Modelling public health improvements as a result of air pollution control policies in the UK over four decades – 1970 to 2010

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Supplementary Material

S1. Atmospheric chemistry transport modelling

The modelling framework utilising the EMEP4UK atmospheric chemistry transport model, driven by meteorological input from the Weather Research Forecast Model, has been described in detail by Vieno et al. (2010). Model performance is routinely validated against observations from the UK Automatic Urban and Rural Network. Comparisons of model results vs observations for several recent years can be accessed at http://www.emep4uk.ceh.ac.uk/aurncomparison, providing a comprehensive overview of model performance for all main air pollutants. The sensitivity of model outputs as a result of emission changes has been specifically investigated by Aleksankina et al. (2019).

More generally, the work by Lin et al. (2017), for instance, was focused on comparison of model outputs and measurements in the context of use of model simulations of NO_2, O_3, PM_{10} and $PM_{2.5}$ for health burden assessment, and was temporally and spatially comprehensive in its analysis, covering a 10-year period (two years for $PM_{2.5}$) of daily averages at all non-roadside measurement sites in the UK Automatic Urban and Rural Network. The analysis also included assessment of model-measurement statistics in comparison to model quality objectives (MQO) defined by the EU FAIRMODE (Forum for Air quality MODelling in Europe) project (http://fairmode.jrc.ec.europa.eu). The annual MQOs were met at 100%, 87% and 73% of the 28, 47 and 44 measurement sites for $PM_{2.5}$, O_3 and NO_2, respectively (expectation is for ≥90% compliance). Most sites not meeting the MQO were very close to meeting it.

S2 Population mapping

Modelled gridded pollutant concentrations were converted to population-weighted values. Population estimates used in this study are described in detail in Naden *et al.* (2015), here we present only a summary of their derivation. Population estimates were based on returns from the 1981, 1991, 2001 and 2011 UK census and were scaled at the devolved authority level (i.e. England, Wales, Scotland and Northern Ireland) to official estimates for the corresponding years for which model runs were conducted, but which did not have a census estimate (Office of National Statistics (ONS), http://www.ons.gov.uk/). As census boundaries have changed over time, gridded population estimates were required to enable spatial comparison between years. Census returns were downloaded from http://www.census.ac.uk at the highest possible resolution; enumeration districts for 1981 and census output area level for 1991, 2001 and 2011. Population estimates for 1970 were based upon census returns from the 1981 census, due to availability at a higher resolution than the 1971 census and were scaled to the 1971 devolved authority ONS population estimates. To make the estimates consistent throughout the time-series, population estimates were rasterized to a 1 km grid resolution. For output areas and enumeration districts that cover multiple 1 km grid squares, land cover was used to distribute the population between grid squares containing suitable land cover types, but excluding areas of waterbodies, woodland, rocky outcrops, etc. where human habitation is highly unlikely, or extremely sparse. This was based on Land Cover Map 2007 (LCM2007: Morton *et al.* 2011; Rowland *et al.*, 2017), for consistency, and the use of a single snapshot in terms of land cover for the period is not expected to result in substantive bias, as urban/suburban development has not occurred across this excluded land cover over the period. Given the uneven distribution of land cover types across the UK, and urban/suburban areas in the context of this study, it is important to represent the irregularly shaped area units of the population distribution (output areas, enumeration districts) appropriately for comparing with the regular gridded areal units of the concentration levels (5 km by 5 km grid cell). This is especially important for large areal units of population with low and uneven population density, so health impacts are accounted for appropriately, to minimise the Modifiable Areal Unit Problem (MAUP, e.g. Hellsten *et al.*, 2018). The population estimates were combined with the 5 km gridded estimates of concentration from the EMEP model to estimate population-weighted concentrations (at 1km grid resolution). UK average population-weighted concentrations were estimated by dividing the resulting surfaces by total population and were used for the health impact assessment.

S3 Limitations and uncertainties

When constructing the spatially explicit emission maps for each ten-year time interval, the same land cover map has been applied for the whole study period. Ideally, emission maps for each modelled year should be based on the land use and land cover for the respective year. However, no time series of land cover map information is currently available that would allow such an assessment.

The assessment of population-level health effects is based on atmospheric chemistry transport model outputs and hence rely on confidence that changes in model outputs adequately reflect the changes in emissions, which serve as primary input data. ACTMs are routinely evaluated against ambient monitoring data, and in addition, Aleksankina *et al.* (2018, 2019) have conducted a systematic assessment of the sensitivity of model outputs to variations in emission input data.

Although we have estimated the individual AFs of mortality associated with three air pollutants in relation to emission controls in the UK, it is important to note that the AFs for each pollutant should not be summed, since the effects of some pollutants are unlikely to be cumulative. For multi-pollutant mixtures, the spatial (and temporal) concentrations of some pollutants are highly correlated which means the concentration-response coefficient applied for a given pollutant may not truly reflect the independent effect of that pollutant alone. This is particularly the case when considering the health impacts associated with NO_2 and $PM_{2.5}$ (COMEAP, 2010; 2018).

In our calculations, we have not used any low concentration thresholds (cut-offs) for $PM_{2.5}$ or NO_2 as recommended in the literature. For O_3, we have estimated the fraction of respiratory mortality attributable to long-term (warm season) exposure (with a threshold of 70 μg m^{-3}) as recommended by WHO (2013), although we recognise that these effects are less conclusive. For all pollutants, we have calculated relative changes in mortality effects over time, rather than absolute burdens.

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