Inaction on climate change could cost one year of life in some European countries *

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Climate change-related excess mortality estimates clearly demonstrate a dramatic impact on public health and human mortality. However, life expectancy at birth is more easily communicated and understood by the public. By properly situating climate change mortality within the contexts of life expectancy, we better represent the cost of climate change on longevity. In this paper, we convert excess mortality estimates due to increases in extreme weather from climate change into potential reductions in life expectancy at birth in twenty-eight European countries. We project climate change extremes to reduce life expectancy at birth by 0.24 years for the average European country with differences in excess of 1.0 years in some countries by 2100. We only estimate the impact of mortality directly related to climate extremes, making our estimates conservative. Thus, the cost of inaction on climate change could approach, and likely to exceed, one year of life in some European countries.

Keywords: Climate change, Life expectancy, Mortality, Demography, Excess mortality, Europe, Public health

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Main Text

Climate change's implications on humanity go far beyond estimates of economic damages (Hsiang et al. 2017), estimates of displacement (Rigaud et al. 2018), or human conflict (Barnett and Adger 2007) but have the potential to contribute to the loss of human life (Forzieri et al. 2017; Pachauri et al. 2014). As impact quantification studies move further from the physical sciences of climate change, properly quantifying and conveying the impact of climate change on public health is of increasing importance (Cloyd et al. 2016; Melillo, Richmond, and Yohe 2014).

Scholars have long estimated the mortality risks associated with climate change and typically use excess or extra mortality (Forzieri et al. 2017; McMichael, Woodruff, and Hales 2006; Wilson et al. 2017; Zanobetti et al. 2012). For example, Forzieri et al. (2017) projected climate change extremes to increase European mortality by 150,000+ persons per year by the end of the century. Although such estimates are useful, the excess mortality estimates are rather sterile – one death is a tragedy, a million deaths a statistic – and difficult to relate to on a personal level. Life expectancy at birth (e_0), on the other hand, provides potent comparisons of mortality vectors and converts excess mortality into an intuitively understood metric, relatable to everyone. To our knowledge, no studies exist that comprehensively examine the potential reductions of life expectancy due to climate change. Without properly situating the potential loss of life within the contexts of metrics such as life expectancy, we risk underestimating the impact of climate change on human mortality.

Using published data on excess mortality (Forzieri et al. 2017), we connect climate change excess mortality to life expectancy in a mortality model. By estimating the increase in age-specific mortality rates associated with previously published excess death estimates, we can assess how much climate change could reduce the anticipated longevity of the average person in twenty-eight European countries. This approach allows us to quantify the impact of climate change on human longevity and answer the following question: What is the cost

of inaction on climate change on human longevity? Our results situate climate change mortality within the broader context of human mortality and can be used to inform public health interventions to prevent such futures.

Our results suggest that climate change could emerge as a potent public health threat in the 20th century. Mitigation strategies (ie reductions in greenhouse gas emisions) and adaptation strategies (ie outreach efforts, retrofitting public buildings, etc.) would help prevent this new public health concern.

Methods and Materials

Data

We estimate changes in life expectancy by combining three primary datasets: excess mortality data due to meterological hazards related to climate change from Forzieri et al. (2017), cause-of-death distributions from the Global Burden of Disease study (GBD) (Disease Study 2015 2017; Wang et al. 2012), and life tables from the Human Mortality Database (HMD) (Database 2017).

Forzieri et al. (2017) combined data from the International Disaster Database (EMCAT) and the Natural Catastrophe Statistics tool (NatCatSERVICE) to create exposure and fatality statistics related to six weather-related hazards – heatwaves, cold waves, droughts, wildfires, river and coastal floods, and windstorms – and estimated excess mortality associated with those hazards during a baseline period of 1981-2010 in 28 European countries. They only considered fatalities *directly attributable* to the event and *exclude* increased deaths from common causes that were observed to rise during the event, such as cardiovascular or respiratory deaths[1]. While the disaster data are not standardized across country, Forzeri et al. imputed data in incomplete time periods and countries. This imputation could mask

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[1]"The fatality data from the two databases considered is likely to not include increased deaths from common causes that were observed to rise at the population level but for which individual deaths could not be attributed to the event. For example,... increased risk of cardiovascular and respiratory deaths ... may be severly underreported in the EMDAT and NatCatSERVICE." (see Forzieri et al. 2017:9, *Supplementary Materials*).

spatial variability at the sub-national level, but here we use their country-aggregated re-sults. They downscaled these exposures rates to 1km grid cells and integrated them into small-area demographic projections for Europe out to 2100 that correspond to a middle-of-the-road socioeconomic scenario (SSP2 with medium fertility, medium mortality, medium migration, and the Global Education Trend education scenario (Jiang 2014; O'Neill et al. 2017; Samir and Lutz 2017)) and based their projected mortality on extrapolations of their calculated exposures. Their results represent business-as-usual climate change and human development without incorporating potential adaptations to climate change. They found a potential 150,000+ climate change related fatalities per year by the mid 2080s with climate change contributing to 90% of mortality rise as opposed to population changes. The number of future anticipated deaths are available in their Supplementary Table S8 (Forzieri et al. 2017) and provide the magnitude of deaths for our study.

The Forzieri et al. (2017) data contain only mortality totals and report no age detail, precluding a direct conversion from excess mortality to life expectancy. To convert excess mortality to life expectancy, we allocate excess multi-hazard mortality for each country based on the observed age-specific mortality schedule for environmental heat and cold exposure deaths from the GBD (Disease Study 2015 2017; Wang et al. 2012). Forzieri et al. found that extreme heat (as opposed to other five weather-related hazards) account for 99% of the anticipated excess mortality by the end of the century. The GBD is the most comprehensive worldwide dataset of epidemiological data produced and provides cause-specific mortality by age/sex/geography/year for 249 causes of death in 195 countries and territories. We gathered data on age-specific deaths and mortality rates (m_x) for mortality from environmental heat and cold exposure (cause C.2.9) for the period 2006-2015 for each country in the study. These data provide a mortality schedule to fit the projected climate change excess mortality from Fozieri et al (Forzieri et al. 2017). Thus, we assume that the age-specific mortality schedules observed between 2006 and 2015 due to environmental heat and cold exposure in
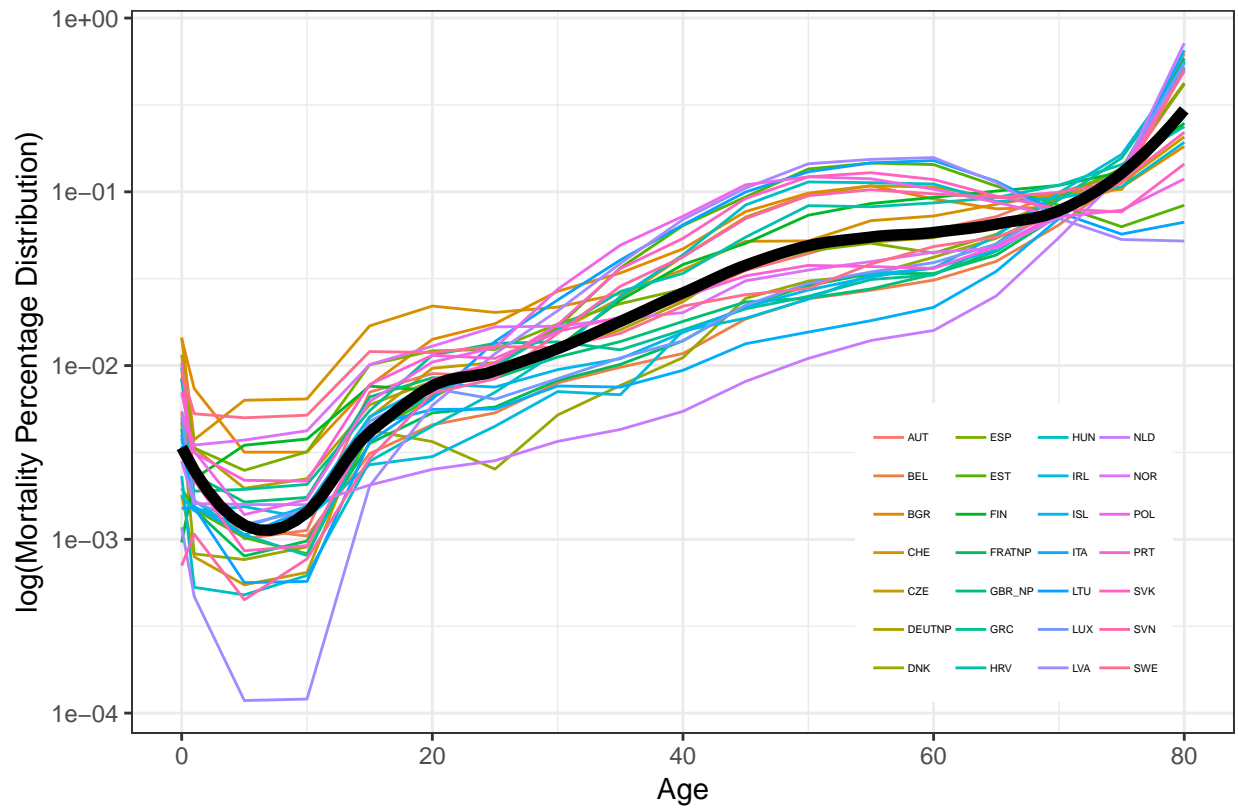
Figure 1: **Mortality distribution of Heat-related mortality in 28 European countries**. The thick black line is the average

Table 1: **Most recent mortality data available by country in the HMD.**

Country	Year	Country	Year	Country	Year	Country	Year
AUT	2014	ESP	2014	HUN	2014	NLD	2016
BEL	2015	EST	2014	IRL	2014	NOR	2014
BGR	2010	FIN	2015	ISL	2016	POL	2014
CHE	2016	FRATNP	2015	ITA	2014	PRT	2015
CZE	2016	GBR	2016	LTU	2014	SVK	2014
DEUT	2015	GRC	2013	LUX	2014	SVN	2014
DNK	2016	HRV	2016	LVA	2014	SWE	2016

the GBD (see Figure 1) are likely to remain unchanged in the future. We only use the GBD to distribute the Forzieri et al. deaths by age.

With the Forzier et al data and the GBD we estimate the anticipated age-specific mortality schedules due to climate change in twenty-eight European countries but we cannot compare life expectancy differentials in the absence of Climate Change using those two datasets alone. To create baseline mortality schedules and life expectancy, we gather data from the Human Mortality Database (Database 2017) for the corresponding European countries. The HMD comprises only complete, official vital event statistics and represents the most accurate and complete compilation of mortality data available. We downloaded the most recent 5x1 (age by year) life table data for the twenty-eight European countries (see Table 1 for a list of countries and most recent mortality data).

We used the following data elements from the five-year age group life table data in the HMD:

1. $_nP_x$ or the population in age group x for n-year intervals from exact age x to $x + n$.

2. $_na_x$ or the average length of survival between ages x and $x + n$.

3. $_nd_x$ or the number of deaths in age group x for n-year intervals from exact age x to $x + n$.

Methods

We derived a number of additional variables to accomplish our analysis. First, we abridged the life table data from the HMD from ages 100+ to 80+ to conform to the GBD cause-specific mortality schedules.

From the GBD data, we derived variable $t_{x,i}$ as the proportion of deaths, D, from each age group x in each country i ($_n t_{x,i} = D^{GBD}_{x,i} / \sum_{\alpha=0}^{80} {}_n D^{GBD}_{\alpha,i}$).

We then derived additional m_x rates for each age group x in each country i for each scenario s ($BASE, LOW, MID, HIGH$) from Forzieri et al (Forzieri et al. 2017).

$$_n m_{x,i,BASE} =_n D^{HMD}_{x,i} / {}_n P^{HMD}_{x,i} \tag{1}$$

$$_n \hat{m}_{x,i,s} = (_n D^{HMD}_{x,i} + (\hat{D}_{i,s} \cdot {}_n t_{x,i})) / {}_n P^{HMD}_{x,i} \tag{2}$$

where $D_{x,i}$ is the number of deaths in age group x in country i from the HMD, $P_{x,i}$ is the population in age group x from the HMD, $\hat{D}_{i,s}$ is the number of deaths from Forzieri et al. (Forzieri et al. 2017) under scenario s, and $t_{x,i}$ is the proportion of mortality experienced in each age group x from the GBD. Thus, the anticipated additional mortality due to climate change is added to each age group based on the underlying cause-specific mortality schedule observed between 2006-2015 in the GBD.

We then calculated q_x values, or the probability of dying, for each scenario s for each country.

$$_n q_{x,i,BASE} = \frac{m_{x,i,BASE}}{1 + (n -_n a_{x,i}) \cdot m_{x,i,BASE}} \tag{3}$$

$$_n \hat{q}_{x,i,s} = \frac{\hat{m}_{x,i,s}}{1 + (n -_n a_{x,i}) \cdot \hat{m}_{x,i,s}} \tag{4}$$

We calculated each additional life table value identically for each scenario s using standard life table equations:

$$_n d_{x,i,s} =_n l_{x,i,s} \cdot_n q_{x,i,s}$$

$$_n l_{x,i,s} =_n l_{x-1,i,s} -_n d_{x-1,i,s}$$

$$_n L_{x,i,s} =_n a_{x,i,s} \cdot_n l_{x,i,s} + ((n -_n a_{x,i,s}) \cdot_n l_{x,i,s})$$

$$_n T_{x,i,s} =_n L_{x,i,s} +_n T_{x+1,i,s}$$

$$_n e_{x,i,s} =_n T_{x,i,s} /_n l_{x,i,s}$$

To determine the differences between life expectancy compared to the baseline, we simply subtract $e_{x,i,s}$ (for scenario LOW, MID, and $HIGH$) from $e_{x,i,BASE}$ as described by (Beltrán-Sánchez, Preston, and Canudas-Romo 2008).Complete life tables for all countries are available in the *Supplementary Dataset* and all computer code to replicate our results are available online[2].

Results

We find that climate change could alter life expectancy by -0.23 years (-2.5 months (-0.1 to -0.39 years)) in the average European country (**Figure 2**) by 2100. This reduction is comparable to mortality due to influenza and pneumonia (Arias, Heron, and Tejada-Vera 2013) in the United States for the year 2000. Although the average European country could see a change of -0.23 years, several countries are likely to experience considerably greater reductions in life expectancy. Luxembourg could see a reduction of up to 2.2 years and the medium-variant of climate hazards could cost the average Spaniard 1.03 years of life.

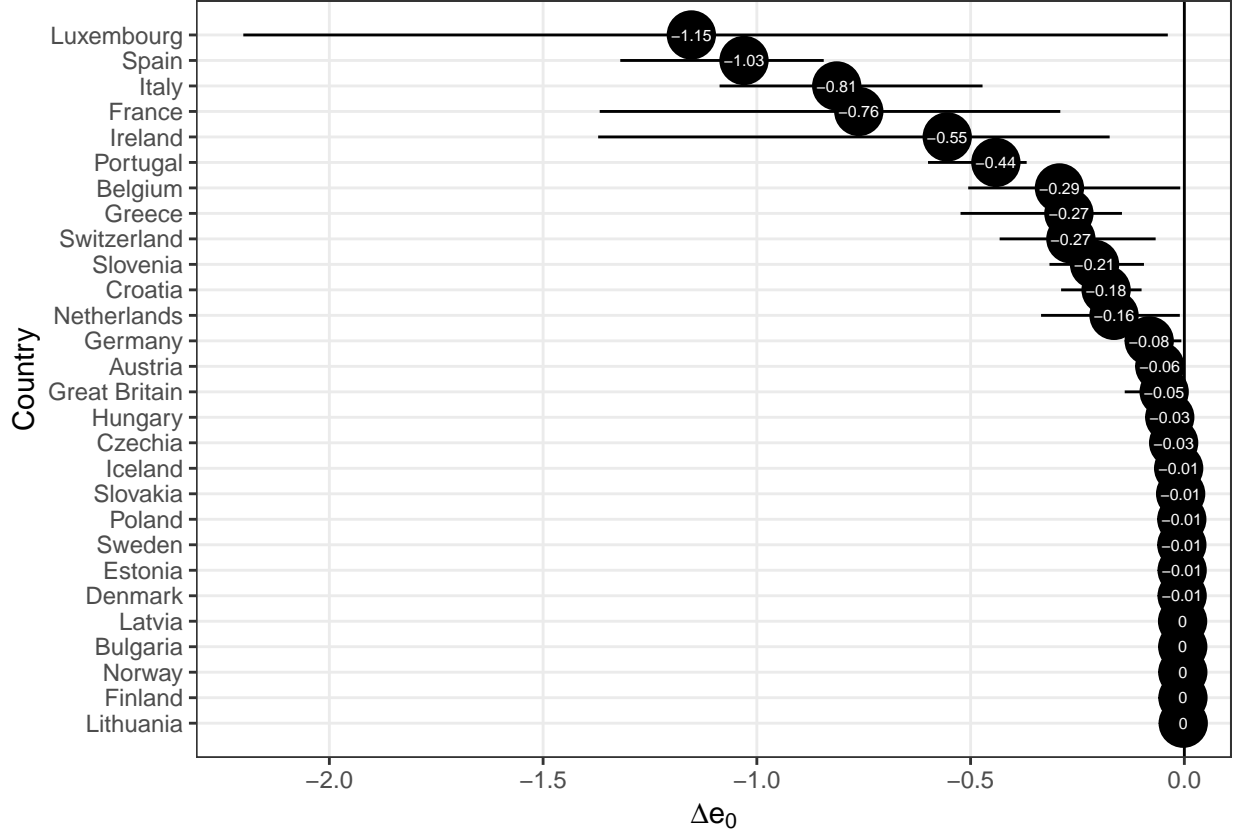[2]Replication files are located here: https://osf.io/fp52x/?view_only= 754d9a72a2ea4f6b8e0c193dc9a590d1

Figure 2: Change in life expectancy at birth (e_0) due to business-as-usual climate change in the 2080s compared to the present e_0. We report changes in life expectancies due to climate change for twenty-eight European countries. The central values represent the ensemble median while the stems represent the upper and lower bounds of the inter-model climate variability.
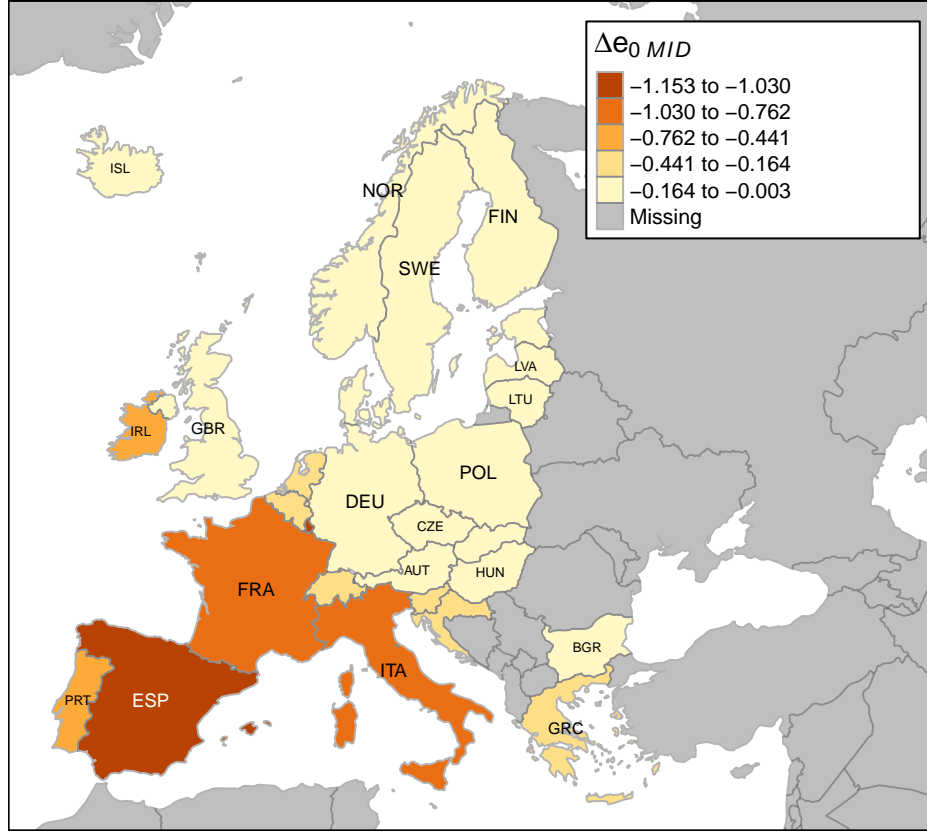
Figure 3: Estimated reduction in life expectancy at birth (e_0) by the 2080s under the MID scenario.

Our results also suggest climate change mortality differentials are likely to unfold along highly uneven geographies (Figure 3). Whereas many Northern European countries could experience negligible impacts on life expectancy, five European countries could see life expectancy changes in excess of -0.5 years (Spain, Luxembourg, France, Italy, and Ireland). This group of countries could see life expectancy changes of more than -1.0 years if climate change hazards are more intense than anticipated. In some countries, climate change could thus become a bigger killer than trachea, bronchus, and lung malignant neoplasms (-0.85 years), acute myocardial infarction (-0.87 years), or all accident related mortality (-0.84 years) (Arias et al. 2013) by the end of the century.

While Forzieri et al's (Forzieri et al. 2017) results suggest that the greatest climate change related mortality will unfold along a north-south gradient, we find the greatest reduction in

life expectancy unfolds along an east-west gradient (**Figure 3**). The most westerly European countries tend to have the greatest reductions. Neighboring pairs of countries at similar latitudes could experience vastly different mortality regimes, but neighboring pairs of countries at similar longitudes seem to experience more similar mortality regimes from climate change. Emergent research in Atmospheric Rivers suggest Western Europe could be more susceptible to these types of events (Ramos et al. 2015). Additionally, these results point to the importance of converting excess mortality into life expectancy to properly quantify the effects of climate change mortality.

Discussion

In this article, we demonstrate the impact climate change could have on life expectancy at birth due to extreme weather events in twenty-eight European countries. Previous studies on climate change and excess mortality potentially miscommunicate the impact climate change could have on human mortality. Contrary to excess mortality estimates, life expectancy is routinely used as a primary metric for communicating overall health outcomes and enjoys widespread use by major international organizations (Marmot et al. 2012; Organization 2015; Salomon et al. 2012). Life expectancy and its derivatives are the recommended metrics for population health (Parrish 2010). Additionally, it connects mortality estimates into intuitively understandable metrics, translating global estimates of mortality into personably relatable outcomes. Our work reveals the extent to which climate change could reduce the average person's longevity by the end of the century, expanding our understanding of climate change and public health; thus linking two of the major areas in current developmental and sustainability discussion at both national and international levels (Abel et al. 2016).

Without adaptation measures, our results suggest climate change could emerge as a significant new mortality vector and could pose a major public health threat for some European countries by the end of the century, echoing previous findings (Forzieri et al. 2017; Patz et al. 2005). Life expectancy has steadily risen across the world for the last century (Gerland

et al. 2014) and our results suggest that climate change alone could spur a sharp reversal in these trends in some countries. We expect two European countries to see life expectancy reductions of more than one year under the middle scenario (Luxembourg and Spain), but if climate change has a greater impact on mortality than anticipated, five European countries (Luxembourg, Spain, Italy, France, Ireland) could see life expectancy reductions of more than one year with Luxembourg experiencing a reduction of more than two. These findings highlight the hyperlocalized impacts of climate change (Forzieri et al. 2017; Kendon et al. 2014; Rosenzweig et al. 2010).

Reductions such as those should not be taken lightly. Many of the children born today are likely to still be alive by the end of the century and will be in the age groups (aged 65+) most threatened by the biggest mortality risk associated with climate change (Keatinge et al. 2000) – extreme heat. If climate change unfolds as a more aggressive mortality vector, only all circulatory diseases combined or all cancers combined would contribute more to mortality rates in numerous European countries. This would make climate change one of the most aggressive new mortality vectors to emerge over the last quarter-century, representing a major threat to public health in many parts of Europe.

Prospective studies on the emerging threat from climate change rely on linking contemporary mortality with future mortality. However, climate change could reshape future mortality through other causes of death. Climate change affects health behaviors that in turn increase mortality risk through increased alcohol and substance abuse, violent behavior, insecurity, increase in post-traumatic stress due to weather-related trauma, increase in stress due to climate change and schizophrenia, increase in the use of medications that reduce the ability to perspire and sweat, etc. (Patz et al. 2005) The International Classifications of Diseases and Related Health Problems (ICD) does not contain "climate change" as an official cause of death, so we can only speculate that the impact of climate change could be larger than reported here. Although we do not model these potential impacts, our results could thus be considered conservative.

We also share the concerns of Lee et al. (Lee and Kim 2017) concerning the business-as-usual climatic assumptions. It is likely that many countries and communities will deploy a wide variety of adaptation measures (Ebi, Kovats, and Menne 2006; Haines et al. 2006; Kovats et al. 2003). These adaptation measures rely on accurate information about the potential mortality vectors. Our models and those produced by Forzieri et al. (Forzieri et al. 2017) present plausible scenarios on the potential impact of climate change on human mortality and provide crucial information to public health officials, national governments, and international organizations. The time frames associated with climate change allow ample time for this potential health crisis to be averted.

These results should also be considered conservative when compared to the broader impact of climate change on human longevity. The disaster databases that Forzieri et al (Forzieri et al. 2017) use in generating their excess mortality estimates probably, though the disaster databases are unclear, only account for the deaths certified as *directly* caused by these hazards and are unlikely to capture the overall numbers associated with these deaths. If the certification of deaths due to weather extremes is similar to the certication in the present, than our results and those of Forzieri et al reflect the exess mortality directly attributable to climatic extremes. Despite this limitation, the impact of these extremes on e_0 is considerable, even if conservative.

Finally, we would like to point out that future research should not only transform excess mortality into life expectancy decrements. Given the influence of climate change in diseases and causes of death, it is imperative to quantify the extent to which climate change will derive in increasing costs for health care systems in these countries. The health care structures are being taxed by population aging (Rechel et al. 2009) and rising health care costs, yet it remains unclear how climate change will exacerbate these pressures.

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