Institution: University of Birmingham

Unit of Assessment: UoA 7 – Earth Systems and Environmental Science

Title of case study: Improving Air Quality in the UK: Developing a mass-closure model for particulate matter

1. Summary of the impact (indicative maximum 100 words)

Particulate Matter is now recognised as the air pollutant with the greatest public health impact, estimated to cost up to £8.5-20.2 billion per annum (in 2005).Roy Harrison has engaged closely with UK policy-makers for decades. This impact case study focuses specifically on the take-up of PM mass-closure techniques developed by Harrison's group into a UK policy-making tool called Pollution Climate Mapping (PCM). Work by the Harrison group forms the basis of the component dealing with airborne particles in the PCM model used by Defra. The work described in this case study has **economic impact** in the form of costs avoided by the UK national, devolved and local governments (reallocation of public budgets away from expensive air pollution monitoring and avoidance of EU financial penalties), **public policy impact** in the form of cost-effective delivery of air pollution mapping, and **environmental impact** in the form of traceable inclusion of research in government policies for air quality improvement.

2. Underpinning research (indicative maximum 500 words)

Development of cost-effective abatement strategies for airborne particulate matter depends critically upon developing a sound quantitative understanding of the contribution of different sources to particulate matter concentrations measured in the atmosphere. This requires advanced receptor modelling and Harrison's group has led this activity in the UK over the past three decades. The case study team comprise: Professor Roy Harrison, Queen Elizabeth II Birmingham Centenary Professor of Environmental Health; Dr Royston Lawrence (Research Fellow, 1999 – 2005); Dr Jianxin Yin (Research Fellow 2001 —); and Dr Alan Jones (Research Fellow, 2000 —).

A particular focus of the research has been how aerosol composition can be used to infer sources of particles. This has included research on "mass closure", which reconciles the measured total mass concentration with measurements of individual or groups of chemical compounds that reside in the aerosol. Mass closure is an essential step in characterisation of the aerosol and hence the contribution of various sources (e.g., traffic, industry, dust resuspension, and natural sources) to the total measured aerosol signal. The group have successfully applied their mass closure and source apportionment techniques to measurements of airborne particles in the UK and have contributed to a number of international assessments.

Insights into particulate matter composition as an indicator of source were gained in the two campaigns of the PUMA consortium project (led by Harrison) in Birmingham in 1999 and 2000 (Harrison et al., 2006). These results were used to inform the design of measurements and analysis of data from the DfT-funded TRAMAQ project, which led to the development of the Pragmatic Mass Closure Model (Harrison et al., 2003) which was a parsimonious empirical model which accounted very closely for the measured mass of airborne particulate matter through measurement of a small suite of chemical components. With funding from Defra, the Pragmatic Mass Closure Model was applied to different size fractions of particles (PM1.0, PM2.5 and PM10)

at roadside, urban background and rural sites in the UK, and its applicability across the full range of particle sizes and composition was demonstrated (Yin and Harrison 2008). Insights gained from the measurement campaigns were also used to inform chemistry- transport modelling activity (Abdalmogith et al., 2006) and elements of each of these papers were taken up by John Stedman and his colleagues in AEA Technology (now Ricardo-AEA) and used in the formulation, parameterisation and development of the Pollution Climate Mapping (PCM) Model.

3. References to the research (indicative maximum of six references)

[The three references which best indicate the quality of research underpinning the case are 1, 4 and 6]

1. A Pragmatic Mass Closure Model for Airborne Particulate Matter at Urban Background and Roadside Sites, R.M. Harrison, A.M. Jones and R.G. Lawrence, Atmos. Environ., 37,4927-4933 (2003). DOI: 10.1016/j.atmosenv.2003.08.025
2. Major Component Composition of PM10 and PM2.5 from Roadside and Urban Background Sites, R.M. Harrison, A.M. Jones and R.G. Lawrence, Atmos. Environ., 38, 4531-4538 (2004). DOI: 10.1016/j.atmosenv.2004.05.022
3. Particulate Sulphate and Nitrate in Southern England and Northern Ireland during 2002/3 and its Formation in a Photochemical Trajectory Model, S.S. Abdalmogith, R.M. Harrison and R.G. Derwent, Sci. Tot. Environ., 368, 769-780 (2006). DOI: 10.1016/j.scitotenv.2006.02.047
4. Measurement and Modelling of Air Pollution and Atmospheric Chemistry in the UK West Midlands Conurbation: Overview of the PUMA Consortium Project, R.M. Harrison, J. Yin, R.M. Tilling, X. Cai, P.W. Seakins, J.R. Hopkins, D.L. Lansley, A.C. Lewis, M.C. Hunter, D.E. Heard, L.J. Carpenter, D.J. Creasey, J.D. Lee, M.J. Pilling, N. Carslaw, K.M. Emmerson, A. Redington, R.G. Derwent, D. Ryall, G. Mills and S.A. Penkett, Sci. Tot. Environ., 360, 5-25 (2006). DOI: 10.1016/j.scitotenv.2005.08.053
5. Pragmatic Mass Closure Study for PM1.0, PM2.5 and PM10 at Roadside, Urban Background and Rural Sites, J. Yin and R.M. Harrison, Atmos. Environ., 42, 980-988 (2008). DOI:10.1016/j.atmosenv.2007.10.005
6. Source Apportionment of Fine Particles at Urban Background and Rural Sites in the UK Atmosphere, J. Yin, R.M. Harrison, Q. Chen, A. Rutter and J.J. Schauer, Atmos. Environ.,44, 841-851 (2010). DOI: 10.1016/j.atmosenv.2009.11.026

4. Details of the impact (indicative maximum 750 words)

Particulate Matter (PM-PM10 and PM2.5) is now recognised as the air pollutant with the greatest public health impact. The continuing importance of this issue was underlined in the UK's Air Quality Strategy (published in 2007) [source 1] which said that the estimated effect of man-made PM pollution in 2005 would be expected to reduce life expectancy averaged over the whole population of the UK by up to about 7-8 months. This health impact in 2005 was estimated to cost up to £8.5-20.2 billion per annum. The assessment estimated that if no further measures in addition to those already agreed at the time were implemented, man-made PM air pollution in the UK would continue to reduce average life expectancy by up to about 5.5 months even by 2020. This health impact in 2020 was estimated to cost up to £6.2-14.7 billion per annum (vol. 1 p42 and vol. 2 pp42-43) [source 1].

Roy Harrison has engaged closely with UK policy-makers for decades. Until recently he served as a member of Defra Science Advisory Council [2009 – 2012], and is currently a member of the

Department of Health Committee on the Medical Effects of Air Pollutants and the Defra Air Quality Expert Group. He has previously chaired the Quality of Urban Air Review Group [1991 - 1997] and the Airborne Particles Expert Group [1998 - 1999] for Defra's predecessor departments and was a member of Defra's Advisory Committee on Hazardous Substances [2001 - 2006]. He led the preparation of the Second Report of the Quality of Urban Air Review Group (1993) which warned of the problems associated with particulate matter and NOx emissions from diesel vehicles.

This impact case study focuses specifically on the take-up of PM mass-closure techniques developed by Harrison's group into a UK policy-making tool called Pollution Climate Mapping.

Pollution Climate Mapping

The results from this research have been used extensively to inform the Pollution Climate Mapping (PCM) model used by the Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations to predict future concentrations of airborne pollutants and to evaluate and compare abatement strategies. (Note: reference to Defra, below, should always be taken to include the Devolved Administrations).

The PCM model is currently the sole model chosen by Defra to help meet EU Air Quality Directive (2008/50/EC) requirements to report on the concentrations of particular pollutants in the atmosphere at ground level (Williams et al., 2011) [source 2]. The PCM model is used for compliance reporting as a substitute for widespread monitoring; it is vital, therefore, that its components have a strong evidence base (vide section 3, above, for the PM component of PCM). PCM is also used for scenario assessment and population exposure calculations to assist policy developments.

The PCM models are run by Ricardo-AEA on behalf of Defra. Work by the Harrison group forms the basis of the component of the model dealing with airborne particles used by scientists at AEA [sources 3 & 4]. Annual reports to Defra are published by AEA summarising the results of UK modelling under the Air Quality Directive (2008/50/EC) [sources 5 & 6]. The model for particulate matter is described in detail in the report for 2010 (AEA, 2011) [source 6], describing the model for particulate matter on pages 70-86. It is clear from the model description that the fundamental formulation is based upon the receptor modelling work and Pragmatic Mass Closure Model developed at the University of Birmingham and the coefficients (e.g. Table 2, page 80 of AEA, 2011) derive directly from the work of the Harrison group as reported in Abdalmogith et al. (2006), Harrison et al. (2006) and the report to Defra cited by AEA (2011) as Harrison and Yin (2006) which was published as Yin and Harrison (2008).

A number of benefits have flowed from use of the model:

1. Under article 7 of Directive 2008/50/EC, the number of monitoring stations may be reduced by 50% if high quality modelling is used to estimate pollution levels in other locations. The total Defra operational budget for automatic air quality monitoring in the UK is £3.1M per annum, of which a substantial portion relates to particulate matter. The capital cost of instruments installed is of the order of £3M.

2. The model output forms the basis of background maps of air quality across the UK produced by AEA on behalf of Defra (http://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html). These maps are considered the definitive information source on air quality used in all environmental impact assessments within planning applications, by local government in their air quality assessments and the Planning Inspectorate in Public Inquiries. Planning applications worth many billions of pounds each year depend upon the background air quality maps in their environmental assessments.

3. The PCM model has formed the basis for evaluating and comparing the potential benefits of mitigation measures designed to improve air quality, which are then subjected to cost-benefit analysis. Examples of the benefits to PM10 concentrations and annual costs and benefits of measures, which may exceed £1 billion for individual measures, appear in Chapter 3 of the Updated Third Report of the Interdepartmental Group on Costs and Benefits (Defra, 2007) [source 7].

4. Implementation of abatement measures is key to the UK compliance with EU Limit Values for PM10 [source 8]. Continued exceedence of the Limit Values will lead to infraction proceedings being initiated by the European Commission with subsequent imposition of large fines upon the UK. In 2011, fines of up to £300 million were narrowly averted by a time extension granted by the Commission. The PCM model was used to support a successful application for a time extension to meet the PM10 Limit Value in London.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volume 1 and Volume 2),* Cm 7169 NIA 61/06-07, July 2007.

2. Williams, M., et al., Review of Air Quality Modelling in Defra, Report to Defra, 7 April 2011, http://uk-air.defra.gov.uk/reports/cat20/1106290858_DefraModellingReviewFinalReport.pdf

3. Corroborating statement from Principal Consultant and project manager for UK Ambient Air Quality Assessment Contract, Ricardo-AEA, dated 19th July 2013

4. Corroborating statement from Head of Air Quality Evidence, Atmosphere and Local Environment Programme, Defra, dated 29th July 2013

5. UK Modelling under the Air Quality Directive (2008/50/EC) for 2009 Covering the following Air Quality Pollutants: SO_2, NO_X, NO_2, PM_{10}, $PM_{2.5}$, Lead, Benzene, CO and Ozone, AEA Technology, Report No. AEAT/ENV/R/3069 Issue 1 (2010).

6. UK Modelling under the Air Quality Directive (2008/50/EC) for 2010 Covering the following Air Quality Pollutants: SO_2, NO_X, NO_2, PM_{10}, $PM_{2.5}$, Lead, Benzene, CO and Ozone, AEA Technology, Report No. AEAT/ENV/R/3215 Issue 1 (2011).

7. An Economic Analysis to Inform the Air Quality Strategy, Update Report of the Interdepartmental Group on Costs and Benefits, Defra, July 2007.

8. Air Quality Expert Group (2005) *Particulate Matter in the UK: Summary.* Defra, London.