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ScienceDirect

Procedia Environmental Sciences 6 (2011) 104–111

Procedia Environmental Sciences

Earth System Science 2010: Global Change, Climate and People

A case study of avoiding the heat-related mortality impacts of climate change under mitigation scenarios

Simon N. Gosling[a], Jason A. Lowe[b*]

[a]*Walker Institute for Climate System Research, University of Reading, Reading RG6 6AR, United Kingdom*
[b]*Met Office Hadley Centre, Exeter EX1 3PB, United Kingdom*

Abstract

We compare heat-related mortality impacts for three European cities, London, Lisbon and Budapest, under five climate change policies representing different dates at which carbon dioxide (CO_2) emissions peak, rates at which emissions decline, and emissions floors, and compare them with a non-mitigation business-as-usual emissions scenario, for three time periods, the 2030s, 2050s and 2080s. Under an SRES A1B business-as-usual emissions scenario and using climate projections from 21 GCMs, heat-related mortality rates (per 100,000 of the population) attributable to climate change in the 2080s are simulated to be in the range 2-6 for London, 4-50 for Lisbon and 10-24 for Budapest. Whilst the policy scenarios serve to reduce the number of heat-related deaths attributable to climate change, by up to 70% of the A1B impacts under an aggressive mitigation scenario that gives a 50% chance of avoiding a 2°C global-mean temperature rise from pre-industrial times, they do not eradicate the effects of climate change on heat-related mortality. The magnitude of avoided impacts is minor in the early 21st century but increases towards the end of the century. Importantly, the magnitude of avoided impacts is more sensitive to the year at which emissions are reduced than to the rate at which emissions are reduced.

Selection under responsibility of S. Cornell, C. Downy and S. Colston.

Keywords: Climate change; heat-related mortality; climate policy; avoided impacts; uncertainty

1. Introduction

Recent climate change impacts assessments indicate that climate change will have generally negative impacts on various sectors including, for instance, water scarcity [1], agriculture and food production [2], human health [3,4], and ecosystems and biodiversity [5]. An increasingly common opinion is that to avoid 'dangerous' climate change, global-mean warming needs to be limited to below 2°C above pre-industrial levels. This is reflected in, for example, the EU's policy target for EU-wide and international climate change mitigation negotiations of 2°C global-mean warming by 2100. Information on the potential impacts that climate change will have for different amounts of

* Corresponding author. Tel.: +44 (0) 118 378 8225; fax: +44 (0) 118 378 8316.
E-mail address: s.n.gosling@reading.ac.uk .

doi:10.1016/j.proenv.2011.05.011

global-mean warming is therefore of considerable importance to policy-makers. Furthermore, the impacts associated with different climate change mitigation policies relative to 'business-as-usual scenarios' can be used to better-inform the decision-making process. The aim of this paper is to assess the potential impacts of climate change on heat-related mortality for three European cities; London, Lisbon and Budapest, that could be avoided by a set of defined climate policies, one of which includes an aggressive mitigation scenario that gives a 50% chance of avoiding a 2°C global-mean temperature rise from pre-industrial times. The paper uses existing temperature-mortality models with climate scenarios representing the effects of a range of different climate policies, and compares impacts under a business-as-usual climate with those under the specified policies.

2. Methods

2.1. Climate change scenarios

We compare climate change policies representing different dates at which carbon dioxide (CO2) emissions peak, rates at which emissions decline, and emissions floors, and compare them with an SRES [6] A1B business-as-usual emissions scenario. The emissions scenarios are summarised in Figure 1(a) and Table 1. For each of the five policy emissions scenarios and the A1B scenario, global-mean temperature change was estimated using a simple climate model; MAGICC [7], run with a large number of parameter combinations. Figure 1(b) shows the global-mean temperature change for each scenario, based upon the median estimate of the ensemble produced by the parameter perturbations. The A1B-2016-5-L policy scenario gives a 50% chance, based upon the parameter perturbations, of avoiding a 2°C global-mean temperature rise from pre-industrial times [7].

Scenarios for change in daily maximum temperature were derived by pattern-scaling and downscaling output from 21 global climate models (GCMs) used in the IPCC AR4, using the ClimGen package [8]. The pattern-scaling approach was used to construct climate scenarios for a given change in global-mean temperature ΔT, as simulated using the MAGICC simple climate model (discussed previously) for the emissions scenarios presented in Figure 1(a). The pattern for each GCM was constructed by fitting a regression, for each month, variable and GCM grid cell, between climate variable and global mean temperature, in order to estimate change in climate per degree change in global-mean temperature. The pattern-scaling approach assumes that the relationship between global temperature change and local climate response is linear and invariant. The pattern-scaling was performed at the original GCM grid resolution and then interpolated statistically to 0.5° x 0.5° resolution. The 0.5° x 0.5° grid cells that contained the location for each city were extracted for use in the analysis presented here. The pattern-scaling technique we employed, using ClimGen, simulated a 30-year long monthly timeseries (i.e. 360 values) of maximum temperature, for each of the 21 GCMs and emissions scenarios displayed in Figure 1(a), for each 0.5° x 0.5° grid cell. The monthly maximum temperature was then statistically downscaled to daily maximum temperature, using the weather generator described by Todd et al. [8]. The maximum temperature anomaly, calculated as the mean difference in maximum temperature between the climate change scenario and the ClimGen baseline (1961-1990) was then calculated and added to the daily time series (1961-1990) of observed daily maximum temperature for each city, following the 'delta method' [3, 9]. Whilst the delta method is considered a robust means of creating a temperature projection time series, an important limitation of the method is that the temperature projection time series inherits the observed present variability, i.e. of 1961-1990 in this case. Therefore we inherently assumed that climate change is associated with only a change in the mean of the temperature distribution but not a change in its variability.

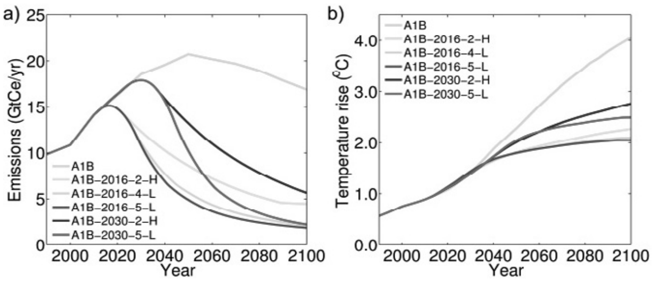

Figure 1. The climate change emissions scenarios (a), and global-mean temperature rise from pre-industrial times (b).

Table 1. The climate change policy emissions scenarios

Scenario name	Pathway to peak	Date of peak	Rate of decline in emissions post-peak	Emissions floor
A1B-2016-2-H	A1B	2016	2% per year	High
A1B-2016-4-L	A1B	2016	4% per year	Low
A1B-2016-5-L	A1B	2016	5% per year	Low
A1B-2030-2-H	A1B	2030	2% per year	High
A1B-2030-5-L	A1B	2030	5% per year	Low

2.2. The temperature-mortality models

Heat-related mortality attributable to climate change was calculated using three city-specific heat-related mortality models, for London, Lisbon and Budapest. Each model quantifies the non-linear relationship between daily heat-related mortality and surface daily maximum temperature. The models were constructed from observed relationships in each city between daily heat-related mortality and maximum temperature. The models have been validated and shown to give an accurate representation of observed heat-related mortality for each city, meaning they can be used reliably for climate change impacts assessment. A more detailed description of the model construction and validation process is described by Gosling et al. [10] and the models have previously been used to assess the impacts of climate change on heat-related mortality by Gosling et al. [3, 4]. The models output the annual heat-related mortality *rate* (i.e. the number of deaths per 100,000 of the population per year) attributable to climate change (i.e. the heat-related mortality death rate that is only due to climate change and which occurs above the 'baseline' expected rate in the absence of climate change). The temperature time series of daily maximum temperature for each emissions scenario shown in Figure 1(a) were applied to the city-specific heat-related mortality models to yield heat-related mortality rates attributable to climate change for each city.

In this application of the heat-related mortality models it is assumed that there is no change in demographic structure in the future. This is unrealistic but at the same time advantageous because it allows for an explicit representation of the sole impacts of climate change on heat-related mortality, which are not affected by changes in population. Therefore the impacts presented here should be interpreted as an indicator of how heat-related mortality might change with climate change. The models do not account for the possibility that populations may acclimatise to warmer temperatures in a warmer future climate. The degree to which populations will acclimatise, if at all, is highly contested within the climate change-health academic community. This is due to lack of evidence, e.g. records of daily temperature and heat-related mortality are generally not expansive enough to observe evidence of historical acclimatisation occurring. However, it has been postulated that in the same way that populations living in hot countries are acclimatised to high temperatures, so populations may acclimatise to warmer temperatures with climate change. However, the rate at which populations may acclimatise is unknown. If some acclimatisation to warmer future temperatures is assumed to happen, then the impact estimates presented here may be considered as being over-estimated.

3. Results

Figure 2 shows the simulated heat-related mortality rates under the business-as-usual scenario (A1B) in the 2030s, 2050s and 2080s, when the city-specific heat-related mortality models are forced with the climate projections from 21 GCMs. In this case, the total heat-related mortality rate is plotted, meaning that the death rate *attributable to climate change* is the deaths that occur above the baseline level (horizontal dashed lines). Climate change has a minor impact on heat-related mortality in the 2030s across all 21 GCMs for all three cities; the heat-related mortality rates attributable to climate change are typically around 1/100,000 for London, 4/100,000 for Lisbon, and 5/100,000 for Budapest. However, the magnitude of the heat-related mortality rates attributable to climate change increases with time towards the end of the 21st century. For instance, using the UKMO HadCM3 GCM, heat-related mortality attributable to climate change for London is 0.8/100,000 in the 2030s, 1.9/100,000 in the 2050s and 4.9/100,000 in the 2080s. The heat-related mortality rates attributable to climate change are even higher for Lisbon using UKMO HadCM3, increasing from 4.5/100,000 in the 2030s, to 10.5/100,000 and 24.0/100,000 in the 2050s and 2080s respectively. Furthermore, whilst the range in heat-related mortality attributable to climate change across all 21 GCMs is relatively small in the 2030s (0.8-1.2/100,000 for London, 1.0-4.0/100,000 for Lisbon, and 2.0-5.0/100,000 for Budapest), this increases considerably by the 2080s (2-6/100,000 for London, 4-50/100,000 for Lisbon, and 10-24/100,000 for Budapest).

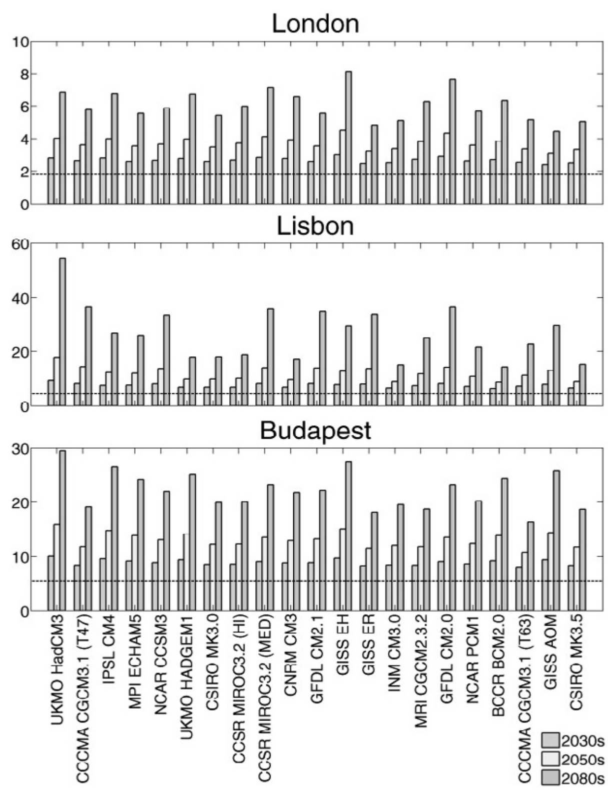

Figure 2. Heat-related mortality rates (per 100,000/year) across 21 GCMs under the A1B emissions scenario for the 2030s, 2050s, and 2080s. The dashed line denotes the baseline heat-related mortality rate; deaths above the dashed line are attributable to climate change.

Our simulations under the business-as-usual scenario are broadly similar to those presented in previous studies. For instance, Donaldson et al. [11] estimated that UK total heat-related mortality would increase by 350% by the 2080s relative to 1961-1990 using UKMO HadCM2 driven by a medium-high climate change scenario and assuming no demographic changes. This compares to an increase of around 250% that we present here for UKMO HadCM3, and is certainly well within our fairly wide uncertainty range when considering all 21 GCMs. Also, Dessai [12] estimated that heat-related mortality would increase by 1,106% in Lisbon using the HadRM2 climate model by the 2080s relative to 1969-1998 for a scenario that involved the doubling of CO_2 concentrations from present levels. Using UKMO HadCM3, we estimate the increase at around 1,300%. Inter-study estimates of heat-related mortality will differ due to the application of different climate and health models and slight differences in emissions scenarios.

Figure 3 shows the heat-related mortality rates attributable to climate change (per 100,000 of the population) avoided under the A1B-2016-5-L policy scenario (relative to the business-as-usual scenario) across 21 GCMs, for each of the 3 time-periods. The thin black bars denote the magnitude of the impact that would need to be avoided in order for climate change to have no impact under the policy scenario. A1B-2016-5-L represents an aggressive mitigation scenario that gives a 50% chance of avoiding a 2°C global-mean temperature rise from pre-industrial times. However, for none of the GCMs are all the A1B impacts avoided, for any city or time horizon. The avoided impacts are negligible in the 2030s but they increase towards the end of the century. For example, with London, none of the heat-related mortality rates under the A1B scenario are avoided by the A1B-2016-5-L scenario but by the 2050s around 0.3-0.8/100,000 deaths are avoided (dependent upon GCM), and by the 2080s, around 2-4/100,000 are avoided. As would be expected from Figure 2, the uncertainty across the 21 GCMs is substantial and increases with time towards the end of the 21st century. For example, with Lisbon, between 40/100,000 (UKMO HadCM3) and 7/100,000 (BCCR BCM2.0) heat-related deaths attributable to climate change could be avoided under the A1B-2016-5-L policy scenario in the 2080s.

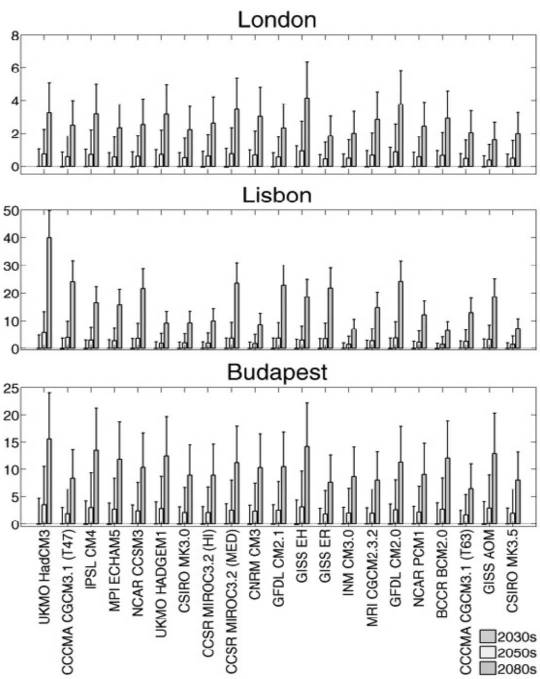

Figure 3. Heat-related mortality attributable to climate change impacts avoided (absolute values, per 100,000 of the population; coloured bars) for the A1B-2016-5-L policy scenario across 21 GCMs, for each of the 3 time-periods. The thin black bars denote the magnitude of the impact that would need to be avoided in order for climate change to have no impact under the policy scenario.

Figure 4 shows the same as Figure 3, except in this case, the avoided impacts are expressed as a percentage of the A1B business-as-usual impacts. Given that the avoided impacts are here represented in a relative sense for each GCM, the uncertainty across the 21 GCMs is relatively small, compared with the uncertainty across the 21 GCMs for the absolute avoided impacts presented in Figure 3. Figure 4 demonstrates that in he 2030s, there are no avoided impacts using any of the GCMs; the avoided impacts are actually slightly negative, due to global-mean temperature being marginally greater under the A1B-2016-5-L scenario than the A1B scenario here (see Figure 1(b)). However, in the 2050s the avoided impacts are greater, around 30%, 40%, and 35% of the A1B impacts are avoided for London, Lisbon and Budapest respectively. In the 2080s, the avoided impacts are 60%, 70% and 60% respectively. However, even under this aggressive mitigation scenario, using no GCM are 100% of the A1B impacts avoided.

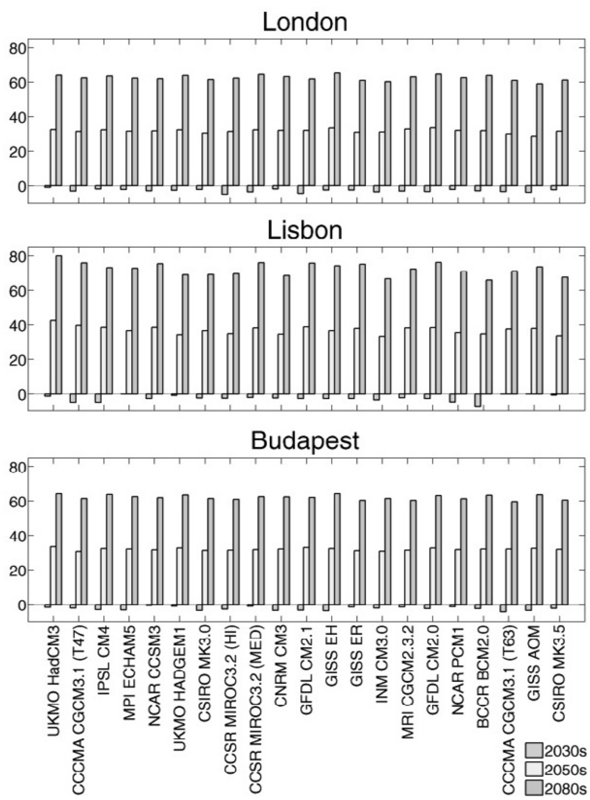

Figure 4. Heat-related mortality attributable to climate change impacts avoided (relative to A1B impacts, %; coloured bars) for the A1B-2016-5-L policy scenario across 21 GCMs, for each of the 3 time-periods.

Figure 5 shows the ensemble mean across the 21 GCMs, of the relative avoided impact (as a percentage of A1B impacts), under each of the five policy scenarios. Also shown is the range across the 21 GCMs for each policy scenario. The relative avoided impacts are minor in the 2030s but they increase with time towards the end of the 21st century, up to 60%, 70% and 65% by the 2080s under the A1B-2016-5-L scenario for London, Lisbon and Budapest respectively. The relative avoided impacts are greater under the policy scenarios where emissions peak in 2016 than when they peak in 2030. For instance, in the 2050s, the avoided impacts for the A1B-2016-2-H, A1B-2016-4-L and A1B-2016-5-L scenarios are all around 31%, 37% and 31% for London, Lisbon and Budapest respectively; whereas for the A1B-2016-2-H and A1B-2016-5-L scenarios the avoided impacts are all around 18%, 20% and 18% for each city. The rate at which emissions are reduced following the peak emissions has little bearing on the magnitude of the avoided impact – for instance, the range in avoided impact between the A1B-2016-2-H, A1B-2016-4-L and A1B-2016-5-L scenarios is about 1% for each city in the 2050s.

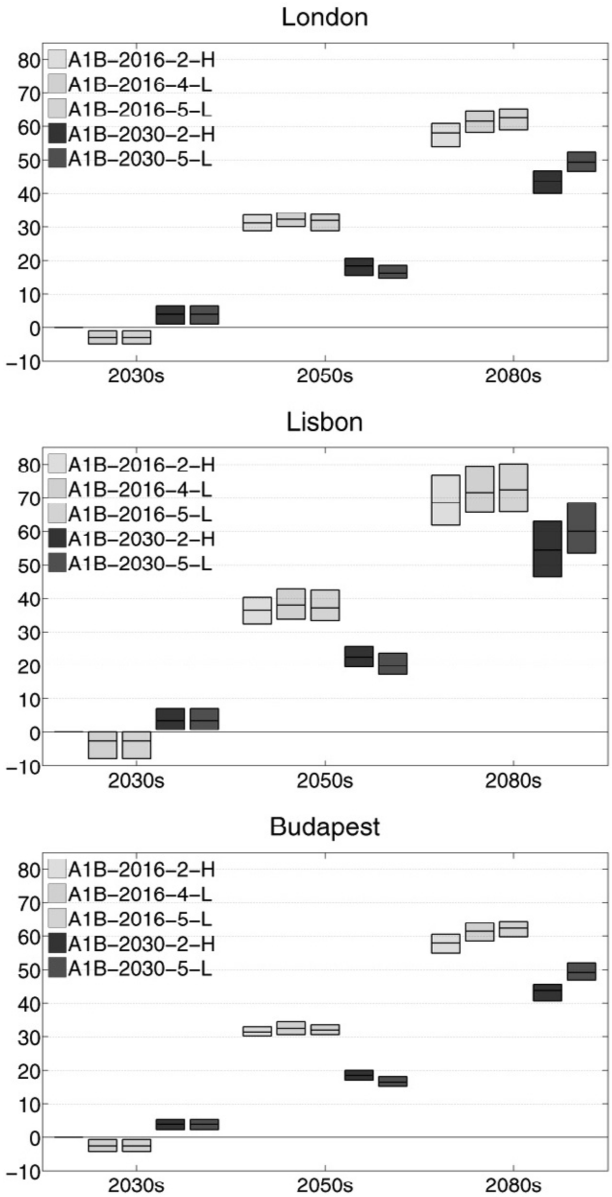

Figure 5. Ensemble-mean across 21 GCMs (horizontal lines within each floating bar) of heat-related mortality attributable to climate change impact avoided by each policy scenario, for each city, for each time period. The floating bar height displays the range across the 21 GCMs.

4. Conclusions

Three main conclusions are drawn from the analyses presented here, all of which have implications for the policy-making process. *Firstly, climate change still has an effect on the number of heat-related deaths for each city, even under climate change mitigation scenarios*. Whilst the policy scenarios serve to reduce the number of heat-related deaths attributable to climate change, by up to 70% of the business-as-usual impacts, they do not eradicate the effects of climate change on heat-related mortality. *Secondly, the magnitude of avoided impacts is minor in the early 21st century but increases towards the end of the century*. For example, for London the avoided impacts in the 2080s are over twice as large as the avoided impacts in the 2050s. *Thirdly, the magnitude of avoided impacts is more sensitive to the year at which emissions are reduced than to the rate at which emissions are reduced*. Moreover, by the end of the 21st century there is a clear divergence in avoided impacts between the three policy scenarios that reduce emissions from a peak in 2016 and the two policy scenarios that reduce emissions from a 2030 peak. Whilst we have shown that the absolute number of heat-related deaths avoided by climate change mitigation policy can be large depending upon the GCM used to provide the climate change projections, there is agreement across the 21 GCMs that the *relative* impacts avoided can be substantial.

Acknowledgments

This work was supported by the AVOID programme (funded by DECC and Defra under contract DECC/Defra GA0215). ClimGen was developed by Tim Osborn at the Climatic Research Unit (CRU) at the University of East Anglia (UEA), UK. ClimGen was run on the University of Reading Campus Grid and so we wish to thank Dan Bretherton (ESSC, University of Reading, UK), University of Reading IT Services and the entire University of Reading Campus Grid team for their support in setting-up ClimGen to run by high throughput computing on the Campus Grid.

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