&cid=1254735976596.

[5] www.czso.cz/csu/czso/registered-number-of-employees-and-their-wages-1-quarter-of-2015.

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Table 7
Roles of Health Professionals and Resource Implications associated with HWWS Implementation.

Heat-wave Plan Alert Level	Role of Health Professionals	Resource Implications
Level 1 – Awareness	Planning at beginning of heat-wave season to protect vulnerable people: – Be familiar with the principles and core elements of the Heatwave Plan – Be familiar with the client heat-wave advice leaflet and give copies to clients as appropriate. – Consider clients' vulnerability to adverse weather conditions and add to at-risk list	One hour per Health Professional, annually Other fixed costs components incurred at Level 1 include: – Weather Office contract fee; – Printing, distribution and storage of information leaflets & documentation
Level 2 – Alert	– Identify list of those from existing caseload who will require daily contact in the event of a heat-wave – Avoid duplicate contact /visits from multiple agencies – Determine what non-essential activities could cease	One and a half hours per Health Professional, each time Level 2 is reached
Level 3 – Heatwave	– Stop nonessential activities – Commence daily contact with clients at risk – Make daily situation reports	Four hours/day per Health Professional, for duration of heat-wave
Level 4 – Emergency	– Continue to do best for caseload – Provide situation reports upwards, as requested, and raise any concerns they may have	Four hours/day per Health Professional, for duration of heat-wave

Sources: Roles and resources based on Department of Health (2010).

(d) The total HP costs for the three cities are calculated for the four different warning levels. We adopt the Summer 2003 heatwave as a historical analogue to which costs can be calibrated. The 2003 heatwave is characterized as a 1 in 100 year event, which is projected to become more frequent under all climate change scenarios.

a. For Level 1, as identified in Table 7, it is assumed that each HP typically spends one hour of time per year meeting its requirements. This day-fraction, (0.125), is first multiplied by the day resource cost identified above. This HP unit cost is then multiplied by the total numbers of HPs in each city. In addition to these costs, the costs associated with the weather office annual contract fee, plus the costs of printing, distribution and storage of information leaflets and documentation are derived to give a total annual fixed cost of the warning system. This is estimated to be €200,000 for the UK Meteorological Office; we assume this to be the same for both Prague and Madrid. This relates to the additional marginal cost for the information provision, and assumes that a baseline climate service is already in place (WHO Regional Office for Europe (2009).
b. For Level 2, the HP unit cost is estimated in the same way as for Level 1. The incidence costs of a level 2 event are estimated on the basis of those incurred in the Summer 2003 event. The probability of an equivalent event occurring is derived from the climate model projections adopted. These probabilities are multiplied by the unit cost; the resulting expected annual HP unit cost is then multiplied by the total numbers of HPs deployed in each year to produce a Level 2 total annual variable cost.
c. For Level 3, the total annual variable cost is estimated in the same way as for level 2. The weather event is assumed to last eight days.
d. For Level 4, using the Summer 2003 experience in London as an analogue, there are assumed to be no additional HP costs to those associated with Level 3. This is a conservative assumption: a more severe event – of the type experienced by Paris in 2003 – is estimated to justify an increase in HP costs of 25–50%.

It should be emphasized that this method under-estimates the true resource costs of heat-waves. The principal reason for this is that the cost estimates derived here are made on the basis of the projection of a single heat-wave frequency/intensity, characterized as equating to the dimensions of that which occurred in August 2003 in Europe. The true total resource costs will be those associated with the heat-wave events to 2064 resulting from the full range of projected heat-wave frequencies/intensities which may be more or less frequent than the 1:100 year event used here as a cost analogue. Our cost estimates are therefore likely to be under-estimates of the true costs.

2.3. Benefits

We measure the benefits of implementing a heat warning system as the reduction in health impacts – whether premature deaths or patient-days. The benefits are determined by the effectiveness of the warning system. To date, there is no published quantitative evidence of the effectiveness of these systems in the three cities we are studying. However, a recent review of the relevant literature by Toloo et al. (2013) identifies a small number of studies on heat warning effectiveness that have been undertaken globally. Two studies in Europe include Fouillet et al. (2008) that compares deaths before and after HWS implementation in France, in 2003 and 2006, respectively and Morabito et al. (2012) that undertake the same comparison in Florence, Italy. Whilst the French study finds effectiveness of 68% when the number of fatalities avoided is used as the measure of effectiveness, the Florentine study finds effectiveness of 9%, using the same metric. Outside Europe, two studies in North America compared fatalities avoided between the 1995 and 1999 heatwaves as a result of HWWSs being introduced between these events. Weisskopf et al. (2002) show a reduction in mortality of 88% in Milwaukee, USA, whilst Palecki et al. (2001) find a mortality reduction of 84%. The Toloo et al. review does, however, highlight the fact that these studies do not attempt to isolate other factors that might have influenced the mortality data, such as people's preparedness based on their recent experience, and the different intensities of the heatwave events that are compared.

In looking to transfer these results to the context of the three cities discussed in our study, other factors such as lack of comparability of HWWSs, availability and cost of air conditioning, and forms of social capital that exist in communities within cities all reduce the reliability of doing so. Furthermore, the type of data that might enable such a transfer to be approximated is not presented in these studies. In the absence of any other data we initially adopt the assumption that for the core analysis, the rate of effectiveness is the mid-point between the two observations from

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the European studies. The mid-point is 38% and, given the lack of evidence on which to differentiate, we apply this same value in all three cities. This is not meant to imply that the three cities are likely to have similar contextual influences; rather, the mid-point value serves as a way of facilitating our method. Subsequent sensitivity analysis adopts the lower estimate of 9%. This uncertainty emphasizes the need for further research effort on HWWS effectiveness.

In order to make an initial comparison between the costs and the benefits of the cities' warning systems, we estimate the benefits in monetary terms that result when the warning systems are implemented. We adopt the values that are currently used by the European Commission in economic appraisal of environmental policy proposals (see e.g. AEA 2011). Thus, in order to monetize the benefits we adopt central unit values of €1.16 m for the Value of a Prevented Fatality (VPF) and €750 per patient-day. There is considerable uncertainty in these unit values and therefore a range of monetary values are often used in appraisals. The measurement uncertainties are captured in the range of low, central and high values given for each of the specific health impacts estimated. Uncertainty ranges are €315,000 (equivalent to seven life-years) and €5.5 m, and €420 and €1080, for the VPF and patient-day, respectively, reflecting those adopted in current appraisal guidance in Europe (AEA 2011).

3. Results

Tables 8 and 9 present the annualized discounted costs and benefits over the next 50 years for the baseline case where no climate change is included. In order to be consistent with the current practice of the EC, a discount rate of 4% is used. These tables serve to provide an indication of the scale of costs and benefits for a single, given, year during the period of interest. Table 8 shows the annual average costs for the three cities, disaggregated by the implementation level of the HWWS.

Level 1 costs are the highest associated with the levels, reflecting the high annual fixed costs associated with having a heat health warning system. Level 3 costs are higher than Level 2 costs, reflecting the fact that in the event of a heat event of this magnitude occurring, the time incurred in providing the care to the population will be substantial. The costs for London are greatest, reflecting the larger number of health professionals who are employed to serve the higher population size.

Table 9 present the annualized benefits of the warning systems in the three cities in the absence of climate change – disaggregated by mortality and morbidity. Madrid has the largest benefits of the three cities, reflecting the fact that the impacts reduced by implementation of the HWWS are higher, resulting from the fact that maximum temperatures are higher in absolute terms and are therefore more likely to result in the HWWS being triggered. Comparison of the annual total benefits with the annual total costs for each of the cities indicates that benefits are significantly greater than costs.

For the three cities, Tables 10 and 11 give the present value (PV) – i.e. discounted – costs and benefits, respectively, summed over the 50 year period for which the HWWS is assumed to operate over, in the baseline "no climate change" scenario, and under the three climate change scenarios adopted.

Table 10 shows the PV costs in each city. Although the costs are shown to be larger in London and Madrid as the climate change signal increases across the scenarios, the variation in costs is less than 10%. In Prague, although the results differ across scenarios, rounding of the results has removed any clear variation. This pattern results from the fact that costs are dominated by the annual costs of weather information provision that are incurred irrespective of heatwave incidence.

Table 11 presents the PV benefits for each of the three cities, assuming a rate of effectiveness of the HWWS of 38% and the use of the core economic values – €1.16 m for each fatality prevented and €750 per patient-day prevented. The results show that the benefits under the climate change scenarios range between 25% and 170% higher than those under the no climate change baseline scenario. In relative terms, the climate signal effect is greatest in London and least in Prague whilst in absolute terms the benefits are greatest for Madrid and least in London. These results seem to reflect the fact that the epidemiological evidence finds that London populations are currently most sensitive to high temperatures, whilst on average temperatures in Madrid are significantly closer to the health vulnerability threshold that is breached in heatwave conditions.

Table 12 presents the results of the cost-benefit analysis undertaken with the PV cost and benefit data shown above. The net present value (NPV) – PV benefits minus PV costs – is presented for each city-scenario combination, alongside the benefit-cost ratio. The results show that in all twelve combinations the NPV is positive and benefit-cost ratio greater than one, suggesting that these HWWS can be justified against the criterion of economic efficiency. The results are most striking for Madrid where the benefits outweigh the costs by between €2 billion and €4.7 billion. The positive baseline results confirm that the HWWS schemes that exist in the three cities are economically efficient, whilst the net benefits increase under the three climate change scenarios adopted.

The Methods section of this paper highlights the fact that there are a number of uncertainties accompanying the assumptions

Table 8
Expected Warning System Costs assuming no climate change, annualized (€, 2010, discounted, 4%).

HWWS Alert Level	London	Madrid	Prague
Level 1	62,000	27,000	16,000
Level 2	200	90	10
Level 3	3600	1300	200
Level 4	N/A	N/A	N/A
Total	65,800	28,300	16,200

Table 9
Warning system benefits, annualized (€, 2010, discounted, 4%).

	London	Madrid	Prague
Mortality	1,400,000	30,000,000	4,000,000
Morbidity	90,000	2,000,000	300,000
Total	1,490,000	32,000,000	4,300,000

Table 10
Warning System Present Value Costs 2014–2065 (€, 2010).

	London	Madrid	Prague
Baseline	5,400,000	2,300,000	1,300,000
Cool	5,600,000	2,400,000	1,300,000
Median	5,700,000	2,400,000	1,300,000
Hot	5,800,000	2,500,000	1,300,000

Table 11
Warning System Present Value Benefits – Core (€, 2010).

	London	Madrid	Prague
Baseline	60,000,000	2,100,000,000	400,000,000
Cool	120,000,000	3,300,000,000	500,000,000
Median	130,000,000	3,300,000,000	500,000,000
Hot	160,000,000	4,700,000,000	600,000,000

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Table 12
Cost Benefit Analysis: Indices – Core analysis.

	London		Madrid		Prague	
	NPV	B-C Ratio	NPV	B-C Ratio	NPV	B-C Ratio
Baseline	54,600,000	11	2,097,700,000	913	398,700,000	308
Cool	114,400,000	21	3,297,600,000	1375	498,700,000	385
Median	124,300,000	23	3,297,600,000	1375	498,700,000	385
Hot	154,200,000	28	4,697,500,000	1880	598,700,000	462

Table 13
Warning System Present Value Benefits – Sensitivity (€, 2010).

	London	Madrid	Prague
Baseline	900,000	29,500,000	5,400,000
Cool	1,700,000	47,400,000	7,400,000
Median	1,900,000	47,500,000	7,500,000
Hot	2,300,000	67,400,000	8,700,000

Table 14
Cost Benefit Analysis: Indices – Sensitivity analysis.

	London		Madrid		Prague	
	NPV	B-C Ratio	NPV	B-C Ratio	NPV	B-C Ratio
Baseline	−4,500,000	0.2	27,200,000	13	4,100,000	4
Cool	−3,900,000	0.3	45,000,000	20	6,100,000	6
Median	−3,800,000	0.3	45,100,000	20	6,200,000	6
Hot	−3,500,000	0.4	64,900,000	27	7,400,000	7

adopted in our economic modelling. Principal uncertainties include: climate sensitivity; valuation of health risks, and; effectiveness of adaptation options. Other potentially significant uncertainties include: discount rate; resource costs of HWWS; population size, life-time of the HWWS, and; heath sensitivity to hot ambient temperatures. Consequently, we re-run our CBA model to test whether the core results are likely to be different when the core assumptions are dropped. Specifically, our sensitivity analysis changes the assumptions relating to the valuation of health risks and effectiveness of HWWS in the benefits analysis in order to test whether the positive CBA findings are altered. In both instances we lower the values; the effectiveness of HWWS is assumed to be 9% – the lower-bound value found in the existing evidence base – whilst the mortality and morbidity risk values are assumed to be €315,000 and €420, respectively.

Table 13 shows the PV benefits resulting from the sensitivity analysis. In all scenario-city combinations, these benefits are very substantially lower than those derived using the core assumptions in Table 13 – at least two orders of magnitude smaller.

Table 14 presents the CBA indices that result from our sensitivity analysis. The most notable finding is that – in the case of London – the NPVs are now negative, and B-C ratios are below one. Thus, for this city the economic efficiency rationale no longer exists under either "no climate change" or climate change scenarios. In Madrid and Prague, the indices are also significantly lower than in the core analysis, though still positive.

4. Discussion

This paper has sought to demonstrate that the value of climate projection information can be used to derive quantitative estimates of both the costs and benefits of information-based measures introduced to reduce climate-related risks. Specifically, information relating to both longer term climate change and weather variability are combined to identify potential resource implications for health service planning when faced with higher frequencies of heatwaves. In practical terms, this may require increased recruitment and training of health professionals on a seasonal basis.

A range of climate projection-city combinations are explored in order to test the robustness of the economic justification for heatwave warning systems in Europe. The analysis highlights that whilst such systems have substantial annual fixed costs, the additional costs incurred in the instance of heatwave events occurring are relatively low, on an annualized basis. The HWWS option also has the merit that it is, in principle, flexible to whatever the degree of climate change – and the frequency/severity of associated extreme weather events – that materializes in the future. However, in practice there is some evidence to show that increased frequencies of extreme weather events may "over-familiarise" people to the risk, leading to a likelihood that they ignore warnings thereby reducing their effectiveness (Sheridan, 2007). This potentiality argues that the HWWS option may be insufficient on its own and that as residual climate risks increase over time there is increased justification for moving along an adaptation pathway that offers diverse and complementary options for risk reduction.

Our results demonstrate that in most cases the HWWS option can be justified in the current climate – it is therefore a "no/low regret" option. Our results also show that whilst costs increase slightly under climate change scenarios, benefits of HWWS are likely to increase more steeply in these European city contexts, whilst the uncertainties in assessment of these benefits prevents easy generalization of these results to country-scale. However, whilst the majority of CBA indices are found to be positive across alternative climate projection-city combinations, in sensitivity analyses where important assumptions are modified together, it is possible to generate negative results in certain geographical contexts. Indeed, with respect to this climate change risk, this analysis has identified that the analysis of key uncertainties is critical in strengthening the case for HWWS implementation.

In interpreting our results it should be considered that our analyses were conducted under the assumption of no future change of the heat-mortality association resulting from population acclimatization/adaptation under a climate change scenario. Despite the fact that some authors have recently found that mortality risk due to heat decreased over time in several countries (Gasparrini et al., 2015), more evidence would be needed to allow formulation of appropriate hypotheses on how much and when in the future the heat-mortality curve will change. This is the reason why in this work we preferred to assume the absence of changes in physiological, behavioral and external factors that could determine future acclimatization.

Additionally, whilst the risk measure used in this study is for the whole population, certain groups, particularly the elderly and those with pre-existing respiratory and/or cardiovascular diseases are at a higher risk of dying during hot weather (Matthies and Menne, 2008). The evidence for this was seen clearly in the France 2003 heat-wave, where excess mortality rates rose dramatically for the 75–94 age group (Pirard et al., 2005). Similarly, the effects of the 2003 heat wave were greatest amongst the elderly in London in

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terms of the number of deaths per head of population (GLA, 2006). Other factors have also been identified as determining the heat-mortality incidence and include whether people live on their own, their ability to look after themselves, the availability and quality of social care or family/peer groups and the quality of care in care homes and hospitals. There is also a further set of factors related to the built environment. Finally, temperatures are often higher in urban environments because of the urban heat island (UHI) effect. London already has a well-documented heat island effect (GLA, 2006), and UHI intensities in excess of 7 °C have been recorded. In our analysis we did not account for these factors, leading to a likely under-estimation of the impact of heat on the three cities.

Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007–2013) under the project: IMPACT2C: Quantifying projected impacts under 2 °C warming, grant agreement no. 282746, and the project: ECONADAPT: Economics of Climate Change in Europe, grant agreement no. 603906.

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