Institute and Faculty of Actuaries

Resource and Environment Issues for Pension Actuaries:

Implications for Setting Mortality Assumptions

by the Resource and Environment Issues for Pensions Actuaries working party

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Knowledge and experience of resource and environment topics is developing rapidly. The original version of this guide was finalised in September 2017, based on the state of knowledge at that time. The guide was reviewed in July 2019 and various edits were made to incorporate more recent information, particularly in relation to air pollutant effects. However, it has not been updated to include all relevant developments since it was originally published. Actuaries are encouraged to keep abreast of resource and environment developments, for example by selecting "resource and environment" in their IFoA communication preferences.

Originally published
October 2017

Contents

1. Introduction

This is the second supporting report for "Resource and Environment Issues: A Practical Guide for Pension Actuaries"[1]. That guide explains where resource and environment (R&E) issues are relevant to pension schemes and the work of pension actuaries. This report expands on the technical aspects relating to mortality assumptions. The first supporting report[2] provides more detail on R&E issues and their implications for sponsor covenant assessments and a third report covers allowing for climate change when setting financial assumptions[3].

This report is aimed at actuaries who advise UK trust-based defined benefit pension schemes, although it may also be useful to trustees, sponsors and other advisers of UK defined benefit pension schemes, and to those insurance actuaries who use mortality assumptions in their work.

This report is primarily for actuaries advising UK trust-based DB schemes. It summarises the research available, identifies areas for further research and helps actuaries comply with the IFoA's climate-related risk alert.

It summarises the mortality-related research currently available and highlights the knowledge gaps and uncertainties that exist, pointing to the need for further research and the importance of actuarial judgement in this area. Whilst it is not possible to draw any robust conclusions in terms of, say, appropriate adjustments to assumed long-term rates of mortality improvement, the report should nonetheless be helpful to pensions actuaries as:

- It gives some sense of the potential range and direction of future mortality outcomes (where quantitative analyses are available).
- It describes various factors which may affect future mortality outcomes thereby giving actuaries a better sense of the scale and complexity of the issue.

This should assist actuaries in areas such as sensitivity analysis, contingency planning and longevity hedging which are important areas for the financial management of DB pension schemes. It will also help them comply with the Institute and Faculty of Actuaries (IFoA) risk alert which says that actuaries should understand and be clear in communicating the extent to which they have taken account of climate-related risks in any relevant decisions, calculations or advice[4].

Section 2 provides an overview of how R&E issues might affect UK mortality rates, noting that very little research has looked at the mortality consequences of macroeconomic effects even though these have the potential to be the most material. Sections 3 and 4 summarise the main research that is available, that relating to air pollution and temperature-related deaths respectively. Even here, there is much uncertainty about the mortality impacts: the effects are not directly attributable and hence are not identifiable from cause of death, and projections of future air quality and temperature are highly uncertain.

This report focuses on the most-researched R&E mortality impacts – air pollution and temperature – but other impacts may be more significant.

Section 5 looks at the implications for actuarial assumptions. It summarises the key figures from the previous two sections and highlights that little work to date has considered the areas most useful for actuaries, namely impacts on life expectancy (as opposed to the number of deaths); the variations in impact by age, socio-economic class and other factors; and trends over time

[1] IFoA (2017) *Resource & Environment Issues: A Practical Guide for Pensions Actuaries.* Available from https://www.actuaries.org.uk/documents/practical-guide-pensions-actuaries

[2] IFoA (2017) *Resource and Environment Issues for Pensions Actuaries: Supplementary Information on Resource and Environment Issues and their Implications for Sponsor Covenant Assessments.* Available from https://www.actuaries.org.uk/documents/resource-and-environment-issues-pensions-actuaries-supplementary-information-resource-and

[3] IFoA (2018) *Resource and Environment Issues for Pensions Actuaries: Considerations for Setting Financial Assumptions.* Available from: https://www.actuaries.org.uk/documents/considerations-setting-financial-assumptions

[4] IFoA (2017) *Risk Alert: Climate-Related Risks.* Available at https://www.actuaries.org.uk/documents/risk-alert-climate-related-risks

(which will be reflected in the data used to construct mortality base tables and improvement projections). Finally, Section 6 provides concluding remarks, summarises the areas where further research is needed, and suggests some practical actions for pensions actuaries in the meantime.

R&E is used here as an umbrella term that encompasses all matters relating to the natural environment, energy and other natural resources. It includes the inter-related topics of climate change, water scarcity, pollution, biodiversity loss, and the price and availability of fossil fuels and other materials. The working party's first supporting report includes more background information on R&E issues, particularly climate change.

2. How might R&E issues affect UK mortality rates?

Air pollution is currently the main environmental health risk globally[5] and may cause the equivalent of 28,000 to 36,000 deaths a year in the UK (see Section 3.1). Improvements in air quality have the potential to reduce this figure significantly over the coming decades.

Meanwhile, climate change poses other potential risks and opportunities for UK health, such as[6]:

Climate change and mitigating actions have various health implications, some harmful and others beneficial.

- Increasing temperatures affecting heat- and cold-related mortality and morbidity
- Flooding, including due to sea level rise
- Disruption to health and social care services, and damage to related infrastructure, due to extreme weather (potentially coinciding with increased demand)
- Vector-borne disease (eg West Nile and dengue viruses)
- Food safety (as infection rates are sensitive to temperature)
- Water quality and water supply interruptions
- Increase in outdoor leisure activities in warmer weather (potentially improving physical and mental health, but also increasing skin cancer risk).

Actions to mitigate climate change – such as increasing walking and cycling, reducing meat consumption and improving air quality – may have beneficial health effects. On the other hand, energy prices could rise (eg due to carbon taxes), making it more expensive to heat and cool homes and to import fruit and vegetables.

Most of the work to date on quantifying these various impacts relates to air pollution and temperature-related deaths. For that reason, the next two sections of this report focus on these topics. However, whilst these are the most readily quantifiable impacts, other R&E impacts may be more significant[7]. In particular, R&E issues could have macroeconomic impacts such as lower economic growth and higher food prices, resulting in lower healthcare spending[8] and poorer nutrition. These have the potential to far outweigh the impacts of better air quality and milder winters, and could work in the opposite direction. Moreover, these macroeconomic

The macro-economic effects of climate change are potentially the most significant and will have wider implications for scheme funding.

[5] WHO (2016) *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*

[6] Committee on Climate Change (2016) *UK Climate Change Risk Assessment 2017: Evidence Report*

[7] Other reports by this working party consider macro-economic impacts in more depth.

[8] Research suggests that cuts in health and social care spending may have contributed to the recent fall in UK mortality improvement rates. See University of Oxford (2017) *'30,000 excess deaths in 2015 linked to cuts in health and social care'* [online]. Available from http://www.ox.ac.uk/news/2017-02-20-30000-excess-deaths-2015-linked-cuts-health-and-social-care

impacts would have implications for sponsor covenant, investment returns and scheme funding assumptions, indicating the importance of taking an integrated risk management approach rather than considering mortality effects in isolation[9].

3. How might air quality affect UK deaths?

3.1. Current UK air pollution-related deaths

Air pollution occurs both outdoors (eg particulates, nitrogen oxides, ozone, sulphur dioxide) and indoors (eg smoke from cigarettes and open fires, volatile organic chemicals from cleaning products, and naturally-occurring radon). Outdoor air pollution is estimated to cause around fifteen times as many deaths as indoor air pollution in high income European countries[10], so only outdoor air pollution is considered here.

Air pollution is associated with a wide range of health problems, including ischaemic heart disease, stroke, chronic obstructive pulmonary disease and lung cancer[11]. The air pollutants of most concern to human health in the UK are particulate matter (PM) and nitrogen dioxide (NO_2)[12]. The main source of both is fossil fuel combustion, particularly from transport but also from factories and power stations.

The main UK air pollutants are particulate matter (PM) and nitrogen dioxide (NO_2).

Two reports by the Committee on the Medical Effects of Air Pollutants (COMEAP) about the effects of long-term exposure to PM on UK mortality are the source of many estimates of UK PM-related deaths[13]. COMEAP's central estimate is that mortality increases by 6%[14] for each 10 µg m^{-3} increase in concentration of $PM_{2.5}$[15], with a 95% confidence interval of 4% to 8% (see Figure 1)[16]. These coefficients apply to the whole population; COMEAP has not published any age- or gender-specific analysis[17].

COMEAP's central estimate, published in 2010[18], was that 2008 levels of human-made $PM_{2.5}$ (8.97 µg m^{-3}) had a long-term effect[19] on annual UK mortality equivalent to approximately 29,000 deaths based on typical ages or a loss of approximately 340,000 life years[20]. These 29,000 attributable deaths represent a modest shortening of life for large numbers of people rather than 29,000 deaths solely due to PM. They are equivalent to a six month reduction in

PM is estimated to reduce UK life expectancy by six months. However, the effects are unlikely to be evenly distributed across the population.

[9] "Resource and Environment Issues: A Practical Guide for Pension Actuaries" includes an integrated risk management case study.

[10] WHO (2014) *Burden of Disease from Household Air Pollution for 2012: Summary of Results* [online]. Available from http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf

[11] Kelly, F. J. and Fussell, J. C. (2015) *Air Pollution and Public Health: Emerging Hazards and Improved Understanding of Risk*. Environ Geochem Health 37:631–649

[12] European Environment Agency (2016) *Air Quality in Europe: 2016 Report*. Ozone is a third pollutant of concern but it accounts for only 1% of the European Environment Agency's estimated UK deaths from the three pollutants.

[13] COMEAP (2009) *Long-Term Exposure to Air Pollution: Effect on Mortality* and COMEAP (2010) *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*

[14] This is expressed as a "relative risk" of 1.06. In other words, over a given time period, the probability of death with a 10 µg m^{-3} concentration of $PM_{2.5}$ is 1.06 times the probability of death in the absence of $PM_{2.5}$.

[15] $PM_{2.5}$ is a mixture of different particles of diameter 2.5 µm or less.

[16] COMEAP (2018a) *Statement on Quantifying Mortality Associated with Long-Term Average Concentrations of Fine Particulate Matter ($PM_{2.5}$).* The confidence interval reflects statistical uncertainty, but not other types of uncertainty.

[17] COMEAP (2009) *op. cit.* considers cause-specific coefficients, namely those for the increased risk of cardiopulmonary mortality and lung cancer mortality. It notes that using cause-specific coefficients reduces the estimated loss of life years and life expectancy. This may be because cardiovascular deaths tend to occur at older ages when life expectancy is lower.

[18] COMEAP (2010) *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*

[19] The estimates represent the effect of both past and current pollution, assuming 2008 $PM_{2.5}$ concentrations and population structure.

[20] The number of life years lost is calculated by multiplying the extra number of deaths at each age by age-specific life expectancies.

average life expectancy, although this estimate is uncertain[21]. Given the link with cardiovascular deaths, the mortality effects are unlikely to be evenly distributed across the whole population. COMEAP speculate that the effects may have been spread across up to 200,000 deaths in 2008, with an average loss of life of about two years[22].

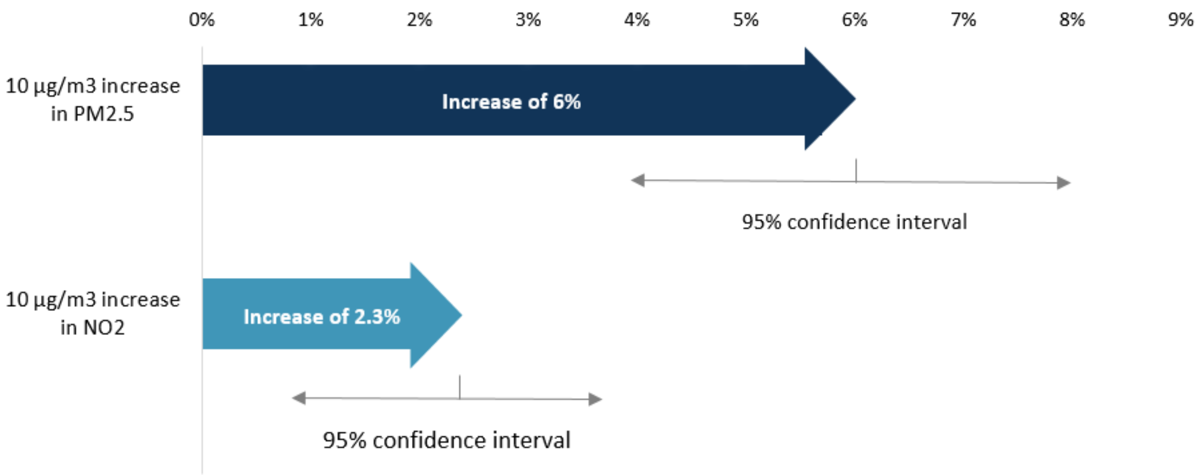


Figure 1. Estimated increase in all-age UK death rates due to air pollutants (Sources and caveats: see text)

There is some evidence for a causal association between NO_2 and mortality, although expert opinion is divided[23]. COMEAP's interim recommendation in 2015 was to assume that mortality increases by 2.5%[24] for each 10 µg m^{-3} increase in concentration of NO_2, with a 95% confidence interval of 1% to 4%[25]. As for $PM_{2.5}$, these coefficients apply to the whole population; COMEAP has not published any age- or gender-specific analysis. Based on an average UK NO_2 concentration of 17.5 µg m^{-3} in 2013, this translates into a central estimate of a 4.3% increase in mortality or 23,500 deaths per year[26]. In 2018, COMEAP updated its estimate of the NO_2 mortality coefficient to 2.3% with a 95% confidence interval of 0.8% to 3.7% (see Figure 1)[27]. However, it cautioned against trying to calculate the number of deaths attributable to NO_2 alone[28].

This is because it is difficult to disentangle the effects of PM and NO_2 since their concentrations are strongly correlated and so the estimated deaths from the two pollutants should not simply be added together. COMEAP has advised that the combined effect of the two pollutants may be

The combined effect of PM and NO_2 may be similar to, or only a little higher than, the effect of one alone.

[21] COMEAP (2010) *op. cit.* used a 75% plausibility interval of one-sixth to double these figures based on expert judgement. COMEAP (2018a) *op. cit.* reported that the statistical uncertainty around its central estimate had reduced following publication of further studies and the distribution of expert views was unlikely to be the same, but it did not update its plausibility interval. Applying the 95% statistical confidence interval from 2018 to the 2010 central estimate would give a range of four to eight months' reduction in average life expectancy.

[22] The discrepancy between the 400,000 life years implied by this sentence and the previous figure of 340,000 life years appears to be due to rounding.

[23] COMEAP (2018b) *Associations of Long-Term Average Concentrations of Nitrogen Dioxide with Mortality*

[24] This is expressed as a "relative risk" of 1.025. In other words, over a given time period, the probability of death with a 10 µg m^{-3} concentration of NO_2 is 1.025 times the probability of death in the absence of NO_2.

[25] COMEAP (2015) *Interim Statement on Quantifying the Association of Long-Term Average Concentrations of Nitrogen Dioxide and Mortality*

[26] Defra (2015) *Valuing Impacts on Air Quality: Updates in Valuing Changes in Emissions of Oxides of Nitrogen (NO_X) and Concentrations of Nitrogen Dioxide (NO_2)*

[27] COMEAP (2018b) *op. cit.*

[28] COMEAP decided against formally deriving an NO_2 coefficient adjusted for effects associated with $PM_{2.5}$. Instead, it suggested that the mortality effects attributable to NO_2 alone may lie in a range of 25-55% of the unadjusted estimate, giving an estimate for the effects attributable to NO_2 alone of a 0.6% to 1.3% increase in mortality for each 10 µg m^{-3} of NO_2.

similar to, or only a little higher than, the effect of one of them alone[29]. A widely-quoted figure for the combined effect of PM and NO_2 is around 40,000 UK deaths a year. This figure was calculated by the Royal College of Physicians report in 2016 using the 29,000 and 23,500 figures above less an allowance for overlap[30].

COMEAP subsequently published a more detailed study on the effects of NO_2 on mortality which included a central estimate of annual UK mortality from long-term exposure to air pollution equivalent to 28,000 to 36,000 deaths at typical ages, associated with a loss of 328,000 to 416,000 life years based on the 2013 pollutant mix[31]. These figures assume that any air pollution, however small, is harmful to health and so extrapolated effects beyond the range of studied concentrations. COMEAP also published lower mortality figures without this extrapolation[32]. Note that these figures represent the combined effect of PM and NO_2 and hence supersede the $PM_{2.5}$ figures above of 29,000 deaths and 340,000 lost life years.

Air pollution is estimated to cause the equivalent of 28,000 to 36,000 deaths a year in the UK, based on the 2013 pollutant mix.

Some work has been done to estimate air pollution-related deaths for smaller geographic areas[33]. The estimated mortality impacts are higher in urban areas, particularly London. These estimates allow for differing pollution levels but use the same coefficients to translate them into mortality impacts (as age- and gender-specific coefficients are not available). However, in practice, people's vulnerability to air pollution varies. The elderly and those with underlying health conditions tend to be more vulnerable, and overweight people may be too[34].

The elderly and those in poor health may be more vulnerable to air pollution.

3.2. Past and future changes in UK air pollution-related deaths

When considering the effects of air pollution on mortality assumptions, knowledge of past and future changes can inform the choice of mortality improvement projections.

Air pollution has affected human health since ancient times, but the type of pollution has changed considerably[35]. Soot and sulphur dioxide from burning coal were major problems in the UK until the 1950s, lead was widely used in petrol between the 1960s and 1980s, and now the major concerns are PM and NO_2[36]. Despite recent reductions in emissions (see Figure 2), many areas of the UK remain in breach of EU limits on NO_2 concentrations and exceed World Health Organisation guidelines for $PM_{2.5}$[37].

Air quality is receiving considerable political and media attention, fuelled by three legal rulings against the UK Government for failing to tackle air pollution[38] and revelations that many diesel engines have higher emissions in real-world conditions than is permitted in laboratory tests[39]. Possible policy interventions include clean air zones in cities, scrapping older diesel vehicles, tighter emission standards for new vehicles and incentives to encourage uptake of electric

There is scope for significant improvements in UK air quality.

[29] COMEAP (2015) *op. cit.*

[30] Royal College of Physicians (2016) *Every Breath We Take: The Lifelong Impact of Air Pollution*

[31] COMEAP (2018b) *op. cit.*

[32] The ranges were 16,000 – 19,000 deaths and 181,000 – 224,000 lost life years

[33] For example, Public Health England (2014) *Estimating Local Mortality Burdens Associated with Particulate Air Pollution* and Walton, H., Dajnak, D., Beevers, S., Williams, M., Watkiss, P. and Hunt, A. (2015) *Understanding the Health Impacts of Air Pollution in London*. Kings College London

[34] Royal College of Physicians (2016) *op. cit.*

[35] Kelly, F. J. and Fussell, J. C. (2015) *op. cit.*

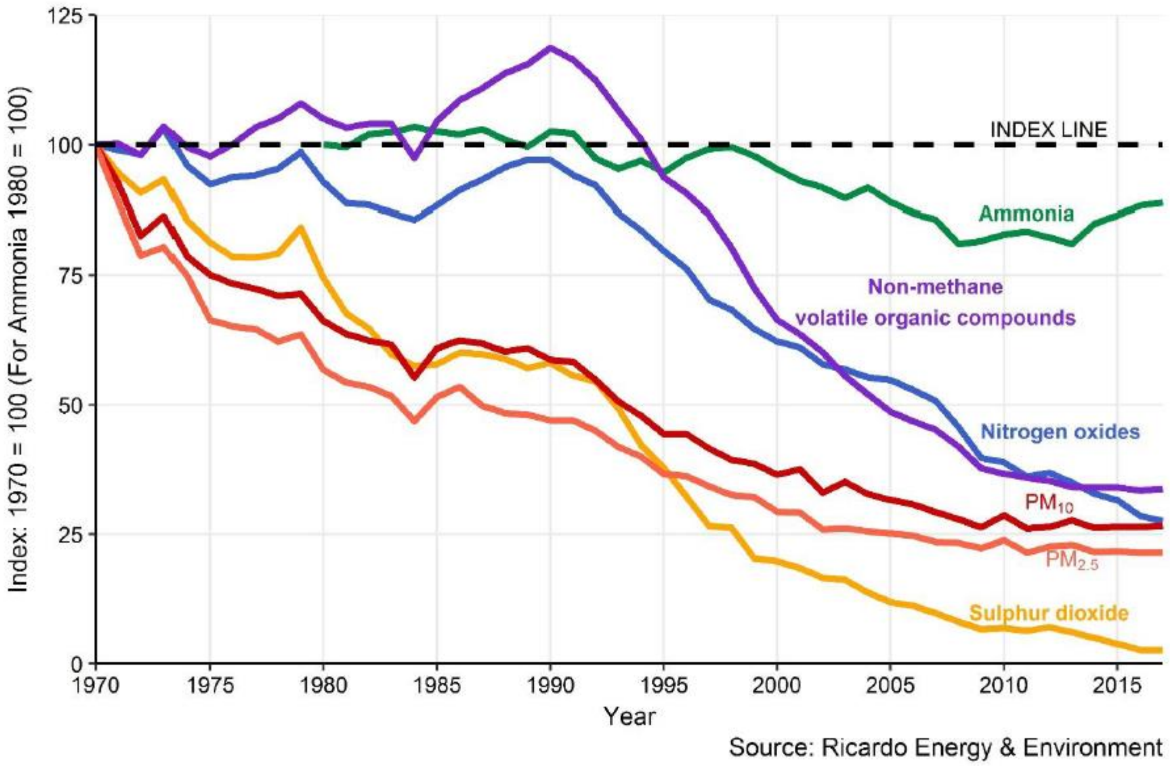
[36] Royal College of Physicians (2016) *op. cit.*

[37] Defra (2018) *Air Pollution in the UK 2017* and European Environment Agency (2018) *Air Quality in Europe: 2018 Report*

[38] Harvey, F. (2018) *Air Pollution: UK Government Loses Third Court Case as Plans Ruled 'Unlawful'*. The Guardian [online]. Available at https://www.theguardian.com/environment/2018/feb/21/high-court-rules-uk-air-pollution-plans-unlawful

[39] Carrington, D. (2017) *Extremely polluting Nissan and Renault diesel cars still on sale, data reveals*. The Guardian [online]. Available at https://www.theguardian.com/environment/2017/may/26/extremely-polluting-nissan-and-renault-diesel-cars-still-on-sale-data-reveals

vehicles[40]. Vehicle technology is improving rapidly: newer diesel vehicles are much cleaner (even in real-world conditions) and electrical vehicles are fast becoming price-competitive[41]. Indeed, the Government has a goal of ending the sale of new petrol and diesel cars by 2040[42] and major automobile manufacturers are accelerating efforts to launch electric vehicles[43]. In addition, there could be considerable synergies between the policy aims of improving air quality and mitigating climate change since reducing fossil fuel use is key to both, although policies need to be carefully chosen so they do not have unintended consequences[44]. Hence it is quite possible that we will see significant reductions in UK PM and NO_2 concentrations over the coming decades. On the other hand, it is possible that other pollutants (perhaps ones that are currently insignificant or unknown) could increase.



The index line is a comparator that shows the level of emissions if they had remained constant from the beginning of the time series.

Figure 2. Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM_{10}, $PM_{2.5}$) emissions 1970-2017[45]

As much of the health burden of air pollution arises from long-term exposure, there will be a lag before air quality improvements translate into mortality improvements. As an indication, COMEAP's main PM estimates from 2010 assume that 30% of the mortality benefit from

[40] House of Commons Environment, Food and Rural Affairs Committee (2016) *Air Quality: Fourth Report of Session 2015–16*

[41] Randall, T. (2016) *Here's How Electric Cars Will Cause the Next Oil Crisis.* Bloomberg [online]. Available at https://www.bloomberg.com/features/2016-ev-oil-crisis/ and International Renewable Energy Agency *Electric Vehicles (EV).* IRENA [online]. Available at https://www.irena.org/costs/Transportation/Electric-vehicles (accessed 14 July 2019)

[42] Hook, L., Pickard, J. and Raval, A. (2018). *UK Stops Short of 2040 Ban on Petrol and Diesel Vehicles.* Financial Times [online]. Available at https://www.ft.com/content/30f7e328-8372-11e8-96dd-fa565ec55929

[43] Campbell, P. (2019) *Electric Carmakers Gear Up for Market Charge*. Financial Times [online]. Available at https://www.ft.com/content/d159ce9c-9f0c-11e9-b8ce-8b459ed04726 http://www.bbc.co.uk/news/uk-40723581

[44] Beevers, S. (2016) *The Impacts of Policies to Meet the UK Climate Change Act Target on Air Quality – An Explicit Modelling Study*. Presentation to LAQN conference [online]. Available at https://www.londonair.org.uk/london/asp/LAQNSeminar/pdf/June2016/Sean_Beevers_Impacts_of_policies_to_meet_UK_CC_Act.pdf

[45] Defra (2019) *Emissions of Air Pollutants in the UK, 1970 TO 2017*

pollution reduction occurs in the first year, 50% in years 2-5, and 20% in years 6-20, and COMEAP suggests using the same lag for NO_2 estimates[46]. Models of future deaths from air pollution are obviously very dependent on assumptions about future concentrations of the main pollutants and this research is at an early stage[47]. For now, it may be more useful to focus on estimates of the total current mortality burden (noting the high uncertainty associated with these) as an indication of the upper limit for potential improvements.

4. How might climate change affect UK temperature-related deaths?

4.1. Current UK heat- and cold-related deaths

Estimates of UK temperature-related deaths usually use statistical definitions rather than underlying causes of death. Very few UK deaths are directly attributable to temperature extremes, for example hypothermia or heat stroke[48]. Instead, temperature-related deaths are determined by assuming a U-shaped relationship between daily temperature and mortality, such as the one shown in Figure 3. Most temperature-related deaths are due to cardiovascular and respiratory causes under this definition[49].

Temperature-related deaths are usually defined using statistical modelling rather than cause of death.

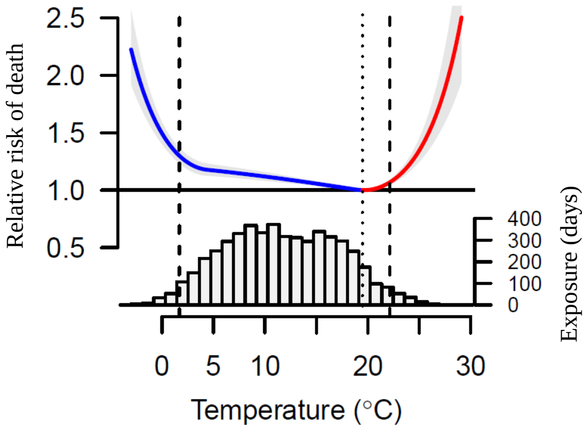


Figure 3. Relationship between temperature and mortality for London, using daily data between 1 January 1993 and 31 December 2006. The optimum (minimum mortality) temperature is shown by the dotted line, and the 2.5th and 97.5th percentiles of the temperature distribution are shown as dashed lines. Daily temperature is calculated as the 24-hour average of hourly measurements. Exposure is the number of days during the 14-year period for each mean temperature[50].

All excess deaths above a certain threshold are classified as heat-related deaths and those below a certain threshold are classified as cold-related deaths. For example, Vardoulakis and

[46] COMEAP (2010) *op. cit.* and COMEAP (2018b) *op. cit.*

[47] Examples include Walton et al (2015) *op. cit.* and M., Amann, M., Heyes, C., Rafaj, P., Schöpp, W., Hunt, A. and Watkiss, P. (2011) *The Reduction in Air Quality Impacts and Associated Economic Benefits of Mitigation Policy: Summary of Results from the EC RTD Climate Cost Project*. Stockholm Environment Institute

[48] Arbuthnott, K., Hajat, S., Heaviside, C. and Vardoulakis, S. (2016) *Changes in Population Susceptibility to Heat and Cold over Time: Assessing Adaptation to Climate Change*. Environmental Health, 15(1), 73-93

[49] Hajat, S., Vardoulakis, S., Heaviside, C. and Eggen, B. (2014) *Climate Change Effects on Human Health: Projections of Temperature-Related Mortality for the UK during the 2020s, 2050s and 2080s.* Journal of Epidemiology and Community Health, 68(7), 641-648

[50] Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M. L., Guo, Y. L., Wu, C. F., Kan, H., Yi, S. M., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P. H., Honda, Y., Kim, H. and Armstrong, B. (2015) *Mortality Risk Attributable to High and Low Ambient Temperature: A Multicountry Observational Study*. Lancet. 2015 Jul 25;386(9991):369-75, Figure S1

colleagues used the 93rd and 60th percentiles respectively[51], whereas Gasparrini and colleagues used the optimum (minimum mortality) temperature – which they found to be the 90th percentile – for both[52]. Vardoulakis estimated that UK mortality increases by 2.5% (95% confidence interval 1.9% to 3.1%) for each 1°C rise in temperature above the heat threshold and increases by 2.0% (95% confidence interval 1.8% to 2.2%) for each 1°C fall below the cold threshold (see Figure 4).

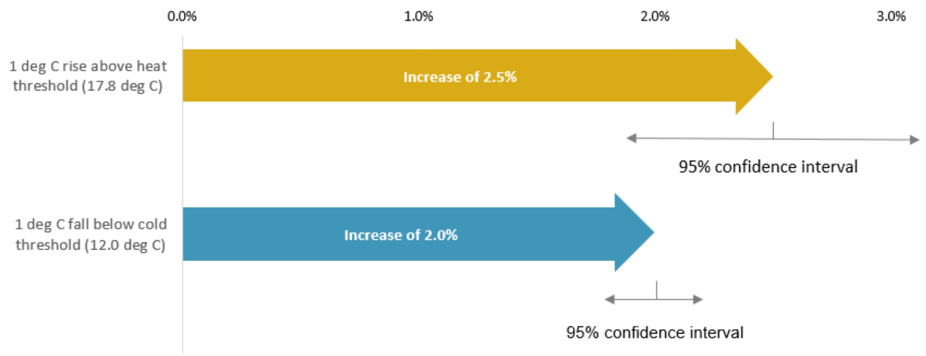


Figure 4. Changes in UK mortality rates due to temperature variations[53]

Using these definitions, there are currently many more cold- than heat-related deaths in the UK. For example, Vardoulakis calculated that there was an average of 31,887 cold-related deaths per year in England and Wales between 1993 and 2006, compared to 1,503 heat-related ones (see Figure 5). The same study showed considerable variation between regions, with annual cold-related deaths ranging from 50 per 100,000 people in the North East to 72 per 100,000 people in Wales, and heat-related ones ranging from 1.4 per 100,000 people in the North East to 4.7 per 100,000 people in London. This is consistent with other studies which have found that temperature-related deaths vary significantly between and within countries due to differences in climate, demographic profile, socio-economic profile and housing stock[54]. Typically, older people and the less wealthy in society are most vulnerable to temperature-related mortality.

The elderly and the less wealthy may be more sensitive to temperature.

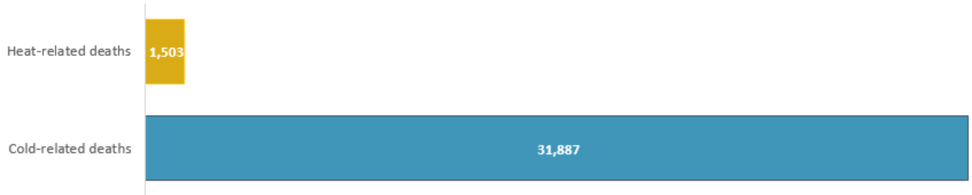


Figure 5. Temperature-related deaths in England and Wales: average number of deaths per year between 1993 and 2006 [55]

An important consequence of the standard statistical definitions is that UK "cold-related" deaths occur throughout the year, not just during winter, many at quite mild temperatures. However, UK public health officials tend to focus on Excess Winter Deaths (EWD) which is defined by

Cold-related deaths occur throughout the year (under the standard definition).

[51] Vardoulakis, S., Dear, K., Hajat, S., Heaviside, C., Eggen, B. and McMichael, A. J. (2014) *Comparative Assessment of the Effects of Climate Change on Heat- and Cold-Related Mortality in the United Kingdom and Australia.* Environmental Health Perspectives, 122(12), 1285-1292

[52] Gasparrini et al (2015) *op. cit.*

[53] Vardoulakis et al (2014) *op. cit.*

[54] *ibid*

[55] *ibid*

the Office for National Statistics as the number of deaths in December to March minus the average of deaths in the previous four months and deaths in the following four months. EWD for England and Wales have averaged approximately 30,000 over the last 15 winters, although with considerable fluctuations[56]. EWD is a somewhat flawed measure: it can be distorted by cold weather occurring outside the four "winter" months and by other seasonal variations such as higher heat-related deaths in summer (which decrease EWD)[57]. Liddell and colleagues found that EWD was a poor estimator of cold-related deaths, particularly for the UK[58].

4.2. Projections of UK heat- and cold-related deaths

Temperatures have already risen in the UK: mean summer and winter temperatures have increased by approximately 0.28°C and 0.23°C respectively per decade since 1960, and extreme maximum and minimum daily temperatures have risen by just over 1°C since the 1950s[59]. Further temperature rises are expected: the UK Climate Projections (UKCP09) indicate an increase in mean summer temperatures of up to 2.8°C (range 0.9 – 4.6°C) by the 2050s compared with the 1961-1990 average[60]. Cold winters are expected to become less severe, less frequent and shorter.

Several studies have modelled how UK temperature-related deaths may be affected by these changes in climate. For example, Hajat and colleagues projected heat- and cold-related deaths for the 2000s, 2020s, 2050s and 2080s, split between twelve UK regions, using a medium greenhouse gas emissions scenario and nine different climate sensitivities[61][62]. From the perspective of actuaries setting assumptions about future mortality rates, perhaps the most useful estimates are the UK-wide death rates per 100,000 people in each of four age groups. Figure 6 puts these in the context of all-cause UK death rates. The modelling implies that, for the UK:

UK projections show a net decrease in mortality rates as the climate warms (fall in cold-related deaths more than offsets rise in heat-related deaths) but this does not allow for changes in the temperature-mortality relationship over time.

- Temperature-related deaths as a proportion of total deaths increase with age.
- Cold-related deaths are expected to fall due to climate change (although see Section 4.3) and would more than offset the increase in heat-related deaths for a constant population.
- More than half of temperature-related deaths currently occur at age 85+ and this is expected to remain the case as the climate warms.

It is important to note the many sources of uncertainty associated with these projections, including:

Projections of temperature-related deaths are very uncertain.

- The choice of definition of heat- and cold-related deaths (eg the percentile used to determine the relevant temperature threshold)
- The change in mortality rates for each 1°C change in temperature (see confidence intervals in Section 4.1)
- Regional variations in temperature-related mortality risk (see examples in Section 4.1)

[56] Office for National Statistics (2018) *Excess Winter Mortality in England and Wales: 2017/18 (Provisional) and 2016/17 (Final)*

[57] Hajat, S. and Gasparrini, A. (2016) *The Excess Winter Deaths Measure: Why its Use is Misleading for Public Health Understanding of Cold-Related Health Impacts*. Epidemiology; 27: 486–491

[58] Liddell, C., Morris, C., Thomson, H. and Guiney, C. (2017) *Excess Winter Deaths in 30 European Countries 1980–2013: A Critical Review of Methods*. Journal of Public Health, 38(4), 806–814

[59] Committee on Climate Change (2016) *op. cit.. Chapter 5: People and the Built Environment*

[60] *ibid*. Central estimate under a medium greenhouse gas emissions scenario.

[61] Hajat et al (2014) *op. cit.*. This used very similar data and methods to Vardoulakis et al (2014) *op. cit.*.

[62] Climate sensitivity measures the strength of the temperature response to a doubling of the atmospheric concentration of carbon dioxide. For details of the climate projection model used, see *UK Climate Projections.* MetOffice [online]. Available at http://ukclimateprojections.metoffice.gov.uk/

- How the climate will respond to increasing greenhouse gas concentrations, noting the existence of "tipping points" beyond which we will experience non-linear and irreversible changes in the climate (under the nine climate sensitivities used by Hajat and colleagues, annual UK-wide cold-related deaths varied from 28 to 56 per 100,000 people in the 2080s and heat-related deaths varied from 7 to 22)[63]
- Future atmospheric greenhouse gas concentrations (Vardoulakis and colleagues projected deaths in England and Wales for three emission scenarios[64], finding that annual cold-related deaths varied from 35 to 47 per 100,000 people in the 2080s and heat-related ones varied from 6 to 14)
- Future changes in the rates of mortality from other causes.

Moreover, these projections exclude any additional mortality impacts of heatwaves and the urban heat island effect[65], and assume that the temperature-mortality relationship will remain constant over time. This assumption seems unlikely to be borne out in practice (see Section 4.3).

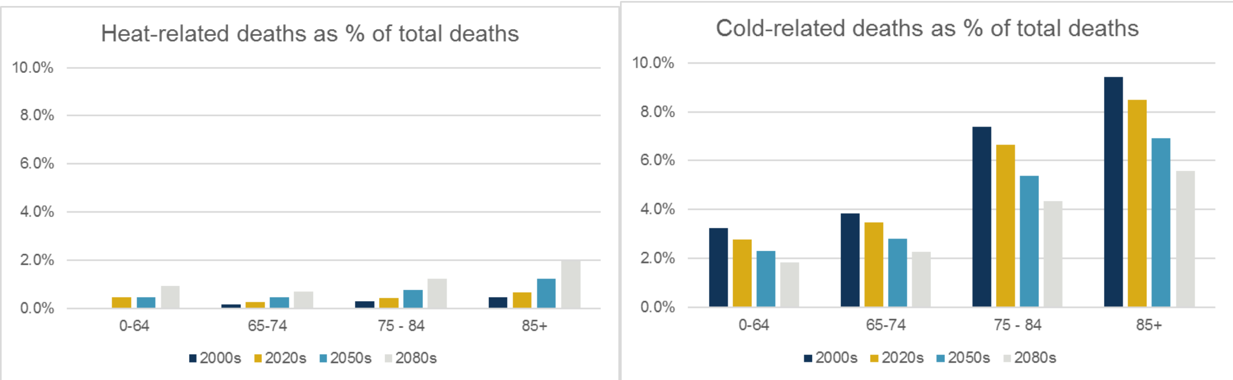


Figure 6. Projected UK temperature-related death rates by age group assuming no change in mortality from other causes (mean of nine climate sensitivities)[66].

4.3. Adaptation to rising temperatures

The temperature-mortality relationship may change over time due to behavioural and policy responses to changes in temperature, as well as wider socio-economic factors. These responses include dressing appropriately when going outdoors, improving building insulation, installing air conditioning, tackling fuel poverty, raising public awareness of temperature-related health risks and issuing alerts when extreme temperatures are forecast. There may also be acclimatisation (physiological adjustment) to higher temperatures.

People adapt to changing temperatures and this may reduce the mortality impacts of climate change.

This adaptation effect is potentially significant, although it may reduce over time as the options for adaptation are exhausted. Gosling and colleagues found that adaptation was often a bigger

[63] In addition to uncertainties about climate sensitivity, some research suggests that the UK might become colder due to cessation of the Gulf Stream (the warm current of water in the Atlantic Ocean which is responsible for the UK's temperate climate), although this would be a multi-decadal effect. See Hakner, J. (2016) *Gulf Stream Slowdown to Spare Europe from Worst of Climate Change.* University of Sussex [online]. Available at http://www.sussex.ac.uk/broadcast/read/36137

[64] The scenarios were B1 (low emissions), A1B (medium) and A1F1 (high) from the Special Report on Emissions Scenarios (SRES) published by the Intergovernmental Panel on Climate Change (IPCC). A summary of the SRES is available at http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=1. Hajat et al (2014) *op. cit.* used the A1B scenario.

[65] There is mixed evidence regarding the importance of these two effects. See, for example, Green H., Andrews, N., Armstrong, B., Bickler, G. and Pebody, R. (2016) *Mortality during the 2013 Heatwave in England: How did it Compare to Previous Studies. A Retrospective Observational Study*. Environmental Research, 147, 343-349, Milojevic, A., Armstrong, B. G., Gasparrini, A., Bohnenstengel, S. I., Barratt, B. and Wilkinson, P. *Methods to Estimate Acclimatization to the Urban Heat Island Effects on Heat- and Cold-Related Mortality*. Environ Health Perspect. 2016 Feb 9 and Heaviside, C., Vardoulakis, S. and Cai, X. M. (2016) *Attribution of Mortality to the Urban Heat Island during Heatwaves in the West Midlands, UK*. Environmental Health, 15(1), 49-59.

[66] Sources: Hajat et al (2014) *op. cit.* Figure 4 (UK temperature-related death rates, derived from 1993-2006 baseline); Office for National Statistics, National Records of Scotland and Northern Ireland Statistics and Research Agency (UK population and all-cause death data for 1993-2006).

source of uncertainty in projections of heat-related deaths than climate and emissions modelling[67]. A study by Jenkins and colleagues modelled the adaptation effect and found 32-69% fewer heat-related deaths in the 2050s for Greater London and the surrounding area under the scenarios considered[68], relative to a no adaptation scenario. Arbuthnott and colleagues carried out a literature review of studies, most of them from the US and Europe, that had investigated changes in the temperature-mortality relationship over time[69]. They found evidence that populations have been becoming less susceptible to heat and heatwaves, but the results for susceptibility to cold were inconclusive, partly reflecting the smaller number of cold-related studies.

Although it is widely believed that UK cold-related death rates will fall due to climate change, as indicated by the modelling summarised in Section 4.2, several recent studies – including one by Staddon and colleagues – have challenged this belief[70]. Changes in the temperature-mortality relationship over time may be one source of this disagreement.

Several recent studies cast doubt on the projected fall in UK temperature-related deaths due to climate change.

Staddon and colleagues performed a regression analysis of EWD in England and Wales between 1951 and 2011. They found that the key factors associated with year-to-year variation in EWD were:

- 1951-1971: housing quality, number of cold days (less than 5°C)
- 1971-1991: number of cold days (less than 5°C), influenza activity
- 1991-2011: influenza activity.

In other words, the authors found there is no longer a strong association between cold temperatures and EWD. They concluded that UK mortality rates may not fall due to climate change. This conclusion has been disputed because the analysis used EWD rather than cold-related deaths (see Section 4.1)[71]. However, Ballester and colleagues found a similar result for cold-related deaths, namely that year-to-year variations in deaths did not correlate strongly with temperature in England and Wales for the coldest 50% of days in the period 1998-2005[72].

Paradoxically, Ballester also found that day-to-day variations in deaths (as used in the analyses by Hajat and Vardoulakis described in Sections 4.1 and 4.2) are strongly correlated with temperature. This result is shown in Figure 7. Note that England and Wales is one of the few European regions without a strong yearly correlation, while simultaneously having one of the highest daily correlations (contrary to the usual pattern that daily correlation is highest among the warmest European countries).

The UK is unusual: day-to-day variations in mortality are strongly linked to temperature fluctuations, but there is only a weak link between year-to-year variations.

Ballester and colleagues attempted to explain this paradox and hence reconcile the apparently contradictory conclusions of Hajat and Staddon. They hypothesised that the anomalous UK result reflects partial adaptation: in warmer years, the temperature-mortality curve (see Figure 3)

[67] Gosling, S. N., Hondula, D. M., Bunker, A., Ibarreta, D., Liu, J., Zhang, X. and Sauerborn, R. (2016) *Adaptation to Climate Change: A Comparative Analysis of Modelling Methods for Heat-Related Mortality*. Environmental Health Perspectives (in press).

[68] Jenkins, K., Hall, J., Glenis, V., Kilsby, C., McCarthy, M., Goodess, C., Smith, D., Malleson, N. and Birkin, M. (2014) *Probabilistic Spatial Risk Assessment of Heat Impacts and Adaptations for London*. Climatic Change, 124(1-2), 105-117. The scenarios were B1 (low emissions) and A1F1 (high), with urban land use and human-related heat emissions either unchanged or 50% higher than baseline.

[69] Arbuthnott et al (2016) *op. cit.*

[70] Staddon, P. L., Montgomery, H. E. and Depledge, M. H. (2014) *Climate Warming Will Not Decrease Winter Mortality*. Nature Climate Change 4, 190–194, Ballester, J., Rodó, X., Robine, J-M. and Hermann, F. R. (2016) *European Seasonal Mortality and Influenza Incidence due to Winter Temperature Variability*. Nature Climate Change, 6, 927-931, Ebi, K. L. and Mills, D. (2013) *Winter Mortality in a Warming Climate: A Reassessment*. WIREs Climate Change, 4:203–212

[71] Hajat, S. and Kovats, S. (2014) *A Note of Caution about the Excess Winter Deaths Measure.* Nature Climate Change 4, 647

[72] Ballester et al (2016) *op.cit.*. Although the main analysis and the charts reproduced in Figure 7 of this paper use winter data.

is further to the right than in colder years, with a larger shift in the UK than in many other countries. Hence UK deaths do not fall as much as might be expected in warmer winters, but within a given year the pattern of deaths does reflect daily variations in temperature. However, whilst some degree of physiological and behavioural adaptation from year to year is plausible, other adaptation measures such as improvements to housing stock represent one-off reductions in vulnerability to temperatures and would shift the cold end of the curve to the left. Further research is therefore needed to understand how the temperature-mortality relationship is changing. In the meantime, there is an unresolved debate about how cold-related deaths may be affected by climate change.

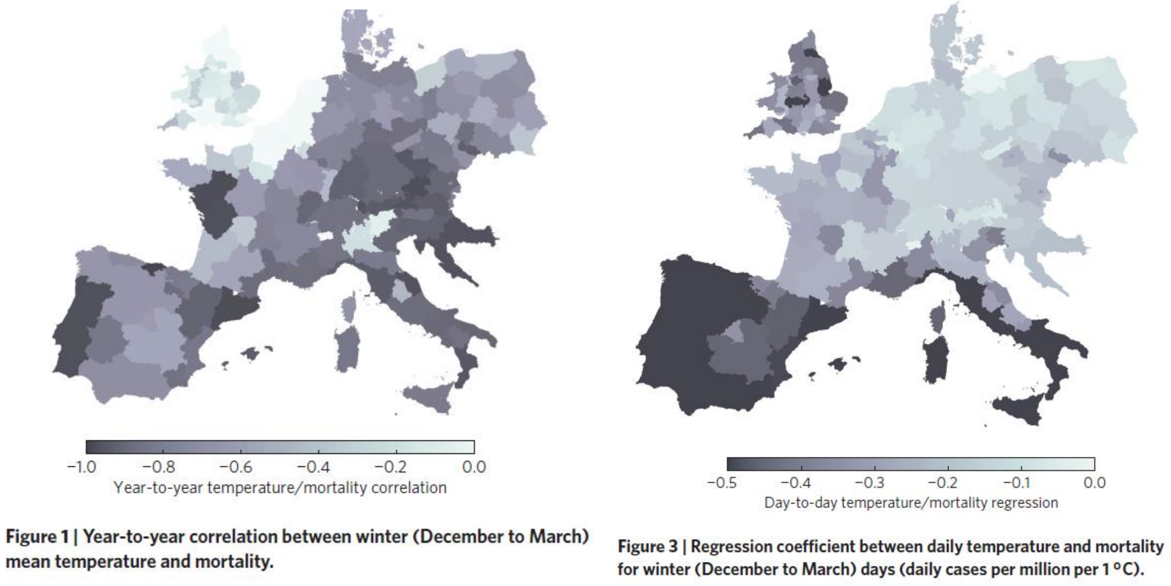


Figure 7. Contrasting pictures of temperature-related mortality in Europe[73].

5. What are the implications for mortality assumptions?

It is important to understand how pollution and temperature-related deaths are reflected in current UK mortality assumptions, and how these deaths may change over time.

Pollution- and temperature-related deaths are already reflected in the base tables used by pensions actuaries because they are present in the data from which these tables are derived. In addition, any historic changes in their rate will be reflected in the initial rates of mortality improvement used in the CMI projections and may also influence the choice of long-term annual rate of improvement if this is set with regards to past trends.

This section summarises information about the extent to which pollution- and temperature-related deaths may already be reflected in base tables and indicates how these deaths may change over time, to inform the choice of long-term annual rate of improvement.

Section 3 reported the latest estimate of the mortality impact of long-term exposure to air pollution from the UK Government's advisory committee on the health effects of air pollutants. This is a central estimate equivalent to 28,000 to 36,000 deaths per year at typical ages, associated with a loss of 328,000 to 416,000 life years, and combines the effects of PM and NO_2 pollution. Earlier work had suggested an impact on average UK life expectancy at birth of 6

[73] Ballester et al (2016) *op.cit.*. The wide regional variation in temperature-mortality relationships demonstrates the importance of using local studies when estimating temperature-related deaths. Non-UK actuaries should bear this in mind when considering the relevance of this report to their work.

months based on $PM_{2.5}$ alone[74], although the combined effects of all outdoor air pollutants may be only slightly higher due to the significant correlation between them. In practice, the effects of air pollution are not uniform: more vulnerable groups are likely to experience larger reductions in life expectancy than other groups.

There is limited information on how air pollution effects vary by age, gender and socio-economic class; this is an area that needs further research (see Section 6). Nonetheless the headline figures above indicate the potential for mortality improvements from reductions in air pollution over the coming decades. Another area for further research is the extent to which mortality improvements due to air quality improvements have already occurred and hence are implicitly reflected in mortality projections that extrapolate from historic data. This would enable actuaries to make more informed judgements of the potential impact of future changes in air quality.

Section 4.1 indicated that approximately 6% of deaths in England and Wales in 1993-2006 were cold-related and approximately 0.3% were heat-related[75]. The central projections in Section 4.2 correspond to approximately a 25% fall in the cold-related death rate and a tripling of the heat-related death rate between the 2000s and the 2050s (see Figure 8)[76]. There are many sources of uncertainty in these figures, including the extent to which we will adapt to changing temperatures. Although much of the modelling indicates that the net effect of warming temperatures will be a reduction in UK temperature-related deaths, some recent research has suggested that the reductions in cold-related deaths may have been overestimated. Nonetheless, Figure 6 indicates considerable scope for reductions in cold-related deaths, particularly at the oldest ages. Further analysis is needed of the extent to which mortality rates have already been affected by rising temperatures and hence projected changes are already reflected in mortality projections.

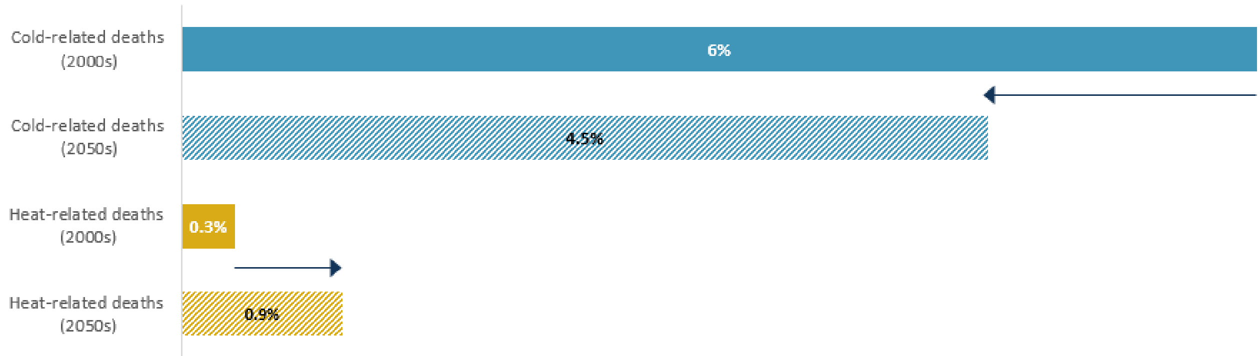


Figure 8. Projected temperature-related death rates for England and Wales[77]

Temperature-related deaths may have a smaller impact on life expectancy, and may change less quickly, than pollution-related deaths.

The projected life expectancy impacts of rising temperatures are lower and more gradual than the potential impacts of improved air quality outlined above. In addition, some research has suggested that temperature changes may bring forward deaths by only a few weeks or months in

[74] To put this in context, the increase in life expectancy between 2017 and 2037 for a male aged 65 is approximately 5 months larger using a 1.75% long-term annual improvement rate than a 1.5% rate, when applied to CMI's 2014 core projections model using 100% of the SAPS 'S2' series tables. This may broadly correspond to a 2-3% increase in the liabilities of a typical pension scheme.

[75] Based on an average of 540,000 deaths per year. Source: ONS Mid-1991 to Mid-2012 Population Estimates: components of population change for Constituent Countries in the United Kingdom; estimated resident population.

[76] Weighted by UK population numbers for 1993-2006.

[77] Hajat et al (2014) *op.cit.*

some cases[78], thus limiting the effect on life expectancy. Hence a given reduction in the death rate may be associated with a smaller loss of life years than an equivalent reduction in the pollution-related death rate. On balance, it seems that changes in temperature-related deaths may be less significant than changes in pollution-related deaths over the next few decades, although there is considerable uncertainty associated with both sets of estimates.

Some actuarial research has been conducted into the relationship between temperature and mortality, although it is not yet sufficiently advanced to be of practical relevance to pensions actuaries. Seklecka and colleagues have developed a stochastic mortality model with a temperature factor, although it uses annual average temperature data so is not able to capture the daily variations that are important drivers of temperature-related deaths (see Section 4.3)[79]. Naqvi and Hall have used a statistical model that incorporates mean monthly temperature data to investigate how changing temperatures might affect older-age mortality differentials between England and Wales and Scotland[80].

As noted in Section 2, changes in air pollution and temperature-related deaths may be less significant than other, less quantifiable, R&E impacts. For example, two illustrative "low trend" mortality scenarios published by Club Vita and the PLSA in 2017 – which both incorporate R&E constraints as one element of their narrative description – correspond to broadly 6% and 16% falls in pension scheme liabilities[81]. More recently, Club Vita has published three scenarios for the effects of climate change and resource constraints. These showed a longevity impact of a 12% decrease ("Head in the Sand"), 4% decrease ("Challenging Times") and a 5% increase ("Green Revolution") in the liabilities of a typical UK scheme[82].

Club Vita has illustrated longevity impacts for a typical UK pension scheme ranging from -12% to +5% of liabilities under three R&E scenarios.

For some schemes, it will be important to consider how annuity prices may be affected in future[83] and how uncertainty regarding future mortality rates might affect clients' decisions about whether to hedge longevity risk. Anecdotal evidence previously suggested that few, if any, life insurers were explicitly allowing for climate risks – either the mortality impacts or more generally – when reserving for, or pricing, annuities. However, the Prudential Regulation Authority has issued a Supervisory Statement setting out its expectations of insurers in managing the financial risks from climate change[84] and the IFoA has advised that all actuaries should consider climate-related risks[85]. Hence insurers' mortality assumptions may soon start to reflect climate change impacts if they do not already.

The uncertainty associated with estimates of R&E impacts on mortality poses challenges for actuaries wishing to incorporate R&E effects in their choice of mortality assumptions. It suggests a focus, at this stage, on illustrating a range of possible outcomes rather than attempting to set a single assumption. Actuaries may wish to consider illustrating a larger range of possible mortality improvements in their advice, including lower life expectancies.

Estimates of R&E impacts on mortality are highly uncertain, not least because many are not readily quantifiable. Sensitivity analysis may be the most useful tool at this stage.

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[78] Vardoulakis et al (2014) *op.cit.*, Ebi and Mills (2013) *op.cit.*

[79] Seklecka, M., Pantelous, A. A. and O'Hare C. (2017) *Mortality Effects of Temperature Changes in the United Kingdom.* Journal of Forecasting

[80] Naqvi, R. and Hall, M. (2017) *Climate Change: Reshaping Mortality Differences within the United Kingdom?* Presented to the IFoA on 6 July 2017

[81] Pensions and Lifetime Savings Association and Club Vita (2017) *Longevity Trends: Does One Size Fit All?*

[82] Club Vita (2018) *Hot and Bothered: How Climate Change Might Affect UK Longevity*

[83] Whilst insurers are better placed to offset mortality risks against longevity risks than pension schemes (which may reduce the sensitivity of insurers' pricing to future mortality estimates), mortality seems to be an important assumption when pricing settlement options.

[84] Prudential Regulation Authority (2019) *Supervisory Statement SS3/19: Enhancing Banks' and Insurers' Approaches to Managing the Financial Risks from Climate Change*

[85] IFoA (2017) *Risk Alert: Climate-Related Risks.* Available at https://www.actuaries.org.uk/documents/risk-alert-climate-related-risks

6. Conclusion and action points

This report has given an overview of R&E issues that may affect UK mortality, focusing on air pollution and rising temperatures as these are the effects that have been studied most, even though they may not be the most material effects. Air pollution and cold weather are associated with a non-trivial proportion of current UK deaths, indicating scope for modest improvements in life expectancy. Life expectancy may also improve as a result of climate change mitigation policies that encourage more active travel and healthier diets. On the other hand, R&E issues may increase deaths from other causes, both directly (eg more heat-related deaths and weather-related disruption to healthcare) and indirectly (eg due to negative macro-economic impacts of climate change, the transition to a low carbon economy or resource constraints), which could more than cancel out these beneficial effects.

It is not possible to say whether the net UK mortality impact will be positive or negative over the next few decades.

It is not clear how actuaries should allow for R&E issues when setting UK mortality assumptions, due to uncertainty about the speed, magnitude and even direction of future R&E impacts on mortality, and also lack of visibility about the extent to which historic impacts are reflected implicitly in current base tables and projection models. Some actuaries may conclude that their mortality advice already makes sufficient allowance for the uncertainties arising from R&E issues. Nonetheless, the information in this report will help them to reach an informed conclusion on this point and to follow the IFoA's guidance that they should understand, and be clear in communicating, the extent to which they have taken account of climate-related risks in any relevant decisions, calculations or advice[86].

This report also indicates that there is considerable scope for further research regarding R&E impacts on mortality rates. From an actuarial perspective, this includes:

- Understanding how pollution and temperature-related deaths have changed over recent decades and hence how they are reflected in current base tables and initial rates of mortality improvement
- Shifting the emphasis from analysis of number of deaths to analysis of how pollution and temperature affect life expectancy
- Understanding how pollution and temperature-related mortality varies by age group, geographic region, socio-economic class and gender
- Researching other R&E effects on life expectancy, including the consequences of a potential decrease in economic growth and healthcare spending
- Investigating how R&E impacts might be incorporated explicitly in mortality models
- Developing evidence-based scenarios that incorporate a range of R&E impacts and could assist actuaries in giving integrated risk management advice
- Keeping abreast of research being done elsewhere on topics such as the links between mortality and temperature and air quality.

The mortality projection models commonly used by pensions actuaries extrapolate from historic data, so any adjustments to these models for R&E impacts will necessarily be broad-brush. In due course, new mortality models that explicitly include causes of death may make it easier to allow for changing R&E impacts. Air quality and adverse temperatures are rarely direct causes of death, but they are important contributing factors in certain causes of death. Models which

[86] *ibid*

can capture the changing prevalence of different causes of death are therefore more likely to be suited to taking account of R&E impacts. Developing such models is an important area of research that is already underway.

We encourage the actuarial profession to contribute to the research outlined above, collaborating with non-actuaries as appropriate, and to highlight the importance of understanding life expectancy impacts (not just number of deaths) and variations in impact across the population (eg by age).

More research is needed, but actuaries can take practical steps now.

Despite the uncertainties, there are actions that can be taken now by actuaries who advise on the mortality assumptions adopted by UK defined benefit pension schemes:

- Learn more about R&E issues to be equipped to discuss them with your clients[87]
- When giving advice, communicate your approach to R&E risks and the associated uncertainty
- Use sensitivity analysis to illustrate how R&E issues may affect mortality, including the possibility of falls in life expectancy
- Consider how uncertainty regarding future mortality rates (including R&E effects) may affect decisions about whether to hedge longevity risk
- Help trustees adopt an integrated risk management approach to R&E risks.

[87] For suggested reading, see footnotes to “Resource and Environment Issues: A Practical Guide for Pension Actuaries”, “Resource and Environment Issues for Pensions Actuaries: Supplementary Information on Resource and Environment Issues and their Implications for Sponsor Covenant Assessments” and “Resource and Environment Issues for Pensions Actuaries: Considerations for Setting Financial Assumptions”

Appendix: Main references

Of the many documents referenced in this report, the ones below are perhaps the most important. They may therefore be a good starting point for those wanting to learn more about the topic, although some are rather long or academic in nature. They are listed below in broadly the order in which they are referenced in the text.

Committee on Climate Change (2016) ***UK Climate Change Risk Assessment 2017: Evidence Report***
An extensive report prepared to inform the UK Government's second Climate Change Risk Assessment, a five-yearly requirement of the 2008 Climate Change Act. The most relevant chapter for mortality is Chapter 5 "People and the Built Environment".
https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/

COMEAP (2009) ***Long-Term Exposure to Air Pollution: Effect on Mortality***
The source of the most-widely quoted estimates of the impact of PM pollution on UK mortality.
https://www.gov.uk/government/publications/comeap-long-term-exposure-to-air-pollution-effect-on-mortality

COMEAP (2010) ***The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom***
A follow-up paper to COMEAP (2009) which translates the mortality coefficients presented there into UK-wide estimates of mortality impacts.
https://www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk

COMEAP (2018a) ***Statement on quantifying mortality associated with long-term average concentrations of fine particulate matter***
This statement updates the earlier advice in COMEAP (2009) and COMEAP (2010) on how to estimate mortality associated with long-term average concentrations of particulate air pollution.
https://www.gov.uk/government/publications/particulate-air-pollution-effects-on-mortality

COMEAP (2015) ***Interim Statement on Quantifying the Association of Long-Term Average Concentrations of Nitrogen Dioxide and Mortality***
Appends interim recommendations on quantification made to the Department for Environment, Food and Rural Affairs (Defra) in July 2015 and outlines COMEAP's work in progress.
https://www.gov.uk/government/publications/nitrogen-dioxide-interim-view-on-long-term-average-concentrations-and-mortality

COMEAP (2018b) ***Associations of long-term average concentrations of nitrogen dioxide with mortality***
This report considers how to calculate the mortality burden of current levels of outdoor air pollution and estimate the benefits of reducing concentrations of nitrogen dioxide.
https://www.gov.uk/government/publications/nitrogen-dioxide-effects-on-mortality

Royal College of Physicians (2016) ***Every Breath We Take: The Lifelong Impact of Air Pollution***
A well-presented, accessible document which provides thought leadership rather than original research.
https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

Vardoulakis et al (2014) ***Comparative Assessment of the Effects of Climate Change on Heat-and Cold-Related Mortality in the United Kingdom and Australia.***
The source of the baseline figures for UK cold- and heat-related deaths presented in this report. Includes projected deaths for the 2020s, 2050s and 2080s.
http://ehp.niehs.nih.gov/1307524/

Hajat et al (2014) ***Climate Change Effects on Human Health: Projections of Temperature-Related Mortality for the UK during the 2020s, 2050s and 2080s.***
The source of the projected changes in UK cold- and heat-related deaths presented in this report. Uses similar data and methodologies to Vardoulakis et al (2014).
http://jech.bmj.com/content/68/7/641.abstract

Office for National Statistics (2018) ***Excess Winter Mortality in England and Wales: 2017/18 (Provisional) and 2016/17 (Final)***
The most recent statistical bulletin on EWD, which analyses 2017/18 data in detail and compares it with previous years.
https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/excesswintermortalityinenglandandwales/2017to2018provisionaland2016to2017final

Ballester et al (2016) ***European Seasonal Mortality and Influenza Incidence due to Winter Temperature Variability***.
Studies day-to-day and year-to-year variations in winter deaths for many European regions and attempts to reconcile apparent contradictions between recent studies.
http://www.nature.com/nclimate/journal/v6/n10/full/nclimate3070.html

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