Institution: University of Glasgow (UofG)		
Unit of Assessment: UoA10 Mathematical Sciences		
Title of case study: Improving air quality in Scotland's cities using statistical modelling		
Period when the underpinning research was undertaken: 2010–present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Marian Scott	Professor	1983–present
Prof. Duncan Lee	Professor	2007–present
Dr. Craig Anderson	Lecturer	2017–present
Period when the claimed impact occurred: 2017–ongoing		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Poor air quality has profound negative impact on human health. UofG has developed a statistical emulator for the urban air quality model (ADMS), enabling the Scottish Environment Protection Agency to quantify the compliance failure risk to air quality regulations under different scenarios. UofG's emulator and statistical modelling informed the design and development of both the Scottish Government's National Modelling Framework and the evaluation of low emission zones (LEZ) in Scottish cities, the first of which came into effect in Glasgow in December 2018. UofG statistical modelling enabled accurate quantification of the health impacts of the different air pollutants in Scotland and provided key insights in terms of modelling and understanding of how implementation of the LEZs would impact public health.

2. Underpinning research

Statistical research in the monitoring of air and water quality has been a long-standing focus of UofG. Colleagues in the Scottish Government (SG) and Scottish Environment Protection Agency (SEPA) have developed strong working relationships with the UofG Environmental Statistics group whose research focuses on the statistical modelling of air and water data. Underpinning UofG research first focussed on the development of air quality indicators (and associated uncertainty) [3.1] using high-quality routine monitoring data. In 2015, SEPA contacted Scott to develop statistical methods to examine and model the output from the proprietary ADMS-Urban air quality model being used in Aberdeen [3.2]). This work focussed on statistically assessing the validity, accuracy and precision of ADMS-Urban. SEPA have subsequently gone on to use ADMS-Urban in other Scottish cities including Glasgow and Edinburgh. This is a complex, proprietary mathematical model, involving traffic flow and topology of the city, being driven by vehicle data and meteorological conditions. The complexity of this model precludes its use in routine decision-making and SEPA approached UofG to develop a more computationally efficient statistical approach to support decision-making.

The UofG statistical research then developed an emulator [3.3] that is a statistical model, which simulates the complex model structure of ADMS-Urban. While ADMS-Urban delivers detailed maps of the air quality across the city, using traffic and meteorological inputs to drive the concentrations across a fine grid, like many complex physico-chemical models, this can be very computationally intensive, hence the need for a statistical emulator that is accurate and computationally fast. Working with an honorary research fellow (Finazzi) and the SEPA team, Scott developed a statistical emulator, whose code was then ported to SEPA to enable direct use of the emulator output. This emulator permits SEPA to explore the impact of a variety of scenarios including intervention measures such as changes in vehicle classes and volume of traffic on air quality, and thus to directly feed into management measures. The emulator is also being used to evaluate the risk that locations in a given city would be above the nitrogen dioxide annual average limit. The UofG research has shown that this risk is driven by uncertainty in meteorological conditions and emissions [3.3].

In 2018–2019 Anderson further developed for SG and SEPA, based on the work in [3.5], an annual average high spatial resolution Scotland-wide air quality index [follow-on work specified in 5.1, page 8], which allows areas with high overall pollution concentrations to be identified. This has produced maps and datasets of Scotland-wide pollution estimates for a range of pollutants (including NO_2, NOx, PM10 and PM2.5) at a variety of resolutions including Scotland as a whole, local authorities and census data zones. The UofG-authored report [3.4] produced for the Scottish Government contains maps (and associated datasets) that display the probability that the level of a particular pollutant is above a given threshold, based on a particular set of environmental conditions. UofG research also produced easy-to-use software enabling users to update maps and estimates as new pollution and/or meteorological data becomes available [G4: 3.4].

UofG research led naturally to the investigation of associated health effects in the Scottish population focusing on the use of novel statistical models to determine the impact of air quality on cardiovascular and respiratory disease, the leading causes of morbidity and mortality in Scotland [G2, G3, 5.7]. This research has revealed a relationship between fine particulate matter (PM10) and cardiovascular ill health and that particulate matter and nitrogen dioxide concentrations both exhibit substantial and independent effects on respiratory health [3.5]. Further research led to the quantification of the potential impact of reducing air pollution in city centres where Low Emission Zones (LEZ) are implemented [G1; 3.6, 3.7].

3. References to the research

3.1 Lee, D., Ferguson, C. and Scott, E.M. (2011) Constructing representative air quality indicators with measures of uncertainty. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 174(1), pp. 109-126. (doi:10.1111/j.1467-985X.2010.00658.x

3.2 Finazzi, F., Scott, E.M. and Fasso, A. (2013) A model based framework for air quality indices and population risk evaluation, with an application to the analysis of Scottish air quality data. *Journal of the Royal Statistical Society*: Series C (Applied Statistics), 62(2), pp. 287-308. (doi:10.1111/rssc.12001)

3.3 Finazzi, F., Napier, Y., Scott, E.M., Hills, A., Cameletti, M. (2019) A statistical emulator for multivariate model outputs with missing data. *Atmospheric Environment* 199, 415-422. (doi:10.1016/j.atmosenv.2018.11.025)

3.4 McIntosh, A. and Anderson, C. (2019) Modelling the Risk of Exceeding Air Quality Monitoring Thresholds in Scotland. Project Report. Scottish Government. eprints.gla.ac.uk/229232/

3.5 Huang, G., Lee, D. and Scott, E. M. (2018) Multivariate space-time modelling of multiple air pollutants and their health effects accounting for exposure uncertainty. *Statistics in Medicine*, 37(7), pp. 1134-1148. (doi:10.1002/sim.7570)

3.6 Lee, D., Robertson, C., Ramsay, C., Gillespie, C. and Napier, G. (2019) Estimating the health impact of air pollution in Scotland, and the resulting benefits of reducing concentrations in city centres. *Spatial and Spatio-Temporal Epidemiology*, 29, pp. 85-96. (doi:10.1016/j.sste.2019.02.003)

3.7 Lee, D., Robertson, C., Ramsay, C. and Pyper, K. (2020) Quantifying the impact of the modifiable areal unit problem when estimating the health effects of air pollution. *Environmetrics*, online early (doi:10.1002/env.2643)

Grants:

- G1: EPSRC SECURE network grant EP/M008347/1. GBP446,638

- G2: EPSRC, A rigorous statistical framework for estimating the long-term health effects of air pollution (2013-2016), EP/J017442/1. GBP269,754
- G3: Scottish Government, Estimation of the spatial and temporal associations of air pollution on health in Scotland. GBP114,000
- G4: Scottish Government, Development of a High Spatial Resolution Air Quality Indicator for Scotland (2018) GBP43,751

4. Details of the impact

Background

In 2010, the UK's Environmental Audit Committee determined that poor air quality results in up to 50,000 additional premature deaths/annum. In 2018, the UK government wrote "Poor air quality is the largest environmental risk to public health in the UK, as long-term exposure to air pollution can cause chronic conditions such as cardiovascular and respiratory diseases as well as lung cancer, leading to reduced life expectancy" (UK Govt, 2018).

The UK and Scotland routinely fail regulatory air quality standards in specific cities. In 2015, the Scottish Government published the Cleaner Air for Scotland Strategy (CAFS) [5.1], which aspired for Scotland to have "the best air quality in Europe". UofG research has supported SEPA in developing modelling tools to assess the likely effect on air quality of introduction of Low Emission Zones (LEZ) and changes to traffic emissions [5.1, p8]. Research on the health impacts of establishing the first LEZs in Scotland, specifically targeting pollution emissions linked to road traffic and local air quality management plans, is a key objective [5.1, p25].

Route to introduction of Emulator into the National Modelling Framework

The CAFS [5.1, pp16-22] set out the National Modelling Framework (NMF) to provide the quantitative evidence to support decisions affecting the planning, design and management of Scotland's public spaces and transport network. The Scottish Government, Transport Scotland and SEPA have been working collaboratively to develop the NMF with a range of partners including UofG (Scott, Lee and Anderson), learning from the success of early pilot work using ADMS and the UofG emulator in Aberdeen.

SEPA staff described the initial statistical analysis (M.Sc. project by Sim) of the ADMS-Urban baseline model in the Aberdeen Pilot report in 2017. *"A detailed statistical analysis of the Base Run was carried out as part of a Glasgow University M.Sc. project (Sim), It was found that using Functional PCA, Clustering Regression and Deming Regression that the ADMS model does not perform well at Wellington Road, but does perform well at other monitoring locations..."* [5.2, p100].

Providing the evidence base to improve Scotland's Air Quality

Following the Aberdeen pilot, the Scottish Government's NMF launched in 2015. UofG research is incorporated into both the NMF and decision support system implemented within SEPA in three ways:

1. The emulator code allows SEPA to estimate the risk (probability) of compliance failure (i.e., of exceeding EU directive levels) under different emissions scenarios, specifically the key effects of meteorological conditions on exceedances. This is essential in developing emission reduction strategies for use at city level and has shown circumstances, under which emission control will not deliver the expected improvement in air quality due to prevailing meteorological conditions [5.3].
   "*SEPA has been working with Professor Marian Scott (University of Glasgow) and Dr Francesco Finazzi (University of Bergamo) on a method to help address model uncertainty. Their method, [3.3], uses a statistical technique to describe the behaviour of the air quality model. This allows model results to be estimated for many more sets of input data than it is usually feasible to run. SEPA have implemented this method to establish the risks posed*

to air quality predictions from uncertainty in future emissions and wind speeds. …the technique will be applied to future detailed LEZ modelling. In this way we will be able to estimate the risk to the success of any measures to improve air quality" [5.4, p20].

2. Design of the LEZ's in Glasgow, Edinburgh and Aberdeen, the NMF requires that the correct evidence (data and modelling) is available to support decision making [5.5, Section 2]. Detailed models supported by the UofG emulator for each city provided evidence for taking direct actions at the city scale to reduce street-level emissions. The Glasgow LEZ was launched in Dec 2018, with a 5-year phased implementation of restrictions.
3. Visualisations developed in [3.1,3.2,3.3] are now in routine use within SEPA for Glasgow [5.6] and Aberdeen for evaluation of air quality monitoring.

This UofG emulator and the risk modelling permits SEPA to explore the impact of a variety of measures such as changes in vehicle classes and traffic on air quality, and thus to directly feed into management measures. "*The emulator has been invaluable in characterising the behaviour of the ADMS model under a wide range of standard input values (emissions and wind speed and direction)*" [5.6].

Impacts on health

Ischaemic heart disease, cerebrovascular disease (including stroke) and chronic lower respiratory diseases are leading causes of death and ill health in Scotland and are clinical and public health priorities for NHS Scotland and Scottish Government. UofG research has shown that improvements in air quality result in significant population health benefits. Lee's expertise in quantifying the epidemiological evidence as to the impacts of air pollution on public health has informed policy and LEZ design. Prof. Lee's research [3.7] has provided evidence of impacts but also highlighted that "Differences in the types of study carried out in Scotland make cross comparison of their findings difficult" requiring improved statistical design of studies. [5.7 p6, 5.8] proposing further developments. "*Professor Lee has been a key researcher on air pollution and health in Scotland in particular and has contributed significantly to improving our understanding in Scotland of the nature of the impacts and how intervention measures may lead to future improvements in preventable morbidity and mortality."* [5.8] In recognition of this work, Prof. Lee was invited to become a member of the UK Government's Committee on the Medical Effects of Air Pollutants in April 2020.

5. **Sources to corroborate the impact**

5.1 [All evidence, including hyperlinked items, made available in PDF format]Cleaner Air for Scotland – annual progress report 2017/18 https://www.gov.scot/publications/cleaner-air-scotland-annual-progress-report-2017-18/

5.2 Aberdeen Air Quality Modelling Pilot Project Technical Report July 2017 http://www.scottishairquality.scot/assets/documents/NMF-Aberdeen-Pilot-Project-Report.pdf

5.3 Email from Unit Manager, OceanMet Unit, Scottish Environment Protection Agency

5.4 SEPA Cleaner Air for Scotland – National Modelling Framework. Air Quality Evidence Report – Edinburgh Nov 2018 https://www.edinburgh.gov.uk/downloads/file/27886/cleaner-air-for-scotland-national-modelling-framework

5.5 Transport Scotland Environmental Audit & Advisory Framework Transport Scotland Task 1 - Developing Cost Estimates for Low Emission Zones in Scotland. September 2017

5.6 Testimonial: Principal Scientist (Air), Scottish Environment Protection Agency

5.7 CAFS Review 2019 Health and Environment Working Group (HEWG). Final Report. June 2019. http://www.scottishairquality.scot/assets/documents/Health-Environment-Working-Group-Report.pdf

5.8 Testimonial: Consultant Epidemiologist, Health Protection Scotland