Public health air pollution impacts of pathway options to meet the 2050 UK Climate Change Act target: a modelling study

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Declared competing interests of authors: Melissa C Lott reports grants from BHP Billiton outside the submitted work. Mike Holland reports personal fees from the NHS during the conduct of the study.

Published June 2018
DOI: 10.3310/phr06070

Scientific summary

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Public Health Research 2018; Vol. 6: No. 7
DOI: 10.3310/phr06070

NIHR Journals Library www.journalslibrary.nihr.ac.uk

Scientific summary

Background

The UK's *Climate Change Act 2008* (CCA; Great Britain. *Climate Change Act 2008*. Chapter 27. London: The Stationery Office; 2008) requires a reduction of 80% in carbon dioxide-equivalent emissions relative to 1990. This large reduction offers the opportunity to make large reductions in air pollution and their impacts on public health, but not all pathways to the target will be equally 'clean' in air pollution terms. This project improves on previous impact calculations and develops a comprehensive system to explore some pathways and calculate their impact on public health.

Objectives

The objectives of the work as set out in the original proposal were as follows:

- To develop a series of policy pathways to achieve the CCA 2050 target, spanning a maximum health benefit scenario at one extreme and a scenario that rejects the 2050 target at the other. In between these, we will identify up to three scenarios that deliver increasingly large benefits for public health.
- On the basis of these scenarios, to produce air pollution emissions estimates for the UK and Europe, for 2050.
- To evaluate the air quality model for the current year and to establish the contribution to concentrations of particulate matter (PM), nitrogen dioxide (NO_2) and ozone (O_3) from sources within the UK and in Europe. These pollutants are the ones for which concentration–response functions (CRFs) are available to allow health impact assessments.
- To forecast air quality across the UK, including detailed modelling in urban areas for the future year and for the chosen policy scenarios.
- To calculate exposures at 9 × 9 km resolution for the UK and at 20 × 20 m resolution in major cities, and to calculate personal exposures using the hybrid time–activity model.
- To calculate the impact of the alternative future policies on mortality (and morbidity) using the life table approach and the associated monetary values.
- To assess the impact of the different climate and air quality scenarios on UK health inequalities in the future years.
- Optimal strategies for maximising the public health benefits of achieving the CCA target for 2050 will be produced.

The original intention was to use the simple spreadsheet 'calculator' produced by the Department of Energy and Climate Change (now the Business, Energy and Industrial Strategy department). However, in the course of the project we formed a collaboration with University College London, which runs the energy model, the UK Integrated MARKAL–EFOM System (UKTM), as used by government and by the Committee on Climate Change (CCC) to formulate strategies to attain the CCA target. We felt that the more detailed UKTM model would give results with greater rigour, as well as consistency with UK government analyses. However, this added to the complexity of the modelling system and we found that converting the UKTM national output into a spatially resolved air pollution emission inventory is a lengthy process. This reduced the number of 2050 scenarios we could model compared with the original objective, although we found that particulate matter of ≤ 2.5 μm ($PM_{2.5}$) and particulate matter of ≤ 10 μm (PM_{10}) emissions peak between now and 2050, and so runs were undertaken in 2035 (not originally part of the project).

Methods

The UKTM model was used to develop four future scenarios. The 'baseline' scenario was consistent with the Fourth and Fifth Carbon Budgets produced by the CCC and envisaged no further climate measures beyond those currently agreed. Two other scenarios achieved the CCA target with two differing levels of nuclear power. The nuclear replacement option (NRPO) scenario assumed that only existing nuclear plants would be replaced and the low greenhouse gas (LGHG) scenario had no policy constraint on nuclear, limiting build only by economic and technical feasibility. Another scenario (the 'reference') was identical to the baseline except that it contained a carbon price (£30 per tonne) to produce a scenario in which some action was taken to reduce carbon emissions despite CCA targets for 2050 not being achieved. We reported emissions for the reference scenario, but it differed little from the baseline so we did calculate the health impact.

The sectoral fuel use outputs from UKTM were then converted into a 1 × 1 km grid of air pollution emissions across Great Britain (GB) for each scenario. The pollutants considered for quantification of health impact are fine particles ($PM_{2.5}$), NO_2 and O_3. These are the pollutants for which evidence of impacts is strongest.

The emission inventories were then used to run an air quality model [the Community Multiscale Air Quality (CMAQ) model]. This has enabled us, for the first time in GB, to model air quality concentrations and their impact on health rather than relying simply on emissions and generalised relationships between the latter and damage costs, as previous studies in this area have done. The outputs from the CMAQ model went beyond those originally planned, giving concentrations across GB at a spatial resolution of 10 km in rural areas and 2 km in urban areas. We also performed calculations at a spatial resolution of 20 m in urban areas. This resolution is more likely to identify pollution 'hot spots' than coarser grids and this is the first time that concentrations at this resolution have been reported in GB.

The concentrations were used to calculate health impact using well-known life table calculations but with the most recent coefficients (and confidence intervals) relating pollution concentrations to health outcomes, as recommended by the World Health Organization (WHO) or by the UK Committee on the Medical Effects of Air Pollutants (COMEAP) for $PM_{2.5}$, NO_2 and O_3. We also assessed the differences in exposure to air pollutants in different socioeconomic classes using the Carstairs index of deprivation.

Results

Scenario emissions

In the two 'CCA-compliant' scenarios, NRPO and LGHG, a high proportion of energy was generated through biomass use (wood burning), with a large increase in $PM_{2.5}$ emissions of approximately 50%, compared with 2011, and peaking in 2035. Although the biomass use was projected to decrease again by 2050, primary $PM_{2.5}$ emissions in 2050 were still marginally higher than 2011 levels. In the baseline and reference scenarios, which did not meet the CCA target, levels of wood burning were lower.

Both the LGHG and the NRPO had a high degree of switching from petrol and diesel fuels to electric, hybrid and alternatively fuelled vehicles in the UK road transport fleet, leading to reductions of around 90% from transport sector oxides of nitrogen (NO_x) emissions in all scenarios except the baseline. In the baseline scenario gas and biomass consumption in combined heat and power plants was higher than in other scenarios, with no obligation to meet the CCA target, and this led to increased NO_2 exposure. In the transportation sector, despite the exhaust emission reductions, the UKTM projections show large increases in traffic activity, with car and heavy good vehicle kilometres projected to increase by roughly 50% in all the scenarios and van kilometres projected to increase by a factor of about 2. This leads to a pro-rata increase in PM emissions from brake and tyre wear and resuspension of road dust, although these findings are uncertain as we have assumed that future emissions factors will remain at current levels. Consequently, non-exhaust emissions could be the dominant source of primary PM from vehicles in future, increasing PM_{10} by about 15% compared with 2011 in the NRPO scenario, for example. This is more of an issue for PM_{10}, as the non-exhaust emissions are coarser.

Pollutant concentrations

Annual mean concentrations of NO_2 are projected to decrease by ≥ 60% in the LGHG scenario and by ≈50% in the NRPO scenario across the whole of GB and in London, but by only ≈20% across GB and ≈42% in London in the baseline scenario.

Annual mean $PM_{2.5}$ concentrations are also projected to fall by around 40% in the top 25% of grid squares, but by only ≈25% in the highest areas. However, concentrations of primary $PM_{2.5}$ are projected to increase in 2035 in the NRPO and LGHG scenarios, by around 30–60% in the more polluted grid squares, as a result of the increase in biomass use. By 2050, in those two scenarios, levels are only slightly lower than 2011 values and, in the highest grid square, very similar to 2011 concentrations. If this amount of primary $PM_{2.5}$ were to be removed, by avoiding the high use of biomass, total $PM_{2.5}$ concentrations could fall even further than projected, by ≈50% in the highest areas compared with a reduction of ≈25% if there is increased biomass use.

Total PM_{10} concentrations are projected to increase in 2035 in many areas of the UK in both the LGHG and NRPO scenarios, despite the reduction in secondary PM precursors, because of the increased use of biomass and the increased non-exhaust emissions from transport. PM_{10} levels decrease again by 2050 but remain only about 15% smaller than in 2011 in the more polluted areas of GB. This is a small reduction and is not larger because of the increasing contribution from non-exhaust emissions. This is of concern as these emissions are potentially toxic.

The reductions in NO_x emissions result in increasing annual average O_3 concentrations in urban areas, leading to higher exposures using the metric recommended by COMEAP for short-term impact on mortality. In contrast, all scenarios show reductions in the metric suggested by WHO for long-term O_3 exposure impact on mortality.

Both O_3 and NO_2 are strong oxidising agents and can play a role in oxidative stress in the human body. This can be quantified through the use of the metric O_x or oxidant ($O_x = O_3 + NO_2$), which has been shown to be associated with adverse health outcomes. Annual average levels are projected to remain virtually constant to 2050. The significance of this for health is that the balance of O_x will shift to O_3 as NO_2 reduces; the former is the more powerful O_x so that the oxidising power of the urban atmosphere in the UK will increase with potentially increased adverse health effects, assuming that the global background of O_3 remains broadly constant.

Health impact

We have calculated the impact on mortality arising from long-term exposures to the pollutants $PM_{2.5}$, NO_2 and O_3, using a life table approach to calculate the loss of life-years in each of the scenarios. This now incorporates birth projections, projected improvements in mortality rates and mortality rates at local authority level. The two scenarios which achieve the CCA target result in more life-years lost from long-term exposures to $PM_{2.5}$ beyond the carbon policies already in place, and the levels of $PM_{2.5}$ still result in a loss of life expectancy from birth in 2011 of around 4 months. This is an important opportunity lost and arises from the large increase in biomass use peaking in 2035. Our estimates suggest that, in the more highly polluted areas of GB, total $PM_{2.5}$ concentrations could reduce by as much as 50% without the biomass contribution.

There is currently some uncertainty over the role of the NO_2 contribution to the CRF compared with $PM_{2.5}$ and other pollutants. However, using the CRFs currently suggested by COMEAP reduced long-term exposures to NO_2, led to more life-years saved and reduced the loss of life expectancy from birth in 2011 in the 'CCA-compliant' scenarios by 2 months compared with the baseline scenario (with the largest benefits arising from the most ambitious scenario, LGHG). Owing to the uncertainties around NO_2, we have not suggested adding the impacts for the different pollutants, nor do we consider that the NO_2 benefits cancel out the adverse health impacts shown for $PM_{2.5}$, for which the health evidence is stronger.

Evidence for and impact on mortality of long-term exposures to O_3 is increasing, although using the quantification recommended by WHO we estimate that life-years lost from this exposure will be smaller than those from $PM_{2.5}$ and from NO_2, by factors of ≈6 and ≈3–4, respectively, if no threshold is assumed for NO_2. However, the short-term O_3 exposure metric recommended by COMEAP suggests that the number of deaths brought forward in a year could be around 22,000, compared with 29,000 from long-term $PM_{2.5}$ exposures.

We also investigated the effect of the changing concentrations on exposures in different socioeconomic classes. We observed differences in air pollution levels in subpopulations for all analysed pollutants and for each geographical area. Differences in exposure were most marked for NO_2 for ethnicity and for socioeconomic deprivation. Wards with higher proportions of non-white residents and higher deprivation are expected to be closer to roads and, therefore, exposed to these higher NO_2 levels. The ratios of exposures in white populations to those in non-white populations were much larger than the ratios of exposures in the most deprived populations to exposures in the least deprived populations in GB and Wales, but this difference was slightly smaller in London. Relative differences between most and least deprived populations were highest in Scotland, closely followed by London; relative differences in Wales were the smallest.

All future scenarios reduced the absolute levels of pollution exposure in all deprivation quintiles across GB, except in those cases where there is a large increase in biomass burning. Differences in exposure between the most and least deprived populations remain in all scenarios, most clearly for NO_2, with little difference between the baseline scenario and the NRPO scenario.

Conclusions

There are several important conclusions which arise from this work. The CCA target in principle offers a great opportunity to make very large reductions in air pollution emissions as the UK energy system is decarbonised. However, the $PM_{2.5}$ emissions from the large increases in biomass use and the increase in non-exhaust PM emissions from transport in the two CCA-compliant scenarios we have studied, mean that $PM_{2.5}$ and PM_{10} concentrations do not reduce as much as they might otherwise have done. One option to improve air quality impact on health would be to discourage the use of biomass in small installations, or to increase the stringency of the emission limits in the Ecodesign Directive. Further research could investigate other possible scenarios which could avoid the problem with biomass use. Further research is also required on the toxicity of primary PM as well as other components of airborne particles.

Particulate matter of $\leq 10\,\mu m$ non-exhaust emissions, and to a lesser extent $PM_{2.5}$ non-exhaust emissions, are projected to increase significantly by 2050 as traffic activity increases. The precise agents in tyre and brake wear and resuspended dust responsible for the potential toxicity of these emissions are as yet unclear, so reformulation of these products would need to await more clarification from toxicological research. However, in the meantime, one solution here is to discourage traffic use, particularly in urban centres.

The project has delivered a sophisticated tool to enable, for the first time, the explicit calculation of public health impact arising from future energy strategies in the UK using an air quality model with an energy systems model. This represents a major improvement over previous damage cost approaches to assess the impact of climate change policy and its influence on air quality.

Funding

Funding for this study was provided by the Public Health Research programme of the National Institute for Health Research.

Public Health Research

ISSN 2050-4381 (Print)

ISSN 2050-439X (Online)

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This report

The research reported in this issue of the journal was funded by the PHR programme as project number 11/3005/13. The contractual start date was in April 2013. The final report began editorial review in January 2017 and was accepted for publication in June 2017. The authors have been wholly responsible for all data collection, analysis and interpretation, and for writing up their work. The PHR editors and production house have tried to ensure the accuracy of the authors' report and would like to thank the reviewers for their constructive comments on the final report document. However, they do not accept liability for damages or losses arising from material published in this report.

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