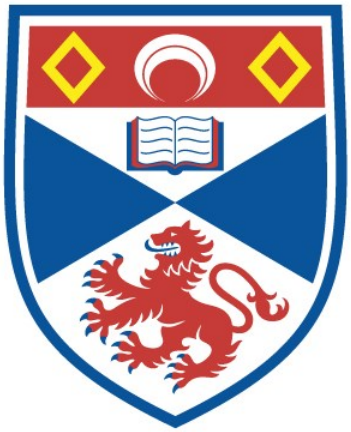
THE HEALTH AND SOCIOECONOMIC IMPACT OF TRAFFIC-RELATED AIR POLLUTION IN SCOTLAND

Jackie Hyland

A Thesis Submitted for the Degree of MD
at the
University of St Andrews



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Jackie Hyland

University of St Andrews

This thesis is submitted for the Degree of Medical Doctorate

At the

University of St Andrews

May 2017

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I, Jackie Hyland hereby certify that this thesis, which is approximately 46 660 words in length, has been written by me, and that it is the record of work carried out by me, or principally by myself in collaboration with others as acknowledged, and that it has not been submitted in any previous application for a higher degree.

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COLLABORATION STATEMENT

Professor Donnelly took time to explore with me my initial concept and discuss the changing thesis structure as the research developed. This included suggestions for areas of investigation, and discussion on interpretation of findings. Dr Jo Inchley provided clarity of direction as the research evolved. She advised on application of scientific rigour, exploration of the findings from the literature review and aspects of the thesis to improve clarity. I received constructive feedback on progress at my annual supervision meetings with Professor David Harrison and Dr Damien Williams. Professor Harrison suggested that I consider Forest Plots as a means of linking study findings. Dr Damien Williams provided guidance on more detailed presentation of study findings. All the supervisors provided guidance on the terminology for literature reviews. Throughout the study I received comments and guidance on various sections from Dr Emma Fletcher (statistics); Dr David McAllister (collaborated on the design of the AQMA epidemiological study, reviewed the literature, collected and analysed the data, and reported on the findings in the Scottish (Air Quality) Health Needs Assessment Report); Mr John Lamb (provided data on air pollution episodes, collaborated in the NHS24 study and provided updates on air quality policies and practice); Dr Malcolm Alexander (provided the data for the NHS24 study); members of Scottish Transport Emissions Partnership (STEP) (participated in the survey and provided comment on sections of the thesis) and Dr Colin Ramsay (shared developments in health and air pollution in Scotland during the time of this study). The thesis has been part funded by NHS Tayside as a result of a recommendation from Dr Drew Walker the Director of Public Health and supported by Mrs Lesley Marley, Public Health Directorate Manager. The funders have had no influence over the concept, how the work was undertaken or interpretation of the findings.

Date…23rd May 2017……Signature of candidate……

PUBLICATIONS AND PRESENTATIONS

Hyland, J. & Donnelly, P. (2014). Air pollution and health - The views of policy makers, planners, public and private sector on barriers and incentives for change. *Journal of Transport and Health*, 2(2),120–126

Hyland J. (2015). *Call for Evidence on the Long Term Effects of Air Pollution in Children and Adults*. Citation. Royal College of Physicians. January 2015 (Appendix 11)

Hyland J*. (2015). Is it possible to monitor the impact of traffic-related air pollution on the health of Scottish residents living adjacent to busy roads? A critique of the epidemiological evidence and implications for policy*. Presentation. University of St Andrews, WiP, April 2015

Hyland J. (2015). *Health based cost benefit analysis of low emission zones*. Presentation. Health Economics Programme. University of Strathclyde, April 2015

Hyland J. (2015*) Air pollution and health. The views of policy makers, planners, public and private sector on barriers and incentives for change.* Presentation. Scottish Faculty of Public Health Annual Conference, Peebles, November 2015.

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Hyland J. (2017). *The Physical and Social Impact of Traffic-related Air Pollution on the Health of Scottish Residents.* Presentation. University of St Andrews, WiP. February 2017

The health and socioeconomic impact of traffic-related air pollution in Scotland

Abstract

Traffic-related air pollution harms health, so whilst it would be advantageous to improve air quality, the socioeconomic impact of air pollution mitigation in Scotland is not fully understood. Evidence from research literature, current regulatory and policy directives and a socioeconomic analysis are required to assess the true health impact. This thesis presents the first health and socioeconomic analysis of traffic-related air pollution and health for Scotland.

A critique of the literature was undertaken to determine the evidence base and the strength of evidence in terms of association and causation, between air pollution and ill health. The evidence was subsequently applied in epidemiological studies of Scottish residents, to assess the actual impact on health in Scotland. The perception of barriers and incentives for change were investigated to understand behavioural influences. Recent policy development in Scotland was reviewed, and a socioeconomic analysis of a proposed air pollution strategy in Scotland, was undertaken.

The evidence from 30 cohort studies and nine literature reviews demonstrated a link between poor air quality, mortality and respiratory ill health, but the results for other health conditions were inconsistent. The links were associative rather than causal and therefore might be attributable to other factors other than air pollution. Furthermore, epidemiological studies on Scottish populations did not show health effects from traffic-related air pollution.

The socioeconomic analysis suggested that an initial investment of between £27m and £44m to introduce Low Emission Zones (LEZ), and an effective active travel programme, might result in a saving of £38m in terms of Years of Life Lost (YLL) and reduction in sickness absence. It is unlikely that the Clean Air For Scotland Strategy will deliver improved air quality and health without substantial investment, better alignment of planning, and a greater public engagement to support public and active transport options. *Word count – 297*

ACKNOWLEDGEMENTS

At a late stage in my career I was keen to develop skills I had not had time to consider in my earlier professional life so, with encouragement from Professor Peter Donnelly, I took the leap and embarked on the journey towards an MD. I have not regretted a moment of the journey and owe much of the excitement in achieving new knowledge and skills to the patience and support I received from my supervisors, Professor Peter Donnelly and Dr Jo Inchley. Both Peter and Jo have been skilful in managing a student who was at times “set in her ways”, but thanks to their guidance I left every supervision session inspired and eager to tackle the next stage of the thesis.

I owe a debt of gratitude to Karen Ross who came to my rescue frequently, particularly in the early days when I needed guidance through the complex University administrative processes. Vicki Cormie set aside time to help me with literature search software and record keeping and I have no doubt this set me on the right track for the rest of the course.

Drew Walker, the Tayside Director of Public Health was immensely supportive and secured the funding which enabled me to undertake the research. We are now seeing the benefits of the work in our responses to community concerns about traffic-related air pollution.

I am grateful to many people who helped me at various stages including Professor David Harrison, Dr Damien Williams, Mrs Lesley Marley, Dr Emma Fletcher, Mr John Lamb, members of STEP (Scottish Transport Emissions Partnership), Dr David McAllister and Mrs Becky Bolger.

Finally I owe a tremendous debt of thanks to my family for their patience in listening to me wax lyrical about particulates and low emission engines at every opportunity. Without their encouragement I would not have enjoyed the process as much as I did.

Abbreviations

AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
ATS	American Thoracic Society
CAFS	Cleaner Air For Scotland
ci	confidence interval
CO	carbon monoxide
COMEAP	Committee on Medical Aspects of Air Pollution
CO_2	carbon dioxide
COPD	Chronic Obstructive Airways Disease
COSLA	Confederation of Scottish Local Authorities
CPT	Confederation for Passenger Transport
CRP	C-reactive protein
CVD	cardiovascular disease
DEFRA	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EC	European Commission
EPS	Environment Protection Scotland
ESCAPE	European Study of Cohorts for Air Pollution Effects
GDP	Gross Domestic Product
GP	General Practitioner
HBs	Health Boards
HPA	Health Protection Agency (now Public Health England – PHE)
HPS	Health Protection Scotland
HR	Hazard Ratio
hs-CRP	high sensitivity C reactive protein
IDW	inverse distance weighting
IHD	ischaemic heart disease
IOM	Institute of Occupational Medicine
IQR	interquartile range
IUG	intrauterine growth
KPIs	Key Performance Indicators

LA	local authority
LBW	low birth weight
LE	life expectancy
LES	Low Emission Strategy
LEZ	Low Emission Zones
LUR	land use regression
MACC	marginal abatement cost curve
MRR	Mortality Rate Ratio
mtDNA	mitochondrial DNA
na	not applicable
NAEI	National Air Emissions Inventory
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NO_2	nitrogen dioxide
NO	nitrous oxide
NOx	oxides of nitrogen
O_3	ozone
OR	odds ratio
PAF	Population Attributable Fraction
PAH	polycyclic aromatic hydrocarbons
PHE	Public Health England
PM	particulate matter
$PM_{2.5}$	particles that are less than 2.5 micrometres in diameter
PM_{10}	particles that are less than 10 micrometres in diameter
QALYs	Quality Adjusted Life Years
REA	Rapid Evidence Assessment
RHA	Road Haulage Association
RR	Relative Risk
RTAs	Road Traffic Accidents
SCOTS	Society of Chief Officers of Transportation in Scotland
sd	standard deviation
SEPA	Scottish Environmental Protection Agency

SG	Scottish Government
SGA	small for gestational age
SMaSH	Scottish Managed Sustainable Health (Network)
SNS	Scottish Neighbourhood Statistics
SO_2	sulphur dioxide
SPCCC	Scottish Pollution Control and Coordination Committee
SUAQ	Scottish Urban Air Quality (Group)
SUMP	Sustainable Urban Mobility Plan
TRAP	traffic-related air pollution
UK	United Kingdom
US	United States
VOCs	Volatile Organic Compounds
VOLY	Value of Life Years
WHO	World Health Organisation
YLL	Years of Life Lost

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CONTENTS

Overview

The purpose of this thesis is to describe the findings from an investigation of the health and socioeconomic impact of traffic-related air pollution on Scottish residents. The thesis evolved through investigation and enquiry, to incorporate an analysis of the effect on health of policies aimed at reducing traffic-related pollution in Scotland. As a result, this is the first socioeconomic analysis (linking societal impact and the economy) of traffic-related air pollution on Scottish residents.

Chapter 1 describes what is known about air pollution in terms of source, pathway and effect on human health. The reader is introduced to historical and current policy aimed at reducing air pollution to protect health. This chapter investigates if current policy is sufficient to make the further reductions necessary to comply with European air pollution objectives, or a new approach is required. However there are financial costs associated with air pollution reduction. To be successful a case for investment could be based on robust evidence of harm from air pollution, but where this evidence is weak there is a need to demonstrate how air quality improvement strategies might impact on health.

In Chapter 2 the evidence linking traffic-related air pollution and health is reviewed. Cohort studies and existing literature reviews are critiqued using literature assessment tools, and the findings are reported in tabular and Forest plot format.

The literature review seeks evidence for a causal link between air pollution and ill health. In theory, policy makers, industry and the public could challenge the evidence if insufficiently convincing. They could assert that other sources of environmental pollution e.g. noise, could be giving rise to the health impact. If this were to be the case then they might correctly argue that the significant investment required to reduce traffic-related air pollution is unjustifiable, when measured against other pressures on limited funding/profit/personal income. Therefore in Chapter 3 each cohort study is critiqued against the Bradford Hill (Hill 1964) criteria to assess the strength of evidence in terms of causation or association.

In Chapter 4 the models identified in the literature search are used to estimate the health impact of air pollution on the Scottish population. The analysis is based on Scottish morbidity and mortality data and is reported as three cross sectional studies:-

1. An epidemiological study that investigates the health impact of traffic-related air pollution on residents living in Air Quality Management Areas (AQMAs), compared to the health of residents of non-AQMAs in Scotland (Scottish (Air Quality) Health Needs Assessment Report, 2014, unpublished. Appendix 1).
2. A pilot study on the short term health effects following local pollution episodes in two Scottish cities (Glasgow and Edinburgh) (NHS24 study).
3. An analysis of local neighbourhood statistics in one Scottish city (Dundee SNS study) to compare the impact of air pollution on health in deprived and less deprived areas.

If public and business resources are to be re-directed to air quality initiatives without convincing evidence of health benefit, this might paradoxically have an adverse impact on health through loss of critical funding for services, or from economic hardship. At the same time, there is a need to be compliant with European air quality objectives otherwise Scotland will be subject to infraction penalties and the fines associated with these. Having said that, a major co-benefit of air pollution reduction policies is that reducing travel by car and increasing physical exercise will improve health. Therefore Chapter 5 describes a survey (Scottish Transport Emissions Partnership (STEP) Survey) to investigate the importance of these issues by identifying the barriers and incentives for improving traffic-related air quality beyond the impact on health.

Chapter 6 builds on the findings from the STEP Survey and reports on how the barriers and incentives are incorporated into policy aimed at addressing air pollution in Scotland. This policy was developed during the time of writing the thesis and the author was a member of STEP – the group responsible for producing *Cleaner Air For Scotland* (The Scottish Government, 2015) – a Scottish strategy to reduce traffic-related air pollution. Chapter 6 describes an assessment of the strategy using a tool for evaluating policy effectiveness. The purpose of the strategy critique is to demonstrate how effectively the barriers and incentives for change have been addressed.

Cleaner Air For Scotland implementation will have a financial cost to industry and the public. In Chapter 7 the costs and benefits of the main element of the strategy – Low Emission Zones and the potential for health improvements expected from these, are estimated. This socioeconomic analysis reports on the potential health and economic costs and benefits, and estimates what the Scottish population might be willing to pay to reduce traffic-related air pollution and protect health.

Chapter 8 summarises the overall findings from the research and describes how the thesis has provided the first health and socioeconomic analysis of traffic-related air pollution documented for Scotland.

A summary of the steps taken in the investigation, from initiation to the conclusions in Chapter 8, is provided in Figure 1.

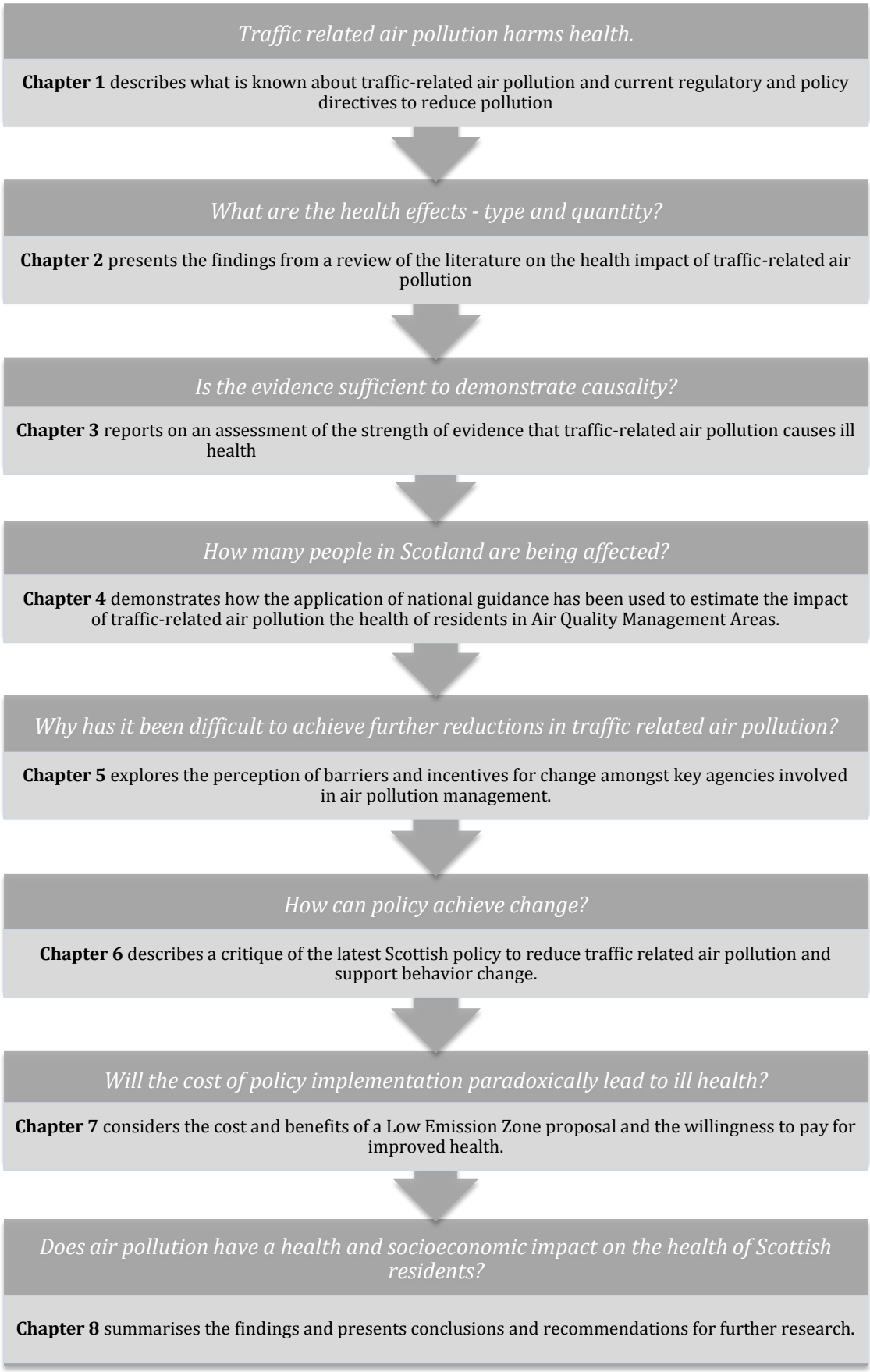


Figure 1: Structure of the thesis – the development of the case.

Chapter 1

A description of what is known about traffic-related air pollution and current regulatory and policy directives to reduce pollution.

Introduction

This chapter describes what is known about traffic-related air pollution and reports on current regulatory and policy directives to reduce pollution. The routes for exposure are explored and vulnerabilities are addressed, with a specific focus on emission sources and trends. To highlight environmental and societal connectivity, current policy is set in the context of determinants of health.

Background

There is increasing evidence that air pollution from traffic has short- and long-term negative impacts on health (Seaton et al., 1995; Bertollini, 2004; Gauderman *et al*., 2005; McConnell *et al*., 2010). Historical records indicate that the detrimental impact of air pollution on health, in relation to industrial coal use in London, may have been noted as early as 1273 (Enviropedia, 2013).

Although laws such as the Public Health Act 1875 Section 91 (HM Government, 1875) have been implemented over time to reduce air pollution from industrial sources, it was not until the Great Smog in London in 1952 that attention finally focused on the contribution of domestic and other sources of air pollution to a significant loss of life. This event resulted in the introduction of the *Clean Air Act 1956* (HM Government, 1956) which legislated for the emission of dark smoke from any chimney, to be treated as a criminal offence.

At that time the key pollutants from industrial processes and domestic coal fires were particulates, carbon monoxide (CO) and sulphur dioxide (SO_2) (Met Office, 2015). However, as smoke control policies became more effective in reducing domestic and industrial pollution, the increasing role of vehicular traffic became apparent. The main pollutants linked to traffic sources are now predominantly oxides of nitrogen (NOx) and particulate matter (PM) and photochemical products such as ozone (O_3) (Brunekreefe and Holgate, 2002).

The introduction of a European Commission (EC) Directive in 1988, regulated for air pollution reduction relating to emissions from vehicles (Christensen, 1987). The European Parliament subsequently set out articles for action to protect health from pollution. These were reviewed in 2013 to ensure policies continued to address changes needed to continue to improve air quality across Europe (European Commission, 2016).

In the UK, the 1995 Environment Act (HM Government *c*, 1995) required Local Authorities (LAs) to monitor and report annually on air quality from all sources. This Act also introduced a requirement for LAs to produce local Air Quality Action Plans (AQAPs) to address poor air quality. Information from local monitoring is reported annually to the European Commission in line with a European agreement for sharing of air quality data (Commission of European Communities, 1996). Emission limits have been amended over recent years, with Scotland currently working to limits set out in the Air Quality Standards (Scotland) Regulations 2010 (Cunningham, 2010). A further amendment to include $PM_{2.5}$ (particles that are less than 2.5 micrometres in diameter) monitoring was introduced in 2016 (McLeod A, 2016).

In response to increasing pressure to meet the legislative requirements, a number of organisations have been working independently and collaboratively across Scotland, the UK and internationally. The input from these organisations, groups and individuals are discussed further in Chapter 5.

The Source-Pathway-Receptor Model

In order to reduce the risk to health from traffic-related air pollution, the process connecting air pollutants and human health must be understood. Traffic-related ill health arises from particles or gases that can cause harm because of their toxicological properties when inhaled. In order to cause harm there must be three criteria:

1. A pollutant source – i.e. vehicular emissions;
2. A medium of travel – i.e. movement of pollutants through the air;
3. A receptor – i.e. human inhalation of toxic pollutants.

These three criteria have been described as the "*source-pathway-receptor model"* (Iroegbu, 2007).

The model provides a basis for actions to reduce ill-health. Application of the model means considering the origin of the pollutants (source), how the pollutants disperse (pathway) and the body that can be adversely affected – in this case humans. Then preventative measures can be applied at one or more of the stages e.g. prevent emissions at source, remove receptors from the dispersal pathway, provide receptors with some form of protection such as facial masks. The model is appropriate for addressing most environmental pollution issues including traffic-related air quality and is described in Figure 2 below:

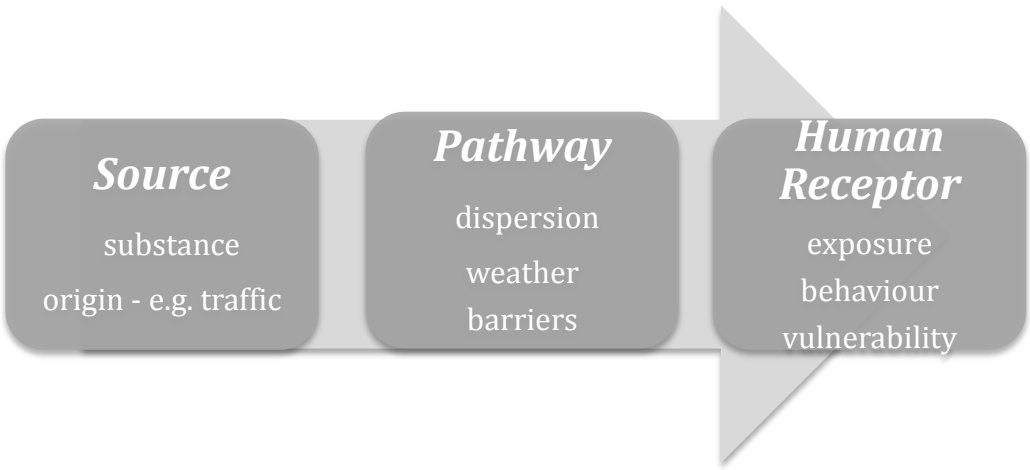


Figure 2: Risk assessment model for air pollution: Source-Pathway-Receptor (Adapted from Iroegbu, 2007)

In the case of traffic-related air pollution it is not possible to remove any of the criteria completely, therefore a risk assessment may be undertaken to investigate options for reducing risk. Environmental risk assessment and management is a well established process (Gormley *et al*., 2011) which follows a structures set of principles:

a) Problem identification – e.g. ill health.
b) Risk assessment – who is affected, where, how are they affected, duration of exposure.
c) Review of options – how can ill health be prevented.
d) Applying risk management process – physical changes, policy or regulation of behavior.

Sources of air pollution

Air pollution arises from a number of sources including industrial processes, agricultural activities and transport. The World Health Organisation (WHO) has been collating and publishing research on air pollution and in 2000 a comprehensive review of pollutants, sources and their effect on health was published (World Health Organisation, 2000). This provided the evidence to underpin guideline levels and recommendations for action to reduce air pollution. Much of this focused initially on industrial sources but emission controls over a number of years have succeeded in reducing air pollution substantially from these sources. Subsequent reviews focused on the main components of traffic-related pollution, i.e. PM (Particulate Matter), NO_2 (nitrogen dioxide) (as a marker), O_3 (ozone) and sulphur dioxide (SO_2).

These pollutants do not exist in isolation. The combustion engine in vehicles produces carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NOx), PM, benzene, other chemicals and heavy metals such as lead. This is a complex mix that constantly changes according to geographic and climatic conditions. For example, fossil fuel combustion (oil and gas) results in the release of NO and NO_2 with the level of NO exceeding that of NO_2. Sunlight and the presence of Volatile Organic Compounds (VOCs) cause the breakdown of oxygen in the atmosphere producing free oxygen radicals. The free oxygen radical reacts with oxygen in the atmosphere producing ozone. The oxygen also reacts with NO producing more NO_2 – both of which are harmful to health. There is less NO from traffic in rural areas so there is less O_3 breakdown and consequently higher O_3 levels. Since sunlight is required for the reaction, greater levels of pollution will be seen on sunny, calm days.

The vehicle fuel determines the type and volume of traffic-related pollutants. Diesel engines produce higher levels of NOx and PM than petrol engines, particularly on shorter journeys when the engine is still cold. Pollutant emission characteristics also depend on the age of the engine, movement of the vehicle, e.g. stopping and starting and use of brakes. Particulates ($PM_{2.5}$, PM_{10} and ultrafine particulates) arise from engine combustion and break and tyre wear, i.e. re-suspension of road dust (World Health Organization, 2006). The $PM_{2.5}$ components (metals, Polycyclic aromatic hydrocarbons (PAHs), organic components) are more toxic than larger particles because they penetrate deeper into the lung and can cross into the bloodstream

(World Health Organization, 2006). Studies now suggest increasing evidence of harm to health even at the guideline levels (World Health Organization, 2006).

In Scotland, transport is a major contributor to air pollution through emissions of NOx (45.1% of total emissions), and PM (19% of total emissions). However in recent years emissions have declined progressively due to tighter industrial emission controls and vehicle standards (Bailey *et al*., 2016) (Figure 3).

Emission standards are set at world and European levels. Currently Scotland is not in breach of guideline levels for annual PM_{10} where these are set at 50μ/m^3 (WHO) or 40μ/m^3 (Europe) (O'Brien, 2016). The data for 2014 show that there are also no breaches of the 24 hour PM_{10} objective for Europe (40μ/m^3). However two sites breached the lower 24 hour PM_{10} WHO objective (20μ/m^3), with levels of 22.1μ/m^3 (Aberdeen, Wellington Road) and 20.1μ/m^3 (Perth, Atholl Street). On the basis that there is no lower safe limit, Scotland has adopted a more stringent target of 18μ/m^3 and in 2014 this level was breached in 3 sites (Glasgow, Dumbarton Road 18.9μ/m^3; Dundee, Lochee Road 18.5μ/m^3; South Lanarkshire, Rutherglen 18.2μ/m^3). Levels of NO_2 have also been declining but there were still 10 areas in Scotland where annual limits were breached in 2014 (40μ/m^3 annual mean for WHO, Europe and Scotland). These are relatively small breaches in emission standards but breaches none-the-less. In Chapters 2 and 3, evidence is provided on the strength of the association between air pollution and health with a view to establishing the impact this level of pollution might make on health.

The harmful effects of emissions from traffic have been recognized globally, with many countries implementing air quality policies to reduce pollution. This has been achieved to some extent through various measures, including improved engine design such as hybrid and electric vehicle design; introduction of catalytic convertors; re-directing traffic flow from congested areas; and encouraging greater use of public transport and active travel (cycling and walking).

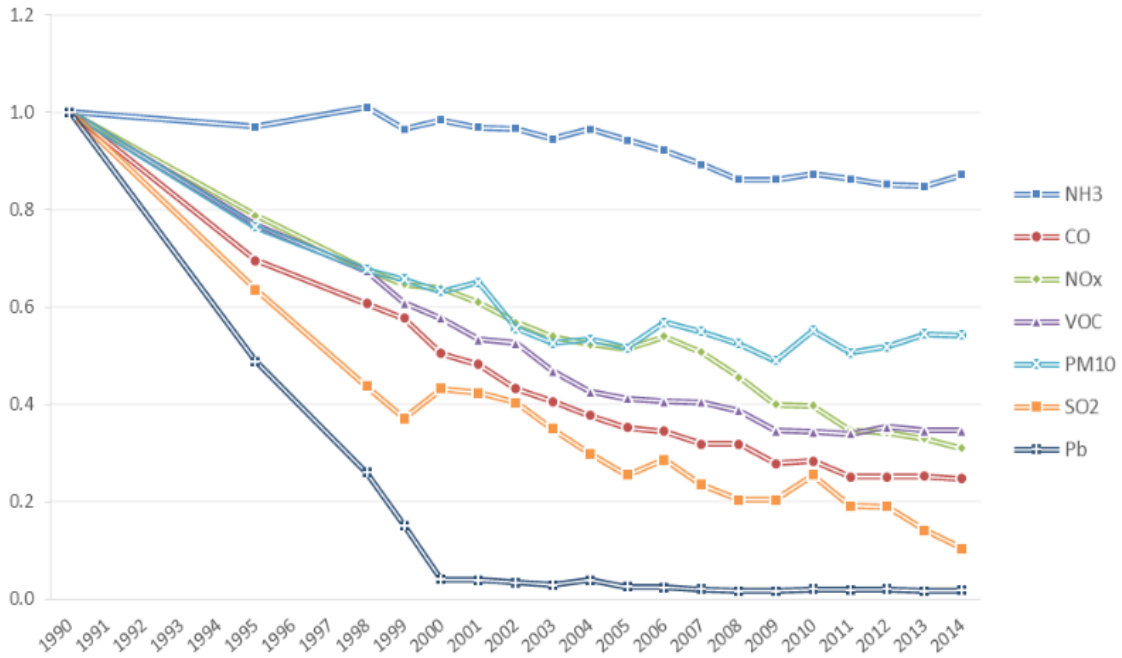


Figure 3: Scottish air pollution trends for all regulated emissions, 1990 (baseline) to 2014 (Bailey *et al*., 2016, p13).

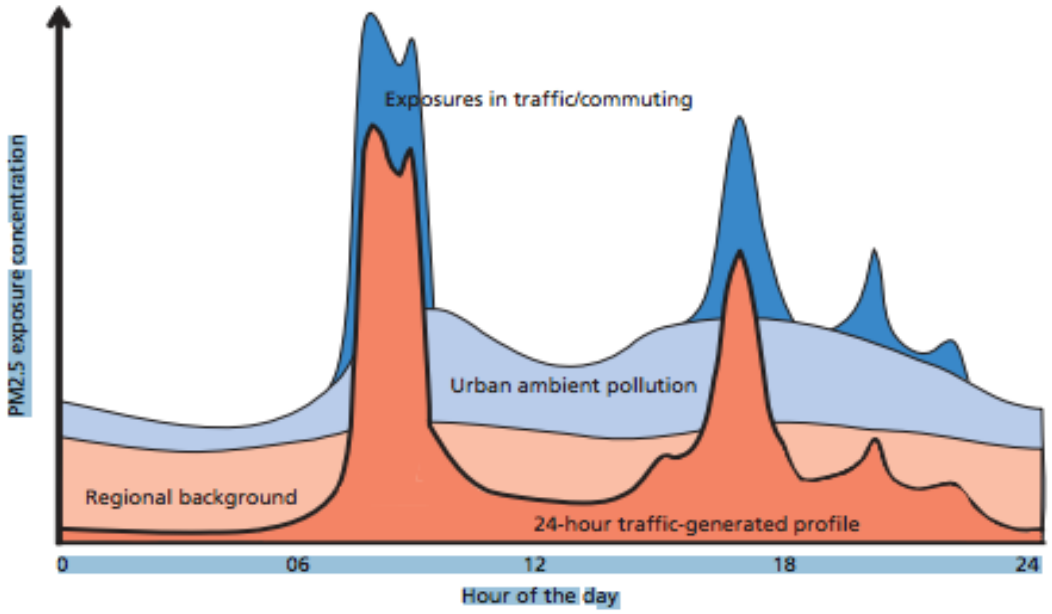
Despite progress in reducing air pollution, there is growing concern that the improvements in technology that are leading to an overall reduction in traffic-related air pollution, might be reversed as a result of an increase in PM and NO_x emissions with the rising number of diesel cars in the UK (O'Brien, 2016).

Pathway

Traffic-related pollution is greatest in areas close to source emissions and by definition this means on or near roads. Scottish data suggests that the average distance travelled by car is 7 miles and at an average of 20 miles per hour (Transport Scotland, 2014). This type of journey provides little opportunity to achieve the potential benefits from engine-redesign technology. These features require longer engine running times and higher engine temperatures to reach levels for greater fuel efficiency and effective pollutant removal systems. Drivers, passengers, cyclists and pedestrians are exposed to higher levels of pollutants in areas where traffic is slow and congested. This is compounded by the fact that there is an increasing volume of traffic on roads and commuting time is increasing (Transport Scotland, 2014).

The level of air pollution exposure depends not only on the vehicle emissions and background pollutants but also on the landscape (e.g. street canyons trap and recirculate pollutants) and air movement (e.g. there is less pollution on windy days). Climate also plays a significant part in that there is more pollution on days of temperature inversion, i.e. colder air is trapped below warm air so pollutant levels build up near ground level. In hot weather sunlight leads to an increase in chemical reactions between NOx and ozone (World Health Organisation, 2005).

Human exposure is also dependent on factors such as concentration of pollutant, time spent in the polluted area and behaviour (e.g. travelling in a car, cycling in traffic, or walking/running). As can be seen from Figure 4 below, there is a background level to which everyone is exposed, and for particulates this is generally higher in urban than in rural areas. The level increases as traffic volume increases during peak travel times. A commuter is exposed to the highest levels if travelling during peak traffic times.



Note. The section bounded by thick lines presents a 24-hour traffic-generated exposure profile for PM2.5. The sections bounded by thin lines show additive total PM2.5 contributions from the regional background (bottom), urban ambient pollution (above) and exposures in traffic/commuting (peaks). Exposure while commuting represents about half of total exposure to PM from traffic.

Figure 4: Relative exposure concentrations of $PM_{2.5}$ and the influence of traffic, according to the hour of the day (Krzyzanowski et al. 2005, p87).

The pollutants can travel some distance from source, depending on the urban or rural landscape, weather and pollutant type. It is problematic in scientific terms however, to assess the exposure of individual commuters. Studies with volunteers carrying monitoring equipment have been undertaken (Steinle *et al*., 2015), but these are difficult to replicate at a population level. The lack of information on actual human exposure in daily activities is compounded because such studies are expensive to undertake, and difficult to power. Most studies undertaken on a population basis use estimates of exposure and link these to health outcomes. This is discussed further in Chapter 2.

However, extensive work is underway to improve monitoring and modeling of traffic emissions in Scotland and future studies may provide more robust assessments of exposure. To date, many published studies have used proximity models as proxies for exposure. Personal exposure is estimated by calculating residential distance from air monitoring sites. The traffic emission and exposure concentrations are modelled from air monitoring site data for NOx, PM and black carbon, and from distance or traffic volume data. These models have been shown to have good correlation with monitored emissions (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010).

In the UK the monitoring is carried out at over 300 sites across the UK (Department for Environment & Rural Affairs, 2015), of which 127 are the automatic monitoring sites that make up the Automatic Urban and Rural Network (AURN). This network has evolved from the longstanding air monitoring programme, first set up in England in 1961, in response to the Great Smogs of the 1950s.

Early studies relied exposure estimates based on the distance from air monitoring sites to residences but these data did not take into account variations in building or road layout, climatic variations or individual behaviour (Huang and Batterman, 2000). As monitoring data and geospatial analyses models improved, additional measures were employed such as traffic volume, flow and distance from roads (Distance Weighted Traffic Volume); climatic variations such as wind direction; average road use by vehicle type; or a combination of techniques as in Land Use Regression Modeling (Habermann *et al*., 2011).

Currently, estimates of traffic pollutant emissions are modelled on direct vehicular emission measures, fixed site monitors and mobile monitoring. Progressively more sophisticated (and expensive) methods for assessing exposure are now being developed in Scotland as part of a National Modeling Framework. This will use air quality data collected from static and mobile monitoring stations to produce air quality models. The models will inform decisions on different transport arrangements and air quality outcomes (Scottish Government, 2015).

Human Receptor

Despite the increasing sophistication of modeling, estimates of personal exposure are limited by a number of factors. Firstly, fixed site modeling does not represent true personal exposure because the individual is not static at one site and exposed to this level of pollution all the time. Secondly, fixed monitors at the kerbside measure an excess of emissions from vehicle tailpipe exhaust and particle dispersal from moving traffic. Monitors traditionally placed at 1st floor building height (bedroom level) are good for external monitoring but do not measure indoor exposure. Vehicular monitors have been used to measure occupational exposure for drivers. Air pollution exposure in vehicles has been shown to exceed levels monitored at the roadside but these measures do not represent exposure levels for the general population (Zagury *et al*., 2000). Individual monitoring would provide more robust evidence of the impact of air exposure on vulnerable individuals, than the population based estimates currently undertaken.

The extent to which air pollution contributes to ill health has been well documented and is discussed further in Chapter 2. Given the evidence of an association between air pollution and ill health, guideline levels have been set to minimize the adverse impact on health. However there may be health effects in more susceptible individuals at levels below guideline levels levels (World Health Organization, 2013).

The impact of air pollutants is greatest on the cardiovascular and respiratory system. Inhaled gaseous and particulate matter cause irritation on the upper and lower airways and very small diameter particulates and chemicals can cross into the blood producing an effect on the cardiovascular system. The effect is both immediate with

irritation of the mucus membranes, and longer term with effects resulting from chronic inflammation and vascular changes (Bertollini, 2004).

The pathophysiological effect from air pollutants arises from the deposition of toxic particles on the epithelial lining of the lung. This stimulates an inflammatory and macrophage response with mucus secretion and phagocytotic clearance of the foreign bodies. Some nanoparticles (very small sized particles between 10^{-9} to 10^{-7} of a metre) penetrate deeper into the epithelial lining and enter the lymphatic and vascular system. There is evidence that the particles contribute to vascular inflammation and the development of atherosclerosis. The stimulation of inflammatory responses may lead to an increase in platelet coagulation with circulatory consequences. The response occurs not only in the short-term (24 hour) but also for several days following short-term exposure. Long-term effects may be due to continued exposure leading to a chronic inflammatory process, and the progression of underlying disease (World Health Organisation, 2013). Chapter 4 describes epidemiological studies to investigate the health impact of short- and long-term exposure to traffic-related air pollution on populations in Scotland.

In summary, the source-pathway-receptor model is a useful tool to demonstrate the link between traffic emissions (source) as a significant contributor to air pollution, exposure due to proximity to traffic (pathway), and impact on health via the respiratory and cardiovascular system (receptor). This model can be used to consider mitigation measures at each stage. Such measures might include reducing emissions at source, adjusting the environment to prevent exposure (eg traffic management measures) or removing the receptor from the hazard (e.g. sending alerts on air pollution days advising people to stay indoors).

Historically, air pollution from industry and pollution from domestic fires has been addressed through legislation and tackling pollution at source with abatement or alternative clean fuel options. However, traffic-related pollution is more complex in that it is produced by vehicular transport systems upon which the economy is dependent. Furthermore, the car remains the most popular form of domestic transport. The following Chapters will describe how air pollution reduction requires a

concerted effort across society, political will and a demonstration of socioeconomic benefits in favour of change.

Policy development and implementation in Scotland

The key legislation driving improvements in air quality in Scotland is the Air Quality Standards (Scotland) Regulations 2010 (Scottish Statutory Instruments, 2010). The Act requires LAs to identify Air Quality Management Areas (AQMAs) and publish Air Quality Action Plans (AQAPs). However it does not require LAs to demonstrate within the AQAP how they will improve air quality within a specified timeframe. As a result, there has been little progress in delivering improvements where these might have a cost, particularly in a climate of economic and public spending austerity. Furthermore, there is some evidence that air pollution is worse in areas of deprivation (Defra, 2006). This is linked to population concentrations in cities and adjacent to busier transport links, driven by the need to live close to areas of employment. Traffic reduction measures therefore, might have a negative impact on local businesses in areas already suffering from economic hardship.

For policy-makers to consider investment in air pollution reduction as a priority, there must be evidence that harm is arising in the population and that reducing exposure will reduce ill health, whilst also balancing the need to prevent economic hardship. At the request of LAs, Public Health England (PHE) produced estimates of air pollution impact on mortality at a LA level (Gowers *et al.,* 2014) to assist in developing options for air pollution reduction. In Scotland the report was reviewed by Health Protection Scotland (HPS) and an interpretation for Scottish AQMAs was published in 2014 (HPS, 2014).

The reports provide LAs with estimated $PM_{2.5}$ data recorded at local and national monitoring sites. These data are applied to adjusted population data. The outcome is a measure of estimated deaths from exposure to $PM_{2.5}$. The reports have raised awareness of air pollution have been used as evidence to support the case for investment to reduce pollution. However the approach is not without its problems and this is explored further in Chapter 3.

A report from the World Health Organisation (2000) recommended consideration of air pollution reduction measures in the context of the wider determinants of health - building on the concept of connectivity between the environment, economy and health. This is demonstrated in the model produced by Whitehead *et.al*. (2001) (Figure 5) which suggests that the health of the individual is influenced by factors at many levels – socioeconomic, cultural and environmental. Many of these, including air quality, are determined by national and local policy. This means that action to reduce the impact of air pollution must take into account social and community, living and working conditions, and socioeconomic and environmental conditions. This has made change challenging and Chapter 5 reports on a study investigating the incentives and barriers to change.

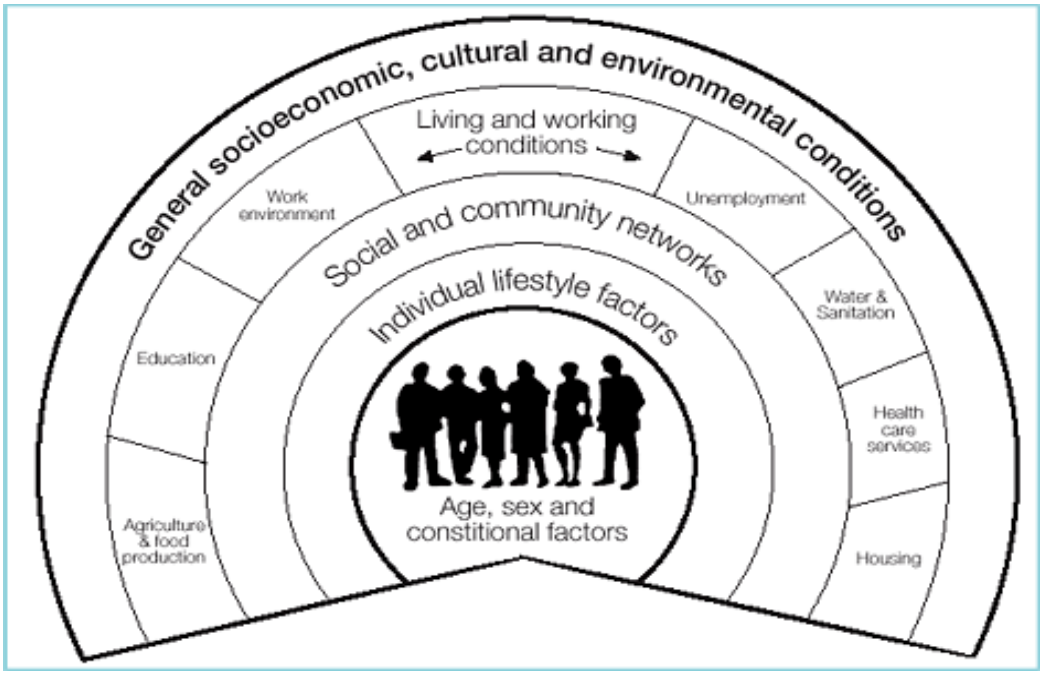


Figure 5: A conceptual model of the main determinants of health – layers of influence. (Whitehead *et al.,* 2001, p314)

In Scotland, the wider influences on health are being addressed in air quality policies. Work has been underway to implement an air quality strategy for Scotland - *Cleaner Air For Scotland* (CAFS) (The Scottish Government, 2015). CAFS has been driven by the need to protect health and support LA initiatives to improve local air quality, whilst at the same time preventing any widening of inequalities, and ensuring economic sustainability. The implementation of the strategy includes the

development of more precise air pollution monitoring and modeling to ensure efforts are focused on pollution sources, and that implementation of the strategy results in measurable improvements in air quality (National Modeling Framework). There are also proposals to investigate behaviour change, not only in terms of transport use, but also to encourage individual and societal support for active transport i.e. walking and cycling. Behaviour change strategies are discussed further in Chapter 6 in the context of environmental initiatives and how these are being addressed in CAFS.

As part of CAFS, Low Emission Zones (LEZ) will be introduced in areas of high traffic-related air pollution in four cities in Scotland – Glasgow, Edinburgh, Dundee and Aberdeen. Local Authorities will consider policies to restrict the number and type of vehicles permitted to enter the LEZ. Such zones have been introduced across the UK and Europe and have shown some reduction in air pollution in the most polluted zones (Sadler, date unknown). What is not yet known is the impact LEZ will have on the local economy and on improvements in health. These issues are addressed in Chapter 7.

In summary, traffic-related air pollution is associated with ill health and legislation has been introduced to regulate for cleaner air. There has been considerable progress towards reducing air pollution but traffic-related contributions continue to play a significant part. In Scotland, work is underway to deliver the CAFS strategy, a societal approach to improving air quality and public health. However successful implementation of CAFS will depend on robust evidence that health is being improved without economic hardship. This theme will be developed in the following chapters.

Chapter 2

A review of the literature on the health impact of traffic-related air pollution.

Introduction

There is a wealth of published evidence linking air pollution from traffic to short and long-term negative impacts on health in different populations. However, what is not known is the extent of ill health that can be attributed to air pollution in Scotland. In order to address this gap a review of the literature was undertaken.

The research question for the review was –
"*Is there a link between physical health status of populations and traffic-related air pollution as measured by residential distance from heavy traffic in Scotland?"*

Method

Defining the scope of the literature search

"Air pollution" comes in many forms and from many sources and can be described in a number of ways including "emissions" and "air quality", so all three terms were included in the initial search. The search did not focus on specific pollutants as these were addressed within the systematic reviews and the studies identified.

The term "health" is very broad but this was included in the initial search so that novel and not widely known conditions, or conditions described in a number of ways e.g. respiratory disease and lung disease, could be included in the search. The key terms identified from the initial search then became the focus for screening out relevant papers, i.e. cardiovascular disease, respiratory disease, lung disease, cancer, pregnancy, newborn.

Finally the search was run to include studies undertaken specifically in Scotland to ensure that the study findings could be used to assess the impact of air pollution in the Scottish context and thereby inform policy.

The research question was expanded to form a sequence of sub-questions. This ensured coverage of each aspect of air pollution and health, as it relates to Scotland. Starting from the initial case that air pollution has an adverse impact on health, the

questions addressed the specific impact and the extent of this in terms of exposure, health effects and the Scottish population:

- What are the sources of traffic-related air pollution?
- What are the pollutants in traffic-related pollution?
- What is known about the physiological impact of traffic-related air pollution on health?
- What level of traffic-related pollution has an adverse impact on each area of health?
- How is the health impact of air pollution assessed?
- What is the evidence that traffic-related air pollution has had an adverse impact on health in Scotland?
- Are there areas in Scotland which are more likely to be affected and why?

Search Methodology

The main health databases of the published literature were searched in line with published guidance (Centre for Reviews and Dissemination, 2009). The search focused on evidence of the health impact of traffic-related air pollution in general, and then specifically in Scotland. The search included electronic databases for peer reviewed journals (EBESCO, OVID Medline, OVID Embase), and an internet search (Google) for peer reviewed publications not identified in the database search, as well as for reports on air quality policy and regulation. Details of the search terms and results can be found in Appendix 2.

In addition, leaders in air quality issues in Scotland were approached to identify further articles and policies to ensure the outcome was relevant to Scotland (Appendix 3).

Search terms

The literature review used the following search terms:

- Air quality,
- air pollution,
- emissions,

- health,
- cardiovascular disease,
- respiratory disease,
- lung disease,
- cancer,
- pregnancy,
- newborn,
- residential distance.

Period of study

The search included the years ‘1999 to current’. This time frame was selected to take into account environmental pollution changes over time. Air quality regulations have reduced pollutant concentrations by nearly 50% between 1995 and 2010 (as previously shown in Figure 3). Papers showing health impacts as a result of exposure to air pollution before 1999 might therefore, not be applicable under current more restrictive environmental regulations.

Type of study

In the field of air pollution and health, cohort studies provide the strongest evidence of potential causality where this might exist, so the search focused on this type of study.

There have been many systematic reviews on air pollution and health, and these have been used to guide international policy. Where the reviews have been undertaken to a high standard they provide robust evidence of the impact of traffic-related air pollution on health and were included in the review.

Policy documents were identified through a *Google* search for the relevant source document.

Inclusion and Exclusion Criteria

Studies were included if they focused on health risk states associated with traffic-related air pollution, pollutants and emission limits in any country including Scotland, within the time period 1999-2013.

Papers were excluded if they did not address air quality and health, were not systematic reviews or a cohort study or were not available in English.

Quality assessment

The papers were assessed against published critical appraisal tools. Systematic reviews were screened according to the PRISMA statement (Moher *et al.*, 2009) and cohort studies screened according to SIGN guidelines (Scottish Intercollegiate Guidelines Network, 2014). An example of a paper critique is shown in Appendix 4.

Database search

The following electronic databases were searched from 1999 to 2013 for peer-reviewed articles:

Medline R/ Medline R Daily Update/ Medline R In Process; Embase; ERIC HMIC; Cochrane; ASSIA; CINAHL; EBSCO, Web of Science, Global Health, Scopus, Google Scholar, Cochrane Controlled Clinical Trials Register, HMIC database, Health Technology Assessment, Evidence Based Medicine (Appendix 2)

There is a considerable volume of information published in the grey literature and available on the internet, which is of high quality but which is not listed in peer reviewed journal databases, e.g. the World Health Organisation review reports. To identify these a Google search for “air pollution” and “environmental protection” was undertaken. Further sites were investigated following recommendations from experts working in the field (i.e. individuals who were identified during the collation of information on Air Pollution Organisations (Appendix 3). Bibliographies of included papers were hand-searched for further relevant studies or reports.

Data abstraction and synthesis

The data were entered on to an excel worksheet recording study author and reference, study design, setting, objectives, description, participants, results and inclusion or exclusion (see Table 1 (cohort studies) and Table 2 (systematic reviews for summary data and Appendix 6 for full data)).

Results

Screening

The database search resulted in papers identified first by title (348), then reviewed by abstract (145) and finally assessed in full (30) and critically appraised according to published templates for systematic reviews or cohort studies (Appendix 4).

The website search followed the same criteria as the electronic database search. The results from the website search were screened by title (570) and then by abstract to remove papers with did not meet the search criteria (548). A full review of the remaining 22 papers resulted in the selection of a final 9 publications suitable for inclusion (Figure 6).

A cross-checking of references across publications, showed that there had been a consistent capture of studies.

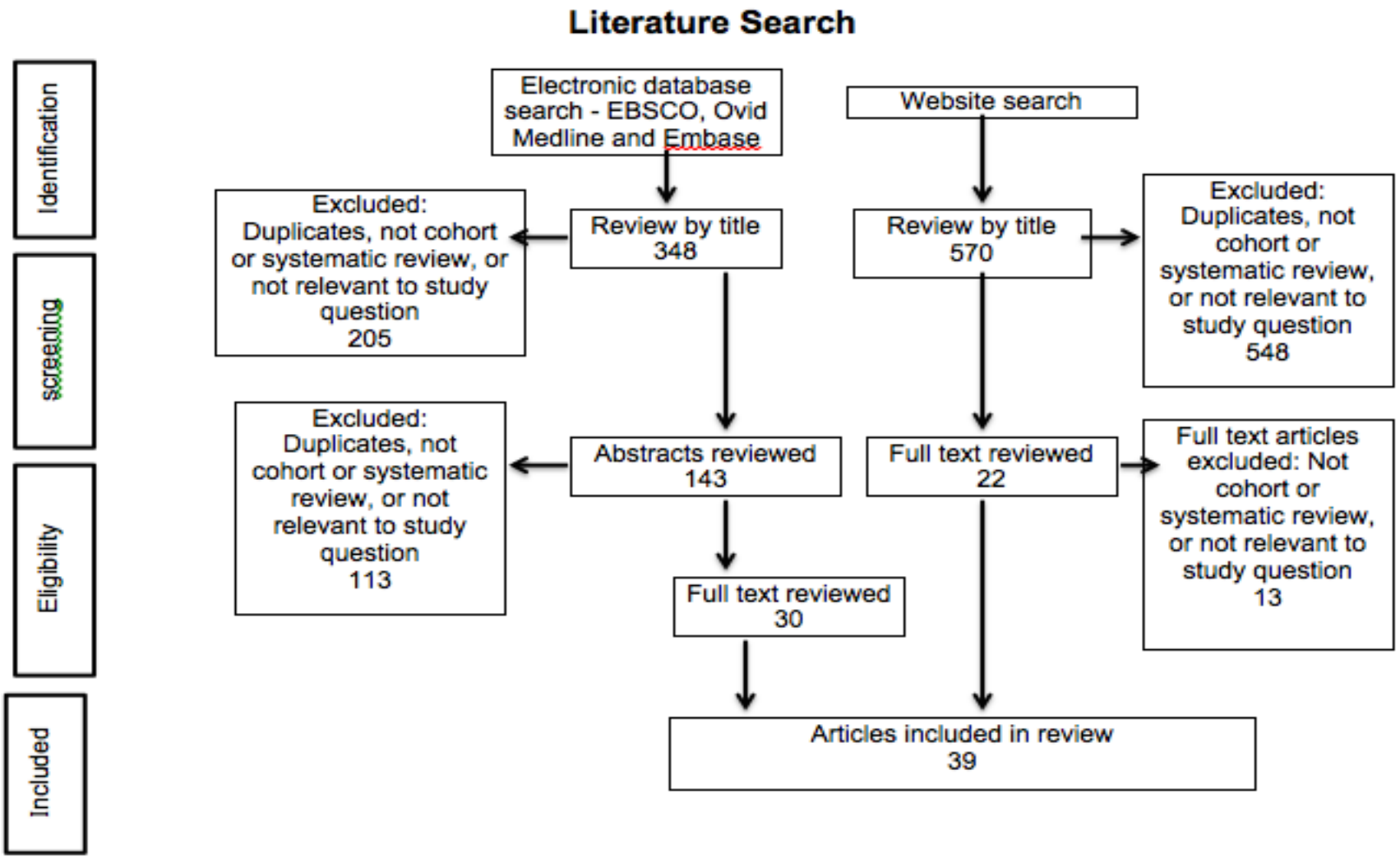


Figure 6: Summary of the literature search (Adapted from: Moher et al. (2009, p5))

The earliest cohort study publication included in this review was published in 2002 (Gehring *et al*., 2002) but most of the studies (19) were published between 2010 and when the literature review for this thesis was undertaken in 2013 (Table 1). Only one of the studies was undertaken in the UK (Beverland *et al*., 2012) and less than half (13) were undertaken in Europe. The study population size varied from 36 (Cowie *et al*, 2012) to 1,265,058 (Cesonari *et al*., 2013). The studies reported on different and sometimes multiple outcomes, with six studies reporting on all-cause mortality; nine on cardiovascular disease; 10 on respiratory or lung disease; two on lung cancer; 12 on pregnancy outcomes; two on neonates and one on cerebrovascular disease.

Nine reviews were published between 2000 and 2013. The majority (six) were published by the World Health Organisation and reported on health effects at different concentrations of air pollution (Table 2).

Table 1: Cohort study results listed by author and showing a summary of the study setting, health outcome investigated and participant characteristics.

Author	**Setting**	**Health outcome investigated**	**Participants**
Anderson *et al*., 2011	Denmark	COPD	57,053, aged 50-64 years
Barnett *et al*., 2011	Australia	newborn health	970 mothers and newborns
Beverland *et al*., 2012	Scotland	mortality	15,331 residents aged 45–64
Brauer *et al*., 2007	Netherlands	asthma and allergies	4,000 children 0-4 years
Brauer *et al*., 2008	Vancouver Canada	gestational age, birth weight, low full-term birth weight,	70,249 births

		preterm birth	
Carleston *et al*., 2011	Vancouver	asthma	184 children birth to 7 years
Cesaroni *et al*, 2013	Italy	mortality	1,265,058 population
Chang *et al*., 2009	California	acute respiratory	3,297 children aged 18 or less
Chen *et al*., 2013	Ontario Canada	cardiovascular effects	205,440 adults age 35–85 years,
Cowie *et al*., 2012.	Australia	respiratory health effects	36 volunteers
Estarlich *et al*., 2011	Spain	measures at birth	2,505 pregnant women
Gehring *et al*., 2002	Munich	health effects	1,756 infants
Gehring *et al*., 2006	Germany	mortality	4,800 women (age 50-59 years)
Gruzieva *et al*., 2013	Sweden	asthma	4,089 children birth to 12 years
Heinrich *et al*., 2013	Germany,	mortality	4,800 women aged 55 years
Hoffmann *et al*., 2009	Germany	systemic inflammatory markers	4,814 participants
Iniguez *et al*., 2012	Spain	foetal and neonatal anthropometry	855 antenatal women
Janssen *et al*, 2012	Belgium	mitochondrial DNA	178 newborns - singletons
Jerrett *et al*., 2009	Toronto	mortality	2,360 subjects from a respiratory clinic,

Laurent *et al*., 2013	California	birth weight.	70,000 births
Medina-Ramón *et al*., 2008	Massachusetts	mortality	1,389 patients
Miyake *et al*., 2010	Japan	allergic disorders	756 mother–child
Pereira *et al*., 2011	Western Australia	intrauterine growth	3,501 births between years 2000-2006
Pereira *et al*., 2013	Western Australia	preeclampsia.	23,452 births
Raaschou-Nielsen *et al*., 2012	Denmark	mortality from cardiovascular disease	52,061 participants
van den Hooven *et al*., 2009	Netherlands	birth and pregnancy outcomes	7,339 pregnant women and their children
Wilhelm and Ritz, 2005	California	low birth weight	146,972 births
Wilhelm *et al.*, 2012	California	low birth weight	220,528 births
Wu *et al*., 2009	California	preeclampsia and preterm delivery	81,186 singleton birth records
Yorifuji *et al*., 2010	Japan	mortality	13,444 residents

Table 2: Results from the search for air pollution reviews, listed by author and health outcome investigated.

Author	**Health outcome investigated**
Ayres, 2006	cardiovascular disease, mortality and morbidity
Brunekreefe and Holgate, 2002	health impact
Health Effects Institute, 2009	health impact
World Health Organisation, 2000	guideline values
World Health Organisation, 2003	health impact
World Health Organisation, 2004	health risk
World Health Organisation, 2005	public health
World Health Organisation, 2008	health impact
World Health Organisation, 2013	health impact

Disease related findings

The findings from the literature review are summarized in Tables 3-9 below. The studies report on different exposures and provide different measures of risk and are therefore not directly comparable. However, where there are three or more consistent outcomes and risk measures, these have been summarized in a Forest Plot below the relevant section. The Forest Plot provides a diagrammatic representation of a meta-analysis of the effect size. Where the number of studies with consistent measures is less than three, it is not possible to produce a Forest Plot with meaningful data.

All-Cause Mortality

Six cohort studies and five reviews reporting on investigations into the effects of traffic-related air pollution on health (Table 3), show evidence of a link between an increase

in mortality and exposure to air pollution. The reported Hazard Ratio (HR) in all-cause mortality for PM_{10} is 1.15 (Heinrich *et al.*, 2013) and for $PM_{2.5}$ the HR is 1.04 (Cesonari *et al*., 2013); the NOx/NO_2 HR lies between 1.02-1.18 (3 studies)/RR 1.17 (Gehring *et al*., 2006) and is insignificant in one study (Yorifuji *et al*., 2010: HR 1.02, CI 0.96-1.08). There is evidence that short and long-term exposure effects are resulting in 21,000 deaths per annum from ozone exposure across Europe (World Health Organisation, 2009), or nine months of life expectancy lost (World Health Organisation, 2013). Effects are seen at levels below guideline levels for NO_2 and PM (World Health Organisation, 2013).

A meta-analysis of the effect sizes for exposure to NOx/NO_2 has been summarized in a Forest Plot in Figure 7 and shows that there is sufficient evidence to demonstrate a mortality impact for NOx/NO_2 emissions. There is insufficient comparable data from the studies to provide a Forest plot for particulates.

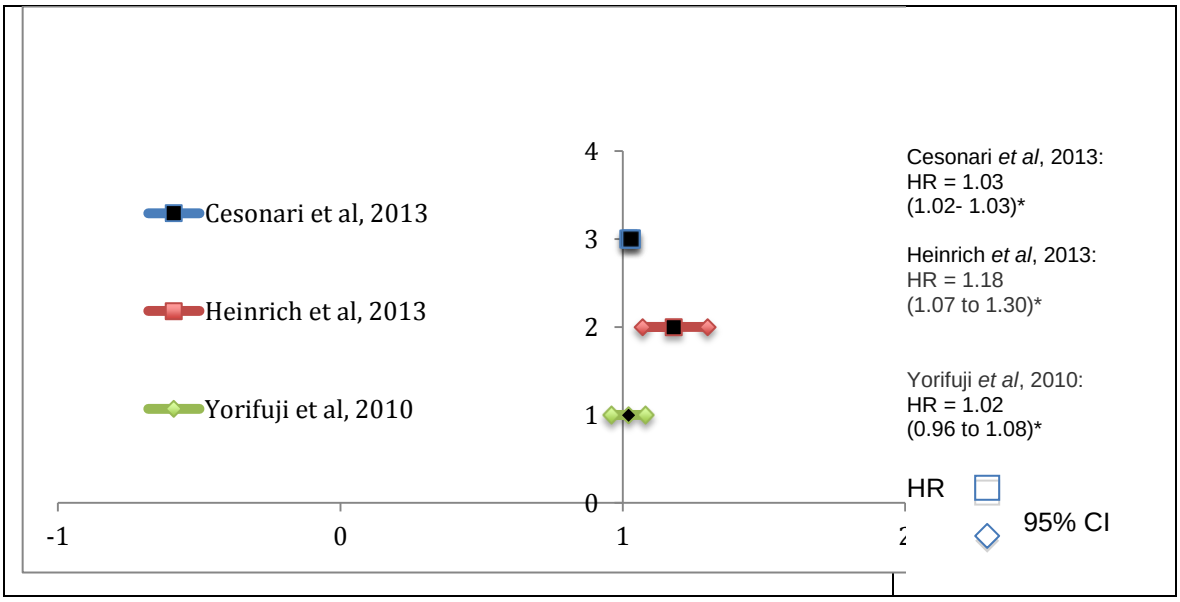


Figure 7: Forest plot showing the HR results for all-cause mortality from exposure to elevated levels of traffic-related NOx/NO_2 emissions

Cardiovascular Disease

Nine cohort studies and four reviews report on the impact of traffic-related air pollution and cardiovascular disease. There is evidence for a negative effect of air pollution on the cardiovascular system in all except one of the studies listed in Table 4 (Ramon *et al.*, 2008). The HR for cardiovascular disease from exposure to $PM_{10/2.5}$ lies between

1.10-1.39 (two studies), and is reported as a Relative Risk (RR) of 1.34 (one study) or as a percentage increase in CRP 23.9% and fibrinogen 3.9% (one study). The HR for NO_2 lies between 1.16-1.55 (two studies), and is reported as a RR of 1.55 (one study), as a Mortality Rate Ratio (MRR) 1.26-1.45 (one study) and as a percentage increase in mortality 12-40% (two studies). For the impact in relation to distance from traffic HR = 1.09-1.15 (one study), and is reported as a RR 1.70 (one study). In contrast Medina-Ramon *et al*. (2008) reported a decrease in health effect with decreasing distance to bus routes (HR 0.88).

Given the low number of reports for each type of pollutant, the greatest evidence for a cardiovascular disease effect is demonstrated in studies monitoring NOx/NO_2 levels. There was however, insufficient consistency between the exposures and risk measures to undertake a meta-analysis and produce a Forest Plot.

Respiratory or lung disease

Sixteen studies (ten cohort and six reviews) (Table 5) report on traffic-related air pollution and the impact of this on respiratory or lung disease. The cohort studies report effects on respiratory health from exposure both to PM and NOx. The Odds Ratio (OR) for exposure to PM_{10} or $PM_{2.5}$ lies between 1.04-3.1 (three studies) and the HR is reported as1.39 (one study). For NOx or NO_2 exposure the OR is 1.40 (one study) and the HR is reported as1.08-1.55 (three studies). The OR for soot exposure (one study) and distance to roads (two studies) show an increase in respiratory disease from greater exposure. The reviews report evidence of an increased risk of reduced lung growth (World Health Organisation, 2003, 2004) and asthma initiation in childhood. The Health Effects Institute (2009) reports an increased risk for the onset of symptoms with traffic pollution exposure. PM increases morbidity and mortality risk where there is pre-existing lung disease (World Health Organisation, 2003). NO_2 exposure decreases lung function (World Health Organisation, 2003) and O_3 exposure in childhood has a negative effect on lung function and may cause lung inflammation in adults (World Health Organisation, 2003). The health effects for PM on respiratory disease are seen at levels below guideline levels (World Health Organisation, 2013). The Forest Plot for HR and NOx/NO_2 exposure can be seen in Figure 8. There is insufficient data to produce a Forest Plot for other hazards.

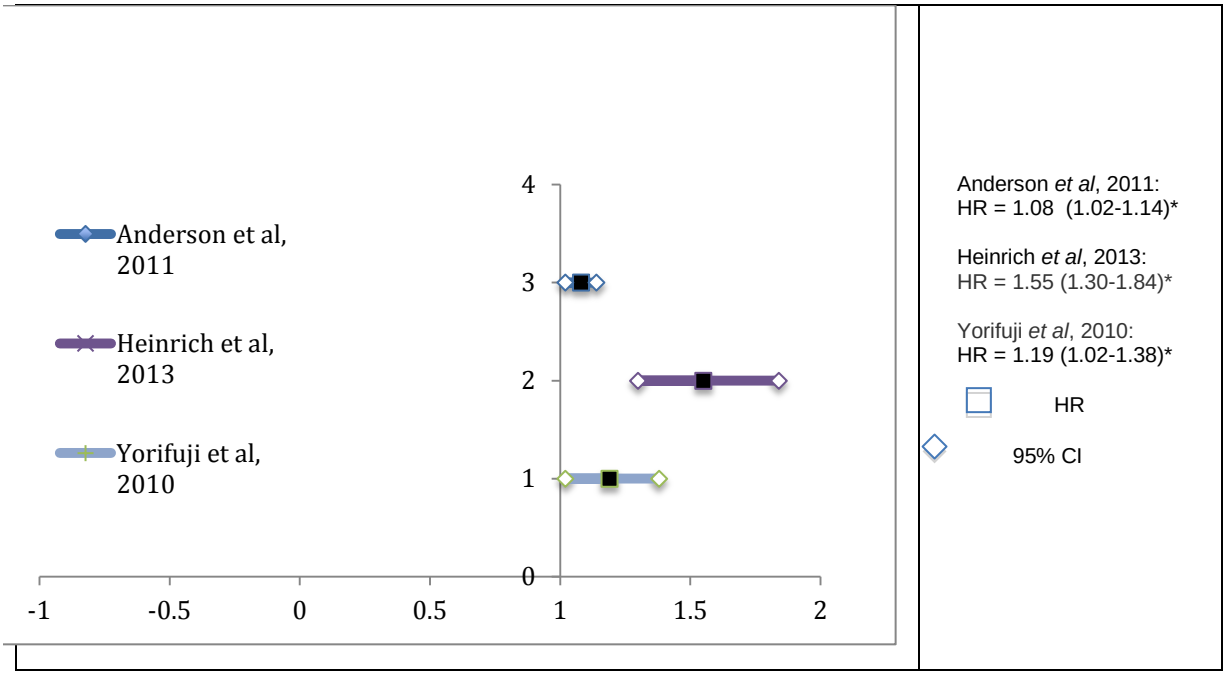


Figure 8: Forest Plot showing meta-analysis for HR for respiratory/lung disease from NOx/NO_2 exposure.

Lung Cancer

Three studi es (two cohorts and one review) report on the link between pollution from traffic and lung cancer risk (Table 6). The Health Effects Institute (2009) reports that there is a lack of evidence to prove exposure to air pollution leads to lung cancer. One cohort study shows an increased risk of lung cancer linked to PM_{10} exposure (Heinrich, 2013). Yorifuji (2010) reports an increased lung cancer risk for NO_2 exposure but this does not reach significance level.

Pregnancy

Eleven studies (ten cohort and one review) (Table 7) report on traffic-related air pollution and the effect on pregnancy outcomes. Exposure to PM_{10} or $PM_{2.5}$ during pregnancy increases the risk of pre-eclampsia (one study). Exposure to NOx/NO_2 also increases the risk of pre-eclampsia (two studies) and gestational size (two studies). Many of the studies (seven studies) base exposure estimates on the residential distance from roads (50 metres to one mile) and report lower birth weight (four studies) or shorter gestational time (one study). However one study reports no link between residential distance from roads and an adverse impact on pregnancy outcome. This finding is supported in another study where neither distance to road, nor exposure to

traffic pollutants, with the exception of O_3, results in adverse birth outcomes. One study reports on a possible link between traffic pollution and mitochondrial DNA (mtDNA) as a possible pathway between pollutants and biological changes impacting on foetal development. In this study changes can be observed both for exposure to PM_{10} and residential distance closer to roads. The studies on pregnancy outcome report on differing exposures and a range of health impacts with no consistent findings across the studies so it is not possible to produce Forest Plots.

Neonates

Three studies (one review and two cohorts) (Table 8) report on the impact of traffic-related pollution and neonatal health. Each study reports on different outcomes. One study demonstrates that exposure to $PM_{2.5}$ and to NO_2 increases the risk of cough and one study reports that exposure to PM_{10} in the neonatal period results in an increased risk of asthma at 12 years of age. The World Health Organisation (2004) reports an increased risk of infant mortality as a result of elevated PM exposure. None of the studies report a consistent outcome against a single exposure.

Other health effects

Finally, the literature search for this thesis (undertaken in 2013) identified some less commonly published effects of air pollution and health (one cohort study and one review) (Table 9). One study investigated the impact of air pollution on cerebrovascular disease but found no association. A report by the World Health Organisation (2013) indicated that there may be a link between $PM_{2.5}$ exposure and neurodevelopmental disorders and also diabetes, but no further evidence was found in the literature at the time of writing, to support this conclusion.

Table 3: Risk of mortality from exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**PM_{10}**	**$PM_{2.5}$**	**NOx/NO_2**
Cesonari *et al*, 2013	↑ mortality.	-	Hazards Ratio (HR)=1.04 (1.03-1.05)*	HR = 1.03 (1.02-1.03)
World Health Organisation, 2003	↑mortality	-	-	-
Gehring *et al*., 2006	NO_2 exposure ↑ mortality.	-	-	RR = 1.17 (1.02-1.3)
Health Effects Institute, 2009	Impact on mortality not conclusive	**-**	**-**	**-**
Heinrich *et al*., 2013	↑ all-cause mortality	HR = 1.15 (1.04-1.27)	-	HR = 1.18 (1.07-1.30)
Jerret *et al*., 2009	↑ all-cause mortality	-	-	17% increase mortality
Raashou Nielson *et al*., 2012	NO_2 exposure ↑ all-cause mortality	-	-	Mortality rate ratio (MRR) = 1.13; (1.04-1.23) MRR fruit =1.25 (1.11-1.42)

World Health Organisation, 2005	↑ mortality per 10µg/m^3 PM_{10}.	HR =1.006 (1.004-1.008)	-	-
World Health Organisation, 2008	21,000 deaths per year from elevated ozone	-	-	-
World Health Organisation, 2013	*9 month ↓ life expectancy*	-	-	-
Yorifuji *et al*., 2010	↑ all-cause mortality	-	-	HR = 1.02 (0.96-1.08)

Note: cells left blank where no data reported
*95% Confidence Intervals

Table 4: Risk of cardiovascular disease based on distance of residence from road and exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**$PM_{10/2.5}$**	**NOx/NO_2**	**Distance**
Ayres *et al*., 2006	↑ cardiovascular deaths	-	-	-
Cesonari *et al*., 2013	↑ ischemic heart disease	HR = 1.10 (1.06 - 1.13)	-	-
Chen *et al*., 2013	↑ mortality cardiovascular disease (CVD) and ischaemic heart disease (IHD)	-	CVD=12% increase (7-17%) IHD = 15% increase (8-21%)	-
Gehring *et al*., 2006	↑ Cardiopulmonary mortality	Relative Risk (RR) = 1.34 (1.06-1.71)	RR = 1.57 (1.23-2.00)	RR = 1.70 (1.02-2.81)
Health Effects Institute, 2009	Impact on CVD not conclusive	-	-	-
Heinrich *et al*., 2013	↑ cardiopulmonary mortality.	HR = 1.39, (1.17 - 1.64)	HR = 1.55 (1.30 - 1.84)	-
Hoffman *et al*., 2009	↑ hs-CRP (C-reactive protein) and fibrinogen	CRP = 23.9% increase	-	-

	levels (men but not women)	(4.1-47.4%) fibrinogen=3.9% increase (0.3-7.7%)		
Jerret *et al*, 2009	↑ circulatory mortality	-	40% increase	-
Medina-Ramon *et al*, 2008	↑ CVD mortality			HR 100m =1.15 (1.05–1.25) HR 300m =1.09 (1.01–1.19) HR bus = 0.88 (0.81–0.96)
Raashou-Nielsen *et al*., 2012	↑ cardiovascular mortality		Mortality Rate Ratio (MRR) = 1.26 (1.06-1.51) MRR fruit=1.45(1.13-1.87)	
World Health Organisation, 2003	↑ mortality and morbidity (pre-existing CVD).			
World Health Organisation, 2013	↑ cardiovascular disease			
Yorifuji *et al*., 2010	↑ cardiopulmonary and IHD mortality		HR CVD=1.16(1.06 - 1.26) HR IHD =1.27(1.02 - 1.58)	

Table 5: Risk of respiratory disease from exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**$PM_{10/2.5}$**	**NOx/NO_2**	**Other**
Anderson *et al*, 2011	↑ COPD incidence	-	HR = 1.08 (1.02-1.14)	-
Brauer *et al*., 2007	↑ wheeze and asthma	-	-	ORsoot = 1.2 (1.0-1.4) $OR_{pollutants\ combined}$ =1.2 (1.0-1.3)
Carlsten *et al*., 2011	↑ asthma	OR = 3.1 (1.3-7.4)	-	-
Chang *et al*., 2009	↑ repeated hospital encounters	-	-	HR_{300m} =1.21 (0.99-1.49) HR_{750m} =1.18 (0.99-1.41)
Cowie *et al*., 2012	↑ airway inflammation	-	-	-
Gehring *et al*., 2002	↑ cough without infection	OR = 1.34 (1.11-1.61)	OR = 1.40 (1.12-1.75)	-
Gruzieva *et al*., 2013	↑ asthma and wheezing	OR = 2.0 (1.1-3.5)	-	-
Health Effects	↑ onset of childhood asthma	-	-	-

Institute, 2009				
Heinrich *et al*., 2013	↑ cardiopulmonary mortality	HR = 1.39 (1.17-1.64)	HR = 1.55 (1.30-1.84)	-
Miyake *et al*, 2010	↑ asthma and atopic eczema	-	-	$OR_{<50m}$ = 4.01 (1.44-11.24)
World Health Organisation, 2003	↑ mortality and morbidity where pre-existing lung disease. ↑ COPD hospital admissions ↓lung function growth in children	-	-	-
World Health Organisation, 2004	↓development and lung function in children	-	-	-
World Health Organisation,	↑hospitalisations	-	-	-

2008				
World Health Organisation, 2013	↓respiratory health	-	-	-
Yorifuji *et al*., 2010	↑Pulmonary disease	-	HR = 1.19 (1.02-1.38)	-

Table 6: Risk of lung cancer from exposure to particulate and oxides of nitrogen, in traffic-related air pollution**.**

Reference	**Impact**	**$PM_{10/2.5}$**	**NOx/NO_2**
Health Effects Institute, 2009	↑ lung cancer mortality	-	-
Heinrich *et al*, 2013	↑ lung cancer mortality	HR = 1.84 (1.23-2.74)	-
Yorifuji *et al*, 2010	↑lung cancer mortality	-	HR = 1.3 (0.85-1.93)

Table 7: Risk of poorer pregnancy outcome from exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**$PM_{10/2.5}$**	**NOx/NO_2**	**Other**
Barnett *et al*., 2011	↓gestation time	-	-	↓gestation time by 1.1%. Range 0.5-1.7%
Brauer *et al*., 2008	↑SGA (small for gestational age) ↑LBW (low birth weight).	-	-	26% increase in SGA (1.07-1.49) 11% increase in LBW (1.01-1.23)
Estarlich *et al*., 2011	↓birth length	-	Decrease in birth length of -0.9mm (-1.8 to -0.1mm)	-
Iniguez *et al*., 2012	↓Biparietal Diameter (BPD)	-	9% decrease in BPD	-
Janssen *et al*., 2009	↓placental mitrochondrial DNA (mtDNA) content.	16% decrease in mtDNA (6-25%)	-	4% increase in mtDNA (CI: 4-8%) with increase distance from roads
Laurent *et al*., 2013	↑LBW associated with ambient O_3 ↓LBW associated with ambient	-	-	OR O_3 = 1.13 (1.02-1.25)

	NO_2 concentrations			
Pereira *et al*., 2011	↓of optimal birth weight	-	-	49% decrease birth weight (standard deviation 0.23%)
Periera *et al*., 2013	↑pre-eclampsia	-	30% increase in pre-eclampsia risk (7-58%)	-
van den Hooven *et al*., 2009	→Residential distance to traffic not associated with birth and pregnancy outcomes	-	-	-
World Health Organisation, 2013	↑increase in preterm birth	-	-	-
Wilheim *et al*., 2005	↑LBW	-	-	OR_{co} = 1.18 (1.09-1.29)
Wilheim *et al*., 2012	↑LBW			
Wu *et al*., 2009	↑pre-eclampsia	OR = 1.42 (1.26-1.59)	OR = 1.33 (1.18-1.49)	-

Table 8: Risk of neonatal disease from exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**$PM_{10/2.5}$**	**NOx/NO_2**
Gehring *et al*., 2002	↑cough without infection	OR =1.34 (1.11-1.61)	OR = 1.40 (1.12-1.75)
Gruzieva *et al*., 2013	↑asthma and wheezing	OR = 2.0 (1.1-3.5)	-
World Health organsiation, 2004	↑infant mortality	-	-

Table 9: Risk of other health outcomes from exposure to particulate and oxides of nitrogen, in traffic-related air pollution.

Reference	**Impact**	**NOx/NO_2**
Chen *et al*., 2013	→cerebrovascular mortality and exposure to NO_2	RR = 0.99 (0.91-1.08)
World Health Organisation, 2013	↑neurodevelopment complications and diabetes.	-

Discussion

Literature review approach

A comprehensive systematic review requires detailed searches across databases in different genres (e.g. medical, sociology, policy), a review of literature in reference lists and personal communications with authors and experts. In this thesis the search was limited to published reviews where this robust approach would have been undertaken. However, a search of cohort studies was also undertaken to assist in making an estimate of the potential impact air pollution might have on the Scottish population.

The method adopted for this review followed the process recommended by Hemingway and Brereton (2009) and is known as a Rapid Evidence Assessment (REA). This is useful where a full systematic review of the literature is not feasible but there is a need to have a summary of the evidence to support decision-making particularly in the area of policy development. The approach taken within the REA complies with many of the criteria for a systematic review, i.e. there is a clearly defined question that addresses People/population, Intervention, Comparison and Outcome (PICO); inclusion and exclusion criteria are defined; the quality of studies are assessed; and data are extracted and synthesized in a systematic manner.

The REA commenced with a search of the traditional medical databases for publications. However it was also recognized that the research question required a review of evidence beyond the bounds of clinical studies. For example, an Air Quality Management Area (AQMA) is not a clinical concept but a geographical area subject to an environmental hazard.

As anticipated, the medical database review did not identify some of the key guidance or policy documents, so these were sought via a Google search using the same search criteria. The search obtained both quantitative and qualitative evidence. Each was relevant because there was a need to seek not only health specific outcomes, but also information on how this evidence had been, or should be implemented in Scotland.

Type of studies

The most robust studies for assessing the impact of environmental factors on health are ecological studies. These include cross sectional studies (population data collected

at one point in time), time series studies (cross sectional data is collected over a series of time points) and case-crossover studies (the individual is the case and the control studied at different points in time). It is noted that randomized controlled trials are the gold standard in evidence-based medicine (Sackett *et al*., 1996). However, for ethical reasons, such studies cannot be performed on populations because they require a comparison between individuals receiving an intervention and a control group. It is unethical to knowingly expose an individual to a known hazard (intervention) such as air pollution. This means that studies in the field of air pollution are reliant on large populations and the demonstration of a statistically meaningful outcome.

Analytical cross sectional studies are relatively easy to perform using data sets collected for routine health purposes or surveys, and then applied to the population with the environmental concern in question. However the data reflect health at one point in time, i.e. prevalence, and therefore may miss many events outwith the point of assessment. Interpretation is limited in that not all the main confounding factors (environmental hazards that may also have had an impact on the outcome) will have been captured.

Time series studies are based on data collected as snap-shots over a time period. Such studies can strengthen the evidence for a link between an environmental factor and changes in health over time. However, since they are in effect a series of cross sectional studies, they suffer from the same issues in terms of confounding.

Case crossover studies take this process one further step with analysis of data at an individual, level linked to environmental exposure before and after the exposure (Jaakkola, 2003). An example would be taking an individual who has suffered a recent acute cardiac event, and investigating the monitored air pollution immediately before and after the event. In that way the individual forms his or her own control, thereby to some extent, reducing confounding.

The findings would imply an association (or lack of) between air pollution in the days before exposure, and the acute event (consequence). Case crossover studies can be used in studies investigating the consequences of short-term exposure events such as myocardial infarction, but they cannot be used for longer-term consequences such as

lung cancer. This is because in the longer term there may have been significant exposures to a variety of confounders.

Cross-sectional, time series and case-crossover studies do not provide evidence of causality, only of association. They show prevalence of a disease but cannot demonstrate evidence of a link between environmental exposures and the onset of the disease. There could be many causes or factors which increase risk of the condition following exposure to an environmental factor, including susceptibility due to pre-existing condition(s), occupation, deprivation and lifestyle factors, to name but a few. These cannot be identified from routine data sets intended for capture of basic health information.

Case-control studies, with good matching between cases and controls, can address confounding to some extent. However, their use is limited in that there is a significant risk of recall bias in such studies (Song and Chung, 2010).

The best available evidence on the impact of environmental factors on the incidence of disease in a population can be gathered from cohort studies. In cohort studies, risk related factors such as occupation, and conditions with longer-term outcomes, e.g. lung cancer, can be accounted for. There is less scope for bias in cohort studies than in case control studies, because the data collection has been undertaken independently of the known outcome. In such studies the data can be either collected prospectively or retrospectively. One risk is that because of the long duration of cohort studies, the results may be affected by loss to follow up (Song and Chung, 2010). However in the field of air pollution and health, cohort studies provide the strongest evidence of potential causality where this might exist. Since cohort studies can be used to measure the incidence of the disease, the relative risk of developing a disease can be calculated when studying the different exposure factors in two (or more) groups of people. The group who develop the disease will have been exposed to a greater extent, and where a relative risk is greater than one this represents a greater risk of the disease from exposure.

The quality of the literature review

The literature review was based on the REA approach as discussed previously. This systematic approach ensured that, as far as possible, all the key documents were identified. Of note is that the peer reviewed literature might be subject to publication bias in favour of reports showing positive links between air pollution and ill health. This was not found to be the case, with some studies reporting no effect (Health Effects Institute, 2009 – no evidence of an effect on mortality; van den Hooven *et al*., 2009 – no effect on pregnancy in relation to distance from roads). This suggests that publication bias may play only a limited role in the overall findings.

Although the search focused on cohort studies, and literature reviews that included cohort studies, there have been a number of significant European multicenter cross-sectional studies published. These are mentioned because of their relevance to the international review reports (World Health Organisation reports). The cross sectional studies were considered in the international reports in an attempt to provide data on the impact of air pollution across Europe. Until recently, most published studies have been based on populations in the United States so there was a lack of data on health impact on European residents. These European cross sectional studies however, show no conclusive evidence of a link between particulate air pollution and cardiovascular or respiratory disease (Timonen *et al*., 2006; Gotschi *et al*., 2008). The authors admit that there may have been variations in individual and environmental factors that affected the results.

Comment on the evidence for health effects

The search focused on widely known health effects and may have missed some unusual but emerging air pollution related morbidity. To address this the review included broad search terms such as health, to identify less commonly know effects on health. However, the search only identified two papers which proposed novel health effects – neurodevelopmental disorders, diabetes and cerebrovascular disease. In terms of neurodevelopmental disorders, researchers make a link on the basis of biological plausibility, since there is evidence of an association between air pollution and poorer intra-uterine development (Estarlich *et al*., 2011; Barnett *et al*., 2011; Brauer *et al*., 2008).

All-cause mortality

The systematic reviews were based on a range of studies including cross sectional and cohort. Despite the differences in approach both study types report consistent findings in terms of an association between mortality and air pollution. Some reviews are more conservative in their conclusions stating findings are "*suggestive but not conclusive*" (Health Effects Institute, 2009, p15) and others providing a clear statement of effect – " *Pollution from PM decreases life expectancy by 9 months across Europe*" (World Health Organisation, 2013, p1).

The guidance from the World Health Organisation report (2005, p159) for a "*0.6% change in mortality with every 10µg/m^3 PM_{10} (range 0.4-1.6%)"* was revised in the most recent review. It is now suggested that health effects are seen even below the guideline level and the 2005 guidance should be used with caution (World Health Organisation, 2013, p6). The cohort studies identified in the review show that NO_2 and PM had a negative effect on mortality in cohorts followed up for periods ranging from 5-18 years (Gehring *et al*, 2006; Raaschou-Nielsen *et al*., 2012 Heinrich *et al*., 2013). The extent of this effect varied but given that the studies included lifestyle questionnaires to adjust for confounders e.g. social class, smoking and occupation, the results add to existing evidence.

The results from North American and European studies (World Health Organisation, 2004) show a greater impact from air pollution on health in the North American studies. However this may be due to the more extensive research in North America than in Europe (page 48). Despite this there is no significant difference in overall results (Figure 9).

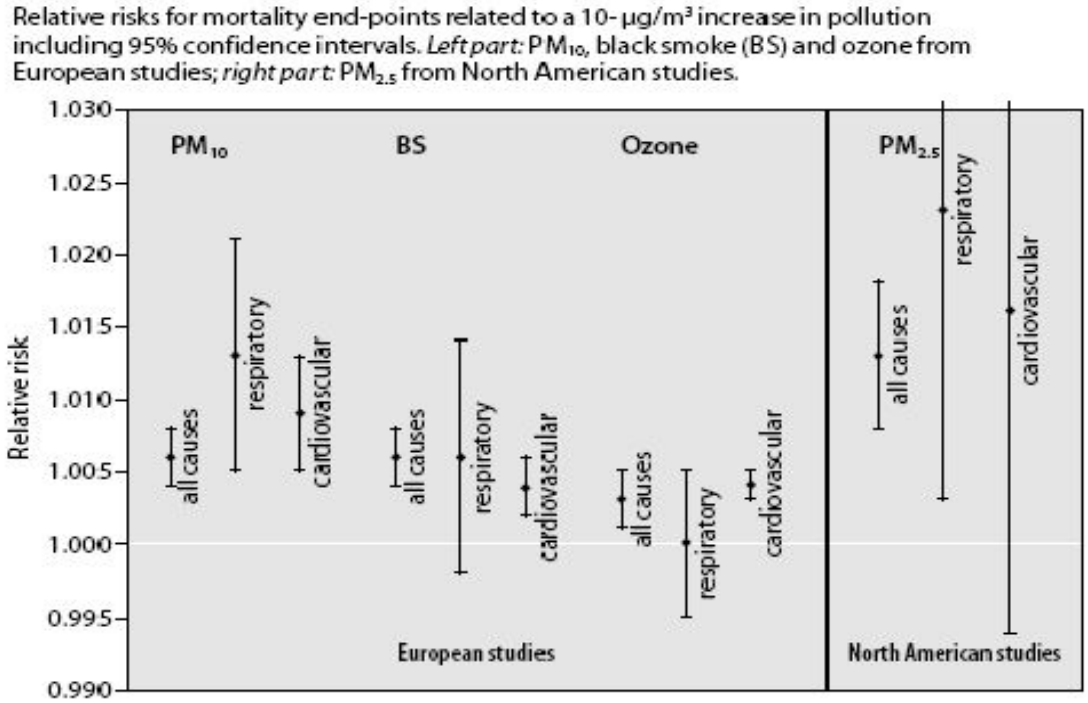


Figure 9: Summary estimates for relative risks for mortality and different air pollutants (World Health Organisation, 2004, p16)

Cardiovascular Disease

The Committee on the Medical Effects of Air Pollutants (COMEAP) undertook a review of the evidence and reported on a link between air pollution and cardiovascular disease. The Committee concluded that there is not only an association between traffic pollution and cardiovascular mortality and morbidity, but that there is also a causal link (Ayres, 2011). One study on the mechanism for an effect of PM on the cardiovascular system, demonstrates a significant increase in vascular inflammatory markers in men after long-term exposure to PM (Hoffmann et al., 2009).

The cohort studies include some adjustments for confounding factors such as smoking and body weight or diet, and the findings are consistent in that the negative effect of pollution on cardiovascular morbidity is seen even when these factors are taken into account (Gehring *et al*., 2006; Yorifuji *et al*. 2010; Raaschou-Nielsen *et al*., 2012; Cesonari *et al*., 2013).

Some studies show that the impact of air pollution is greater where there is pre-existing diabetes (Anderson *et al*., 2011; Pereira *et al*., 2013). However, Chen *et al*. (2013) report that they found no evidence of a link between air pollution and cerebrovascular disease. This is of note given that cerebrovascular disease and cardiovascular disease are linked in terms of pathological processes. Therefore a more recent study by Chen *et al*. (2017) reporting on evidence of a link between dementia and exposure to traffic, does add to the strength of association between air pollution and vascular effects.

Respiratory or lung disease

There is considerable research in this field focusing on lung disease, on the basis of biological plausibility. Perhaps surprisingly, the evidence identified in this REA is less convincing than that for cardiovascular effects. The findings from the literature review suggest that there is a link between traffic pollution and asthma symptoms (World Health Organisation, 2003; World Health Organisation, 2004; Health Effects Institute, 2010), but there is insufficient evidence to suggest a causal link for asthma onset in children or adults (Health Effects Institute, 2010).

The studies on childhood asthma show a range of findings, with some indicating evidence of symptoms resulting from early exposures (Gehring *et al*, 2002; Miyake *et al*., 2010), and others providing evidence only after longer periods of follow-up, i.e. after 8-12 years (Gruzieva *et al*, 2013). The authors of all these studies admit to limitations in the assessment of exposure. This makes it difficult to assess what, and when, interventions should be applied to reduce exposure. One study includes adjustment for sensitisation to allergens such as food, and despite the adjustment, reports a significant association between traffic exposure and wheeze (Brauer *et al*, 2007).

Lung Cancer

The association between lung cancer and traffic-related air pollution is supported by several studies (Health Effects Institute, 2010; Yorifuji *et al*., 2010; Heinrich *et al*, 2013). A German study based on the follow-up of a cohort of women (Heinrich *et al*, 2013) and a Japanese study (Yorifuji *et al*, 2010), including both men and women, both conclude that there is an increased risk of lung cancer that persists amongst non-smokers. However, the results of the Japanese study report this risk is non-significant.

Pregnancy

The results for studies in pregnancy are very mixed, reporting different effects as a result of exposures at different times in pregnancy (Wilhelm *et al*., 2005; Iniguez *et al*, 2012; Periera *et al*., 2013). Pregnancy cohort studies are comparatively easy to undertake because of the captive nature of the study participants and the ease of access to data on potential confounders. However, the duration of exposure is relatively short and this may give rise to difficulties in producing robust and consistent results. Despite this, the 2013 World Health Organisation review reported possible links between O_3 exposure and pregnancy outcome. The observation is supported by a Californian study (Laurent *et al*., 2013), but the Laurant study also reports no effect from other air pollutants. This is in contrast to other published studies (Wilhelm *et al*., 2005; Estralich *et al*., 2011; Barnett *et al*., 2011; Periera *et al*., 2011; Iniguez. et al, 2012) and the authors question their own analysis, given the unexpected results.

The mechanism by which air pollution may have an effect in pregnancy is tested in one study that measures placental mitochondrial DNA (mDNA) (Janssen *et al*, 2012). Mitochondrial DNA is responsible for regulating metabolic processes and, if altered, may lead to metabolic effects from oxidative stress. Further research is required to assess if this is affected by air pollution or the result of damage by confounding factors.

Neonates

The studies on neonates are reported within the findings from studies on respiratory morbidity (Gehring *et al*., 2002; Gruzieva *et al*., 2013). A specific section on children's health in the 2004 World Health Organisation review expands on the physiological basis for increased effects of air pollution in the early years. The greater effect is based on the vulnerability of the developing lung, as well as the smaller lung capacity, and a greater tidal volume requirement, as a proportion of body weight. This is compounded by the fact that children tend to be prone to a greater exposure, due to more time spent exercising outdoors.

Other effects of air pollution

What has not been widely explored is the possibility of a link between air pollution and mental health and wellbeing. An initial search revealed little research in this area. The

REA included health as an overarching search term and this should have identified other issues including mental health. No mental health issues were identified and this may have been because the search engines used (Ovid, Embase and Ebesco) focus predominantly on physical rather than psychosocial health.

A search extended to include PsychINFO via Ebesco identified one survey of well-being in residents adjacent to busy roads in Japan (Yamazaki *et al*., 2005). This cross sectional study reports higher Health Related Quality of Life Short Questionnaire scores for people living further from busy roads. In contrast, a study by Clark *et al*. (2012) describes no link between air pollution and cognitive function of primary school children adjacent to Heathrow airport. However the authors report that air pollution in the area of the primary school is moderate. Furthermore, the children spend a limited time in the school environment so it is difficult to demonstrate an exposure effect. Islam *et al* (2011) report increased asthma symptoms in children living in areas of traffic pollution where family stress is a contributory factor. The study however, is based on questionnaires to the parents rather than an assessment of stress in the asthmatic children.

The American Thoracic Society (ATS, 1999) recognises the need to consider quality of life in air quality impact assessments. Quality of life is a difficult area to measure because it is influenced by many personal and societal factors (Whitehead, 2001, Figure 5). A holistic understanding of the health effects of traffic-related air pollution on health as suggested by the ATS (1999), requires an assessment of the psychosocial impact of traffic on residents in areas affected by traffic-related air pollution and this will be considered further in Chapter 7.

It could be hypothesized that living in areas of high traffic volume increases stress, and that in turn is manifest as physical responses such as CVD and poorer pregnancy outcome. If an underlying increase in stress is the driver for CVD, this would support efforts to address traffic-related air pollution alongside wider health improvement and traffic reducing measures. These include active travel initiatives and green space development, both of which have been shown to improve mental wellbeing (FPH, 2010).

Inconsistency of findings

In this REA the 30 cohort studies report on investigations involving different populations, with different exposures and outcomes. With the exception of evidence of an association between NOx/NO_2 exposure and all-cause mortality and lung disease, there is limited consistent evidence from the cohort studies to support the hypothesis that traffic-related air pollution harms health in other ways. There was inconsistency in findings for particulates, such that it was not possible to undertake a meta-analysis for the studies. This may be due to the variation in study methods, the air pollutant being measured, observed outcomes and method of analysis between the studies. Therfore, any application of the findings to the Scottish population may be problematic without further understanding of the strength of the evidence and confounding factors.

The inconsistencies may also be due to how the papers were assessed. For the REA, the studies were critiqued against a recognized checklist for study review (SIGN, 2015). This tool requires a subjective assessment of population and exposure factors. For example, each study is assessed on the basis that population selection is appropriate to the exposure being studied. However, the populations in the REA cohort studies differ in terms of size, age and duration of exposure so it is difficult to compare outcomes.

More importantly, the assessment tool requires a judgement based on the information provided in each study method, that all the relevant confounding factors have been taken into account. There are many confounding factors for air pollution and health and the studies each accounted for different confounders. In undertaking the REA each study was scored on the basis that the study included any confounding factor and not necessarily all the relevant factors. Therefore applying the SIGN appraisal tool might not have ensured a sufficiently robust assessment to ensure the studies included in the cohort study review were in fact of adequate and comparable quality. Given the importance of this in assessing the strength of evidence, this is explored further in Chapter 3.

Notwithstanding the issue of confounders, the inconsistency in findings might be arising from factors that cannot be accurately measured at a population level such as:

- Air pollution data collection or modeling is not a reliable reflection of actual air pollution. The data collection is dependent on fixed site monitors that only record pollution within a limited radius and models may be affected by changing traffic densities, climatic conditions or local activity such as building works. This leads to errors in estimating source pollution.
- The exposure estimates do not reflect actual exposure. Individuals do not spend all their time at one point but are exposed to different levels of pollutant as they move around. This leads to errors arising from data based on pathway exposure estimates.
- The individuals in the study are subject to a variety of confounding factors making it difficult to attribute health impact directly to traffic pollution alone, and difficult to asses their vulnerability and hence health outcome. This leads to errors as a result of receptor exposure and outcome estimates.
- The effect size is relatively small so health impacts will only be seen for very large populations and/or high levels of exposure are required to demonstrate an impact on health.

Conclusion

There is evidence of an association between exposure to NOx/NO_2, and all-cause mortality and lung disease. There is a lack of consistent evidence for an effect from PM exposure. The evidence from the cohort studies and literature review does not consistently support the hypothesis that traffic-related air pollution harms other aspects of health. This may be due to the variation in study methods, the air pollutant being measured, observed outcomes and method of analysis between the studies. Chapter 3 describes further analysis of the studies to investigate why the findings were inconsistent and to consider the implications for assessing the health impact of traffic-related air pollution on Scottish residents.

Chapter 3

An assessment of the strength of evidence that traffic-related air pollution causes ill health.

Introduction

With the exception of all-cause mortality and lung disease associated with NOx/NO_2 exposure the Rapid Evidence Assessment (REA), as reported in Chapter 2, did not provide consistent evidence of a link between traffic-related air pollution and ill health. This is at odds with international opinion and worth exploring further.

The variation in study findings may be due to heterogeneity in the study parameters as described in Chapter 2. Alternatively, the explanation may depend on the fact that the studies in this analysis demonstrate an association rather than causality between traffic-related air pollution and health. This failure to demonstrate causality may in part or all, be due to confounding factors inadequately addressed in the study method – weakening the argument that air pollution alone harms health. For example, could noise rather than air pollution, account for cardiovascular disease by way of sleep deprivation and stress?

The evidence to support the case for reducing traffic-related air pollution would be greatly enhanced if a causal link were to be demonstrated – strengthening the argument that exposure to traffic-related air pollution harms health. To explore this further, the studies in the REA were subjected to a more detailed analysis to determine if there was evidence of causality, rather than simply association, or if there were confounding factors other than air pollution that might be giving rise to health effects.

The distinction between association and causality was first described by Sir Austin Bradford Hill in 1964 in a paper discussing the relationship between exposures and ill health in the workplace (Hill, 1964). Hill set out criteria to guide an assessment of the strength of association that, if sufficiently robust, could lead an interpretation of causality. These criteria are:

- *Strength of evidence* – is it obvious that the hazard caused harm?
- *Consistency* – harm is observed repeatedly.
- *Specificity* – limited to certain exposures with particular outcomes.
- *Temporality* – logical sequence of events.
- *Biological gradient* – is there a clear dose-response curve?
- *Plausible* – biologically possible given the knowledge of the day, taking into account that not everything is known.
- *Coherent* – fits with what is known about the disease.
- *Experiment* – is there evidence from experimental data to draw on?
- *Analogy* – are there similar circumstances for which there is supporting evidence?

The objective of the review of the cohort studies for confounding, as described in this Chapter, is to:

- list the factors from the international review reports (consensus opinion) which demonstrate a link between air pollution and health (Step 1);
- assess how robustly the factors are measured in each cohort study and identify factors which are not included in some or all of the studies (Step 2);
- review the cohort studies against the Hill criteria and make an assessment of the strength of association that might suggest a causal effect (Step 3).

Method

The reviews identified in Chapter 2 were scrutinized to identify and list all the factors that the report authors considered important in assessing the link between traffic-related air pollution exposure and ill health (Step 1) (Appendix 5). These factors were grouped according to similarity and recorded across the X-axis of an excel spreadsheet. The factors were listed on the axis in line with the source-pathway-receptor model, starting with the general and demographic findings.

Each cohort study (listed on the Y axis) was then assessed against these criteria (Step 2) and reported in the relevant section (Appendix 6). The studies were scored as follows:

- Good = the study demonstrates good evidence of having addressed the specific confounder. For example, the study accounts for changes in weather affecting traffic-related air pollution concentrations.
- Inadequate = the study addresses some but not all of the specific aspects of a confounder. For example, the study refers to data collection but this was undertaken using self-administered questionnaires and these might have been subject to bias.
- Absent = the study does not refer at all to the confounder. For example, no account is taken of air pollution from non-traffic-related sources.
- na = not applicable. The factor was not relevant in the study.

The assessments were colour coded for ease of viewing. The colour coding enabled a rapid assessment of which confounders have been included in all, a few or none of the studies. Each cohort study could then be screened to assess how well the study adjusted for the confounder.

A second excel spreadsheet was then set up with the Hill (1965) criteria listed along the X axis and the cohort studies on the Y axis (Step 3). The findings from Step 2 were then used to assess how well the study addressed the Hill criteria for association and causation (Appendix 7). The results were colour coded using the same coding system.

Results

Step 1 - review of air pollution and health confounders

The REA revealed many factors that might contribute to ill health associated with traffic-related air pollution (Appendix 5). These included:

- *Source* of emissions – age and type of vehicles, other sources of air pollution, climatic conditions, data capture/handling/statistical analysis
- *Pathway* between source and receptor – time spent in polluted area, physical activity, barriers (e.g. time indoors)
- *Human Receptor* – co-morbidities, lifestyle factors such as smoking/obesity, socioeconomic factors.

Step 2 - assessment of the cohort studies for causality

When grouped according to type, there were 46 different factors relevant to traffic-related air pollution exposure assessment and health impact, identified from 30 studies. The results from the assessment of each cohort study against these factors findings are reported below, and can be seen in Appendix 6.

Study features and demographic factors:

Years population studied

Three of the cohort studies report on exposure in populations before 1999 (orange). In 15 other studies (yellow) the exposure data is modelled on measurements taken during or since 1999.

Health related outcome in cohort studies

The reported health outcome varies across the papers but there is a dominant focus on pregnancy outcome in terms of neonatal parameters (ten papers), and all-cause or cause-specific mortality (nine papers) (Table 10). One study is marked yellow (inadequate) because the link between mitochondrial placental activity and air pollution effects is a hypothesised mechanism based on an indirect pathway.

Table 10: Number of papers reporting each health-related outcome

Outcome	Count
Negative birth outcome – small for gestational age, low birth weight, small head circumference, length	10
Cause-specific mortality – CVD, IHD, cerebrovascular disease, respiratory disease, lung cancer, all-cause	9
COPD/respiratory infections	4
Asthma	4
Allergies	2
Pre-eclampsia	2
IHD/CVD	1
Stroke	1
Diabetes	1
Systemic inflammatory markers	1
Mitochondrial function	1

Population size

All the studies include a population size of over 100 with the exception of one (Cowie *et al*., 2012). In this study the authors report to have sufficient study power based on an effect noted in one other similar study of smaller size.

Age

The age of study participants range from neonates to 85 years of age. On this basis the studies cover the impact of air pollution over a whole life span in one form or another. (Note there is no age range identified in the Cowie *et al*., 2012 study.)

Exposure:

Exposure Sources - Exposure to airborne dust, allergens or chemicals in the workplace is known to contribute to ill health. Researchers in eight studies sought this information.

Exposure Duration – Researchers in three studies measure actual duration of exposure. In eight studies information is collected on occupation in order to identify

people who spent more time at home. In other studies this factor is assessed by estimating or recording time spent indoors (eight studies), or how long participants lived at the same residential address (16 studies).

Exposure Concentration – Two studies refer to natural air pollution events that might have influenced pollution levels and seven studies consider other sources of ambient pollution such as industry. The level of air pollutants vary across the studies and where maximum levels are recorded these show a maximum level of 68 $\mu g/m^3$ for NO_2 (UK air quality objective is 40$\mu g/m^3$ for NO_2).

Pathway:
Seasonal or temporal adjustment – Climatic conditions have an impact on air quality through air pollutant reactions in the atmosphere or dust dispersal in calm or windy conditions. Fifteen of the studies take account of seasonal or temperature factors.

Topography – air pollution concentration or dispersal is influenced by topography, e.g. the presence of tall buildings alongside roads that can lead to a canyon effect with air pollution being trapped and re-circulated. Five of the studies do not report on the impact of topography.

Monitoring methods – the position of monitoring stations is crucial to accurate exposure estimates as is validation of monitors and robust sampling techniques. These issues are addressed to some extent in almost all the studies where air monitoring was undertaken. In other studies these measures are not relevant because the distance from roads and traffic volumes were used to estimate exposure.

Data management – the analytical techniques are described in all but two of the studies where this is relevant. However data handling and particle adjustment to describe how pollution for non-traffic sources is accounted for is not covered in most of the studies.

Health factors (Human Receptor):

Source of health data

Thirteen of the studies rely on questionnaires to identify self-reported health symptoms. Nineteen studies use national registers, allowing for capture of very large numbers of people. In seven studies direct clinical examination or laboratory testing is undertaken.

Health Factors

The outcomes from all the studies have been reported in detail in Chapter 2.

Smoking

Smoking is addressed in 23 of 28 of the studies. Exposure to passive tobacco smoke is included in 13 of the studies.

Socioeconomic data

In the studies, socioeconomic status is estimated from information on education level, occupation and/or income data gathered either through questionnaires or using state recorded data modelled on an area basis. The latter is most common (13 studies).

Noise

Only one study considers noise as a confounding factor (Raaschou-Nielsen *et al*., 2012).

Stress

None of the studies include stress as a confounding factor.

Control condition

No studies include a control condition.

Comorbidity adjustment

The studies vary in the adjustments made for confounding factors, with the most common confounder being obesity (Table 11). None of the studies take into account all the main comorbidities as confounders for the outcome studied.

Table 11: Confounding factors considered in the cohort studies

Confounding condition	**Number of studies taking each condition into account**
Obesity	14
HT	13
Asthma	12
CVD	11
Diabetes	11
Respiratory disease	11
Diet	10
Allergies	7
Exercise	6
Hyperlipidemia	4
Viral outbreaks	4

Alternative explanations for symptoms

The authors in 17 studies acknowledge the limitations of their methods and provide possible alternative explanations for the findings, the most frequent of which is exposure to pollutant mixes.

Evidence of health Improvements with pollution reduction

One of the studies notes health improvements when air pollution is reduced. None of the other studies demonstrate that removal from air pollution alters the health outcome in question.

Step 3 - analysis of the studies against the Hill (1964) criteria – association or causality (Appendix 7)

Strength of evidence

In all studies where the authors identify a link between traffic-related air pollution and health, the association ranges between a 1-45% increase in risk. There are no claims of direct causality.

Consistency

Eight of the studies refer to inconsistencies in findings within their own work (e.g. effects on women but not on men experiencing similar exposures), or to similar work that shows differing, or null results.

Specificity

All the authors suggest that the outcome reported in the studies might arise from other causes rather than air pollution alone. There were many forms of exposures (NOx, PM, soot, distance from road) and many outcomes (asthma, pre-eclampsia, low birth weight) reported in the studies.

Temporality

There is no specific date of first exposure reported in the studies and hence it is not possible to estimate lead-time to outcome. Anderson *et al*. (2010) report on the longest duration of study in which participants were followed up from 1971-2006.

Biological gradient

All the studies consider biological gradient in that exposure is measured or modelled on distance from residence. Where an outcome is noted (i.e. a detrimental effect of traffic-related air pollution and health), a distance gradient was demonstrated.

Plausibility

All the studies link air pollution and health.

Coherence

There is a coherent argument for the negative effect of traffic-related pollution not only from the population studies, but also from the laboratory-based studies such as that of Janssen *et al*. (2002).

Experiment

In the Heinrich *et al*. (2013) study the impact on the health of participants was noted to have decreased in a follow-up study and this was attributed to a decrease in PM_{10} concentration in the area.

Analogy

The closest analogy to population exposure to air pollution and ill health lies in the studies undertaken on direct and passive smoking.

Discussion

This is the first time a more detailed analysis has been undertaken to determine association and causality in traffic-related air pollution and health using the Hill (1965) criteria. Therefore there are no models against which to compare the findings from this review.

Having said that, since the REA was undertaken (2013) the results from the ESCAPE collaboration (European Study of Cohorts for Air Pollution Effects) (ESCAPE, 2014) have been published. This was a collaborative review of cohort studies. The programme involved the development and application of a methodology for standardizing baseline data and reporting on a statistical meta-analysis of European cohort studies. To do this they used the information provided by the study authors but do not however, make adjustments for confounding factors if they were unaccounted for the in the original study.

The conclusion from the ESCAPE collaboration study for non- malignant respiratory mortality is consistent with the REA findings. Both reviews find no association between particulate air pollution and respiratory mortality. However unlike the REA, the ESCAPE review reports no association for respiratory mortality and NOx/NO_2 (Dimakopoulou *et al*, 2014). The study authors suggest that their findings may have been affected by a lack of information on total personal exposure, since the exposure data are based on place of residence and do not take account of exposures in other settings.

Other studies in this programme that report no association between air pollution and health include a report of no association between air pollution and chronic bronchitic symptoms (Cai *et al*., 2014) and no association between cardiovascular mortality and air pollution exposure (Wang *et al*., 2014).

Some studies in the ESCAPE collaboration do provide evidence of an association between poorer health and various aspects of air pollution. These studies report on evidence of: a weak association between PM_{10} and pneumonia in early life (Fuertes *et al*. 2014); no association with long term lung function but short term effects in people who are obese (Schikowski *et al*., 2014); an association between particulate air pollution and cardiovascular events (Cesonari *et al*., 2014); an association between mortality from natural causes and exposure to air pollution (Beelan, *et al*., 2014); an association between particulate air pollution and lung cancer but no association for NOx or traffic intensity exposure and lung cancer (Raaschou-Nielsen *et al*., 2014)

Therefore, despite attempts being made to standardize study data there continues to be a lack of consistent evidence for an association between air pollution and health, and insufficient evidence to demonstrate causality. The authors in the ESCAPE reviews suggest the weakness in their findings may be due to confounding factors. Across the studies there may be one or more significant confounding factors that continue to remain unaccounted for.

Step 2 - *Demographic factors*

Years population studied

Air pollution has changed over the years with legislation requiring more stringent controls, particularly on industrial processes. Although the cut off point for papers in the REA was 1999, three studies undertaken on exposure in populations before 1999 were included in the review. In theory there is little to be gained from reviewing studies based on air pollution before 1999 because more stringent regulations have led to improvements in air quality. However these three studies were included in the REA and in the review because in some of the studies the health effects have been studied in years since 1999, and ongoing exposure may be a contributory factor.

In the REA, no studies matching the search criteria and reporting on the health of Scottish residents were found. However, two studies on air pollution and health in Scotland have been undertaken. Although these studies did not fit the REA review criteria one of the studies (Yap *et al*., 2012) was a cohort study and although it covered population exposures between 1970-79, it was included in Step 2 to identify

features that might inform health impact in Scotland. The second Scottish study (Willocks *et al*., 2012) was a cross-sectional study and therefore was not included in the Step 2 review. This study, which was based on an analysis of routine health data, did not show an effect for air pollution on cardiovascular disease in populations in Glasgow and Edinburgh. The study by Yap *et al*. (2012) studied populations in the Renfrew/Paisley area and did show that black smoke exposure did have an impact on mortality. However despite being published in 2012 the exposure period was in fact 1970-1976 and outcomes were based on modelled black smoke emissions between 1970 and 1979. Neither study provided evidence of an association between ill health and traffic-related air pollution for Scottish residents at current air quality levels.

Outcome

The Step 2 review demonstrated a strong focus on pregnancy outcomes and neonatal parameters. One of the cohort reviews in the ESCAPE collaboration reported an association between low birth weight and exposure to air pollution in pregnancy (Pederson *et al*., 2013). However, recruiting a cohort of pregnant women is relatively achievable given this group have a definable condition requiring regular health care contact over a specific period of time. Pregnancy progress and outcome is closely monitored so the data is fairly readily available. The disadvantage is that the follow up duration is relatively short, so attributing birth outcome to traffic-related air pollution exposure alone is problematic.

On the same principle it is theoretically feasible to measure outcome based on mortality since the data is readily available in death registers. However over a lifetime of exposures, it is difficult to attribute death, or the contribution to death from traffic-related air pollution exposure. Furthermore, cause of death is reported differently in different countries (Dimakopoulou *et al*, 2014) so health effects related to air pollution are not necessarily recorded as a contributory factor in cause of death.

The Step 2 review identified that a range of outcomes from the cohort review, suggesting that air pollution is associated with many health effects (Appendix 5). The ESCAPE collaboration process involved the collation of studies with similar

outcomes but the exposure factor differed – air pollution in general, particulate, NOx, and traffic density exposure. The findings where positive, demonstrate an association rather than causation.

Population size

In most of the cohort studies multivariate analysis was undertaken to account for a variety of study factors, e.g. exposure measures and confounding factors. To achieve a level of significance the study population should be of a minimum size. The minimum population size required to demonstrate an effect varies according to the size of the effect, e.g. if a small exposure produces a large effect then a smaller population is needed to demonstrate significance. In the case of air pollution the effect size is not necessarily immediately obvious and is complicated by many confounding factors, so larger populations are required in such studies. For example, if the effect being measured is the onset of wheeze (the measurable effect) following exposure to traffic pollution (the measurable intervention), this can be complicated by individual factors such as simultaneous exposure to other pollutants such as pollen, and different sensitivities of the individual to each.

The optimal study size is usually computed with the use of software packages. In the Step 2 review all the studies had a population size of over 100, with the exception of one (Cowie *et al*. 2012). In the ESCAPE programme the meta analysis of cohorts included populations over 300 000 (Dimakopoulou *et al*, 2014). Despite its size, the Dimakopoulou study did not find an association between air pollution and respiratory mortality.

Age

The study results for older age groups are influenced by life time exposure (early life, childhood, occupation) and underlying conditions, so adjustment for appropriate confounding factors is important. However, it is not possible to capture every lifestyle and exposure factor during a lifetime, and to consider this against changing air quality over time. Lifetime exposure is an area currently at the early stage of being explored by researchers (Beyea *et al*., 2013). Early work is demonstrating that the modeling processes are complex but if such data capture proves possible, it may shed light on precipitating factors for ill health effects of air pollution.

Source

Source of air pollution

The Step 2 review demonstrates that air pollution arises from many sources and can manifest in a variety of ways in terms of health effects (Appendix 6). External exposures from other sources such as industry, natural pollution events (e.g. dust storms, fires, volcanic activity) were considered in only some of the studies (eight) in the Step 2 review. It is difficult therefore, to attribute the specific health outcomes reported in the studies, to traffic pollution alone.

Whilst historically the smogs of the past, arising from industrial and domestic pollution, could demonstrate strength of effect through a dramatic increase in morbidity and mortality during and immediately after an event, the levels of air pollution today in most UK cities do not generally reach such obviously harmful levels for a persistent period. That is not to say that pollution episodes are not causing harm, but rather that harm is difficult to prove. In addition, pollution from traffic is only a portion of all pollution so calculating the specific additional negative impact traffic pollution has on health is problematic (World Health Organisation, 2003).

In addition, air quality is influenced by temperature, wind direction, topography, concentration, chemical composition and light, so accurate measurement of exposure requires complex modelling that takes these factors into account. To have an effect, the individual must not only have been directly exposed, but their vulnerability, duration and concentration of exposure, and the synergistic effects of other pollutants, are amongst some of the issues that need to be considered to assess impact (World Health Organisation, 2000).

Some studies in the Step 2 review adjusted for industrial pollutants using national pollution inventories. However, where these data are available they are monitored at a limited number of sites and these sites are not necessarily representative of individual exposure. In addition, the estimation of local pollutant concentrations are based on measurements from distant sites and do not necessarily account for topographical or seasonal variables.

The ESCAPE collaboration studies considered pollution modeling to assess exposure but little work was done on assessing the traffic-related component alone. If the traffic-related component contributes to only a proportion of air pollution, then efforts to reduce pollution through traffic management interventions will have little effect on exposure. This is addressed in more detail in Chapter 4.

Exposure

Exposure to airborne dust, allergens or chemicals in the workplace and indoors is known to contribute to ill health but few of the researchers identified in the Step 2 review sought this information (eight studies). This is particularly relevant to life time exposure estimates (World Health Organisation, 2000). Studies using distance from road to estimate personal exposure also require adjustment for changes to industrial emissions and traffic volume over time, particularly in cohorts of long duration (Gehring *et al*, 2006). This is important where traffic-related pollution has decreased over time as has been described in Figure 3. Only three studies on the Step 2 review considered these adjustments in study design.

Duration

People spend time is different locations such as home, work, recreational activities so it is difficult to monitor exact exposure duration for any individual. Estimates of exposure based on time spent indoors, often based on a residential address, are reliant on assumptions that outdoor air pollutants dominate air pollution exposure. A personal exposure study using portable monitors showed that the greatest exposure to particulate air pollution ($PM_{2.5}$) occurs within the home or private residential building (Steinle *et al*., 2015). It has been reported that the most adults spend 85-90% of their time indoors, 7-9% in traffic and 2-3% outdoors. This rises to 100% for the most vulnerable groups such as babies (World Health Organisation, 2013). Particulates and NOx exposure indoors contributes to up to 50% total daily exposure (World Health Organisation, 2013).

Despite the significance of indoor and occupational exposure only one study in the Step 2 review considered this aspect in their study design (Hoffman et al., 2009).

Concentration

The levels of NO_2 reported in the Step 2 studies, were comparable to the high levels of NO_2 recorded in Scotland's most polluted street, Hope Street Glasgow. Here, the annual mean NO_2 has been recorded consistently at 65 $\mu g/m^3$. It might therefore be expected that the health effects from air pollution in European cities would be mirrored in the population of Glasgow. This is addressed further in Chapter 4.

Pathway

Seasonality, topography, monitoring and data analysis

As discussed previously, studies based on outdoor air pollution monitoring do not reflect actual personal exposure so complex modeling systems have been developed to account for exposure variables. These have been improved over years to include not only pollution estimates based on existing central or local monitoring stations, but also adjustments based on topography, season, time of day, traffic flow, distance of residence from road. Such models include land use regression, dispersion modeling, and geocoding.

Although all the cohort studies in the Step 2 review describe the monitoring method, none report how they adjust air pollution estimates for all the issues listed above. This calls into question the air quality data and exposure estimates used in the studies. Having said that, the validity of the data capture cannot be verified in this review because, although supplementary material was provided in some studies, assessment of the monitoring process is complex, and beyond the scope of this thesis.

Health assessment

Source of data

Many of the studies relied on questionnaires to identify self-reported health symptoms. It was acknowledged by authors that this introduced some element of bias in that for example, parents who were asthmatic might be quicker to notice and respond to breathing symptoms in their children, than parents without asthma. Other studies used national registers allowing for capture of very large numbers of people. However health registers are insensitive to specific health related factors such as comorbidities. There were a number of papers where the information was drawn

from existing cohort studies set up to identify a different health issue, therefore not all the relevant confounders could be accounted for.

Outcomes

The outcomes have been discussed previously in Chapter 2 and are therefore not repeated here.

Smoking

It is surprising given the importance of smoking in respiratory, cardiovascular health and pregnancy outcome, that it was considered as a confounding factor in only 23 of 28 of the studies (two of these studies related to children's symptoms where passive smoking was addressed). Exposure to passive tobacco smoke was included in only 13 of the studies. Since cigarette smoke is a significant confounding factor for all of the outcomes, the results from the studies where this has not been accounted for should be viewed with caution.

Socioeconomic data

Deprivation has a significant impact on health but it is also a relevant consideration in terms of exposure risk and vulnerability. It has been shown that people living in more deprived areas are exposed to an increase in air pollution mainly because air pollution is concentrated in urban areas, as are the more deprived populations (AEA Technology, 2006). The pattern in Scotland is slightly different with higher exposures in both the least and most deprived areas. Decile 1 (most deprived) has the highest annual mean level of NO_2 and PM_{10}. The lowest levels are seen in deciles 5 and 6 before the levels rise again in the more affluent areas (deciles 9 and 10). There are higher levels of O_3 and SO_2 in the less deprived areas. However, other studies have shown an inverse correlation between deprivation and the effects of pollution. For example the Rome Longitudinal Study showed that residents who lived in areas with higher NO_2 levels tended to be better educated (Cesaroni *et al*, 2010).

In the Step 2 review, socioeconomic status was assessed from information on education level, occupation and/or income data gathered either through questionnaires, or using state recorded data modelled on an area basis. The use of

state recorded data was most common (13 studies) but least accurate at an individual level. A more robust assessment of socioeconomic status should also include specific measures of deprivation (Grundy *et al*, 2001).

Noise

Only one study considered noise as a confounding factor (Raaschou-Nielsen *et al*., 2012). This study demonstrated a noise effect which was additive to the NO_2 effect once all other confounders adjusted for – in other words noise made some contribution to the health outcome. Physiological changes have been shown in volunteers who are exposed to several hours of heavy traffic (World Health Organisation, 2011). Other studies show a persistent effect on health from traffic after adjustment for noise (Gehring *et al*., 2006). A recent published review showed that noise and air pollution had little confounding effects on cardiovascular disease (Tétreault *et al*., 2013).

Stress

None of the studies included stress as an indicator. It may have been assumed that this is too difficult to measure and indirect measurements such as socioeconomic status, and blood pressure were intended to provide some measure of stress. Since stress is a significant confounder for cardiovascular disease and pregnancy outcome this may be an area for future research.

Control condition

Although cohort studies do not by definition have control groups, the inclusion of a control condition would test the hypothesis that specific health outcomes are linked with exposure to air pollution (Rushton *et al*., 1999). This would reduce the risk of researcher bias where the study looks for known health outcomes linked to air pollution and misses previously unrecognised outcomes. For example, if the study showed a health impact on the control condition such as a gastrointestinal condition following exposure to air pollution, the researcher should be looking for other precipitating factors as well as air pollution exposure. Precipitating factors rather than air pollution, could account for symptoms in the condition being studied e.g. CVD and an effect on the control condition (gastrointestinal disease). For example, a recent study demonstrated a link between passive exposure in the home to bleach

and an increase in childhood respiratory infections (Casas *et al*., 2013). Account was taken of other indoor pollutants but no account was taken of a possible association with outdoor exposures. It might be that childhood symptoms are explained more by indoor exposures rather than exposure to traffic-related pollution. In the Step 2 review none of the studies considered a control condition.

Comorbidity adjustment for confounding

As discussed above, confounding factors have a significant effect on the validity of study results. The cohort studies in the Step 2 review were very varied in the adjustments made for confounding factors (Appendix 6). These included CVD, hypertension, hyperlipideamia, respiratory disease, family history of asthma, allergic conditions, diabetes, obesity, diet, lack of exercise and viral outbreaks which may all have had an impact on health measures. The two studies that came to closest to addressing all the relevant confounders were Gruzieva *et al*., (2013) and Raaschou-Nielson *et al*., (2012). Gruzieva reported a possible association between pollution exposure in the first year of life and asthma up to the age of 12. However, the study population was recruited from children born between 1994-1996 and therefore, as discussed previously, current air pollution levels are lower than at that time so the results cannot be directly applied to current populations. Raaschou-Nielson (2012) reported an association between pollution and cardiovascular disease and all-cause mortality with a larger effect on people consuming less fruit and vegetables. However, although this study followed up participants in 2009, the participants were recruited from 1993 and air quality exposure data went as far back as 1971. It is therefore difficult to apply the findings to current populations given the significant changes in air pollution exposure today.

Alternative explanations

The authors in the Step 2 review cohorts acknowledged the limitations of their studies and provide possible alternative explanations for the findings, the most frequent of which was exposure to pollutant mixes. This is particularly relevant where participants are in the older age groups and will have been exposed to higher levels of pollution in childhood, pregnancy and within occupational and indoor settings before more stringent pollution controls were put in place. The Clean Air Act (UK Government, 1993) introduced Smoke Control Zones and this will have

contributed to a reduction in indoor and outdoor air pollution exposure in people born since this time. It is difficult therefore, to assess if the health impact is a result disease processes started when exposed to higher pollution levels in earlier life, or due to ongoing lower pollution exposure.

Health improvements with air pollution reduction

There was little evidence that attempts were made in the studies to demonstrate an improvement in health over time if air pollution in the study area was reduced. However, one study (Heinrich *et al*., 2013), demonstrated that the cardiovascular risk for PM_{10} exposure was no longer evident in a cohort after air pollution regulations reduced pollution from local industry. Despite this, the cohort continued to show effects related to distance from major roads. This might imply that the traffic-related effect could be from noise, NOx or another confounding factor.

Summary

The Step 2 review demonstrated a lack of consistency across the cohort studies and a failure to account for many confounding factors. Despite this, it may be that there is sufficient evidence from across the studies to suggest that the strength of association between traffic-related air pollution and ill heath demonstrates causality. The Hill criteria were therefore applied in Step 3 below, to produce an overall assessment of the strength of evidence for association and causality.

Step 3 – The Hill criteria

Strength of evidence

The authors of all the studies conclude that there is evidence of an association rather than evidence for causation linking health and air pollution (Appendix 7). This is supported in the REA reviews, most of which conclude that there is an association between air pollution and morbidity. However these reports also advise that air pollution is responsible for the onset of symptoms in vulnerable people, such as people with asthma, the elderly and very young (World Health Organisation, 2013). Overall, the evidence presented supports association rather than a causal link.

Consistency

The authors acknowledge inconsistencies in findings within their own work (e.g. effects on women but not on men experiencing similar exposures), or to similar work showing differing or null results. This is not unexpected since there is much variation between study populations and exposure metrics. This suggests that the evidence for a link between air pollution and health is weakened because of the lack of consistent evidence.

Specificity

In some of the studies the measure and outcome is not sufficiently specific to identify all cases of illness. Databases and registers of health data collected for different purposes, do not necessarily capture the health data specific to exposure to air pollution. For example CVD may be caused by many factors but these are not necessarily listed in the register or database. Furthermore, there may be individuals who do have the outcome of interest but this might not have been recorded due to priority being given to other morbidities or causes of death. In the Step 2 review, studies were considered as lacking in specificity if they derived data only from registers, or they used data from cohorts designed to study other health outcomes e.g. cancer and diet. However, a number of the studies undertook physiological measurements which provide a more accurate outcome measure than data from registers or questionnaires.

Temporality

It is difficult to assess any of the studies in terms of temporality since there is usually no specific date for onset of exposure against which to measure lead-time to outcome. The studies undertaken in pregnancy do have an onset date in terms of conception but there may be maternal effects that have influenced the outcome before conception. The longest duration of study is that reported by Anderson *et al*., (2010) where participants were followed up from 1971-2006. The lack of evidence for temporality weakens the evidence for a link between air pollution and health.

Biological gradient

The studies do focus on the biological gradient in that exposure is measured or modelled on distance from residence. Where a positive outcome is noted (i.e. a

detrimental effect of traffic-related air pollution and health), a distance gradient is demonstrated. This was well covered in most of the studies and was presented as evidence of a link between exposure and ill health.

Plausibility

There is good evidence from occupational health and laboratory studies that air pollutants harm health so it is biologically plausible that traffic-related air pollution is harmful to health. Moreover, there is sufficient evidence in the literature to show that direct exposure to traffic-related pollutants in sufficient concentration for a period of time will harm health - as was seen in the London smog of 1952. However, at current lower levels of pollution it is not clear if the same effects might be seen.

Coherence

There is a coherent argument for the negative effect of traffic-related pollution not only from population studies, but also from laboratory-based studies such as that of Janssen *et al*., (2002).

Experiment

Although cohort studies cannot demonstrate an effect as clearly as randomized controlled trials, there is an opportunity to see if by natural experiment there is a change in effect. Such an experiment would include assessing the impact on health if traffic-related pollution exposure were to be decreased or eliminated by way of a reduction in traffic pollution or change of residence away from traffic exposure. In the Heinrich *et al*., (2013) study the impact on the health of participants was noted to have decreased in a follow-up study and this was attributed to a decrease in PM_{10} concentration in the area.

Analogy

It would be fair to state that the closest analogy to population exposure to air pollution lies in the studies undertaken on direct and passive smoking. Whilst the exposure levels from personal exposure are considerably more that exposures to traffic-related air pollution in most UK cities and towns, there is clear evidence that inhalation of particulate matter and gaseous toxins does have a detrimental effect on health.

Conclusion

The Step 2 review confirms the conclusions from the REA in Chapter 2 – that there is some, but limited evidence that traffic-related air pollution harms population health. The Step 3 analysis concluded that there is evidence of an association but not of causality. This means that, given the complexity of assessing individual exposure, concentration, duration, and taking into account other sources, comorbidity and vulnerability, it might be difficult to prove that traffic pollution, at current levels in Scotland, is harming health.

The analysis has identified that the fundamental reason for the limited evidence lies in the difficulty in accurately measuring health impact and exposure. Such measures are required to support assessment of individual vulnerability and promote behaviour change (personal and societal) and reduce harm. An investigation of the health impact of air pollution on the Scottish population exposed to traffic-related air pollution, will be explored further in Chapter 4.

Chapter 4
Findings from epidemiological studies assessing the impact of traffic-related air pollution on the health of residents in Scottish Air Quality Management Areas.

Introduction

There is evidence in Chapters 2 and 3 of an association between traffic-related air pollution and health effects. On this basis it is worth exploring the potential effect of traffic-related air pollution on the health of Scottish residents. The findings from Scottish studies should then inform policy-makers and Local Authorities (LAs) in Scotland of the expected health impact from traffic-related air pollution reduction measures. Furthermore, in theory, changes in air pollution and health monitored over time, could provide evidence to support a programme for traffic and urban development, improve the uptake of active travel options, and ultimately improve the health of the Scottish population.

This chapter describes three studies that were undertaken to assess the impact of traffic-related air pollution on the health of Scottish residents:

1. Scottish (Air Quality) Needs Assessment study - an analysis of the long term impact from exposure to historical air pollution;
2. NHS 24 study - a study on the health impact of short-term exposure to high levels of air pollution; and
3. Scottish Neighbourhood Statistics study - a pilot area-based assessment that tests existing health and deprivation databases to assess if the current data is sufficient to inform LA decision-making.
4. The findings from these studies are then compared with expected health impacts in a critique of air quality and health modeling based on national data in the Public Health England (PHE) report (Gowers *et al.*, 2014).

1. Scottish (Air Quality) Needs Assessment

Introduction

Health Protection Scotland, in collaboration with the Scottish Government, produced a report describing the health impact from air pollution for Scotland and by LA area (HPS, 2014). This report was produced to support Scottish LAs interpret the data

produced originally by Public Health England (PHE) (Gowers *et al*., 2014). These data provide an estimate of the mortality burden of particulate air pollution in each LA area. In theory the data can be used to prioritise investment in air pollution reduction initiatives within Air Quality Management Areas (AQMAs) and assess progress in reducing air pollution and protecting health over time.

In this Chapter the assumptions made in the PHE (2014) report are tested. The findings provide information on the extent to which the PHE model might be used to monitor the impact on health of changes in air quality in Scotland.

The PHE report provides a crude estimate of attributable deaths and Years of Life Lost (YLL) (premature deaths arising from a preventable cause) based on routine air quality monitoring data. The estimates are modelled on annual mean data from fixed site monitors and do not necessarily reflect individual exposure or susceptibility. However, little is known about the impact of air pollution on health in Scotland in AQMAs other than from these published estimates. The PHE report should therefore, be of value to LAs making decisions on traffic management initiatives aimed at reducing air pollution exposure and improving health.

Soon after the release of the PHE report, the author (JH) initiated a study to test the model in the Scottish population. The investigation hypothesised that living in AQMAs resulted in poorer health of local residents. The study was progressed by a public health trainee under the supervision of JH. The data collection, analysis and report writing were undertaken by the trainee with JH providing input on background literature, data review, evaluation of findings and report preparation. The details and findings of the study (described as the Scottish Health Needs Assessment Report) (Appendix 1) are provided below. The public health trainee has given permission for this study to be included in the thesis.

Method

A literature search was undertaken to estimate the mortality risk for specific pollution exposure levels. Data on hospital admission and mortality (myocardial infarction, stroke, Chronic Obstructive Pulmonary Disease (COPD), bronchiectasis and asthma, fracture, and transportation related causes, and ‘all-cause’) over a 5-year

period from 2008-2011 was sought for Scottish residents. Fracture data was captured as a control condition. Demographic data (age, sex and deprivation category) were also considered.

Air quality data (PM_{10} and NO_2) was sought from the agency collecting air quality data for Scotland, Ricardo AEA. Data for these areas were averaged and annualized for each year so that AQMAs and non-AQMAS could be identified. Estimates of population exposure by area were calculated using the postcode area of residence matched with the postcode for AQMA and non-AQMA.

The Population Attributable Factor (PAF) (the proportion of the population who would not suffer ill health if the exposure were removed) was calculated based on an estimated risk of 1.04 per 10 μgm^{-3} change in PM_{10} derived from a review of the literature. A change in annual mean PM_{10} from 31 μgm^{-3} (the highest average level in the most polluted street in Scotland) to 18 μgm^{-3} (guideline level) as the upper limit (13μgm^3 difference) would be required to improve health for people living in air quality management areas.

Results

The study showed that less than 1% of Scottish residents live in AQMAs and of these, most are aged between 29-40 years (75%) and are men (54%). Only 19% of AQMA residents are in the most deprived quintile (lowest 20% of the population). Mortality and hospitalization rates were lower in AQMA residents from all causes except for COPD mortality rates in the most deprived group. Reducing air pollution by 13μgm^3 is estimated to reduce attributable deaths in Scotland by 73 per annum in AQMAs, whereas a 1μgm^3 reduction in air pollution in non-AQMAs would result in a reduction of 153 attributable deaths. Likewise, for hospitalisations there would be a smaller impact in AQMAs despite the larger reduction in air pollution (AQMA attributable hospitalisations = 1,961; non-AQMA attributable hospitalisations = 27,517).

Discussion

The expected health outcomes based on literature reviews and modelled estimates were not identified in this study. Unlike study populations in the Rapid Evidence

Assessment (REA) described in Chapter 2, data for Scottish residents living adjacent to busy roads did not appear to show greater morbidity or mortality for air pollution related diseases.

It may have been that the Scottish populations in AQMAS tended to be younger and have lower levels of morbidity and mortality. The difference may also have arisen because of a link between age and increased residential mobility (students and professionals in inner city accommodation), so any health effects may be less severe and may not be identified using hospital inpatient or death data. It may also have been that air pollution in Scotland is not consistently high. Any influence of climatic conditions leading to exceptionally high levels of pollution may only occur in Scotland over very short periods of time (Willocks *et al*., 2012).

Notwithstanding, the anomaly requires further investigation. If it is shown that shorter duration symptoms related to air pollution episodes were being reported in the AQMAs but not captured in hospital admission or mortality data, then it might be possible to show an effect related to short-term exposure (Mustafić *et al*., 2012).

Conclusion

There is no evidence that air pollution in AQMAs in Scotland is resulting in an impact on health in terms of an increase in hospital admissions or mortality.

2. NHS 24 Study

Introduction

Several options for capturing data on the impact on health from short term exposure to high pollution levels. One approach is to look at General Practitioner (GP) attendances that might reflect more immediate symptomatology than hospital contact data. Patient diagnostic data are only recorded in a very small sample of practices (10%) across Scotland (spotter practices) so GP data is not sufficiently robust to monitor changes in air pollution related illnesses.

NHS 24, the Scottish acute care telephone advisory service, was considered as an option for data capture. In Scotland all calls to NHS 24 are recorded and demographic, symptom and outcome data are collected. It is possible therefore to

collate and analyse health data that might be associated with episodes of air pollution. Such episodes can be identified via SEPA (Scottish Environmental Protection Agency) operated monitoring stations across Scotland.

SEPA noted that in March 2012 there was an episode of particularly high air pollution in the Central Belt of Scotland over a period of 5 days. The Central Belt is the most populated area in Scotland and covers an area of land that includes Edinburgh in the east across to Glasgow in the west.

From the REA there was evidence that the impact of air pollution declines with 300-500m of major roads (Health Effects Institute, 2010). Therefore the NHS 24 study set out to investigate if there was evidence of an increase in health complaints in the population living within 500m of air pollution monitors, linked with the episode of poor air quality during the period of increased air pollution (20th-28th March 2012 inclusive).

Method

In order to capture a representative population sample from across the Central Belt, monitoring results from one air monitoring site in Edinburgh and one in Glasgow, were selected for this study. The Scottish Neighbourhood Statistics (SNS) database was used to identify populations within postcode areas up to 500m from monitoring site. This database is an open access online database of population demographic and socioeconomic data (http://www.sns.gov.uk/ (accessed 14 August 2014)).

Air pollution plots for these sites (Edinburgh and Glasgow) were produced using the Openair tools on the Scottish Air Quality website (Open Air (online) (accessed 14 August 2015). Air pollution levels were also measured at Auchencorth Moss – this a remote rural site, located on a moor to the south of Edinburgh and is used as a control site. There are no pollution sources in the vicinity of the Auchencorth monitor and results from this site are referred to as the background level.

Data on calls by type and number for the selected postcode areas were collected for specific conditions during, and for one week after the pollution episode, and compared with calls one week before the episode. The conditions were selected on

the basis that they are recognised symptoms of air pollution exposure. Caldicott Guardianship approval and St Andrews Medical School Ethics Committee approval was granted (Appendix 8).

Information that was requested from NHS 24:

1. Total number of calls to NHS 24 for Scotland (population 5,254,800)
    - during this period,
    - one week before (control) and
    - one week after

2. The total calls for:
   Edinburgh St Leonards and Glasgow Central areas for postcodes and population by equivalent datazones)
    - during this period,
    - one week before (control) and
    - one week after

3. The number of calls during the study period for irritation of the eyes, nose or throat, coughing, phlegm, wheeze, breathlessness, chest tightness, chest pain or any other symptom collected by NHS 24 which would reflect air pollution affecting health.

4. The call type for the Edinburgh and Glasgow postcodes within 500m of the monitoring station and for and the rest of Scotland.

Results

Concentrations of $PM_{2.5}$ increased on 22 March and remained high until 28 March 2012 (see Figures 10 and 11). The Auchencorth Moss data show that the levels of $PM_{2.5}$ were high across the Central Belt during this time period and not just at the Glasgow and Edinburgh sites.

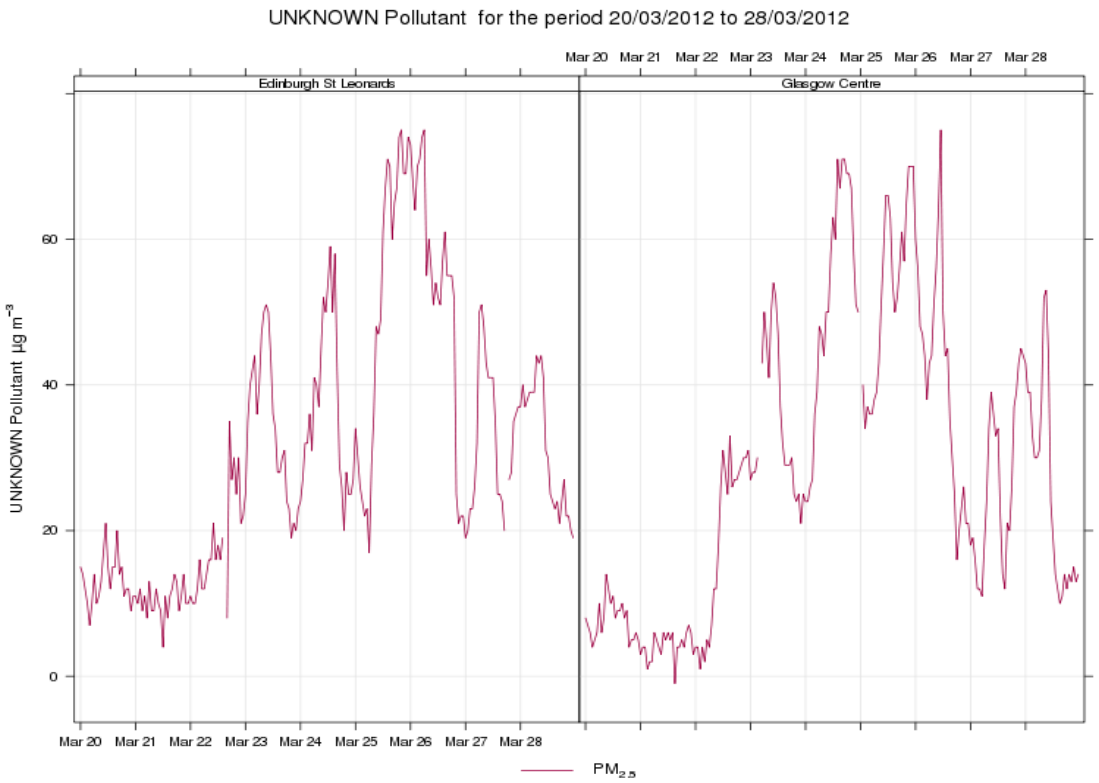


Figure 10: Record of air pollution levels recorded at air quality monitoring sites in Edinburgh and Glasgow, 20-28th March 2012.

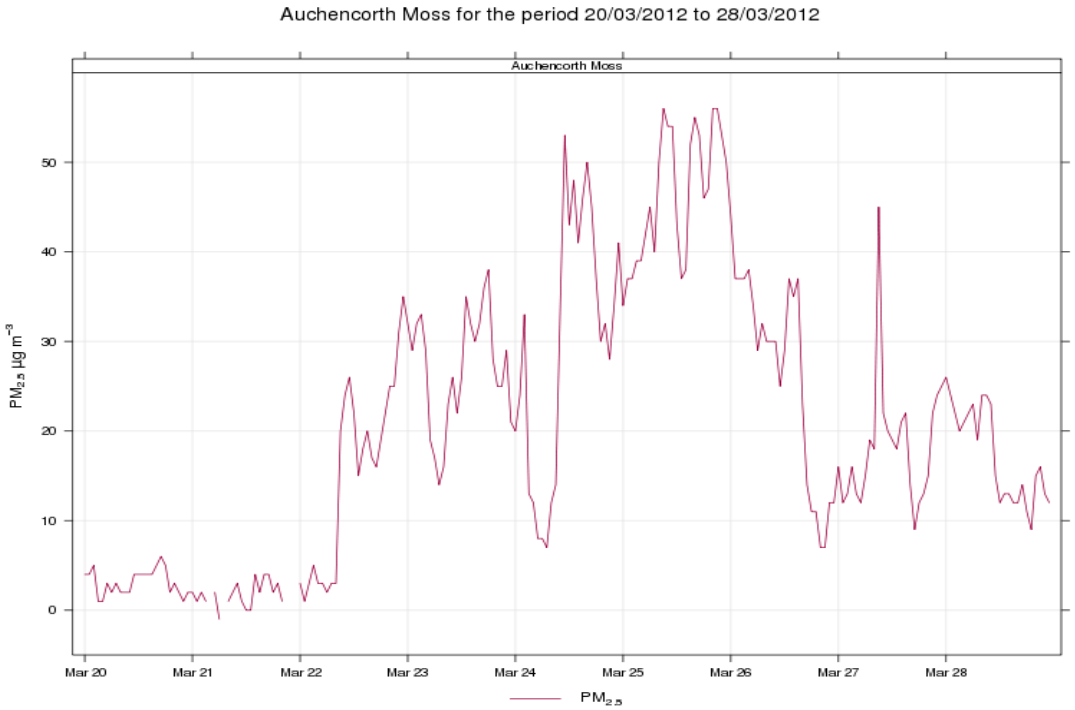


Figure 11: Record of air pollution levels recorded at Auchencorth Moss – background air pollution monitor.

The population by postcode search identified 8,339 residents in the Edinburgh zone and 6,748 residents in the Glasgow zone (Table 12).

Table 12: Population (2011) by datazone resident within 500m of an air quality monitoring site in Edinburgh and Glasgow

Edinburgh

Data Zone	Total Population : 2011
S01002060	792
S01002066	1186
S01002071	771
S01002086	684
S01002087	1060
S01002104	1548
S01002108	1008
S01002118	1290

Glasgow

Data Zone	Total Population : 2011
S01003358	1553
S01003373	1471
S01003399	2538
S01003410	1186

Source: SNS http://www.sns.gov.uk/ (accessed 14 August 2014)

Table 13 shows the number of calls to NHS 24 for Scotland, Edinburgh and Glasgow between 13 March and 04 April 2012. The total number of calls increased across Scotland during this time period while the calls for Edinburgh St Leonards decreased. The Glasgow Central calls increased during the week of the air pollution episode but returned to previous levels the following week. Calls for symptoms, which might be related to air pollution, decreased for Edinburgh over this period and for Glasgow the calls increased during the air pollution week before returning to previous levels.

Table 13: NHS 24 calls for air pollution related symptoms one week, during (20/03-28/03/12) and one week after high levels of air pollution recorded in Glasgow and Edinburgh

		Records by Area		Possible Pollution Symptoms	
Date Range	**Total Records**	**Edinburgh St Leonards**	**Glasgow Central**	**Edinburgh St Leonards**	**Glasgow Central**
13/03 - 19/03/2012	26,709	43	111	10	22
20/03 - 28/03/2012	29,459	40	147	8	37
29/03 - 04/04/2012	39,780	39	114	4	22
TOTAL	**95,992**	**284**	**30,152**	**228**	**691**

Note: shaded row indicates the week of elevated air pollution.

The record of calls for air pollution related symptoms showed that the majority of calls during the time period under study were related to chest pain complaints in the Glasgow area (three calls in the week before, ten calls during the period of pollution and 5 calls in the week after the pollution episode). The number of chest pain calls increased during the air pollution episode for the Glasgow area but not for the Edinburgh area. All other symptoms remained fairly static over the period under investigation (Table 14).

Table 14: Symptoms reported to by NHS 24 by air monitor area, 13 March – 04 April 2012

	Edinburgh St Leonards			Glasgow Central			Grand Total
Protocol Title	**13/03 - 19/03/2012**	**20/03 - 28/03/2012**	**29/03 - 04/04/2012**	**13/03 - 19/03/2012**	**20/03 - 28/03/2012**	**29/03 - 04/04/2012**	
A&D Earache	0	1	0	2	1	0	4
A&D Sore Throats or Potential Cold in Patients aged 5 years or more	0	1	0	2	2	0	5
A&R Minor Ailments	0	0	0	0	1	0	1
Abdominal Pain	1	0	0	0	0	1	2
Allergic Reactions Toddler (Age 1-4 years)	0	0	0	0	1	0	1
Asthma	0	0	0	0	0	1	1
Back Injury	0	0	0	0	1	0	1
Breathing	0	0	1	2	0	1	4
Breathing Difficulty Adult	0	0	0	0	0	2	2
Chest Pain	**1**	**0**	**1**	**3**	**10**	**5**	**20**
Chest Wall Pain	0	0	0	0	0	1	1
Cough	1	0	0	1	0	0	2
Cough Adult	0	0	0	1	1	0	2
Cough Toddler (Age 1-4 years)	0	0	0	1	0	0	1
Coughing Up Blood	1	0	0	0	0	0	1
Croup Infant (Age 0-1 year)	0	0	0	0	1	0	1
Croup Toddler (Age 1-4 years)	0	0	0	0	1	0	1
Diarrhoea Adult	0	0	0	0	1	1	2
Dizziness	0	0	1	0	0	0	1
Ear Discharge Adult	1	0	0	1	0	0	2
Ear Pain Child (Age 5-16 years)	0	0	0	0	0	1	1
Earache Adult	0	0	0	0	1	0	1
Ears	0	0	0	0	2	0	2

Ears - Child	0	0	1	0	0	0	1
Eye Discharge Adult	1	0	0	0	0	0	1
Eye Pain	0	0	0	0	0	1	1
Eye Redness	1	0	0	0	1	0	2
Eye Stye	0	0	0	1	0	0	1
Eye Visual Disturbance	0	1	0	0	1	1	3
Eyelid	0	0	0	1	0	1	2
Eyes	2	1	0	2	2	1	8
Fever Adult	0	0	0	1	0	0	1
Haemoptysis	1	0	0	0	0	1	2
Headache Adult	0	1	0	0	0	0	1
Leg Numbness	0	0	0	0	1	0	1
Medication Enquiry - Generic	0	1	0	0	0	0	1
Nose	0	0	0	0	1	0	1
Nose - Child	0	1	0	0	0	0	1
Nosebleeds Adult	0	0	0	1	0	0	1
Rash Generalised	0	0	0	0	1	0	1
Rib Pain	0	0	0	0	0	1	1
Sore Throat	0	1	0	0	2	0	3
Suicide Ideation	0	0	0	0	1	0	1
Throat	0	0	0	1	2	2	5
Urinary Frequency Adult	0	0	0	0	0	1	1
Vaginal Bleeding Heavy	0	0	0	1	0	0	1
Vomiting Infant (Age 0-1 year)	0	0	0	1	0	0	1
Wheezing or Asthma	0	0	0	0	2	0	2
Grand Total	**10**	**8**	**4**	**22**	**37**	**22**	**103**

Note: shaded columns indicate the week of elevated air pollution.

Discussion

There was no overall change in trend between the calls to NHS 24 around the time of the air pollution event. Although calls from the Glasgow residents increased during the week of air pollution this increase was not experienced in the Edinburgh residents. This might be due to differences in population demographics such as deprivation indices and this was not recorded for this study. However the Scottish (Air Quality) Health Needs Assessment Report showed that the population in AQMAs where the monitors are sited, tend to be younger. It would not be expected that young people would present with air pollution associated chest pain without also presenting with other symptoms such as asthma which is more common, and has been shown to be linked to air pollution. In the NHS 24 study there was no observed increase in calls for asthma in the Edinburgh area. In the Glasgow area there were more calls for asthma but also for conditions unrelated to exposure to pollution.

This study was a pilot to test the feasibility of undertaking a longer-term assessment linking air pollution episodes and health responses. There were a number of issues that would be difficult to address in a longer-term study and therefore would limit the value of any findings:

1. The residents may not have spent much of this time in the area (e.g. they may have been out at work/college elsewhere) so the health impact data may be lower than if they had been exposed for longer.
2. The health impact data may not show if people passing through the area were affected since their postcode of residence would be elsewhere.
3. There were no noticeable increases in health related calls for other symptoms such as asthma. This might suggest that air pollution needs to be considerably higher than objective levels for a period of time, to show an effect large enough for residents to seek health advice.

A similar study was undertaken by HPS at the time of Bonfire Night in November 2014 (Telfar, 2014) when air pollution levels were noted to be very high. This study validated the findings of the NHS 24 pilot in that the researchers did not find any difference in NHS 24 calls for symptoms that could be linked to air pollution between the 5th and 6th November 2014.

The results from both Scottish studies are not consistent with a UK wide syndromic surveillance study (Smith *et al*., 2015) which has shown that during a period of very high air pollution (March and April, 2014), there were over 3500 additional health consultations for respiratory problems compared with periods outwith these events. The levels of air pollution during the period of the study were very high and attributed to dust pollution from the Sahara. The cross sectional study did not consider alternative explanations for these calls but did note that during the second period of the study there was a high level of media interest that may have had some bearing on the increased contact with NHS services.

It is difficult to explain the differences in findings between the Scottish and UK study given in all the studies air quality was classified according to the same categorization system (COMEAP, 2011) i.e. very high. What is of interest is that the calls to health services in the UK study were considerably higher in September to December of the preceding year, outwith the air quality events. The report authors did not explain this anomaly.

Conclusion

The short-term health studies did not demonstrate a measurable effect on health when air pollution levels were high for limited periods of time.

3. Scottish Neighbourhood Statistics (SNS) Study

Introduction

If LAs are to secure the necessary financial and public support to address air pollution in AQMAs, they will need to demonstrate that their traffic management proposals not only deliver improved air quality, but also that this translates into health improvements. The PHE report (2014) was produced to assist LAs by providing estimates of health impact based on modelled air pollution for each area.

To apply this in Scotland the first step in estimating health impact is to establish a baseline of health for the AQMAs. To address this an analysis of air pollution and the health for an AQMA in Dundee was undertaken using the Scottish Neighbourhood Statistics database. Dundee is Scotland's fourth largest city with a population of just under 150 000 and Dundee City Council has declared the whole city as an AQMA with particular hotspots on 6 streets across the city. Lochee Road was selected for this study because it is a main arterial route through the city (Figure 12). The Dundee City Air Quality Progress Report 2013 showed that in 2012 NO_2 levels exceeded short-term national objectives 36 times over 20 days and PM_{10} levels exceeded national short-term objectives 3 times over three days (Dundee City Council, 2013). Air pollution levels in the area have raised local concerns (Smith, 2014). A health impact study would facilitate discussion with local councilors and foster better understanding amongst the public about the limitations of scientific data. It might also provide an opportunity to discuss the importance of supporting active travel to improve health.

Method

The Scottish Neighbourhood Statistics database was accessed online. Hospital admission data for cardiovascular and respiratory disease for 4 years (2002-2005) were selected for the two Wards (electoral register area) either side of Lochee road. The Ward area was mapped to postcodes and then to health data by postcode. The data were adjusted for age, sex and were recorded on an Excel spreadsheet.

Results

The results show wide variation across all the Wards (Figures 13 and 14). The West End constituency population has fewer hospital admissions for respiratory or

cardiovascular disease than neighbouring populations. The deprivation profile for Dundee West End shows a high percentage of the population are of working age (75%) and a low proportion at pensionable age (13%) (Figure15). The area has lower levels of income deprivation than other areas in Dundee, is below the Scottish average for income deprivation and is not classified as a deprived area. Incapacity Benefit or Severe Disability Allowance is claimed by 2.6% of the population which is below the Dundee and Scottish average. This is in contrast to Coldside on the opposite side of the road, where there is a higher rate of admissions for cardiovascular and respiratory disease and a higher level of income deprivation (Figure 14). The other Wards show levels of health and deprivation between these data.

Discussion

The Scottish Neighbourhood Statistics database was an online tool that allowed for the selection of health, social and economic statistics to be mapped against geographical areas across Scotland at different levels of detail. Since this study was undertaken in 2014 the online tool is no longer available and data is currently presented as completed reports. This means it is no longer possible to undertake analysis for specific scenarios.

For the purpose of this study in 2014, the database was used to identify the postcodes and Wards for the populations who resided alongside Lochee Road. The Ward areas are very large and many of the residents will reside more than 500m from Lochee Road (Figure 12). Therefore health records for the larger population living some distance away, will have masked the health data for residents in the immediate vicinity of the monitor. However, in theory this would be the level of data available for analysing health impacts in air pollution areas and is thus representative of the difficulty posed in determining health improvements from traffic management initiatives.

The health information was only available up to 2005. There is a time lag between collection of data and publication, and this will have an impact on local interpretation in terms of effectiveness of traffic management measures. Moreover, individuals

may suffer ill health consequences without requiring hospital admission and these outcomes will remain unrecorded.

The results show the range of health outcomes arising in the Wards throughout Dundee city with the most extreme differences arise in the Wards bordering the Lochee Road. The data for the West End population are consistent with a fairly healthy population. The neighbouring ward of Coldside shows a different picture. Income deprivation is linked to poorer health and an increase in hospital admission rates for respiratory and cardiovascular disease would not be unexpected. This suggests that any difference in health effect is due to deprivation rather than proximity to Lochee Road.

Overview maps of Dundee (available online at www.sns.gov.uk/ in 2014 and no longer available) show that there are no particular hotspots for cardiovascular or respiratory disease linked to road networks. However the information on these maps reflects health based on hospital admissions for large populations and does not necessarily indicate health issues at an individual or local level.

Conclusion

Air quality in the Lochee Road area does not meet National Air Quality Objectives. Although there is evidence that short and long-term exposure to poor air quality is detrimental to health, the data currently available do not show evidence of a negative impact on respiratory or cardiovascular health for the local population. There is evidence of a higher rate of admissions for cardiovascular respiratory disease in the Coldside population but there is also a high level of income deprivation in this Ward. The difference in admission could be accounted for by deprivation given both Wards are exposed to the same air pollution.

This relatively crude analysis of health was an attempt to investigate the feasibility of monitoring health impact from traffic management initiatives in one LA area. The results show that the information available on health at the time of the study was insufficiently robust to demonstrate if the health of local residents could be improved if air quality was improved.

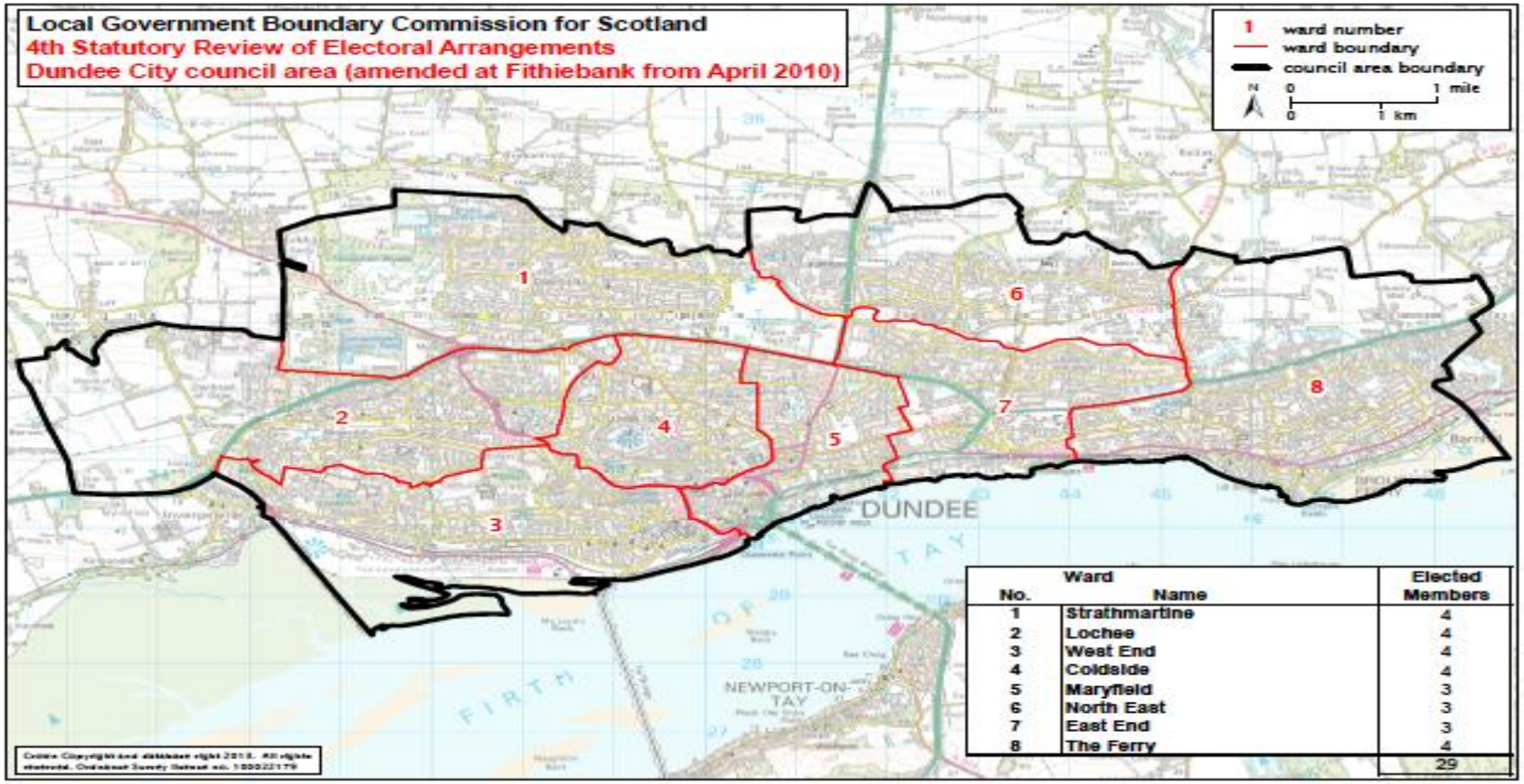


Figure 12: Dundee City Council Ward areas

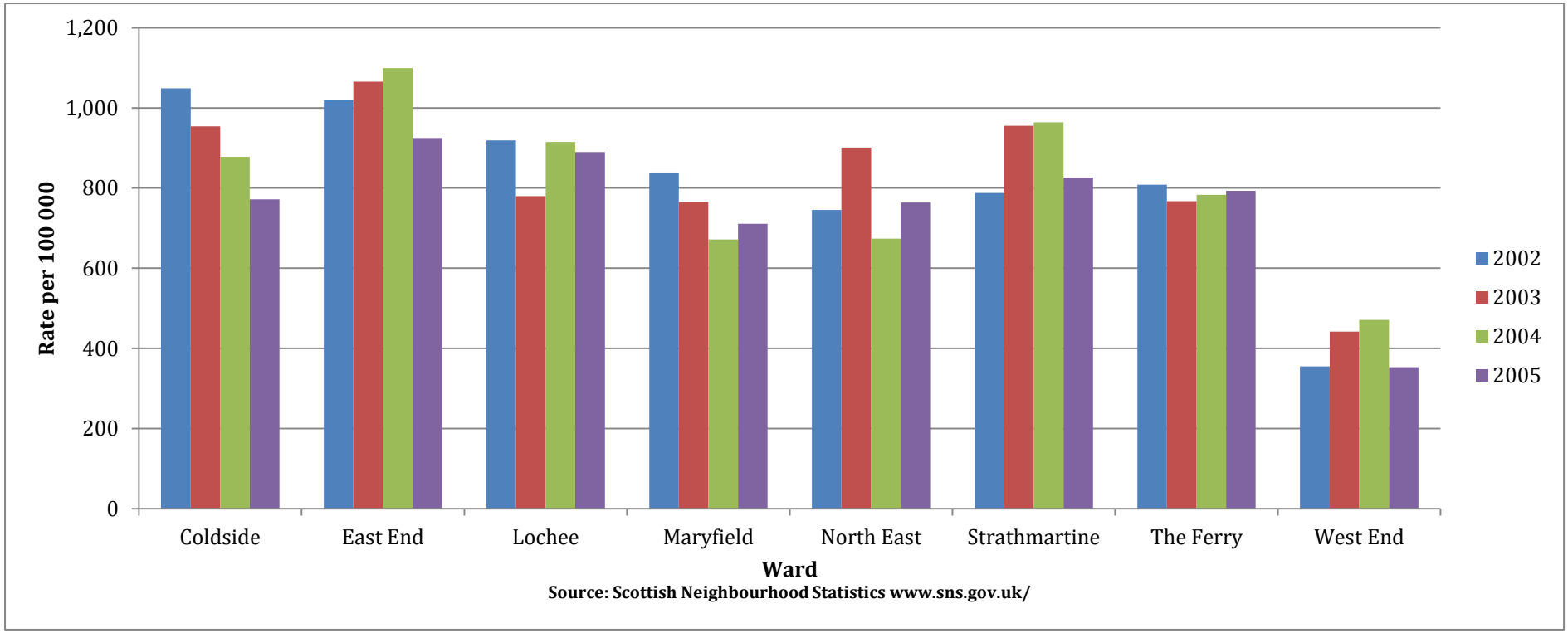


Figure 13: Coronary Heart Disease Admissions, by Dundee Ward, both sexes, all ages, 2002-2005

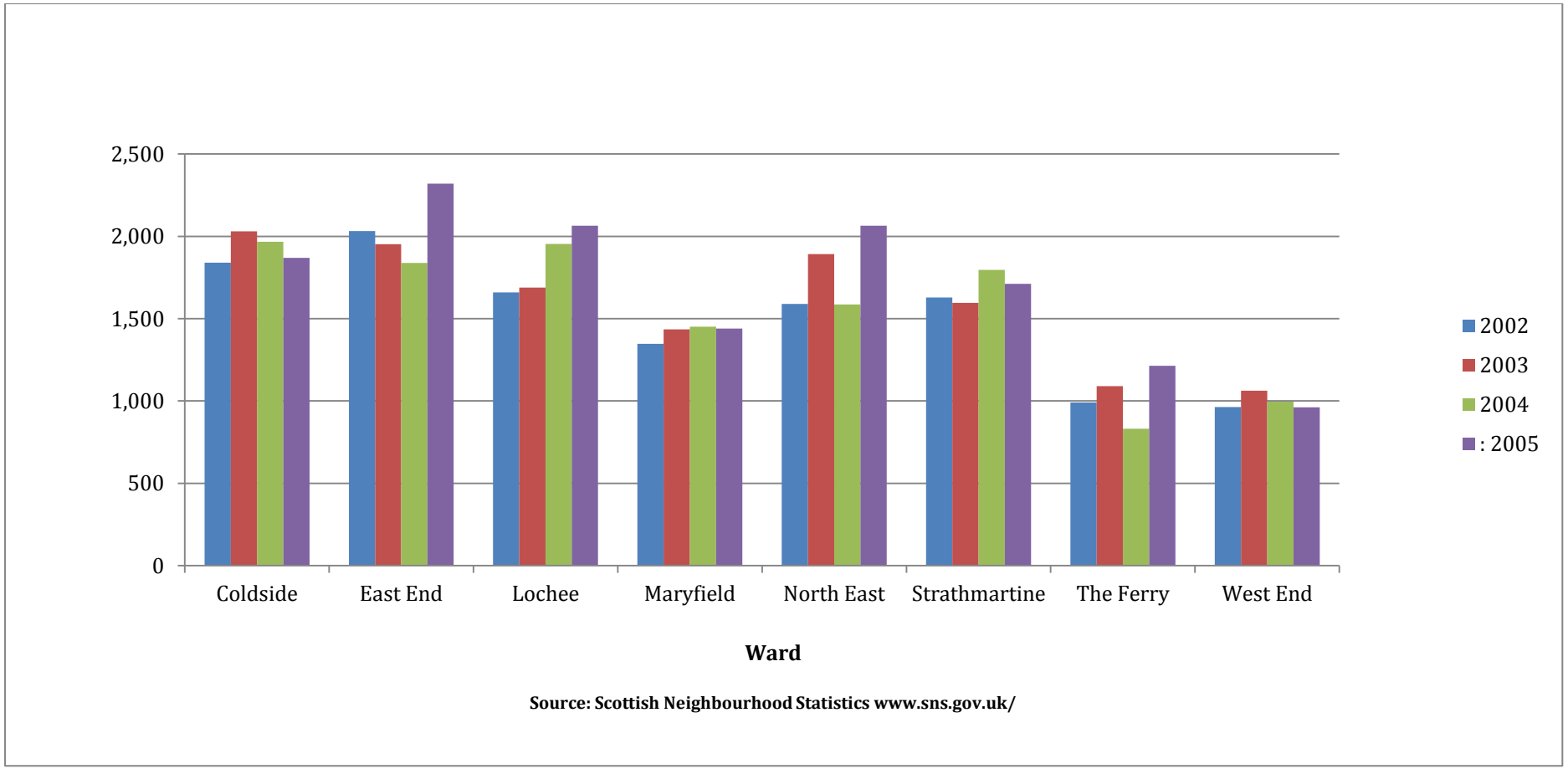


Figure 14: Respiratory Disease Admissions, by Dundee Ward, both sexes, all ages, 2002-05

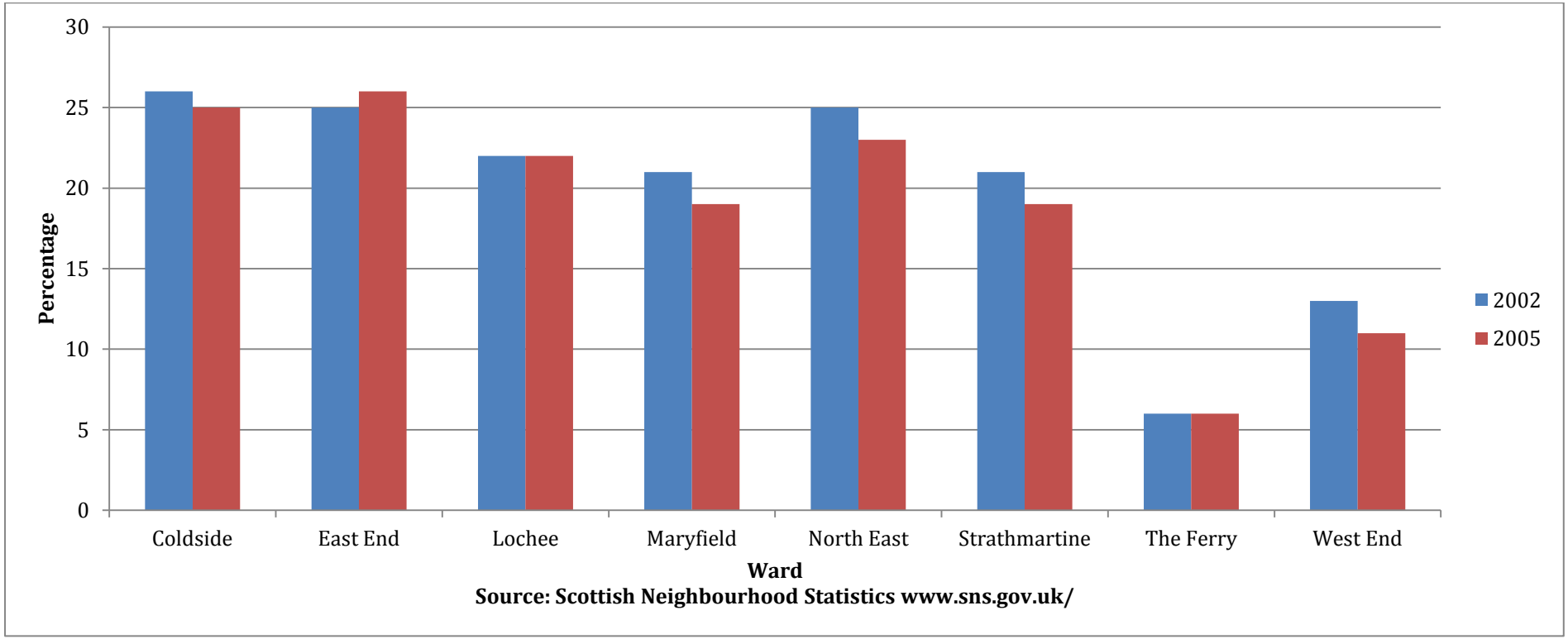


Figure 15: Percentage of population Income Deprived, by Dundee Ward, 2002 and 2005

4. Critique of air quality and health impact modelling

Introduction

The Scottish study by Willocks (2012) and the verification studies in this thesis - (Scottish (Air Quality) Health Needs Assessment Report; NHS 24 pilot; Scottish Neighbourhood Statistics study) - have not shown a link between air pollution in Scotland and the health of Scottish residents. This is at odds with the predicted mortality and Years of Life Lost (YYL) reported for Scottish LAs in the PHE report (Gowers *et al*.,2014). Therefore further scrutiny of the PHE report was undertaken to review the assumptions in national modelling data and investigate why they had not been verified in the Scottish studies.

The PHE report draws heavily on international guidance including health impact assessment guidance to produce mortality estimates (World Health Organisation, 2005). This guidance provides a model to link particulate exposure, vulnerability and outcome in terms of morbidity and mortality (Figure 16).

To calculate the expected number of deaths due to air pollution (E), we take the product of:

$$E = \text{beta} \times B \times P \times C$$

where:

E = expected number of premature deaths due to short-term exposure

beta = percentage change in mortality per 10-µg/m3 change in PM_{10}

B = incidence of the given health effect (deaths per 1000 people)

P = relevant exposed population for the health effect

C = change in PM_{10} concentration (µg/m3 x 0.1)

Figure 16: Population mortality estimation from air pollution exposure**. (**World Health Organisation, 2005, p164)

As discussed in Chapter 1, it is not feasible to separate each component of air pollution such as particulates and attribute each to specific health impacts. However, taking pollution in general, it is possible to estimate the impact on mortality for populations at a local level.

The PHE estimates are based on $PM_{2.5}$ particles, but air monitoring in Scotland measures PM_{10} particles. That said, both particle groups are indicators of pollution. Moreover elevated PM_{10} levels would include a proportion of $PM_{2.5}$ particles.

In the PHE guide it is estimated that particulate air pollution in Scotland is contributing to an additional 2 094 deaths per annum. However this was not borne out in the Scottish (Air Pollution) Health Needs Assessment Report where it has been shown that there is no evidence of a link between air pollution and health in Scotland. The Scottish study found a lower mortality rate (192 per 1000 person years) in AQMAs compared with (257 per 1000 person years) non-AQMAs).

A detailed assessment of the PHE report might explain this anomaly and show that either the approach taken in the Scottish (Air Quality) Health Needs Assessment Report was flawed, or that the assumptions in the PHE report are too crude to provide robust estimates of effect. The PHE report authors (Gowers *et al*., 2014) do in fact emphasise that there are weaknesses in the assumptions they have made within the calculations, and they provide an accuracy range from one sixth to double the figures provided. If these figures were applied to the estimated mortality data for Scotland this would result in a range from 349 to 4188 excess deaths from air pollution. The lower figure is closer to the Scottish (Air Quality) Health Needs Assessment Report estimate. Therefore this raises the question - is the PHE data reliable for use in Scotland?

Method

The PHE report was reviewed and the assumptions listed. An assessment of the validity of the assumption was tested against the evidence in the literature.

Results

The PHE analysis is based on attributing all PM exposure to regulated emission and traffic-related sources. The $PM_{2.5}$ levels are modelled estimates. The health outcomes are based on studies in populations exposed before 1999. Exposures (SO_2) and lifestyles (e.g. smoking and diet) have changed over time (Table 15).

Table 15: PHE Report (Gowers et al., (2014)). Estimating local mortality burdens associated with particulate air pollution - critique of the underlying principles.

Page	Assumption	Comment
1	Air pollution is from traffic	Sources of pollution vary according to local industry, agriculture, dust, fires and climatic conditions. The report advises that the assumptions do not adjust for background/non vehicular pollution other than estimates from the NAEI (National Air Emissions Inventory).
1	Evidence is based on historical data used in studies by Dockery *et al*., (1993) and Pope *et al*., (2002)	Health outcomes in these studies reflect exposure prior to 2000 when air pollution regulations were very different to current standards. Would the same study run today provide the same results? Dockery study was based on: - Populations between 1974 and 1986; average age of 50 so this reflects exposure from 1920s onwards; - Single central monitoring site in each city therefore very crude assessment of local pollutant levels; - Little if any assessment of alternative sources of pollution i.e. no comment on pollution sources (e.g. passive smoking), distance from source or time spent in polluted area; - No comment on confounding factors such as noise, dietary or lifestyle factors. Pope study: - Did not include consideration of environmental confounding factors such as noise; - No comment on passive smoking; - Spatial modeling used to estimate exposure rather than detailed measurements. - Longer follow up with decreasing pollution over the time of the study shows the same results – is there a different explanation than air pollution? Pollution levels for $PM_{2.5}$ and sulphur dioxide decreased by 1/3 during 20 years of

		study. Ozone increased by 23% in 20 years. - No indication of modeling sites in relation to populations. - No information on monitoring tools or validity assessments. - No $PM_{2.5}$ monitoring information available during the study but these were estimated from monitoring in periods before and after the study. - Problems with accurate sulphur monitoring. - Decrease in mortality associated with $PM_{2.5}$ and sulphur (fig 5) but no comment on contribution of either – could the health effect have been primarily due to sulphur? - Biological plausibility query – cardiopulmonary mortality risk was greater for "never smokers" compared with smokers – suggesting smoking protective? - Not all cardiovascular disease-confounding issues were included e.g. intake of fruit and veg changes at this time with increase in fast food consumption. Fig 2 indicates adjusted for diet but no explanation in methods. - $PM_{2.5}$ levels approx. 15μgm^{-3} (Fig 1) which is below European standard of 25μgm$^{-3.}$
1	Estimates based on $PM_{2.5}$ emissions	$PM_{2.5}$ levels are not measured routinely in Scotland so there is little opportunity to validate the PHE estimated levels. Levels will differ across the UK depending on local geography, building layout, climatic conditions, traffic sources, transboundary flow.
1	Evidence based on reports (COMEAP, 1999; COMEAP, 2001,and 2009; World Health Organisation, 2006).	Data in reports up to 2001 would have been derived from evidence on exposures and populations before 1999. The levels of air pollution have decreased so a lifetime exposure would be less. In addition, there may be disproportional decreases in some pollutants e.g. SO_2 which may have been the most significant contributor to ill health. Would the same findings arise in cohort studies of the same populations by applying other (confounding) factors e.g. CVD associated with changing eating trends by era?
1	Air pollution has decreased over time	The outcomes seen in terms of health reflect past exposure at much higher levels than seen today – any health effects could be due to historically very high exposures from pregnancy through infancy and childhood into adulthood at a time when there was great exposure to non traffic-related pollution such as passive smokers, industry, coal fires or from less regulated vehicular emissions.
2	15% reduction in urban	Current $PM_{2.5}$ levels are unlikely to be exceeded in Scotland (HPS, 2014, p13).

	background $PM_{2.5}$ from 2010 levels expected within 10 years	Historic exceedances have been associated with elevated levels across the UK linked to easterly winds and Saharan dust events. 15% reduction in Scotland would mean decreasing levels from 8.6 μgm^{-3} at the highest modelled estimate to 7 μgm^{-3}. Both levels are below the Scottish objective of 12μgm^{-3}
2	COMEAP (2010) stresses importance of using data with caution. Impact on life expectancy is not an estimate but a method of representing the impact. Note air pollution is contributory and not sole cause of death. Model based on removing all anthropogenic $PM_{2.5}$ – reduction of 8.97 μgm^{-3} Assumptions include no change in air pollution over time, no time lag for effect, no change in size or age structure of the population,	Reference list - No new studies reported since 2002 Current Scottish $PM_{2.5}$ at background levels (not traffic- related) is 12 $\mu gm^{-3}$and roadside is up to 18 μgm^{-3}so a decrease at proposed 8.97 $\mu gm^{-3}$is unlikely. Calculations adjusted for a lower level of decrease (8.97 $\mu gm^{-3}$to 6 μgm^{-3}i.e.1/3 less) will result in even fewer attributable deaths (1400 Scotland) and YYL (3 months). This would also have to be adjusted for the number of people exposed which in Scotland is approximately 0.4% of the population = 560 deaths and 48 days. If the uncertainty calculation is applied this would result in a range of attributable deaths of (560/6) 93-1200 and YLL from 8 to 96 days. There are assumptions made on concentration and duration of exposure, pre-existing or confounding conditions.
2	Estimates produced to assist LAs to manage AQMAs using health data	Guide strongly advises against misinterpretation of data and COMEAP (2010) indicates that these are not estimates but representations.
3	Report to support communication	Difficult to communicate at levels as low as 3-4 months YYL or attributable death concept.

4	*"the methods used are not intended for the quantitative evaluation of the health impacts of local measures to reduce air pollution"*	Yet LAs requested estimates of health impact on which to base evaluations of traffic management initiatives (p2).
7	Hoek *et al*., (2013) confirms COMEAP assumptions	Difference in outcomes according to educational status – "*it is likely that multiple life style related factors may play a role in the stronger effects observed in less-educated subjects. These may include dietary factors such as lower fruit and anti-oxidant intake, higher risk of obesity or other pre-existing diseases, higher actual exposures than assumed in the studies, lack of air conditioning and possibly interaction with other risk factors such as poorer housing conditions e.g. moisture."* Hoek *et al*., (2013) Is this the underlying cause of any increase in cardiopulmonary effect?
8	Uncertainties in modeling pollution exposure	Applied universally across the UK irrespective of local emissions. National Air Emissions Inventory (NAEI) applied but insensitive to local conditions.
8	Background exposure used to model personal exposure	Cannot account for variation in duration or concentration of traffic exposure at individual level and hence cannot measure effect of reduced exposure.

Discussion

The PHE report identifies a number of areas where assumptions have been made and which could on their own, or in combination, lead to an under or over-estimate of health effect. The key issues for Scotland are:

- $PM_{2.5}$ monitoring is not routinely undertaken across Scotland so exposures are estimates.
- The health impact is based on papers produced in 1993 and 2002 and the air quality for populations up to this time was very different from that today.

A further explanation may be that in Scottish AQMAs there is a different demographic with young and more affluent residents and therefore possibly healthier populations living in city and town centres. In addition, higher rents may prohibit occupation by families with young children, and the older structures may reduce accessibility for the elderly. This is consistent with the findings of the Scottish (Air Quality) Health Needs Assessment Report.

To test the model further the data were applied to a London borough to see if the data were more applicable in English authorities. Taking Inner London as an area with the greatest level of pollution in the UK (Gowers et al., 2014), it can be seen that the highest anthropogenic $PM_{2.5}$ levels occur in Kensington and Westminster (14.9 μgm^{-3}both affluent areas. Yet the highest YLL occurs in Southwark (deprivation area) (1651 compared with Kensington 1403 and Westminster 1164). Kensington has a healthy life expectancy of 66.7 years and in Southwark it is 60.3 years compared with the average in London of 64.2 years (PHE online, 2013). This suggests that the predominant effect on YYL may not be due to air pollution but to lifestyle factors.

Finally, it is worth looking at air quality, deprivation and longevity in countries comparable to the UK in economic terms (OECD, 2015). From a selection of countries geographically adjacent to the UK it can be seen that France has the highest economic indicator, greatest passenger Km road use, highest level of $PM_{2.5}$ and yet has the greatest life expectancy (Table 16). This suggests that the impact of

air pollution on health is determined by a very complex set of factors that cannot easily be attributed to any one factor, such as particulate air pollution.

Table 16: Comparison between UK and GDP similar countries in terms of air pollution and life expectancy.

Country	**Economics composite leading indicator 2015**	**PM2.5 μgm^{-3} (road transport 2012)**	**Road in million passenger-km: of which passenger cars (2012)**	**Life expectancy at birth (2012)**
UK	100.1	16	643 000* ↓	82.8
Netherlands	100	4	145 000 ↑	83.0
France	100.7	31	819 000 ↑	85.4
Denmark	100.3	2	61 000 →	82.1

*arrows showing change since 2002

The evidence for a health impact from air pollution has traditionally been based on population metrics, despite the fact that the impact is at an individual level. This might explain why, when applied in Scotland, the estimated health effect at a population level is failing to identify the small number of vulnerable people who may be affected. Air pollutants may be causing harm, but there are too many variables to provide a robust estimate of the health impact of traffic-related air pollution on the health of residents living adjacent to busy roads in Scotland.

The explanation for this may lie in the measurement process. Air pollution exposure is currently based on estimates modelled on levels measured at fixed site monitoring at points, averaged of periods of time (24 hour or annual mean levels) and reported annually. Below (Figure 17) is an example of air monitor position location (Dundee) and reports from static monitors from this area. The air quality however, may change dramatically from hour to hour (Figure 18). Thus at any one time an individual in the area may suffer from symptoms related to exposure to a high level of air pollution, but this exposure may be time limited in terms of emissions and period spent in the vicinity.

Victoria Road / Meadowside

Figure 2.16 NO $_2$ Diffusion Tube Locations in Victoria Road / Meadowside

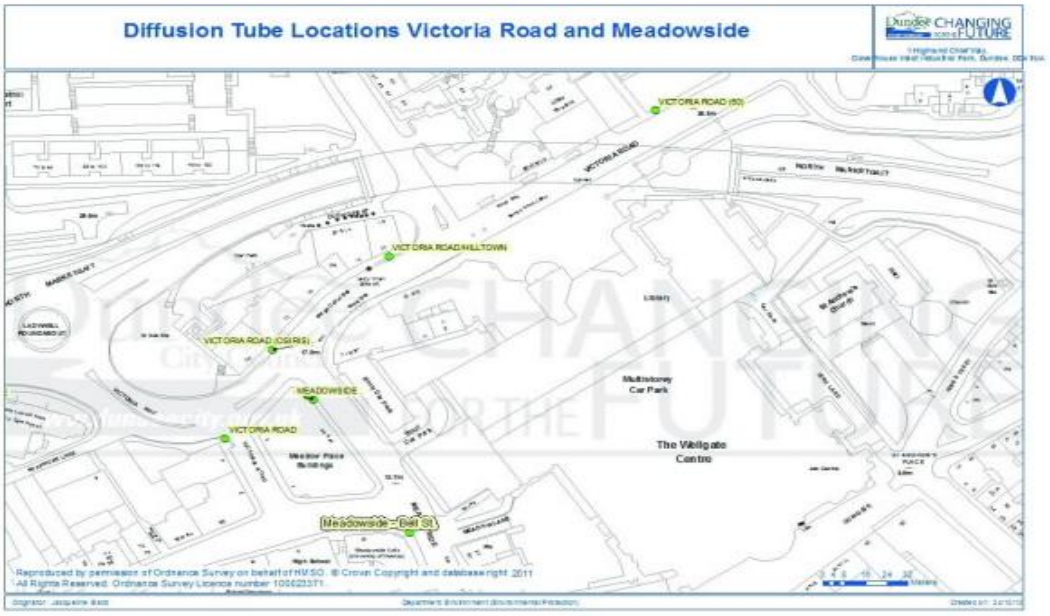


Figure 2.17 Trends in NO $_2$ Diffusion Tube Concentrations in Victoria Road / Meadowside.

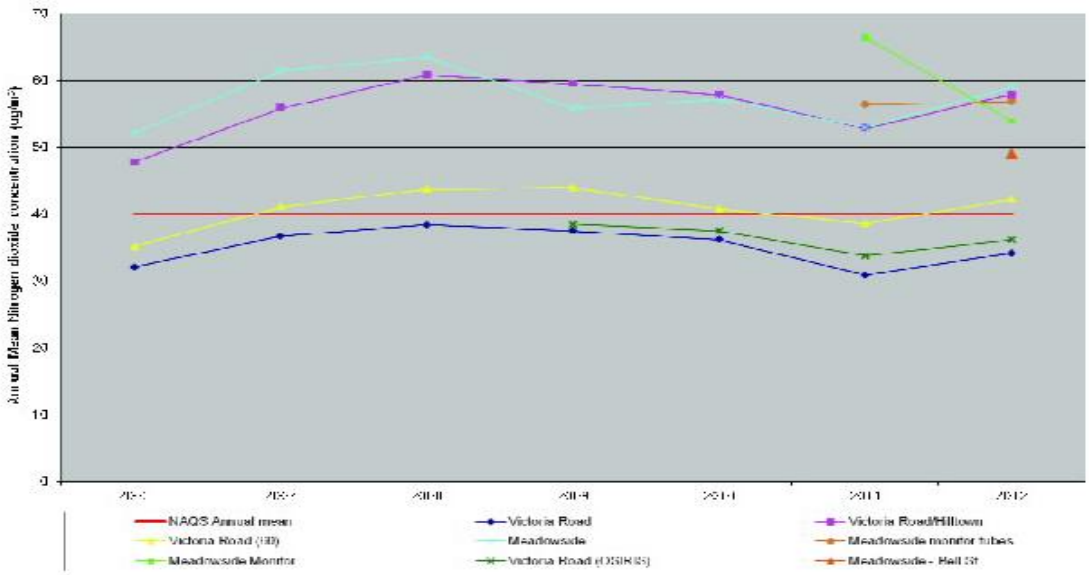


Figure 17: Map of Dundee city showing air monitoring stations and reports from static monitors for Victoria Road and Meadowside, Dundee 2013. (Dundee City Council, 2013, p52)

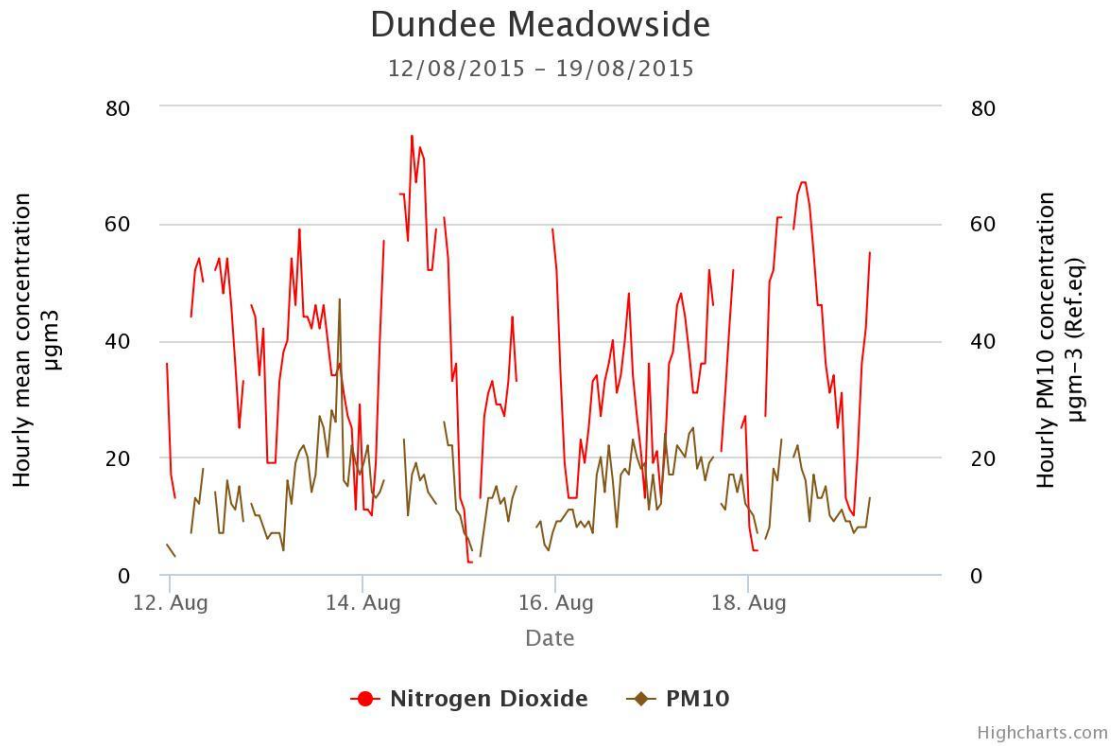


Figure 18: Hourly monitoring of PM_{10} concentrations over a 1 week period for Dundee Meadowside, 2015 (Air Quality Scotland, accessed 17/02/2017))

In Scotland, LAs managing AQMAs have identified problems with estimating exposure due to difficulties in adjusting for:

- Pollutant type – industry or traffic, building works, transboundary emissions from e.g. Europe
- Gradient of roads
- Speed of traffic
- Traffic lights
- Congestion
- Junctions
- Vehicle type

Other issues to be considered in assessing air pollution levels include

- Diurnal pattern of emissions
- Climate
- Data quality (validation)

Local Authorities are struggling to address air pollution in AQMAs where pollution exceeds guideline levels but does so by relatively small amounts and for short periods. Furthermore, the case for a health impact is not strong. Therefore a multiagency group has been established in Scotland to review and advise on an enhancement of air quality monitoring and modeling in recognition of the inaccuracy of current monitoring and modelling methods when applied at local level. Systems to capture real time air pollution are now being employed to validate modelled data with a view to providing more accurate measures of population exposure. Monitors are placed in different areas for a period of time and the validity of the readings is measured against static monitor readings. This will enable a more accurate assessment of air pollution taking into account the factors identified above.

What would be of greatest benefit would be the ability to monitor personal exposure. This has in the past been limited by the reliability of data from mobile monitors (Snyder *et al*., 2015). With new technological developments in monitoring systems linked to geographical location data, there will be greater scope to more accurately monitor personal exposure, assess the impact of traffic changes on air pollution, determine the positioning of fixed site monitoring and involve the public in citizen science approaches to understanding the environment and influencing behaviour.

Conclusion

Studies in Scotland have so far not shown evidence of a health impact on populations exposed to levels of air pollution higher than guideline levels. In addition, the PHE mortality estimates may be invalid in Scotland due to the low levels of $PM_{2.5}$ exposure and the particular socioeconomic characteristics of residents in AQMAs.

Developments in technology are required to enable robust personal monitoring. This might provide more person-centred information such that vulnerability and behaviour in terms of daily activity and exposure, can be taken into account.

Chapter 5

An investigation of possible strategies to reduce traffic-related air pollution

Introduction

This thesis has considered the physical effects of air pollution and found some evidence of association between respiratory health and traffic-related air pollution exposure (Chapters 2 and 3). However it has not been possible to provide evidence of this effect in populations in Scotland at current air pollution levels (Chapter 4). Without good evidence of an effect it is difficult to build the case for reducing traffic-related air pollution at a local area level. Furthermore, pollution is invisible, the benefits in terms of health may be marginal, and vehicular transport is critical to socioeconomic development. In light of these factors, current policies to tackle air pollution are not proving sufficient to bring about significant change. This is not unusual in that effective policy is driven by pressure to address a variety of issues and may include reference to economic impact, regulation and health rather than scientific evidence alone. This chapter describes a semi-structured survey of national stakeholders, investigating the specific barriers and incentives for change and how these might affect current policy in Scotland.

Transport Study

Introduction

The author undertook a study as part of this thesis, to investigate the views of policy makers, planners, lobbyists and representatives from the private sector on barriers and incentives for reducing traffic-related air pollution (Hyland & Donnelly, 2015). The findings would provide evidence for developments that could underpin policy and encourage the Scottish population to alter travel behaviour. The study was published in the Journal for Transport and Health. The Figures used in this Chapter have been included in that publication.

Method

The author designed the semi-structured interview questionnaire, identified and recruited the participants, undertook the interviews and analysis, and reported on the findings. The participants were identified on the basis that they represented a broad range of professionals with an interest in air quality. They were drawn from a national air quality working group (Scottish Transport Emissions Partnership – STEP). This group was set up by SEPA (Scottish Environmental Protection Agency) and is responsible for advising the Scottish Government on its Strategy for improving air quality, including the introduction of Low Emission Zones (LEZ). The author prepared and submitted the study protocol and consent forms to University of St Andrews Teaching and Research Ethics Committee, and ethical approval was granted.

The questionnaire for the interviews was piloted with two members of the group and minor adjustments to wording were made. The semi-structured interviews were undertaken by the author in person or by phone and took approximately one hour per interviewee. Information was sought on the interviewees current role in traffic-related pollution reduction, what had been undertaken in their organisation to date, their personal perception of barriers and incentives for change and what they would recommend as a key message to influence change in travel behavior in the Scottish population.

A grounded theory method was used to identify emerging themes (Crowther and Lancaster, 2009). The responses were captured as written notes during the interview and then transcribed on to an excel spreadsheet. A table was developed for each question and populated with a list of key words or phrases that had arisen during the interviews. Words or phrases that were similar were grouped together in common themes (axial coding). When a word or phrase was mentioned it was scored once for each interview even if it was repeated a number of times when discussing the same question in that interview. The total number of times a word or phrase was mentioned across the interviews was summed for analysis.

Results

Nineteen from a possible 22 participants were available for interview. Their responsibilities varied from strategic to planning advice as can be seen in Figure 19.

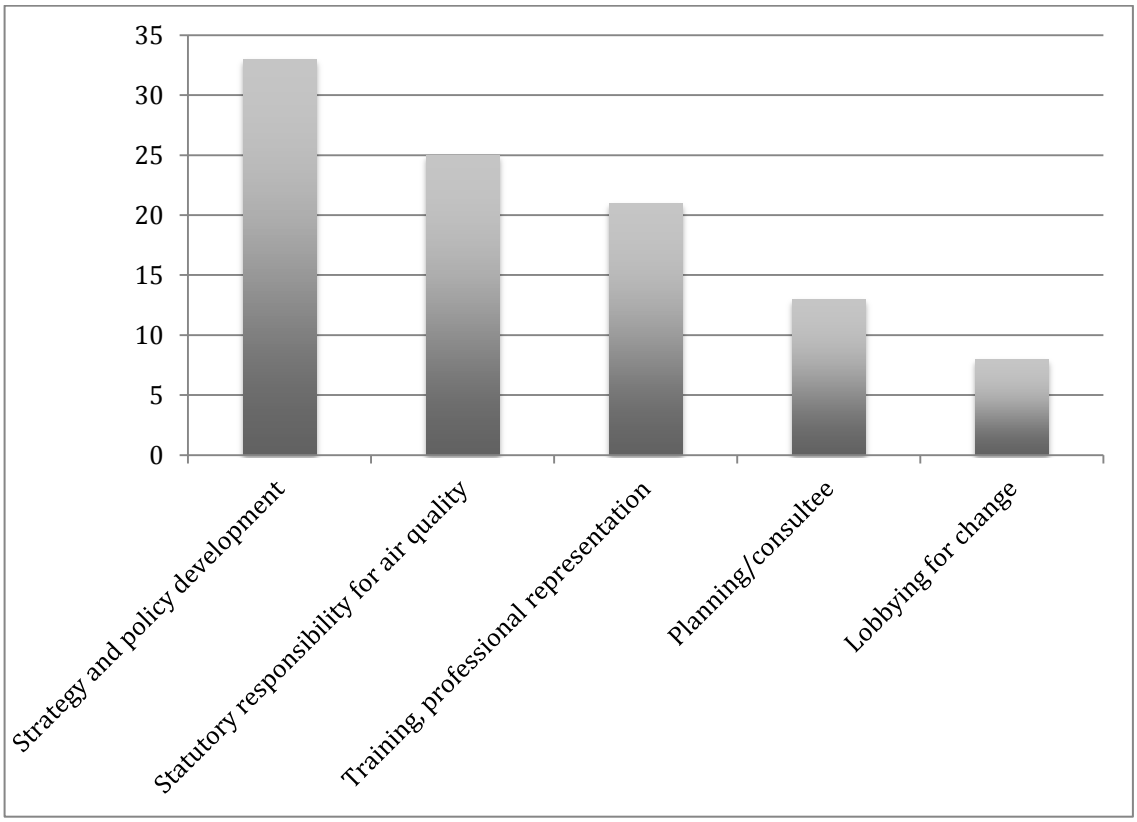


Figure 19: The percentage of responses for each activity in the field of traffic-related air pollution.

The majority of interviewees (50%) had been involved primarily in planning and air quality reporting with fewer involved in direct implementation of air-pollution related improvement initiatives, such as active travel (13%) (Figure 20).

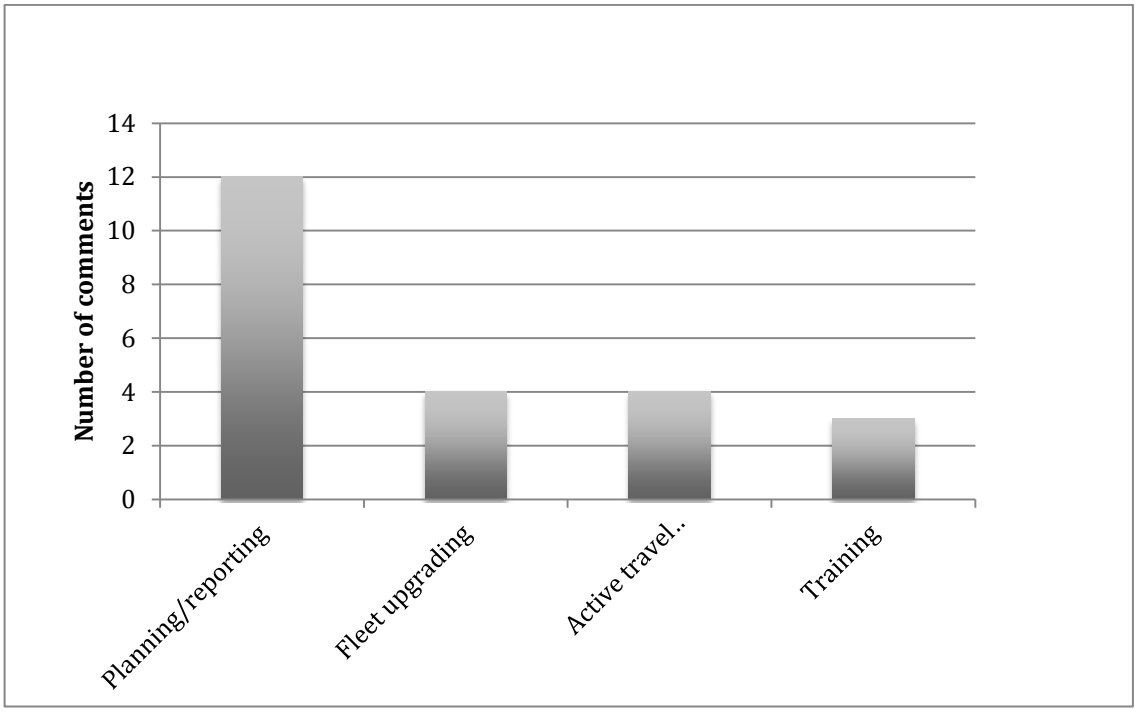


Figure 20: Activities undertaken by interviewees to reduce traffic-related air pollution.

As demonstrated in Figure 21, the most frequent barrier to changing to less polluting travel choices was the perceived lack of commuting options as a result of inadequately integrated urban and rural planning (80%). Interviewees described how this affected core activities of daily living such as travel between residential areas (in particular the growing number of newer out-of-town housing developments) and essential destinations such as shops, schools and employment centres.

The interviewees commented on the poor integration of transport systems (e.g. roads, footpaths, cycle lanes, public transport options) to allow for efficient, timely and low cost travel options. Where public transport options are in place they are often costly, particularly in rural areas or where more than one person in a family is travelling. In such instances, transport by car is often more convenient and cheaper in getting family members to multiple destinations in one journey.

The interviewees suggested that there was a lack of understanding amongst the public about the health risks because of the invisibility of air pollution. Moreover the public were, in general, unaware of the greater risk for vulnerable people, particularly children.

Other barriers included the need for clear transport targets such as the number of people cycling and the length of journeys. There was a perceived lack of political will for change from politicians, given their position is dependent on the voting public, and banning car use is not a vote-winner. A number of interviewees referred to contradictory policies such as the drive for more housing developments in the periphery of towns in conflict with moves to privatise bus services, leading to reduced public transport in less used out-of-town routes. A few interviewees were in favour of hard options such as high parking charges and reduced parking availability to force commuters on to public transport. Finally, there were comments on the need to engage with the public in finding a solution, particularly in light of the lack of uptake of public transport options.

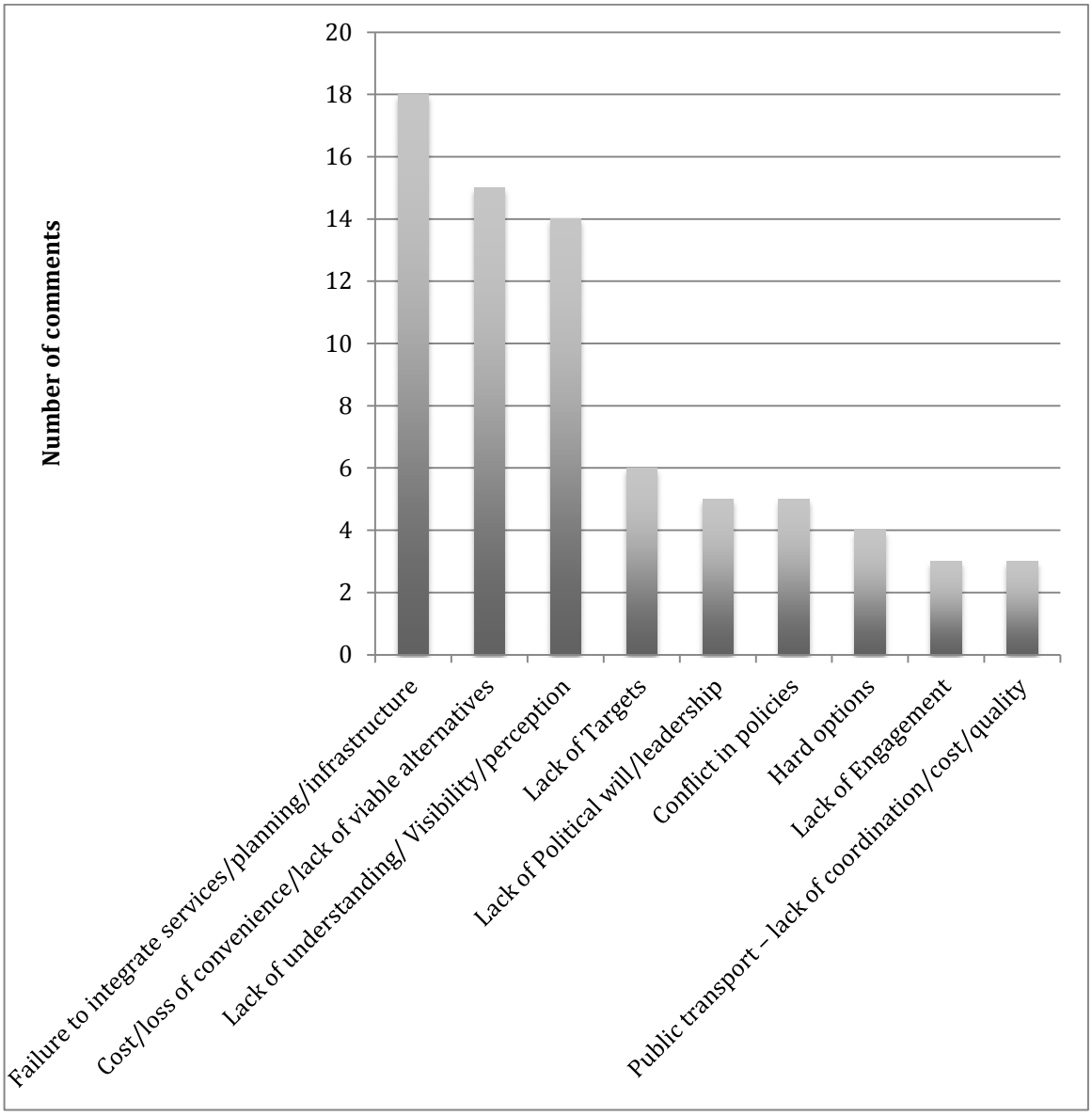


Figure 21: Perceived barriers to change as reported by study participants

The responses identifying incentives for change were very varied (see Figure 22). The most quoted solution focused on improved access to, and use of, public transport through better co-ordination of services and subsidised fares (54%). The suggestion for better public engagement (50%) and for more integrated planning (50%) were seen as almost as important. Some interviewees felt that a focus on the health impact was an important driver for change, particularly where an individual felt they were contributing to the wider good in society by reducing personal car use (36%). There were a number of suggestions for investigating potential financial benefits through an economic analysis of vehicular use versus congestion, and air

pollution in terms of health care costs. Other suggestions included the promotion of travel planning through the internet and encouraging the use of travel apps to alert commuters to travel problems, including air pollution events. This was supported with proposals to promote cleaner travel and a more pleasant environment as a benefit both to the economy and to well-being. Where this fails, hard options such as banning vehicles or making car use difficult could be an effective alternative. There were a number of interviewees who described how improvements in engine technology and a move away from diesel as a fuel to petrol, and even hydrogen powered engines, would be a solution in the medium to longer term. A few suggested that it was time to consider fines for the most polluting vehicles and this would incentivise businesses to invest in newer, cleaner technology. There was mention by a few of the need to be inventive to address the practicalities of business and industry where there is a dependence on vans and lorries for deliveries. Out-of-town delivery depots and transport by rail might offer some solutions.

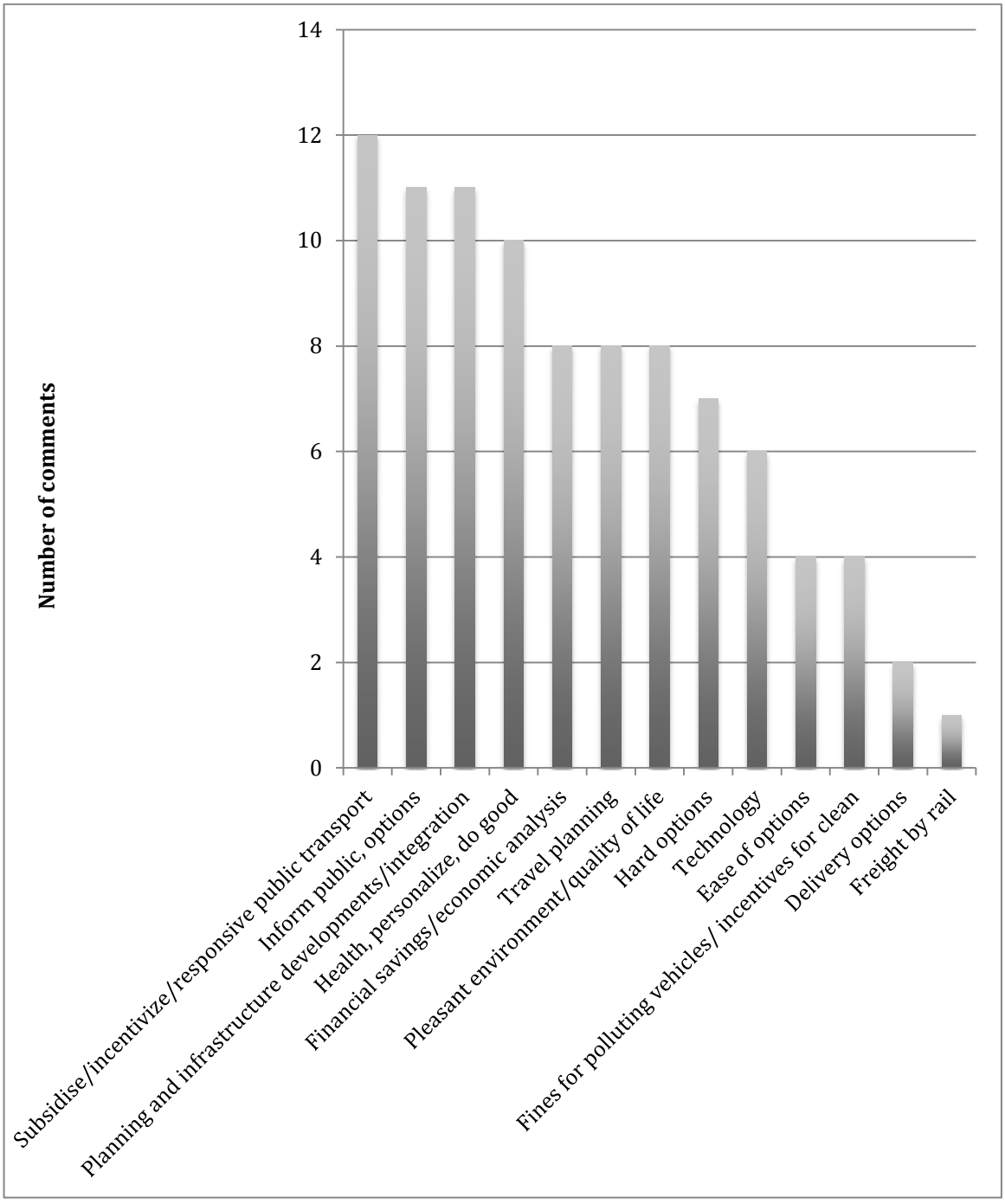


Figure 22: Perceived incentives for change as reported by study participants.

The participants were asked what they believed could encourage people to change their behaviour at an individual level, from motorized to active forms of transport, thereby reducing traffic-related air pollution (Figure 23).

The most consistent theme was the promotion of healthier lifestyles (22%) and cleaner air through increased active travel – walking and cycling. The benefits could be shown as a reduction in ill health for the more vulnerable populations, such as individuals suffering from respiratory conditions including asthma, and also as a personal benefit from increased physical exercise. There was a view amongst the interviewees that a reduction in air pollution and traffic would make for a more pleasant environment (18%). Other themes to underpin a message to reduce air pollution were varied and included promoting cost savings for the NHS through reduced ill health (13%); encouraging social responsibility and awareness of individual contribution to the greater good of society; contributing to the climate change agenda; reducing car accidents by having fewer vehicles on the roads; engaging with media companies to promote a positive image of active transport and low vehicle cities to counter the current image of the car as a clean and luxurious household essential; promoting competition between cities for cleaner air; and promoting an image of cities where people find it easier and safer to move around.

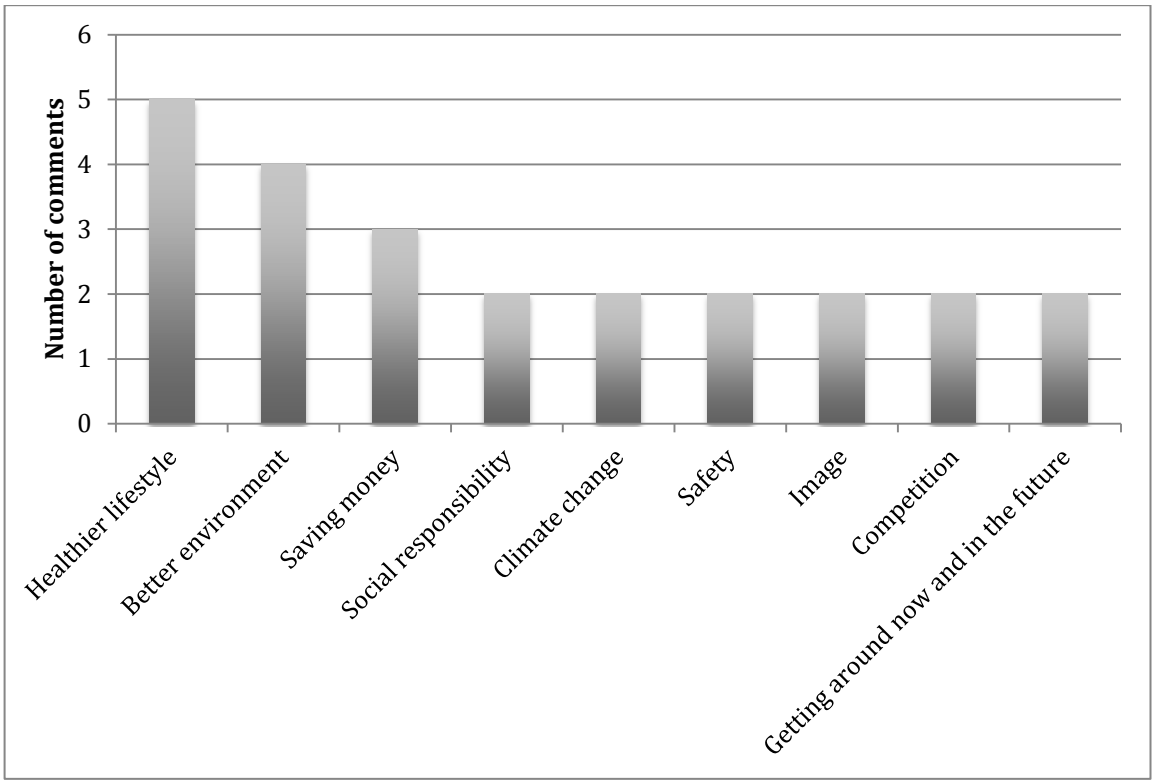


Figure 23: Key themes to encourage behaviour change

Discussion

The study was designed in a semi-structured interview format to allow for specific areas to be addressed through free-flowing discussion. There were some sensitive issues raised where the interviewees indicated that their views were personal and might be considered contentious. However, the assurance about confidentiality and the sharing of the report prior to wider circulation and publication provided sufficient reassurance to allow sensitive issues to be recorded anonymously. Some participants were pleased to have an opportunity to express opinions they previously felt unable to address fully in the wider STEP group.

The study shows that interviewees came from a wide range of professional backgrounds from government to local authority to lobbyist. The results therefore reflect a range of views in addressing this complex issue. However it is noted that the selection of the participants from an existing group may have biased the results to some extent in that the interviewees had been meeting together for some time and may have developed some “group think” around air pollution.

The participants were involved mainly in planning and strategic activities but also had significant control over air pollution regulation in their work in local authorities and fleet management in the public transport sector. They were therefore very experienced at trying different approaches and felt that over time, much had been done to reduce air pollution to current levels. This had been achieved through regulation, fleet management, local planning and public engagement. However, despite improvements in air quality there were still air pollution events that were proving frustratingly difficult to avoid. In almost all areas the air quality exceedances were marginal, but due to historical urban developments and the need to ensure economic sustainability, it was proving very difficult to reduce traffic in these critical areas.

There was agreement that in Scotland, the best option was an approach which encompassed regional and national changes to traffic management given that as much as possible had already been done at a local level. Implementing changes

across Scotland would prevent inequities in any economic impact, i.e. if one town were to restrict traffic it might be detrimental to local businesses because traffic and businesses would move to a less traffic restricted area. A Scotland-wide approach would also see a larger population based air quality benefit as had been suggested in the Scottish (Air Quality) Health Needs Assessment Report (Appendix 1).

The economic argument was further influenced by the requirement to address Scotland's demand for more housing as a matter of urgency, and the need for a road network to support this. While this would place even great pressure on LAs to address traffic congestion and air pollution, LAs do not currently have the necessary powers to determine planning at a regional or national level. One solution would be to encourage the upgrading of vehicles to less polluting engine types. However this is costly particularly for the smaller businesses, and would not alleviate the growing problem of congestion.

These issues could be addressed to some extent, if there were better co-ordination of traffic options to include improved infrastructure for public and active transport (cycling and walking) options. However, such options require investment and political will. Politicians must make a case for change and to do this they need public support if Scotland is to implement traffic-related policies and invest in infrastructure. This case will only be made if there is a clear benefit from change and, at present, the pace of life and the relatively high cost of public transport in many areas mean that using public transport to get to work or school is not seen as a viable option. Transport for goods and services are also driven by convenience and minimal cost. If each travel option is listed against potential limitations it can be seen that in socioeconomic terms, vehicular travel may still be the most popular option (Table 17).

Table 17: Potential socioeconomic limitations, by transport option***.**

Transport	**Speed**	**Distance**	**Capacity**	**Limiting features**
Walk	Slow	1-2 miles	Small	Weather, lack of pavement. Personal safety perceptions.
Cycle	Slow/ medium	1-25 miles	Small	Weather, lack of cycling lane. Personal safety perceptions.
Car	Medium/fast	Unlimited	Moderate	Person carrying capacity. Purchase and running cost.
Bus	Medium/fast	Unlimited	Large	Lack of connections Cost per journey.
Rail	Medium/fast	Unlimited	Large	Lack of connections Cost per journey.
Light goods vehicle/ heavy goods vehicle	Medium/fast	Unlimited	Large	Cost per journey.

*Estimates for illustration only

The participants in the Transport study had considered many options for how their agency or others might contribute to reducing traffic-related air pollution. They made a number of suggestions for change, including both punitive and behavioural measures:

- *Punitive measures* e.g. congestion zones, low emission zones, reduced parking capacity, parking charges.
- *Behavioural measures* such as home working, out-of-town delivery depots, further public transport subsidisation and smart ticketing, re-regulation of public services, daily roadside air quality displays.

These suggestions were subsequently included in *Clean Air For Scotland* Strategy (The Scottish Government, 2015), the Scottish Government strategy to improve air quality. This will be discussed further in Chapter 6.

The survey demonstrated that there is no single approach to improving traffic-related air quality. Participants had undertaken considerable research within their own field for solutions that for the most part, had been implemented. For example, the road haulage businesses have been upgrading their engine models to ensure they are the cleaner Euro standard compliant models.

The participants did however, identify a need to do more to improve health awareness and encourage low polluting travel choices. An example of this might be to include pollution information on televised weather reports and on roadside transport messaging systems. At times of higher pollution travellers might consider alternative forms of transport, car sharing or home working to reduce further deterioration in air quality.

This type of information has already been made available on the internet. Air pollution monitoring data across Scotland, and health indicators (low, medium and high), are made available to the public in Scotland on the Air Quality in Scotland site (http://www.scottishairquality.co.uk/) and in the rest of the UK on the Defra site (https://uk-air.defra.gov.uk/). In addition, people who are susceptible to symptoms when air pollution is high in Scotland, can register for a text alert through the Scottish Know and Respond service (http://www.scottishairquality.co.uk/know-and-respond/). An evaluation of a text alert service for Sussex and for London has shown that users find the service of benefit and have changed behaviour to reduce health effects when they have received warnings of increased air pollution (Smallbone, 2011).

Conclusion

The survey of key stakeholders indicates that a lack of progress in reducing air pollution may be related to the invisibility of the problem both in health and economic terms. This is not unique to Scotland. Despite close partnership working there is a disconnect between planning and development priorities at a national and local level which means vehicular transport is still the most efficient and cost effective option for personal and business transport. Political commitment is needed to align policies and use both hard (punitive) measures and soft (behaviour choice) measures to reduce traffic-related air pollution in urban areas, and to protect and improve health. In addition, air pollution and health impact information must be made widely available in a manner that enables commuters and businesses to make healthier short and longer term travel choices.

Chapter 6
An assessment of policy development and behaviour change

Introduction

This Chapter describes how policy is being used to drive behaviour change and reduce traffic-related air pollution in Air Quality Management Areas (AQMAs). Thirty-nine AQMAs have been declared across Scotland. These have been identified on the basis of air pollution arising from elevated NOx and/or particulates originating primarily from transport.

In an attempt to bring about change through greater collaboration across agencies the Scottish Environmental Protection Agency (SEPA), Transport Scotland and the Scottish Government set up the Scottish Transport Emissions Partnership (STEP) (SEPA, 2013) in October 2012. The remit of this group is to support LAs in achieving the air quality targets through collaboration and stakeholder engagement. The author is a member of this group, representing the NHS, and has been providing epidemiological and health advice since 2013.

The group has evolved slowly, initially providing a platform for agencies to engage and share initiatives. However it became apparent that there was a need to explore more radical options to reduce traffic-related air pollution given the lack of progress in reducing pollution in AQMAs. Therefore STEP took forward work on the development, consultation and implementation of a Low Emissions Strategy (LES) (latterly known as *Cleaner Air For Scotland*, CAFS). STEP reports to the Scottish Urban Air Quality Network (SUAQN) - an overarching steering group responsible for air quality policy development.

The purpose of *Cleaner Air For Scotland* is to present the evidence and an action plan for improving air quality, whilst at the same time securing sustainable economic growth in Scotland (The Scottish Government, 2015)

The strategy is based on two core themes:

- improvements to modelled air quality data;
- guidance to assist LAs in establishing Low Emissions Zones.

The development of the strategy included a review of the literature on air quality and health, and on behaviour change (Cowie *et al*., 2015); presentations from LEZ operators in the UK and across Europe; consultation workshops; the establishment of working groups to inform the strategy; publication of the consultation document; review of the consultation comments, and publication of the final strategy. The author provided specific comments on the chapter on Transport, to ensure the strategy linked with the Scottish Government's Cycling Action Plan for Scotland (2013) and the National Walking Strategy (2014).

The consultation on CAFS resulted in 305 responses of which 36 respondents made a comment on health. Of these, most comments suggested either that morbidity and mortality would be difficult to measure and could not be used as key performance indicators or, that there should be more detail on morbidity and mortality as key performance indicators. These comments reflect both the knowledge amongst some, and lack of understanding amongst others, of the difficulty in expressing health effects for traffic-related air pollution in a meaningful way given the complexity of factors influencing health as described previously.

Respondents also suggested that inequalities should be addressed specifically within the document. As the Scottish (Air Quality) Needs Assessment study demonstrated, this is less relevant in terms of air pollution areas in Scotland compared with other areas of the UK (Chapter 4). Furthermore, public transport use is already greater in areas of deprivation in Scotland, with 41% of people using public transport to travel to work compared with 27% in the least deprived areas (The Scottish Government, 2017).

However, there is an opportunity for CAFS to shift the mode of travel from vehicular to active transport and thereby improve health. Scotland is already well behind in

walking and cycling compared with some European countries. In a European city study (EEA, 2013) between 30% (Stuttgart) and nearly 70% (Amsterdam) of people walked or cycled, 10-15% travelled by public transport and 35-55% travelled by vehicular mode. In Scotland, data from 2012 show that walking accounted for 23% of journeys, cycling 1%, public transport 20% and car or van accounted for 61% of journeys (Transport Scotland, 2015). However, the data are not directly comparable given that travel distances are not recorded so it is not possible to say that active travel and access to public transport are available to the same extent in Scotland, particularly given that 18% of the Scottish population do not live in cities (The Scottish Government, 2015a) compared with only 10% in the Netherlands (Trading Economics, 2017). This is supported by the evidence that walking, bus and rail commuting is higher in urban than rural areas (Figure 24).

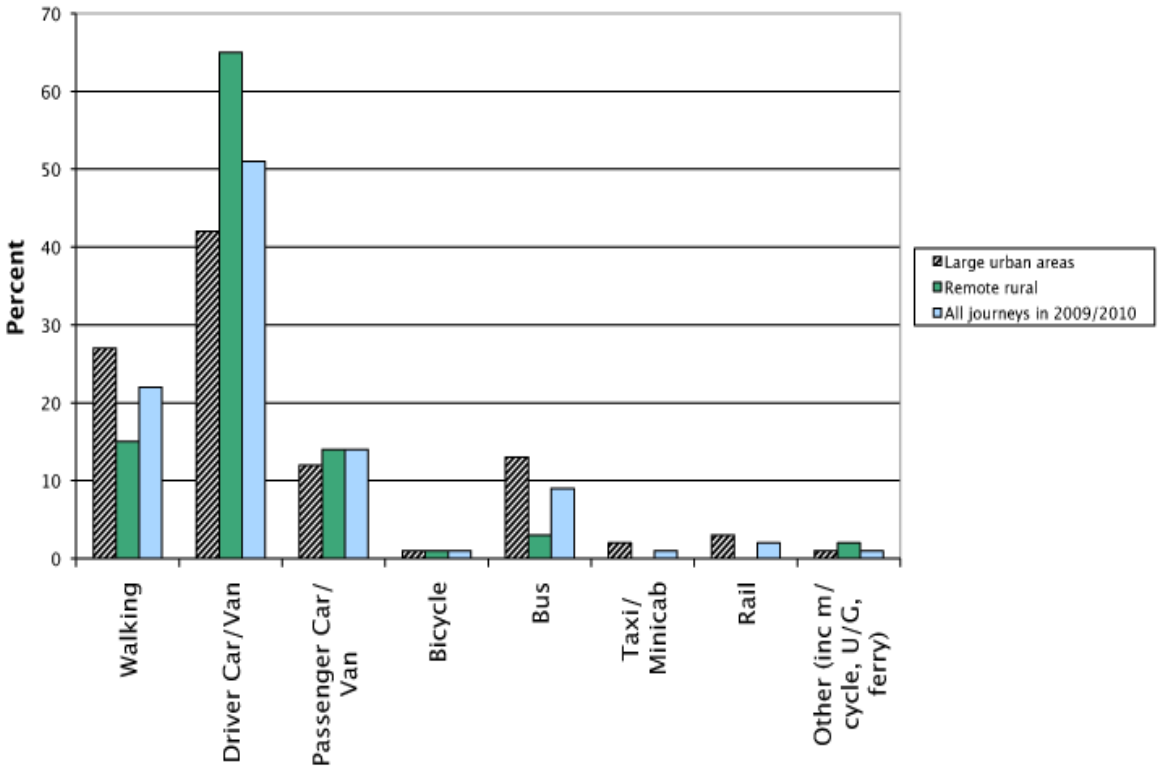


Figure 24: Main mode of travel - large urban, remote rural and Scotland, 2009/2010. (Transport Scotland, 2017)

Given the evidence that active travel options are not the main mode of travel in Scotland for a variety of reasons (weather, lack of cycle lanes, distance to be travelled – urban vs rural journeys), any strategy to increase uptake will have to demonstrate significant socioeconomic benefits. CAFS promotes active travel as one of the key options to support improvements in air quality. If progress is to be made in this area, it was worth reviewing CAFS against criteria for effective policy development to assess if this strategy might be successful in reducing air pollution and increasing active travel. This assessment is described below.

Method

The first phase of the assessment involved reviewing the literature for a validated behaviour insight tool commonly used for policy assessment. One such tool identified was MINDSPACE (Dolan *et al*., 2010), developed by the UK Government Behavioural Insights Team. It is a behaviour change checklist for policy makers to assist in achieving outcomes by focusing on behaviour rather than regulation, to achieve compliance with government policy. The checklist addresses the **M**essenger, **I**ncentives, **N**orms, Salience, **P**riming, **A**ffect, **C**ommitment and **E**go. On the basis that this is a validated tool it was used to evaluate the CAFS. The observations were recorded in Table 19.

Results

The analysis of CAFS against the MINDSPACE tool revealed the following:

The **M**essenger is primarily the Scottish Government.

The **I**ncentives have been driven by potential financial penalties imposed by the European Commission.

The **N**orms could be altered if policies and services were to be better aligned.

Defaults require redesign of infrastructure to facilitate improved access to services.

Salience – there is a need to support new technology in transport management and means of travel.

Priming - There is a need to improve public understanding of air pollution.

Affect – there is a need to promote positive emotions around cleaner travel.
Commitment – policy-makers should demonstrate consistency of message and ensure policy alignment to deliver improved air quality.
Ego - there is some evidence that a small group of champions are altering behaviour to reduce travel-related pollution for the benefit of society.

Table 18: Evaluation of CAFS development against the MINDSPACE tool.

Criteria (Institute for Government, 2010)	**Action proposed in CAFS**
M*essenger - we are heavily influenced by who communicates information.*	The LES is led by the Scottish Government.
I*ncentives - our responses to incentives are shaped by predictable mental shortcuts such as strongly avoiding losses.*	There will be support for retrofitting buses to improve emission standards. The regulations affecting buses will be reviewed to reduce restrictive policies and improve economic viability of services.
N*orms - we are strongly influenced by what others do.*	Businesses are encouraged to develop travel plans to support employees adopt cleaner travel options. This links with the national Walking and Cycling Strategies. An air quality promotional campaign is proposed.
D*efaults - we "go with the flow" of pre-set options.*	CAFS focuses on data capture for both air quality and traffic management. The aim is to support LAs in assessing the need for LEZ as a regulatory action to improve air quality in AQMAs.
S*alience - our attention is drawn to what is novel and seems relevant to us.*	The action plan includes reference to improvements in the national plug-in road map for electric vehicles, and in supporting the development of new technologies, such

	as hydrogen as a fuel.
P*riming - our acts are often influenced by sub-conscious cues.*	Providing wide public awareness will lead to travel behaviour change.
A*ffect - our emotional associations can powerfully shape our actions.*	The driver for change is the risk of ill health at an individual level, or through a sense of responsibility for how our actions affect the health of others.
C*ommitments - we seek to be consistent with our public promises, and reciprocate acts.*	CAFS makes references to links across policies and alignment between local planning and transport links, with the aim of reducing vehicular transport.
E*go - we act in ways that make us feel better about ourselves.*	CAFS makes recommendations for an alignment with existing active travel and environmental strategies such as the Greener Scotland communication campaign, Paths for All, National Walking Strategy, and Cycling Action Plan for Scotland.

Discussion

CAFS combines personal, social and legislative approaches in the recommendations for achieving change. From the MINDSPACE evaluation it can be seen that there are some areas where CAFS is not well developed and which require further work – **N**orms, **P**riming, **A**ffect, **C**ommitments and **E**go. Co-incidentally these are areas the Transport study identified as barriers, i.e. encouraging behaviour change and alignment of policies and planning. This is discussed further below.

At every stage in the development of the strategy, attempts were made to include private and public sector bodies, including campaigning organisations and members of the public. CAFS implementation will be led by the Scottish Government but

CAFS steering group does not include the private sector or lobbying groups. It will therefore, be important to identify champions in different communities and business sectors to take on a role as **M**essenger and appeal to specific groups.

A significant driver for change in the UK is the infraction penalty imposed by the European Commission for breaches in air quality objectives (Defra, 2014). This has been an important driver for change, particularly where the health data is unconvincing at a local level. The situation may change post-Brexit, but in the meantime financial penalties should provide a strong **I**ncentive for investment in cleaner travel options. However it may be that the infraction penalties are less than the cost of change and if so, these will fail to be effective drivers for change.

CAFS proposes that there should be additional support to bus operators to retrofit buses with cleaner technology, and for a review of legislation to make bus routes more economically viable. However CAFS does not address the need to **I**ncentivise the public through subsidies for bus and rail passengers. Even with such subsidies, there may not yet be sufficient incentive for change from car and road haulage, to active travel or bus and rail options. Significant disincentives to private vehicle use may be required before public transport and active travel to become more attractive options. Such disincentives might include increasing tax on fuel, or penalties for more polluting engine models in AQMAs.

The strategy goes some way to addressing behaviour change by supporting adjustment of group and population based **N**orms by advocating travel planning. This might be effective where the employer, school and business travel plans are backed up by changes such as start/finish times tied into public transport options, working from home, and greater flexibility in service delivery options etc. Although travel planning is a requirement of schools, in most LA areas in Scotland there is still much to be done to encourage parents for example, to consider the alternatives to the school run by car. Moreover, there needs to be greater **C**ommitment to connecting policies and planning so that travel options include active travel opportunities through safe and accessible walking and cycling routes.

The strategy is heavily dependent on areas where good communication will be key – **P**riming, **A**ffect, and **E**go. The CAFS steering group is preparing an air quality promotional campaign to raise awareness. Although this will include support for the Walking and Cycling action plans, it is as yet unclear what the key message will be and to whom this will be targeted.

Commuters and businesses will choose the option of least resistance or greatest gain – the **D**efault option. CAFS is heavily weighted towards actions that improve air quality monitoring and the implementation of LEZ rather than encouraging or legislating directly for change. It is assumed that providing more accurate air quality data will result in the establishment of LEZ in AQMAs and this will then drive widespread change in travel behaviour. This may be based on an assumption that the public will make a choice to use active or public transport options rather than the car because of cost. Theoretically this would in turn, lead to an increase in the use of public transport and bus companies might reduce costs and extend and align travel routes. Likewise, industry and business would be forced to change their method for transporting goods because of prohibitive costs of travelling through a LEZ. However, **D**efaults require more than information and financial penalties. To achieve change the default mode will require a redesign of infrastructure to facilitate improved access to services. This would include better facilities for walking, cycling and public transport rather than investment which supports car or LGV/HGV transport modes. This will be explored further in Chapter 7.

Improvements in engine design might provide opportunities to reduce air pollution in the same way that engine redesign has resulted in a reduction in emissions of lead (unleaded petrol) and carbon monoxide (catalytic converters). The public and industry are showing a growing interest in electric and hydrogen fueled vehicles but currently the cost and access to refueling stations continue to make such vehicles unviable for most journeys. When the public and businesses have a **S**alient interest in this area, the vehicle manufacturers see this as an opportunity for market share growth. Industry marketing campaigns have long shaped public opinion and, if

managed through regulation, this may be an opportunity to address air quality in the medium to long term.

Commuters need support to review travel options. In some places across Europe such as Stuttgart (DW, 2016) and recently London (BBC News, 2017), there have been public messaging campaigns during episodes of higher pollution. This form of **P**riming provides an opportunity for commuters reconsider travel options in the short and longer term. The CAFS action plan promotes the use of variable roadside signage to alert commuters when air pollution is high.

The media has been instrumental in highlighting the impact on health of air pollution. Likewise CAFS has evolved in response to strongly held views across sectors from health campaigners to businesses, all conscious of how the media is portraying air pollution. At present the **A**ffect is generally negative with fear and concern about ill health, increasing regulation, cost and inconvenience. There is some way to go before this can evolve into positive emotions associated with the convenience of active travel, cleaner environments in cities and reduced cost low polluting options. In the main, journeys are made because of a need to reach a destination. Furthermore, car manufacturers promote the journey as a pleasant experience and tend to play down issues such as vehicle emissions, traffic congestion or air pollution (ACEA, 2017).

CAFS refers to the need for **C**ommitment across agencies. For example, the action plan highlights the need for planning departments, businesses and the health sector to ensure that policies are aligned and that initiatives are subject to impact assessments for air pollution (CAFS, 2015). This will be an important step in ensuring that planning applications for e.g. new housing developments or biomass plants, take into account the impact these will have on air pollution and health.
A successful air pollution reduction policy should build on the **E**go of commuters and businesses and reward the pursuit of cleaner travel options for the benefit society. There are many travellers who do opt for active travel options and some businesses that do invest in cleaner vehicles as priority. However, for many commuters, the

range of options is limited due to time pressure, cost of transport, lack of vehicle free routes between destinations, and distance.

There is an evolving school of thought around how to influence behaviour via policy. As part of the Scottish Urban Air Quality Network (SUAQN) work programme a study was undertaken to identify behaviour change models (Cowie, *et al*, 2015). The report concluded that in terms of air quality, behaviour change is most likely to arise from the implementation of road charging initiatives and reviewing taxation to encourage the use of low emission vehicles. In addition, the provision of information to support personal travel planning and changes to road infrastructure to improve perception of safety, particularly at crossings, may be influential in changing behaviour.

The behaviour study (Cowie *et al*., 2015) however, reviewed studies in the field of health psychology and transport. It did not take into account the need to consider the wider aspect of policy development and the lessons from economic, social and environmental policy development and implementation. Whilst it would not be feasible to undertake a full review of behavior change strategies in this Chapter, some key behavior change models have been identified. These should assist in determining how effective CAFS might be in to reducing transport-related air pollution and protecting the health of Scottish residents.

One model explaining behaviour change processes, which includes reference to external, internal and social factors, is the Social Marketing Foundation Behavioural Economics Approach (Collier *et al*., 2010). This is relevant to CAFS in that social marketing may be more suited to air pollution reduction than individual psychological influences. Social marketing addresses the wider determinants of health (Whitehead, 2001) more effectively than traditional health education messages, which focus on individual behaviour in isolation, rather than in the context of the world we live in. Behaviour will only change if the change is perceived as easier, cheaper, unconscious, increases personal satisfaction or provides some form of personal gain (Figure 25). The public is generally aware of the health risks

associated with traffic-related air pollution and this has been the subject of much media attention in recent times. Therefore, in terms of external factors, many individuals are making an effort to reduce their contribution to air pollution, changing travel habits and believe they are doing good (effort). This is the common approach to policies to bring about behavior change (red dotted box in Figure 25). However, this has to be balanced by the pressures against change such as the higher cost of petrol vs diesel, car travel is easier and pleasant (reward, cognition), most people travel by car (norms). To effect change there is a need to redress the balance towards making car travel costly and inconvenient and active transport inexpensive and convenient, as well as socially rewarding.

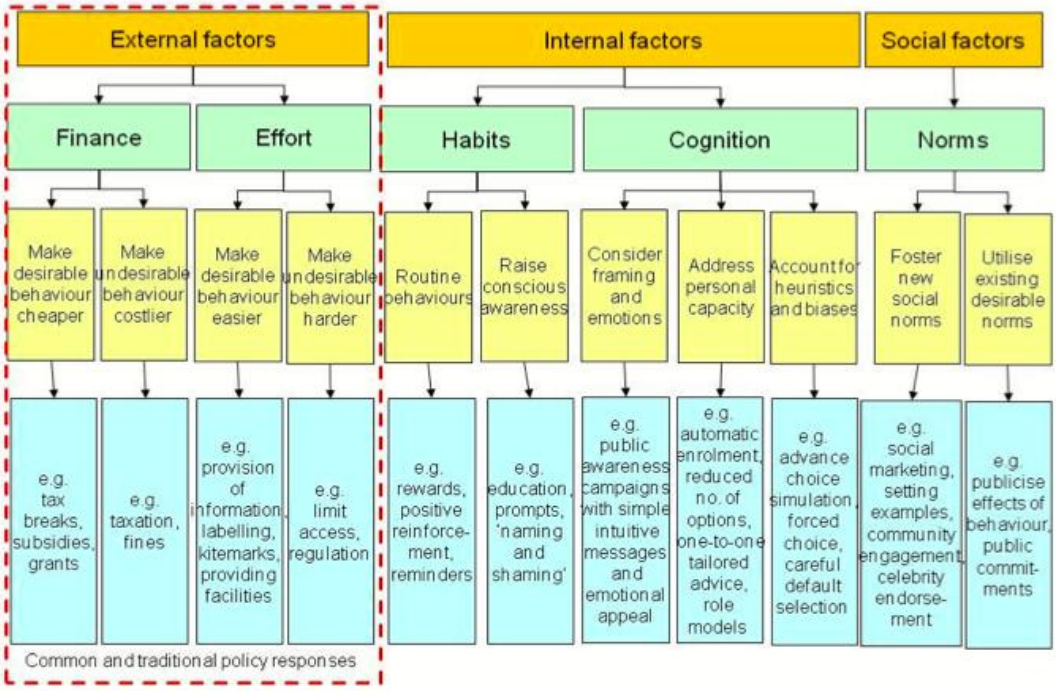


Figure 25: Understanding and influencing behaviours (Collier *et al*., 2010, p38)

CAFS focuses on the penalty system through proposals to increase cost and inconvenience of car travel with the introduction of LEZ. However there is still an absence of emphasis on rewards associated with cleaner active travel options since these require longer term planning and policy alignment.

If CAFS is to be successful, behaviour change is needed at both individual and societal level. The MINDSPACE tool provides a model for addressing this with a combination of actions at a number of levels – Going with the Grain: Explore, Encourage, Engage, Exemplify, Enable, Evaluate (Figure 26).

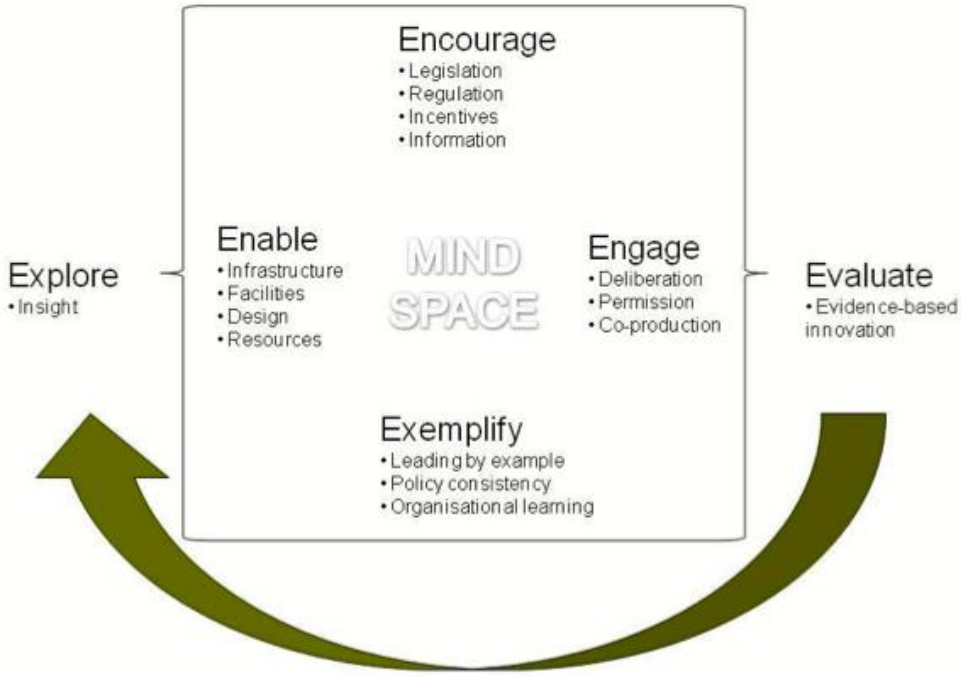


Figure 26: Going with the Grain, MINDSPACE (Collier *et al*., 2010, p40)

The first step is to Explore and gain a full understanding of the situation. In the case of air pollution this would include not only reference to the impact of air pollution on health, the levels of air pollution and the underlying causes, but also the awareness of the willingness of the pubic and businesses for change.

The next step involves looking at what has been and what could be done to Encourage change. This will include incentives to choose cleaner options because it is cheaper and healthier, and disincentives to vehicular travel such as cost and social disapproval. In CAFS, LEZ are proposed as a disincentive to use vehicular travel and an incentive to use cleaner vehicles. However, given the LEZ will affect very few commuters and most will continue to use cars to travel outwith AQMAs, there is a need for more incentives for active travel and cleaner vehicles.

The Enabling factor arises when planning and transport are aligned to make clean travel an easier option. This means greater investment in cycle lanes, footpaths and public transport connections.

The strategy does address Engaging with businesses through regional partnerships. As at May 2017 the communications campaign has yet to be agreed and the extent to which this will target the appropriate groups with the most effective messages is yet to be seen.

There is a need to lead by Example and the strategy does require LAs to have travel plans in place. As employers this will cover a large proportion of the population and affect families through school travel plans and businesses as suppliers.

Finally the strategy will need to be evaluated so that lessons learned can inform future policy direction.

Conclusion

The analysis has demonstrated that CAFS is strong on disincentives for vehicular travel and has a good track record of wide engagement. However there is little in the strategy to incentivise the public and businesses to change behaviour in a way that rewards positive actions and ensures cleaner travel options become the norm. The focus is on transport data capture and LEZ. Given the problems with accurate air pollution monitoring and the range of assumptions that prevent robust assessment of the effect of air pollution on health outcomes (Chapter 5), it is questionable whether or not CAFS will improve health. There is considerable work to do to change public and business attitudes in the absence of hard evidence of a local health impact. In addition, substantial investment is required for urban redesign to support active travel choices and achieve health benefits. Chapter 7 will explore the socioeconomic benefits of the LEZ in the context of CAFS, in more detail.

Chapter 7
A socioeconomic analysis of the proposed Low Emission Zones

Introduction

There is a general consensus that current levels of traffic-related air pollution are harming health. However, interestingly this did not show up in the local Scottish studies discussed in Chapter 3 so it is difficult to demonstrate that traffic-related air pollution is harming the population in Scotland. It is widely acknowledged that a lack of evidence is not evidence of a lack of effect. It may be that the data used to measure an effect in Scotland are not powerful enough to demonstrate an effect. It may be that despite this absence of evidence of a health impact at a population level, air pollution episodes may give rise to symptoms in vulnerable individuals at times of high pollution. However, the impact of air pollution on vulnerable people is difficult to monitor given the limitations in undertaking robust assessments of exposure at an individual level, and on an ongoing basis.

Therefore it is important to improve the evidence base for air quality and take action to protect vulnerable people. This is the driver for *Cleaner Air For Scotland* (CAFS, 2015) and was discussed in detail in the previous chapter. The CAFS work programmes are focusing on improvements to air quality data collection and modeling, and reducing air pollution in the most polluted areas (Air Quality Management Areas - AQMAs) through the establishment of Low Emission Zones (LEZ). The data modeling and LEZ work will provide a framework to enable LAs (Local Authorities) reduce traffic-related emissions through improved traffic management and road design, supporting vehicles with better engine technology and encouraging a greater uptake of active transport options. However all this comes at a cost. The benefits are potentially wide ranging and a present theoretical but may include reduced congestion, increased investment in technology and hence employment opportunities, and better physical and mental health through the uptake of, or increase in physical exercise. Within this context the purpose of this chapter therefore, is to consider the balance of costs in a socioeconomic assessment of

introducing LEZ. A socioeconomic analysis is an analysis of how the health and well being of society may be affected by economic changes.

Method

The socioeconomic assessment sought to address two questions:

1. How much will it cost to make improvements in air quality to deliver levels below guideline limits?
2. Might the opportunity cost of making these improvements result paradoxically, in deterioration in health and wellbeing?

Much of the information required for this analysis is not published in academic journals, so information was collected from an internet search for reports on the cost of implementing a LEZ, and evaluations of active travel initiatives. In addition, the minutes from the STEP (Scottish Transport Emissions Partnership – a group of experts in traffic management and air pollution) were reviewed to identify the social and economic impacts of LEZ. This provided background to CAFS and supported an interpretation of the assessment.

The review identified reports on estimated and actual costs for implementing a LEZ in the UK, and these data were used to estimate the costs for Scotland. If LEZ are to be implemented it is proposed that these will come into force in four cities – Glasgow, Edinburgh, Aberdeen and Dundee. Businesses and commuters may avoid areas with a LEZ so the aim of a multi-city approach to ensure so that no area is disproportionally economically disadvantaged.

The benefits from a LEZ may arise from not just from a reduction in air pollution but also from associated consequences such as an increase in the uptake of active travel. The study sought to identify the wider costs and benefits of LEZ and quantify, where possible the opportunity costs.

In order to estimate the cost of reducing air pollution to levels within EU guideline levels, information was sought on the extent of air quality exceedances in Scotland.

The data on exceedances was then used to prepare an estimate of what level of investment might be required to achieve the reduction to meet EU guideline levels.

Not all air pollution arises from traffic so changes to transport systems might not bring about the required reduction in air pollution. For the purpose of this analysis the transport contribution and the worst case scenario for air pollution from transport, was used in calculations.

Baseline costs for the current health impact are calculated from modelled air quality data and data on YLL (Years of Life Lost) and sickness absence attributable to traffic-related air pollution. It is recognized that this does not reflect personal exposure or the differential impact on more vulnerable people, but this is currently the basis for most of the published health-related population studies.

Results

1. *How much will it cost to make improvements in air quality to deliver levels below guideline limits?*

The potential financial cost of air pollution

In the UK it has been estimated that air pollution from particulates results in a health impact in terms of a loss of life expectancy of about six months, with a financial cost of around £16 billion per annum (Defra, 2015). However, this is based on health and air pollution models reported by Gowers (2014) and, as discussed previously, the evidence on health impact in Scotland is not consistent with the findings in this report. The results from a more detailed analysis, including socioeconomic impacts based on Scottish data, are reported below.

The potential socioeconomic impact of LEZ

The theoretical risks and benefits of LEZ are presented in Figures 27 and 28. These were identified from a review of the STEP meeting minutes available on the internet (The Scottish Transport Emissions Partnership, 2017). As listed, the main risks might arise from increased costs to business and consumers from vehicle retrofitting

or renewal, emission penalties and reduced access to key areas. The potential benefits include direct health benefits from clean air and increased active travel, as well as from a reduction in noise pollution and ultimately more pleasant environments.

- Banning vehicles has a negative effect on local economy by making deliveries and access to shops and services more difficult, time-consuming, costly and stressful.
- Costs of setting up and running a LEZ are substantial – air monitoring, vehicle registration system, administration of penalties.
- Vehicle emissions are higher than factory predicted therefore there would be less of a reduction than anticipated.
- LEZ may shift congestion and pollution to other areas.
- Social exclusion for residents who are dependent on private transport to engage with family, friends or services.
- Increase in social hardship as greater household spend on public transport costs in addition to fixed costs for car.

Figure 27: The potential risks associated with LEZ

- Reduction in ill health and premature mortality.
- Reduction or banning vehicles creates a more pleasant environment – quieter, less noise, less stress, reduction in accidents.
- Increase in internet shopping and home deliveries allows more time for leisure activities.
- Opportunity to invest in technological developments to improve engine operation as well as more rapid turnover of vehicles could lead to increased employment, training and thereby improved life circumstances.
- Reduced congestion and air pollution in LEZ.
- Increase community engagement through more opportunities for walking, using public transport, car sharing

Figure 28: The potential benefits of a LEZ

The socioeconomic analysis is based on reported costs and benefits from existing LEZ. London was one of the first cities in the UK to establish a LEZ. The London Low Emission Zone feasibility study estimated that the improvement in air quality

should result in estimated health benefits worth £100m (Watkiss, 2003). This was based on a predicted reduction in air pollution of 23% PM_{10} and 19% NO_2. Reports for data to 2010 show that there has been little, if any, change in air pollution in London (Deamley, 2012).

Not all air pollution arises from sources within the UK so transboundary emissions may be undermining the effectiveness of LEZ. At a televised review of air quality by the UK Environment Audit Committee (2014) the Panel asked a group of experts if the Mayor of London's Air Quality Strategy had been effective. The Panel reported concerns about the lack of progress. For example:

"No – the LEZ is not effective, as it fails to target some groups of key polluters." Alan Andrews, Health and Environment Lawyer, Client Earth.

"It was a worthwhile exercise, but it is not 100% effective." Mike Galey, Chair, Environmental Industries Commission Air Quality Working Group.

When the panel of experts was asked why there had been little progress, Professor Alastair Lewis, Deputy Director of the National Centre for Atmospheric Science commented that:
"Transboundary effects are an important consideration in the case of the larger urban centres. Pollutants emitted from outside the LEZ could drift into the LEZ and undermine its success."

Transboundary emissions contribute significantly to air pollution levels. It is estimated that 50% of $PM_{2.5}$ and 60% of NOx are transboundary emissions (Scottish Government, 2015b).

Traffic contribution to air pollution in Scotland
Transboundary emissions contribute to local air pollution but cannot be managed by LEZ. Therefore to make a fair assessment of the benefits of LEZ this contribution

need to be factored into the socioeconomic analysis by removing the transboundary element from the baseline air pollution measures.

Baseline air pollution levels are measured in Scotland through 16 air monitoring stations reporting NO_2 levels and 15 stations reporting PM_{10} levels. The maximum annual mean level at any of the Scottish air monitoring stations in 2013 for NO_2 was 65µg/m^3 (Glasgow Centre) and 23µg/m^3 for PM_{10} (Ricardo-AEA, 2014). To reduce air quality to below World Health Organisation guideline levels would require a reduction in the most polluted streets in Scotland of up to 25µg/m^3 NO_2 and a reduction in PM_{10} of up to 3µg/m^3.

Traffic contributes up to 40% from NOx and 20% PM_{10} (Scottish Government, 2015). Whilst the actual pollution level is not necessarily the combined sum of these figures since the same sources provide a mix of pollutants, the worst case scenario is that 60% of air pollution is attributable to traffic. Based on this estimate a *pro rata* traffic-related contribution might result in a reduction of 15µg/m^3 in NO_2 and a reduction in PM_{10} of up to 1.8µg/m^3 in the most polluted areas.

To assess what the financial implications might be for reducing air pollution to guideline levels the research sought examples of where traffic management measures reported on the outcome in terms of air quality improvements. The Aberdeen the transport feasibility study (Aberdeen City Council, 2006) was one such study in which air quality modeling data was collated to assess the benefit of transport management options to reduce air pollution. The study reported that without any change in traffic management, three city centre sites would fail for NO_2 and none would fail for $PM_{10.}$ The national downward trend in air pollution, due to stricter industrial regulations was noted at that time. However this alone would not be sufficient to comply with air pollution objectives without taking action to address traffic emissions.

The feasibility study then applied air quality modeling for a proposed road redesign (a peripheral ring road) and estimated that this would improve NO_2 for two out of the

remaining three sites. PM_{10} levels at the 2005 level would continue to pass in 2010. However, since 2005 the air quality guidelines have changed and become more restrictive in Scotland, reducing PM_{10} levels from an objective of 50µg/m^3 to 18µg/m^3. On this basis ten sites would fail for PM_{10} in 2010 despite an ongoing downward trend for PM_{10}. Furthermore the proposed peripheral route would result in a PM_{10} reduction to guideline levels in only two sites. The remaining sites would see a decrease in PM_{10} of 1-2µg/m^3 taking them down to a level of between 18-26µg/m^3 but this would be insufficient to meet new guideline levels. Furthermore, background levels were reported between 14-17µg/m^3. With more streets included the AQMA there were fewer options for traffic re-direction from the most polluted streets and solutions to meet guideline levels would be potentially more costly for a very small adjustment in air quality.

Costing a Low Emission Zone (LEZ)

In a costing exercise for a LEZ there are many variables to consider and it is difficult to quantify exact costs and benefits in monetary terms. Table 19 lists the information available from studies on LEZ planned, or already in place, across the UK. Some of the costs are based on budget allocations to areas such as feasibility studies, and on hardware investment to monitor traffic and air pollution. Other costs are dependent on changes in behaviour and this will vary over time. For example, initially some vehicle owners may consider it cheaper to pay a fine for entering a LEZ with a higher polluting vehicle, rather than invest in newer and cleaner vehicles or retrofit clean engine technology. Other drivers may take a longer route to avoid the fines, but this may result in increasing pollution in previously cleaner areas. The most difficult costs to identify are the costs of any consultation process, policy development and expenditure to cover fines and vehicle upgrades. However, a rough estimate suggests that based on costs for London and assuming Scotland has roughly the same population, setting up a LEZ might cost between £6-10m for LAs and £64-135m for HGV operators. The LA costs might be offset by revenue from fines of between £1-4m.

Table 19: Cost data for a LEZ in Scotland.

Cost base	Cost
LEZ feasibility study	Range from £15 000 (Horsham District Council) to £120 000 (Bradford City Council) (BVRLA, 2015).
LEZ consultation	This includes time by a range of stakeholders and is impossible to quantify.
Investment in hardware to monitor traffic, link to DVLA info and administer charges	This depends on the number, type and maintenance of monitors; administration costs in terms of direct staff and indirect costs of all agencies. London LEZ estimated for manual scheme - £2.8m to set up and £4m pa running costs (Watkiss, 2003). Where congestion charging cameras are used then an automatic scheme (preferable) would cost £6-10m set up with running costs of £5-7m pa. Estimated revenue from fines ranges from £1-4m pa. The scheme when approved was not expected to be self-financing.
Investment by road users in cleaner vehicles.	Determined by current vehicle emissions and alternatives. London LEZ estimated costs for HGV operators nationally at £64-135m.
Charging scheme	Cost recovery depends on a balance between operators' willingness to pay fees or to pay for the upgrade of vehicles. 1. If there are few fines then the cost to the LA is high (little cost recuperation despite investment) and the cost to the vehicle operator is high to upgrade vehicles. 2. If there are many fines the LA costs may be covered; the costs to the operator will be less but not nil – the vehicle will enter the zone but the fine may be less than the cost of upgrade - and there will still be an air pollution effect. 3. If the operator takes a different route there is less

	money for the LA, less cost for the operator (longer distance but no fine and no upgrade) – air pollution would be moved around but not reduced.

As a key part of a cost benefit analysis, Bowkett and Harris (2010) have suggested that a cost effectiveness analysis of the main cost drivers is an essential aspect in an option appraisal. In this approach the cost of each element is graded against the predicted reduction in air pollution. Since the vehicle type (predominantly buses and HGVs) is a key driver for emissions, some feasibility studies have considered and costed this specific component of a LEZ. An example of this is the comprehensive cost effectiveness and cost benefit analysis that was undertaken for the Leeds LEZ proposal (Highways and Transportation, 2014). In this study the authors apply cost abatement guidance from Defra modeling to a range of options for reducing NO_2 levels in the city.

Concerns over claims about emission abatement for newer vehicles have come to light in recent years. There is now published evidence that real world emissions from Euro standard vehicles are higher than predicted. A recent study shows that due to vehicle loading, driver acceleration and braking behaviour, engine temperature, driving conditions and engine design, factory emission assessments are not an accurate reflection of real world emissions (European Commission, 2013). In Figure 28 below it can be seen that the expected NOx emissions decrease and the NO_2 emissions remain low with improvements in engine design. However, in reality (graph on the right), there is little change in NOx emissions and an increase in NO_2 emissions in real world operation with the supposedly improved engine design.

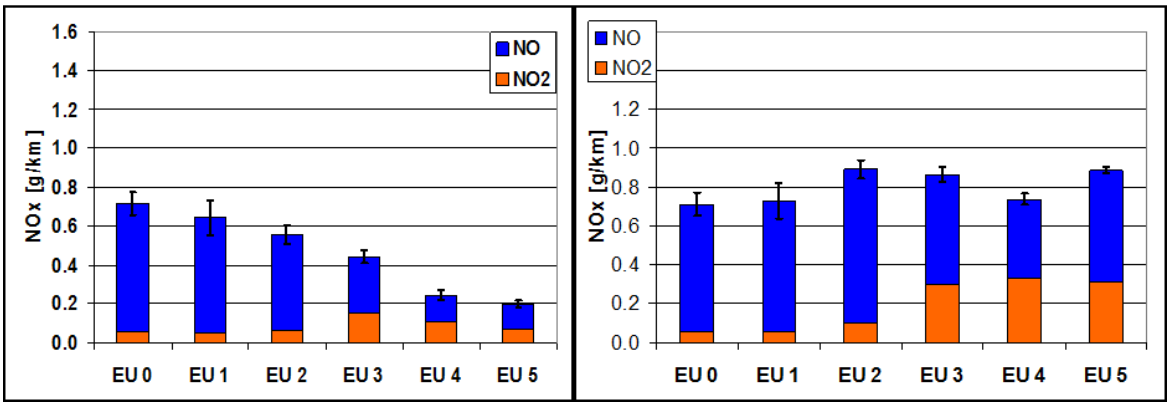


Figure 29: Type approval (left) and real-world emissions (right) from diesel light duty vehicles across Euro standards. **(**European Commission, 2013, p22).

This is relevant for a LEZ cost benefit analysis. When the abatement data were applied in the Leeds study, additional factors had to be taken into account to produce an estimate of the cost and benefit. These included, amongst other things, the number of vehicles of each engine type, discounting over time and the cost of enforcement measures. Therefore the calculation of the cost of LEZ in Scotland will need to take account of not only the volume of traffic and the adjustments reported in the Leeds study, but also Scotland wide transport systems and movements across regions. An estimate of the total costs is presented in the final section of this Chapter.

2. *Might the opportunity cost of making these improvements result in deterioration in health and wellbeing?*

The opportunity costs

In their recent enquiry, the UK Environment Audit Committee (2014) sought information on the costs of the London LEZ initiative. Included in responses to the UK Panel was a comment from Dr Ian Mudway, (Lecturer, Respiratory Toxicology, Environmental Research Group, King's College London) on the potential health benefits and an assumption of willingness to pay:

"Investment has to be seen against health benefit costs otherwise you can never make the justification. £20m sounds like a lot of money, but when you compare it

against Defra's estimated annual mortality cost of £16 billion (Defra, 2013), the figure is not so bad."

The European Commission Staff Impact Assessment (European Commission, 2013) reported that air pollution is the number one environmental cause of premature death in the EU, responsible for over 400,000 premature mortalities in 2010. The total cost of the health impacts (direct and indirect) is estimated to range from €330 to €940bn (3-9% of EU GDP). These figures include the estimated loss of over 100 million workdays per annum costing industry about €15 billion due to reduced productivity (EuroHealthNet, 2014).

The health impact cost data can be derived from air pollution exposure estimates from across Europe (EEA, 2014). However, it is first worth considering if these data can be directly applied in Scotland where the levels of pollution are lower than in many European states. In Scotland the average PM_{10} level is below 40µg/m^3 **(**EU annual standard of 50µg/m^3**).** On the other hand NO_2 levels are greater than 50µg/m^3 at some air monitoring sites, particularly in Glasgow and Aberdeen **(**EU annual standard of 40µg/m^3**)**. Given that some Scottish pollution levels are comparable with sites in Europe, the cost and benefit data for Europe can be applied in Scotland as a direct proportion of the population exposed. However, the results should be treated with caution since the exposure concentration is different for different pollutants. Furthermore, many of the exceedances in Scottish AQMAs are marginal so the health impact and potential cost savings from cleaner air would be expected to be considerably less than in areas of Europe with significantly higher pollution levels.

Nevertheless, since much of the evidence for costs and benefits is only available at the European level, this will be used in the Scottish analysis. Applying the European estimates to the Scottish situation in terms of air pollution levels and health outcomes should provide an indication of the minimal cost and health benefit that might be achieved in meeting European regulatory levels. Actual costs might be expected to be higher to achieve the same reduction in pollutants since the reduction required is marginal and low cost options have all been applied over

recent years. In addition, the actual health benefit might be expected to be lower since the long-term exposure to high levels of air pollution is not now the case with progressive improvements in air quality. This means that health improvements will not be realised to the same extent.

It is worth noting that a further adjustment should be made for transboundary emissions. However it is difficult to calculate the proportion of these emissions and their impact will vary depending on seasonal and climatic conditions. An example of this is the episode of elevated PM pollution in March 2014 that affected wide areas of Europe including southern UK (discussed in Chapter 4). This resulted from calm climatic conditions, high temperatures and an accumulation of pollutants (EEA, 2014). Because of the difficulty in apportioning pollution sources, data in this economic evaluation will not be adjusted for transboundary emissions. However it is worth noting that the contribution is not insignificant as noted previously, and therefore local measures will not necessarily eliminate pollution.

Taking a conservative approach and applying the data for Scotland on a population proportional basis, a number of adjustments must be made. The European data is based on exposure in urban populations. It can be seen in Table 20 that a higher proportion of the population live in urban areas in Scotland than do in Europe as a whole. This suggests that there might be a higher adverse health impact in Scotland from exposure to air pollution. It is estimated that in Europe, 85% of the population are exposed to levels of air pollution (all sources) higher than the World Health Organisation guideline levels (EEA, 2016). However only 0.5% of the population in Scotland is exposed to levels in breach of World Health Organisation guideline levels (Scottish (Air Quality) Health Needs Assessment Report, Appendix 1). The World Health Organisation estimates that exposure in Europe is giving rise to 479,000 premature deaths per annum (0.1% of the population) (World Health Organisation, 2017). Applying the same percentage (0.1%) to the exposed Scottish population (24,066) suggests that exposure in breach of World Organisation Health regulations is giving rise to 24 premature deaths per annum.

To estimate the true traffic-related aspect of air pollution a further adjustment should be made to account for the fact that in Scotland traffic contributes to 40% of air pollution from NO_2 and 20% of air pollution from PM_{10} (Bailey *et al*., 2016). This impact is not necessarily additive since the evidence for the health impact does not distinguish between different pollutants arising from the same source i.e. traffic. However, taking the worst-case scenario and combining the effect of each pollutant, the estimated traffic-related air pollution contribution would be 60%. Therefore the air pollution statistics for costs and health impact must be adjusted to reflect the traffic-related portion of 60%. Applying this to the health impact data suggests that traffic pollution in Scotland is contributing to 14 premature deaths per annum.

Cost and willingness to pay to reduce premature mortality

Economic studies in the past have focused on applying a cost of life, based on averaged costs for health services and a willingness to pay estimate, to mortality rates. This produces a total cost – the cost to prevent a fatality. For example, the cost of a Road Traffic Accident (RTA) is estimated to be £1.7 million per fatality (Department for Transport, 2011). However this estimate was based on accident data and is therefore difficult to apply to a less immediate life impact such as an environmental exposure with longer-term health outcomes.

There are a number of other factors that pose problems when trying to apply mortality data to environmental exposure. These include:

- Mortality is not simply a result of air pollution but of a complex mix of lifetime factors within which it is impossible to identify the air pollution contribution alone.
- The loss of life expectancy tends to be at the later stages in life and therefore tends to be in months rather than years.
- Current estimates of population effects cannot indicate the range of effect from very little to significant in the more vulnerable individuals.
- Epidemiological studies are based on sample populations over a period of time but cannot account for the changing age structure of the population as a

whole. COMEAP have addressed this to some extent by modeling data on an estimated average loss of life of 12 years (Gowers *et al*., 2014).

To account for these issues, the concept of Years of Life Lost (YLL) has been used as this is more representative of the impact of exposure to air pollution on life expectancy. To undertake an economic analysis of actions to reduce YLL the evaluation requires the addition of a monetary value that reflects life years. The monetary value is based on published calculations of the Value of a Statistical Life (VSL) (World Health Organisation, 2015).

Applying these data to the Scottish population proportion based on European estimates and using the UK estimated VLS (World Health Organisation, 2015), the total cost to Scotland from traffic-related deaths in terms of a VSL would be £32.2m per annum. This calculation is shown in Table 20 below.

Table 20: Estimated cost of premature deaths from urban air pollution exposure, Europe and Scotland.

Data	**Europe**	**Scotland**
Total Population	510,100,000[1]	5,373,000[2]
Percentage population urban	73.6%[3]	81%[4]
Urban population exposure above WHO guideline levels	446,034,600[5]	24,066[6]
Premature deaths from ambient air pollution	446,035[7]	24[7]
Adjustment for traffic-related contribution to air pollution	-	14[8]
Value of a statistical life (VSL)[9]2010	-	£32.2m[10]

[1]Eurostat ,2016

[2]National Records of Scotland, 2016

[3]GeoHive, 2015

[4]ONS, 2012

[5]85% of the population exposed in urban areas (EEA, 2016)

[6]0.5% of the Scottish urban population exposed in AQMAs (Scottish (Air Quality) Health Needs Assessment Report)

[7]0.1% of urban exposed

[8]premature deaths related to air pollution x60% (proportion attributable to traffic) (Bailey *et al*., 2016)

[9]VSL calculated per country (World Health Organisation, 2015)

[10]£2.3m (VLS UK) x14 (traffic pollution proportion of premature deaths in Scotland)

However, there are a greater number of individuals whose health is affected by air pollution, but for whom premature death is not necessarily the outcome. If the Scottish population were to be assessed on the basis of European level exposures and ill health, we might estimate that air pollution leads to a loss of 31,286 days productivity per annum. This does not capture all ill health because it only relates to employee sickness levels, but it does suggest an estimated cost in terms of lost productivity in Scotland of £5,755,443 (Table 21).

Table 21: Estimated cost of loss of productivity due to air pollution related illness, Europe and Scotland.

Measure	**Europe**	**Scotland**
Restricted activity days per annum	569 million[1]	
Number of days per exposed person (days/exposed population)	1.3[2]	1.3[3]
Total days lost activity		31,286[4]
Cost	£184 per day[5]	£5,755,443[6] per annum

[1]European Commission, 2013

[2]days/exposed population = 569 000 000/446 034 600

[3]based on European average of 1.3 days per person exposed

[4]population(Scotland) exposed 24 066 (Scottish (Air Pollution) Health Needs Assessment Report) x 1.3 (European average per person exposed)

[5]£975/5.3 days (CBI, 2013) = £184 per day

[6]£184 x 31 286 days = £5,755,443 pa

Willingness to pay is a concept used to assess how much an individual would be prepared to pay to gain benefit or avoid loss. So how much is Scotland willing to pay to prevent traffic-related premature mortality and morbidity? In the field of economics work has been undertaken to assess how much a society would be willing to pay to prevent a premature death (World Health Organisation, 2015). In health, this concept is used to assess the value put on interventions to prevent premature death and is measured as VOLY (Value of Years of Life Lost).

However there are co-benefits from reducing traffic. Improving active travel is estimated to reduce deaths from IHD, respiratory disease and many forms of cancer by at least 30% if inactive people were to do a minimum of 7.5 hours activity per week (Arem, 2015). A more recent study in the Scottish population (Celis-Morales, 2017) reported a significantly lower risk of death from cancer, cardiovascular disease and all cause mortality in commuters who cycled regularly. At the same time, there is a perception that walking and cycling might increase the risk of injury and death from traffic-related accidents (The Kings Fund, 2017). However, when put into context, there are significantly more deaths from inactivity related illnesses than from Road Traffic Accidents (RTAs) (Figure 28). Appropriate urban planning and improved opportunities for safe active travel should lead to fewer RTAs as well as a reduction in premature deaths from cancer, heart disease and air pollution related disease. Further evidence for this is that, despite the increase in traffic volume and an increase in cycle and pedestrian journeys in recent years, there has been a decrease in pedestrian and cyclist fatalities on Scottish roads (Transport Scotland, 2014).

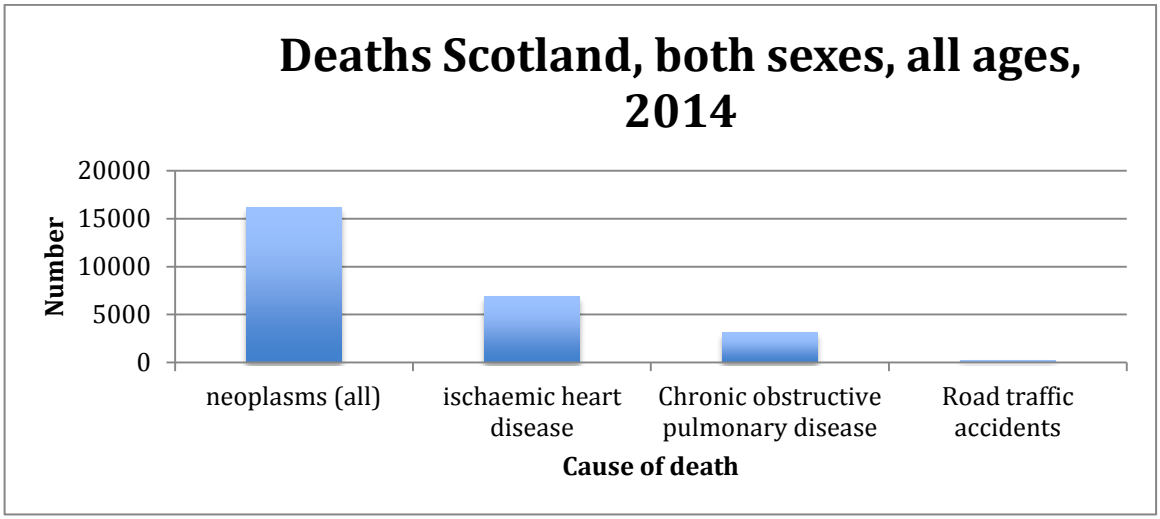


Figure 30: Deaths Scotland from neoplasms, ischaemic heart disease, chronic obstructive pulmonary disease and road traffic accidents, both sexes, all ages, (Adapted from National Records of Scotland. *Vital Events Reference Tables 2014 Section 6: Deaths – Causes*)

Thus in the first instance, the costs of implementing LEZ could be balanced against the willingness to pay to prevent ill-health and avoidable mortality. The economic costs would then be offset against health and well being benefits.

Active travel options

In addition to considering traffic management policies, some LEZ feasibility studies have estimated the wider costs and benefits of active travel options. The feasibility study in Leeds (Highways and Transportation Directorate of City Planning, 2014) included estimates of costs and benefits from a local TravelSmart programme, offering support to reduce car journeys and increase walking and cycling. This Department of Transport programme, originally developed in Australia, involves introducing cycle lanes, promoting live travel information and encouraging sustainable transport. The programme is estimated to produce a benefit to cost ratio of 2.5:1 (Department of Transport, Government of Western Australia, 2011). In an active travel cost benefit analysis commissioned by the National Institute for Health and Care Excellence (NICE), the programme was predicted to be cost effective if it were to result in a decrease in car use of 10% - calculated at a cost of £25 per person (Brennan *et al*., 2012). It would be cost neutral if it resulted in a 2.2%

reduction in car use. Therefore TravelSmart will only be cost effective if the programme results in a decrease in car use and an increase in active travel.

Active travel programmes are of greatest benefit to individuals who take up active travel where previously they were classed as “inactive” i.e. doing less than 30 minutes moderate activity at least five times per week. However it is estimated that activity levels have dropped by 20% over the last 50 years and are predicted to decrease by a further 15% by 2030 (UKActive, 2014). Reducing car use by 10% in the inactive population is a demanding target, particularly in light of the increasing trend in inactivity.

However, even if the decline in activity was halted and a steady state was achieved, health benefits in the most inactive population might arise from a decrease in air pollution alone. This increases the importance of the LEZ in contributing to health improvement for the general population. Moreover, active travel initiatives also increase opportunities to support and improve health in people already active or in people willing to take advantage of the opportunities TravelSmart or similar programmes offer. Within this group there should be additional health benefits if active travel options facilitate a wider choice of journeys such as to and from work, school, shopping or recreational opportunities.

There are models that can be applied to facilitate costing of active travel programmes. One example is the detailed cost benefit analysis that was commissioned by NICE (Brennan *et al*, 2012) in which the benefits of walking and cycling initiatives were calculated in terms of QALYs (Quality Adjusted Life Years). This is an economic measure to estimate a monetary value to quality of life and years of living. On the basis of these estimations active travel initiatives would cost in the range of £1m to £42m to reduce the $PM_{2.5}$ portion of traffic-related YLL (Years of Life Lost) in Scotland. The most cost effective would be the TravelSmart programme which, if adopted as a result of CAFS, might support a reduction in the number of car journeys and an increase in active travel amongst the active and inactive population (Table 22).

Table 22: The cost comparison for active travel interventions in Scotland, based on YLL and cost per QALY.

Active Travel Intervention	**Cost per QALY[1]**	**Cost to reduce YLL in Scotland[2]**
Cycling Demonstration Town (Government funded initiative to encourage cycling 2005-2008)	£5,000	£22,474,000
Sustainable Travel Towns (Government initiative to support Smarter Choices and sustainable travel 2004-2009)	£900	£4,045,500
TravelSmart Department of Transport funded initiative running 2013-2015)	£300-£2,500	£1,348,500 - £11,237,500
Pedometers (local initiatives)	£2,900 - £9,400	£13,035,500 - £42,253,000
Get Walking Keep Walking (Ramblers)	£2,700	£12,136,500

[1]Brennan *et al*, 2012

[2] 22,474 YLL (Gowers *et al*., 2014) adjusted for 20% attribution of $PM_{2.5}$ to traffic = 4,495 x QALY

Economic models can be used to estimate how much the public is willing to pay to reduce air pollution. Desaigues, *et al*. (2011) undertook a pan-European study using the concept of Life Expectancy (LE) and Value Of Life Years (VOLY) in an air quality study based on a sample of the population for major cities. The VOLY study showed that participants would be willing to pay £29,000 (€40,000) for each VOLY if there was a 3 month gain in life. If applied in Scotland this would mean for the estimated 22,474 YLL due to particulate air pollution (Gowers *et al*., 2014) the public would be willing to pay £651,746,000 per annum. However this YLL estimate is based on total

anthropogenic PM exposure of which traffic contributes to 20%. Applying this adjustment would suggest there would be an estimated 4,495 YLL and a willingness to pay £130,349,200.

Based on these data it is suggested that the population in Scotland might accept an estimated budget of approximately £130m to implement LEZ in Scotland. If this initiative were to reduce air pollution to below guideline levels in all AQMAs it would be expected that there would be a reduction of 14 premature deaths per annum at a value of £32m (Table 20). There would be a benefit to industry from reduced sickness absence of £6m per annum (Table 21) – totaling £38m per annum in the initial years (Table 23). As pollution was reduced it would be expected that this level of benefit would also decrease. However this represents an overall cost of between £33-118m in the initial years.

Table 23: Cost benefit analysis of LEZ in Scotland – annual estimated value

	Cost (£m)	**Savings (£m)**
LEZ[1]	70-145	
TravelSmart[2]	1 - 11	
Reduction premature deaths		32
Reduction in sickness absence		6
Total for Scotland[3]	**71-156**	**38**

[1]Table 19 – LEZ £6-10m plus cost for HGV operators of £64-135m = £70-145m

[2]TravelSmart is only one example of active travel options. Further details and costs can be seen in Table 23.

[3] Scotland would implement 4 LEZ – Glasgow, Edinburgh, Aberdeen and Dundee

Discussion

The economic and health costs from air pollution are complex. They include the costs of traffic-related initiatives to reduce air pollution such as retrofitting older buses. There are also potential economic costs to businesses that might arise from traffic restrictions imposed under a LEZ. At the same time it is suggested that current air pollution levels are leading to costs to businesses from ill health and costs to the health service for treatment of preventable illness.

The review in this chapter identified a range of costs and benefits from LEZ as presented in Figures 28 and 29. Ideally a robust cost benefit analysis would include a cost for each element in this range and provide evidence of effectiveness for consideration in a LEZ option appraisal. However the availability of data that would be needed to populate the cost of each element is either absent or is associated with complex underlying assumptions. For the purpose of the cost benefit described in this Chapter, existing data was used as the basis of a rough estimate of the impact of LEZ.

The purpose of LEZs are to reduce traffic-related air pollution through a number of measures including improved air monitoring, vehicle emission charging, a review of transport planning and promotion of active travel. London has been one of the first cities in the UK to implement a LEZ but evidence from recent enquiries suggests that the LEZ may not be having the effect anticipated. The predicted air pollution reductions appear not to have been borne out in practice in the London experience (UK Parliament Environmental Audit Committee, 2014). The measurement of air pollution is however complex, in that it is affected by factors often outwith local control, such as transboundary emissions. This may explain why efforts to reduce air pollution by action to reduce emissions from traffic in London, are having a limited impact.

The London enquiry published data on costs for implementing a LEZ but these did not include costs and benefits for commuters and businesses, or benefits in terms of health from an increase in active travel. Given the limited success in terms of air pollution reduction, it is likely that there has been little, if any, impact on health.

Furthermore, since 1990 NOx emissions have decreased by nearly 50% and PM_{10} emissions have declined by over 50% across the UK. Much of this decline can be attributed to increasingly stringent pollution control regulations for industry and the introduction of catalytic converters in cars (Bailey *et al*.). At the same time the GDP (Gross Domestic Product) for the UK has risen steadily (Everett *et al*., 2010). This

suggests that the cost to industry and vehicle owners from these regulations has not had a substantial effect on the economy in the longer term.

However further emission reductions are required to meet World Health Organisation guideline levels for air pollution and action to address this may result in economic hardship in some sectors. There is a concern that more intensive efforts to improve air quality will be costly and have a negative impact on industry and the national economy. Initiatives that lead to economic hardship may, in turn, have an indirect adverse impact on health (UCL Institute of Health Equity, 2012). Therefore any potential negative economic impact on business should be factored into a health impact assessment. Such impacts include, "…*a wide range of factors including levels of income (absolute and relative), health status, educational attainment, housing conditions and environmental quality*."(Everett *et al*.,2010).

This cost benefit analysis is more complex in Scotland where air quality exceedances are very small and infrequent. Furthermore, air pollution reductions in Scottish AQMAs are difficult to address given that many arise as a result of historical town developments where large volumes of traffic pass through canyons of older buildings in cities and towns. However there are tools available to support LAs estimate the viability of a range of options available for reducing transport-related air pollution. Defra have developed tools to assist LAs in assessing the financial costs and the potential health impact of air pollution reduction measures (Department for the Environment & Rural Affairs, 2013). These have been used to support the case for different infrastructure options in the feasibility studies. The Aberdeen study (Transport Scotland, 2006) is a good example of how these tools can be used to estimate the costs and benefits of implementing traffic management initiatives.

The Aberdeen feasibility study concluded that even with significant traffic management infrastructure changes, the potential reduction in PM_{10} would be marginal. Significant investment in infrastructure would not address all the sites and the AQMA designation would remain. Unfortunately there are no costs attached to

the Aberdeen feasibility study, but even before the proposal reached the stage of costing, it could be seen that significant changes in traffic management would make little impact on air pollution. A different and more active approach was required to reduce air pollution.

Both the Scottish (Air Quality) Health Needs Assessment Report on health impact, and the Aberdeen study (Transport Scotland, 2006) on traffic management options, demonstrate that an area-focused approach may be excessively costly and have a minimal impact on population health. This adds weight to the case for supporting a multifaceted, Scotland-wide approach to reducing traffic-related air pollution. Cleaner air might therefore be achieved by combining traffic management, emission regulations and behaviour change approaches through the development and implementation of initiatives across Scotland. The cost estimations in this Chapter have shown that the economic impact of introducing LEZ is substantial. Furthermore, as has been shown in Chapter 4, it is difficult to demonstrate significant health improvements from local health data to justify the investment.

How much will it cost to make improvements in air quality to deliver levels below guideline limits?

Returning to the original question posed at the start of this chapter, it has not been possible to fully answer this question given the range of uncertainties compounded by the marginal decrease in air pollution required to meet guideline levels in Scotland. The Aberdeen study showed that considerable infrastructure changes would make little difference to air pollution levels. The Leeds study suggested that investment in newer Euro VI and CNG vehicles might be cost effective in terms of reduced pollution and the London study estimated that the costs of this to the bus and HGV operators would be substantial. These costs would be passed on to the public in terms of increased bus fares and costs to businesses. An estimate of the willingness to pay (p156) demonstrated that the public might cover the cost of LEZ up to the value of £130m although the cost of LEZ in Scotland might be as high as £145m. Having said that, when reduced mortality and absence for sickness are

taken into account, the net cost becomes £33-£118m which is within the estimated figure that the population might be willing to pay.

Might the opportunity cost of making these improvements result in deterioration in health and wellbeing?

The driver for change is health, so it would be important to demonstrate potential improvements in health from a reduction in traffic-related pollution. As previously reported in Chapter 4, the Scottish (Air Quality) Health Needs Assessment Report compared the health of residents in AQMAs and non-AQMAs for conditions that could be related to air pollution such as cardiovascular disease and respiratory disease. Surprisingly, compared to similar studies in the literature, the findings from the Scottish study showed no difference in health between the populations. This might be explained by the finding that people living in Scottish AQMAs were younger and had fewer health related incidents than people in non-AQMAs. Robust health information for such studies is limited to hospital admission data and mortality data. Both are very crude indicators of health but are the main quality assured indicators currently available for epidemiological studies, so the results must be viewed with this in mind.

Nevertheless, the findings were sufficiently informative to suggest that it would take very large changes in air pollution in AQMAs to show even a small effect on health. Moreover, the greatest population health benefit should arise from a national approach to traffic management where small changes should benefit a much larger population.

Public concern about the negative health impact from air pollution might mean that, as a country, there is a willingness to invest in air pollution reduction initiatives. However there will be an opportunity cost and this chapter has considered if the investment to improve air quality might paradoxically, result in deterioration in health and wellbeing through loss of investment in other areas within the local economy. A key consideration is that the impact of a LEZ will be experienced in the immediate future in terms of increased costs, but the more substantial longer-term benefits to

health will be less obvious to the public or businesses. The findings from the analysis suggest that it will be important to provide and explain the evidence, and promote longer-term potential benefits across the sectors. This includes direct health benefits from reduced hospital admissions and deaths and indirect benefits arising from an increase in active travel and a secure household income.

There is no evidence that implementation of a LEZ in the UK has resulted in economic downturn, unmanageable costs to industry or opportunity costs to health. However this may be because, to date, studies in this field have not considered all these aspects in the analysis. The health benefits of cleaner air are not disputed, but as air pollution has decreased in recent years and health care demand has increased, mainly due to an aging population with multiple co-morbidities, any health benefits will not necessarily be translated into visible service savings. However, if Scotland were to set aside a budget to support LEZ implementation, it is suggested that the public might accept an investment of £130m in initial years, with reductions over time as health improved. It may be that there will be additional savings of £32m to society from a reduction of premature death and to industry of £6m from a reduction in loss of productivity.

Conclusion

This chapter has assessed the potential cost of LEZ and the benefits in terms of deaths prevented if traffic-related air pollution were to be reduced to levels below the World Health Organisation guideline levels. It has not been impossible to fully cost a LEZ because there are many variables for which financial data are not available. Nevertheless, if the data available from experience elsewhere are applied, it is possible to produce an initial estimate on the cost and benefits of a LEZ. The key question is - would the public be willing to pay for the implementation of LEZ given the initial cost and the lack of evidence from Scottish health data that this will improve health?

The evidence suggests that implementing LEZ across Scotland would be costly but the public may be willing to pay to see the expected reduction in premature death.

The health improvements from reduced air pollution would be expected to be exponential as opportunities for active travel increase both through punitive and supportive policies for greener travel options.

Note: All the data used in this Chapter are derived from published estimates. Within the literature there are variations in the figures for similar issues therefore the data provided above is presented as only as an indicator of costs and potential health impact.

Chapter 8

Conclusions and recommendations for future research

Introduction

There is little doubt from historical experience of the Great Smogs in London that air pollution has a detrimental effect on health. These events led to the introduction of legislation to reduce emissions from polluting industrial and domestic sources. Since then air quality has improved substantially but in some areas the levels of pollutants, particularly particulates and NOx remain above levels the World Health Organisation recommends are safe for health. Furthermore, there are studies that claim to show that health is affected even when air pollution is below the guideline levels.

In recent years traffic has made a progressively larger contribution as a proportion of total (but overall decreasing) air pollution. As Local Authorities (LAs) strive to comply with air quality legislation and pollution through Air Quality Action Plans (AQAPs), their attention has become focused on traffic management initiatives. It has been proposed that the implementation of measures to reduce traffic emissions should lead to an improvement in health. These measures require investment so LAs and the public are seeking assurances that the measures will indeed lead to reductions in ill health in the local area. The purpose of this thesis was to gather the evidence to support LAs and the public in taking action to reduce air pollution and promote active travel as a secondary benefit for health.

The first step in the process was to consider the legislative setting in Scotland that drives air quality and this was covered in Chapter 1. This included development of an understanding of the elements that contribute to exposure and harm through the Source-Pathway-Receptor model. On this basis it was concluded that air pollution reduction requires the combined efforts of individuals, businesses and policy-makers who all have an interest, not only in physical benefits but also in the social implications of air quality improvement initiatives.

The literature was reviewed through a Rapid Evidence Assessment (REA) process, to identify studies which might provide some indication of the strength of effect air pollution has on populations, particularly in Scotland. There were no Scottish studies that met the strict criteria for inclusion in the review. However, there were sufficient cohort studies and reviews to enable a meta-analysis to be undertaken for all-cause mortality and respiratory effects. The findings showed that there is evidence of an association between traffic-related air pollution from NOx and all-cause mortality and lung disease. What was unexpected is that there are many studies in this field reporting on an association between air pollution and health, but given the different subjects being studied and different pollutant exposures, the evidence is not consistent. Furthermore, despite the extensive work in this area there was no conclusive evidence that air pollution was causing the conditions under investigation.

This conclusion led to a more detailed analysis of the studies using a model developed by Hill (1965). Hill set out criteria by which to assess the strength of evidence that an outcome was associated with, or actually caused by, an intervention. When the studies were assessed against this model (Chapter 3) it was noted that many had not accounted for some of the key confounding factors in their study design. For example, place of residence is not necessarily a good proxy for exposure because people move around and are exposed to different concentrations of pollutants from different sources for different durations.

On the basis that the health evidence is not strong but that there are air pollution guideline limits that must be achieved, further work was undertaken to investigate the specific health impacts in Scotland. The first approach was based on a cross-sectional study comparing the health of Scottish residents living in AQMAs with residents in non-AQMAs (Scottish (Air Quality) Needs Assessment Report. The study concluded that the residents in AQMAs tended to be younger and therefore healthier. However this study was based on data for hospital admission and mortality so if the population in AQMAs is younger it might not be expected that illness would manifest itself as hospital admissions. It might be that symptoms

arising from air pollution are experienced at a level requiring only general practice advice and support. Unfortunately there is insufficient data at this level to allow for any meaningful analysis. The NHS 24 system however, collects data on requests for health advice and these data were used to assess ill-health linked to specific episodes of air pollution. However, the study showed that reports of ill health did not increase significantly during a short episode of air pollution. A further study to support LAs who are seeking health data for local populations in order to estimate the impact from traffic management measures, was undertaken. The Scottish Neighbourhood Statistics (SNS) database captures health data in each LA area. However, the SNS data only records hospital admission and deaths and does so for populations who reside not only adjacent to, but also some distance from, air quality monitors. Therefore these data are not sufficiently specific to support decision making and evaluate outcomes.

On the basis that the health and geographical data is insufficiently robust to make a case for traffic interventions, Chapter 5 investigated what actions experts in Scotland had already taken to address traffic-related air pollution. Furthermore, information was sought on what they thought were barriers and incentives for change. The study found that the key themes which may have an influence on reducing vehicular travel, relate to lifestyle choice and social pressure – i.e. the need to achieve many tasks within a limited time period and travelling by car/van/lorry is the most flexible mode of transport. This is compounded by the fact that town planning has over the years, favoured vehicular transport over active travel options. It was noted that there is a need for the development of policies to support changes in mode of travel and reduce traffic-related air pollution.

Scotland has developed a strategy (*Cleaner Air For Scotland - CAFS*) that addresses the need for a policy shift in travel options to reduce traffic-related air pollution. Given the importance of this in addressing the barriers and incentives for change identified in Chapter 5, the strategy was critiqued using a policy assessment tool MINDSPACE. The findings demonstrate that CAFS focuses on punitive measures such as Low Emission Zones (LEZ) and recommends improvements in

communication to engage the public and business in adopting cleaner forms of travel. There is little in the document to incentivise a modal shift in travel.

However given the central role of LEZ in reducing traffic-related pollution, Chapter 7 focussed on the costs and benefits of LEZ in terms of health and socioeconomic outcomes. The data in this area are far from robust but there is sufficient evidence to suggest that if such zones are to be introduced, then the public might be willing to pay to achieve perceived health benefits. However, health benefits are difficult to demonstrate and will be realized at some time in the future, whereas the costs of implementing LEZs are more immediate. LEZ have been in place in cities across Europe for a number of years but while they are controversial because they may or may not reduce pollution, they have not been reported to have had a detrimental impact an social and economic outcomes. Furthermore, if they are introduced alongside health-promoting schemes such as TravelSmart, then the added health benefit reduces the negative economic cost. This supports the ecological model proposed by Whitehead (2001) (Chapter 1) in that individual health is not only affected by personal vulnerabilities but also by lifestyle, occupation and socio-economic factors. Long-term health protection and improvement measures must take account of factors at all levels of the model.

Conclusion

The evidence from the literature and epidemiological studies in Scotland show that there is little impact on population health from traffic-related air pollution at current emission levels. However, although air quality has been improving in recent years, air pollution levels on some sites continue to exceed guideline levels. The Cleaner Air For Scotland strategy aims to address this but relies heavily on the introduction of Low Emission Zones (LEZ) to reduce pollution. This initiative will be costly to implement, not only in terms of public investment in infrastructure, but also as a result of the impact on industry and services in and moving through these zones. For this reason, the wider socioeconomic benefits of improving air quality in Scotland must be considered in the context of policy development and implementation. The thesis presents the case for a more holistic approach to traffic

management that focuses on societal needs that are both economically and environmentally sustainable and by doing so delivers improved health. This is the first time a fully comprehensive approach to traffic-related air pollution from problem to policy has been documented for Scotland.

Research recommendations

Source reduction

There will be, for the foreseeable future a need for vehicular traffic, which at this time gives rise to pollution. Further research is required to improve emissions from vehicles to counter the increasing demand for vehicular transport.

There is a need to review urban planning systems to plan out engine driven air pollution and support sustainable modes of transport.

Research is required to find mechanisms to engage with Scottish communities to reduce vehicle use and increase sustainable forms of transport.

Pathway

The current processes for monitoring air pollution are based on modeling, estimates and small person-centred studies. There is a need for research to improve understanding of how behaviour of individuals gives rise to increased exposure and how this can be minimised.

Health

There should be a continual attempt to lower air pollution to as low as reasonably practicable, to protect vulnerable people.

Population health will improve not only from reductions in preventable air pollution but also in the uptake of active travel. Therefore active travel options should be included as a fundamental part of traffic management initiatives.

Policy development

Further research is required to explore mechanisms to improve multisectorial collaboration within and across Europe, linking health with economic development and transport.

A more detailed economic analysis is required to fully assess the costs, opportunity costs and benefits by sector (business, health, society) taking into account changing background levels, new technology and policy implementation over time.

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List of Appendices

Appendix 1

Scottish (Air Quality) Health Needs Assessment Report

Authors

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Executive summary

This report summarises an analysis of the health of people living in air quality management areas (AQMAs), the areas of Scotland identified as having poorer air quality.

People living in AQMAs are more likely to be male and of working age and are on average healthier than people living in the rest of Scotland. The small overall number and better health of people in AQMAs mean that even large improvements in the air quality in AQMAs would be unlikely to improve health substantially, particularly compared to a small change in air quality in the whole of Scotland. People living in AQMAs do not have greater health needs than the general Scottish population.

Background

Policy

In Part IV of the 1995 Environment Act, following the “Air Quality Meeting the Challenge” of the same year, air quality management areas were introduced into legislation. This legislation imposed a duty on the Secretary of State to “to prepare and publish an air quality strategy setting out standards and objectives for air quality, and the measures to be taken by Local Authorities and others for the

purpose of achieving those objectives (section 80)" and on Local Authorities "**to review** the quality of air in their areas, and to assess whether or not the standards and objectives set out in the strategy are likely to be met (section 82)".[1] Local Authorities are required to designate any area where the standards and objectives are unlikely to be met as Local Air Quality Management Areas (AQMA). Following devolution the duties and powers of the Secretary of Scotland have passed to the Scottish Government.

As a major driver of improving air quality is health, other relevant policy documents include Equally Well, the major public health document in Scotland, which although not mentioning air quality, does advocate improvements to the physical environment and increased active travel (ie public transport, walking and cycling).[2] Similarly, the Early Years Framework emphasises improving the physical environment including access to green spaces and open space. Good Places Better Health states that "the quality of the air that we breathe and the water that we drink may be uniformly high", but also advocates active travel and increased physical activity.[3] A major focus of Equally Well is in reducing health inequalities, which is also of relevance to the discussion around Air Quality Management Areas.

Following designation of an area as an AQMA there are standard procedures to assess air quality, generate improvement options, consult stakeholders on these options, apply changes and evaluate the effect of these changes. The process is complex and resource intensive.

According to a 2010 review of Local Air Quality Management in 2010 throughout the UK, AQMAs were intended to have a specific limited role in improving the air quality in areas with unusual and severe problems, while the majority of the improvement in air quality was to be driven by national and international action.[4] In fact, as of 2010, 58% of Local Authorities had declared AQMAs, some covering very large areas. As such, rather than dealing with unusual and severe cases, AQMAs have become widespread.

Although widespread, the report argues that despite the “formidable amount” of process involved in the Local Air Quality Management approach, it has had a very limited impact. According to the report action plans are created but are not leading to significant improvements in air quality, largely as a result of wider factors such as increased car usage. Nonetheless, the report recommends persisting with the Local Air Quality Management approach because it raises the air quality agenda within Local Authorities, and because it is valued by Air Quality Officers, who are the main proponents of the importance of improving air quality within Local Authorities.

Aim

The aim of this report is to describe the health needs of people living in air quality areas in order to make recommendations for Local Authorities, Health Boards and other decision-makers.

Objectives

- To describe the demographic and socioeconomic characteristics of people living in air quality management areas
- To describe the health (deaths and hospital admissions) of people living in air quality management areas
- To quantify the impact on death and hospitalisations of levels of PM_{10} (and if possible NO_2) which are above the Scottish targets, for both air quality management areas and the rest of Scotland

Methods

Systematic review air quality and health outcomes

The impacts on air quality, particularly particulate matter, on health are well attested. In order to estimate the impact of air quality, specific estimates of the effect on death and hospitalisation of differing levels of PM_{10} and NO_2 were obtained from the published literature.

We did not have the resources to undertake a systematic review of original articles, and instead performed a systematic review of systematic reviews. We searched

Medline (via Ovid) using the following (exploded) search terms ((air pollution or particulate matter or nitrogen dioxide) and (death or hospitalisation or myocardial infarction or stroke or chronic obstructive pulmonary disease or asthma). We found 6,953 titles, and after restricting the search to systematic reviews using the Ovid filter and the Scottish Intercollegiate Guideline Network (SIGN) filter (http://www.sign.ac.uk/methodology/filters.html#systematic), which has good specificity in identifying systematic reviews. [5] The OVID filter resulted in 137 titles and the SIGN filter 133 titles, of which 50 titles had not been identified using the Ovid filter. Although we intended to search only for systematic reviews, we did not exclude multi-centre studies that we had retrieved.

We screened 187 titles and identified 38 potentially relevant studies. Of these, 7 were duplicates, 1 concerned biomass and 5 were narrative reviews. Of the remaining 25, 17 were excluded (2 single centre, 2 were in Italian, 1 was not available electronically (published 1998), 4 reported results for symptoms only, 1 reported sub-daily effect estimates only, 4 did not report results for PM10 or NO2, 1 reported effect modification estimates only, and 2 did not include a meta-analysis). Results for PM_{10} and/or NO_2 for the remaining 8 studies identified are summarised below.

Following completion of this review, the results of a large long-term exposure study of mortality and air quality conducted in 22 European cohorts were published (ahead of print) in December 2013,[6] the results of which confirmed the findings of Kunzli *et al*.

Author	**Outcome**	**Exposure**	**RR / increment**	**Method**
Barnett *et al*[7]	Cardiac hospitalisation aged >65	PM10	1.011 (1.002 to 1.020)	Multi-site, case-crossover
	Cardiac hospitalisation aged ≤ 65	PM10	1.003 (0.992 to 1.013)	Multi-site, case-crossover

	MI	PM10	NS, not reported	Multi-site, case-crossover
Bhaskaran *et al*[8]	MI	PM10	1.012 (1.003 to 1.021)	Multi-site (registry based) case crossover
		NO2	1.011 (1.003 to 1.018)	Multi-site (registry based) case crossover
Kunzli *et al*[9]	Mortality	PM10	1.043 (1.026-1.061)	Meta-analysis of Dockery et al and Pope *et al* (both long-term cohort studies)
	Respiratory hospitalisation	PM10	1.013 (1.001-1.025)	Meta-analysis of Spix *et al* Wordley *et al* and Prescott *et al* (time series or similar designs)
	Cardiovascular hospitalisation	PM10	1.013 (1.007-1.019)	Meta-analysis of Wordley *et al*, Polonieki *et al*, Medina and Prescott et al (time series or similar designs)
Li *et al*[10]	Stroke admission	PM10	1.028 (1.00 to 1.057	Meta-analysis of 12 studies both case-crossover and time series
Medina-Ramon *et al*[11]	Hospitalisation for COPD	PM10	1.0029 (0.9999 to 1.0058) per 10 μgm^{-3}	Case-crossover design, 36 US cities
Nawrot *et al*[12]	MI	PM10	1.02 (95%	14 studies examining

			CI 1.01–1.02)	"triggers" of MI, predominantly case-crossover design
	Death (natural cause)	NO2	1.01 (0.99-1.03) per 10 μgm^{-3}	As above
Mustafić H *et al*[13]	Incident MI or MI death	PM10	1.006 (1.002-1.009) per 10 μgm^{-3}	Systematic review. Case-crossover and time series designs
	Incident MI or MI death	NO2	1.011 (1.006-1.016) per 10 μgm^{-3}	Systematic review. Case-crossover and time series designs
Sunyer *et al*[14]	Asthma admissions and ER visits in people aged Aged 15-64	NO2	1.029 (1.003 to 1.055)	Multi-city, time-series design
	Asthma admissions and ER visits in people aged Aged <15	NO2	1.026 (1.006 to 1.049)	Multi-city, time-series design
Beelen *et al*[6]	Death (natural cause)	PM10	1.04 (0.98-1.04)	Multi-city cohort study: adjusted for gender and calendar time, smoking status, smoking intensity, smoking duration, environmental tobacco smoke, fruit

		intake, vegetables intake, alcohol consumption, body mass index, educational level, occupational class, employment status, marital status and area-level socio-economic status

All estimates are rate ratios or odds ratios per 10 μgm^{-3}

Death and hospitalisation data

Scotland has excellent health data and the NHS Information Services Division (NHS ISD) and National Records of Scotland (NRS), formerly the General Register Office for Scotland, produce statistics on hospitalisation and deaths respectively for specific geographies (such as Health Board and Local Authority Areas) and for datazones, which are contiguous groups of census output areas containing 500-1000 people. Datazone boundaries broadly reflect community boundaries, and were designed to allow users to aggregate multiple datazones in order to construct larger geographies which are specific to their particular needs. These data can be accessed via the Scottish Neighbourhood Statistics website (http://www.sns.gov.uk/default.aspx).

Unfortunately, however, AQMAs are not one of the specific geographies reported in Scotland, nor is there a one-to-one match between postcodes comprising AQMAs and datazones. As such, ISD agreed to provide death and hospitalisation statistics, by age, sex, Scottish Index of Multiuple Deprivation (SIMD) quintile and calendar year (which would not have been available from the Scottish Neighbourhood Statistics website) for both Air Quality Management Areas within Scotland, and for the rest of Scotland. The SIMD is an area-based measure of socio-economic deprivation which is the main measure of socio-economic status used in Health and Social data in Scotland. Each datazone in Scotland is assigned a deprivation rank (1 to 6,505) and these ranks are commonly grouped in quintiles or deciles.

Briefly, the data was provided by ISD as follows:-

1. Ricardo-AEA provided a list of postcodes for AQMAs which was sent on to ISD
2. For 2008 to 2012 ISD produced counts of admissions and deaths (myocardial infarction, stroke, Chronic Obstructive Pulmonary Disease (COPD), bronchiectasis and asthma, fracture, and transportation related causes, and 'all-cause') for people living in AQMA postcodes and non-AQMA postcodes (hereafter, rest of Scotland)
3. ISD produced estimates of the population living in AQMA postcodes and non-AQMA postcodes by age band and sex based on the 2011 census
4. ISD aggregated 2 and 3 according to age-bands, sex, calendar year and AQMA postcode (yes/no) and provided the aggregated data to DM for further analyses. Note that the data was aggregated at the level of all AQMAs (and the rest of Scotland) not for specific AQMAs as this would have resulted in an unacceptably high risk that an individual could be identified from the aggregated data, with a loss of privacy.

The data used are available from NHS ISD subject to satisfying the Caldicott Officer at NHS ISD (responsible for maintaining privacy) that the data will be stored, analysed and presented in a manner which does not risk disclosure of personal information. The data, although aggregated, are potentially disclosive due to the small number of events in some cells and so cannot be shared without these additional approvals. Tables presented in this report have been reviewed by NHS ISD and deemed not to be disclosive and so can be distributed. Individuals wishing to access the original data can contact DM to discuss this further.
Additional details on the methods used by ISD to produce the data are provided in the accompanying metadata which has been included as an appendix.

Statistical analyses of data

Summary statistics for the population (age, sex and SIMD) and rates of admissions and deaths for AQMAs and non-AQMAs for all-causes and specific causes were calculated. For the rate calculations the numerator was the count of events, and the

denominator was the person years for the relevant at-risk population (person years was calculated crudely as the population in 2012 x number of years of observation, we did not correct for deaths). Multiple admissions for the same individual are counted multiple times.

In Poisson regression models, we estimated the rate ratio for hospitalisations, deaths and hospitalisation or deaths for all-cause and cause-specific events. The latter is presented to increase power and deal with the issue of competing causes. We provide unadjusted rate ratios and rate ratios adjusting for age, sex, calendar year and SIMD quintile.

Analyses were performed in R version 3.0.1 (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.)

Exposure data

In addition to postcodes, Ricardo-AEA provided us with annual mean results for PM_{10} and NO_2 for one or more monitoring site at each AQMA. These estimates include roadside, kerbside and background monitoring. Where monitoring at more than one site was provided for an AQMA (Dundee City, Edinburgh and Midlothian, Falkirk, Paisley and Perth) a simple average was taken. No modelling or more complex analysis was used.

ISD used postcode-specific population data to calculate the mean concentration for each pollutant, weighted for the population in each site, for each year in which data was obtained.

We had originally intended to use these weighted averages to estimate the average exposure to PM_{10} and NO_2 in AQMAs in Scotland. As these data were not thought likely to reflect the true exposure experienced by people resident in these postcodes, however, we instead adopted a simpler approach of using the largest recorded PM_{10} level for further calculations (see Table 1 below) and these weighted averages were not used in any further analyses. They have been presented in this

report to demonstrate what sort of data could be produced if better estimates of air quality were available (for example from modelling).

Table 1 Mean concentration of PM10 and NO2 weighted by population

Year	PM10 (μgm^{-3})	NO2 (μgm^{-3})
2008	20	42
2009	17	45
2010	19	45
2011	19	43
2012	15	35

Population attributable fraction

Having analysed routine data sources in order to provide total counts for deaths and hospitalisations in AQMAs (and the rest of Scotland) we used the well-established approach of calculating the Population Attributable Fraction (PAF) in order to estimate the impact of a change in air quality on health in AQMAs and non-AQMAs. The PAF can be interpreted as the proportion of total cases in a population due to a particular exposure (e.g. total cases of death attributable to PM_{10}). It is defined as the difference between the rate of an event in the total population and the rate in people not exposed, as a proportion of the rate in the total population. When PAF is used to influence policy decisions, the additional assumption is usually made that a change in the exposure (e.g. we assume that a reduction in PM_{10} of a given amount would reduce mortality to the extent implied by the causal relationship between PM_{10} and death).

We used the standard method to calculate the PAF from estimated rate ratios.[15]

$$Population\ Attributable\ Fraction = \frac{Prevalence(rate\ ratio - 1)}{Prevalence(rate\ ratio - 1) + 1}$$

This equation assumes that the rate ratio is a true measure of the causal relationship between the exposure and the outcome in the population of interest, i.e. that there is no confounding. As is usual when calculating PAF for a whole-population exposure such as air pollution we assumed that all residents are exposed to air pollution, hence the prevalence of the exposure is assumed to be 1. An additional assumption is that the relative impact of a change in PM_{10} concentration is the same regardless of the baseline PM_{10} concentration, or, in other words that the association between the exposure and the rate of death is (log) linear. Under these assumptions, the PAF is the same whether, for an average change in exposure across a population (e.g. a 20 μgm^{-3} change in PM_{10}), we directly calculate the effect of that average change in PM_{10} across the entire population (e.g. all AQMAs) or we calculate the effect of particular changes in PM_{10} for multiple sub-populations and then aggregate the separate estimates.

We used rate ratios from the published literature as these are the best estimates for the causal relationship between air quality and mortality and morbidity (since they used a variety of methods to remove the effects of bias and confounding). We used single-pollutant models only. In our review of systematic reviews rate ratios/odds ratios were less than or equal to 1.04 per 10 μgm^{-3} for all causes of hospitalisation and mortality. Consequently, we used 1.04 per 10 μgm^{-3} change in PM_{10} as the rate ratio for all outcomes to estimate the largest feasible impact of an improvement in air quality.

The rate ratio for a given change in an exposure is calculated as:-

$$Rate\ ratio\ per\ change\ in\ exposure = Published\ rate\ ratio^{(change\ in\ exposure/unit\ change)}$$

The highest annual mean PM_{10} level for AQMAs was 31 μgm^{-3}, which was recorded at a Glasgow kerbside monitoring site during 2008, whereas under the air quality strategy for Scotland (www.scotland.gov.uk/Topics/Statistics/Browse/Environment/TrendPM10) the target PM_{10} level is 18 μgm^{-3}. Hence, we calculated the rate ratio for a fall in annual mean

PM_{10} from 31 to 18 μgm^{-3} as the upper limit for the impact on health of improving PM_{10} for people living in air quality management areas ($RR = 1.04^{((31-18)/10)} = 1.05$).

For comparison we calculated the rate ratio for a fall in annual mean PM_{10} of 1 μgm^{-3} for the rest of Scotland to consider the impact of a population-wide approach ($RR = 1.04^{(1/10)} = 1.004$). These rate ratios were used to calculate each PAF as described above.

We did not have any estimate of the proportion of time people not resident in AQMAs spend in these areas, hence we did not calculate the effect of improving air quality in AQMAs on people not resident in AQMAs. Similarly, we did not calculate the effect of improving air quality throughout Scotland on people resident in AQMAs.

We applied the proportion calculated to the total number of deaths (and admissions) in order to calculate the number of deaths (and admissions to hospital) attributable to air pollution.

Results

Demographics

Less than 1% of the Scottish population reside in air quality management areas (AQMAs). The age, sex and deprivation characteristics of people living in AQMAs, compared to people not living in AQMAs in 2012 are summarised in Table 2.

Table 2 Number of people resident in air quality management areas and in the rest of Scotland, by age, sex and Scottish Index of Multiple Deprivation (SIMD) quintile

	AQMA, n	AQMA, %	Rest of Scotland, n	Rest of Scotland, %
N	24066		5,490,135	
Age, years				
<10	1189	4.7	568,913	10.4
10 to 19	1682	6.7	598,159	10.9
20 to 29	9978	39.5	758,685	13.8
30 to 39	5199	20.6	725,997	13.2
40 to 49	2640	10.5	842,211	15.3
50 to 59	1784	7.1	748,391	13.6
60 to 69	1225	4.9	612,410	11.2
70 to 79	967	3.8	399,750	7.3
80 to 89	501	2	199,446	3.6
≥ 90	90	0.4	36,173	0.7
Female	10,997	43.5	2,774,546	50.5
Male	14,258	56.5	2,715,589	49.5
SIMD				
Quintile1 (most deprived)	4936	19.5	1,142,918	20.8
Quintile2	8299	32.9	1,099,511	20
Quintile3	6052	24	1,089,228	19.8
Quintile4	5086	20.1	1,080,208	19.7
Quintile5 (least deprived)	882	3.5	1,078,270	19.6

SIMD – Scottish Index of Multiple Deprivation

People aged 20 to 39 are more likely to live AQMAs, particularly people aged in the 20 to 29 range, while people in every other age group are less likely to live in air quality management areas. The largest difference was for people aged 40 to 79. Men are more likely to live in AQMAs than women (54% versus 49%). Compared to the rest of Scotland, people living in AQMAs are less likely to be in the most deprived SIMD quintile (Q1). Quintiles 2 and 3 (with deprivation ranks in the middle to high range) are over-represented in AQMAs compared to the Scottish population, but the proportion in the most deprived quintile for Scotland and AQMAs is similar. In summary, therefore, few people in Scotland live in AQMAs. Young adults who are not resident in the most or the least deprived areas are most likely to live in AQMAs, as are men.

Mortality

Total numbers and rates of deaths from any cause, myocardial infarction, stroke, chronic lower respiratory disease, fracture and transport accidents for people living in AQMAs and the rest of Scotland are presented in Table 3.

Table 3 Mortality in AQMAs and the rest of Scotland

	AQMA, n (rate per 1,000 person years)	Non- AQMA, n (rate per 1,000 person years)	Unadjusted rate ratio (95% CI)	Adjusted rate ratio (95% CI)
All-cause	1475 (7.17)	269255 (9.84)	0.73 (0.69 to 0.77)	1.03 (0.98 to 1.09)
Myocardial infarction	375 (1.82)	66505 (2.43)	0.75 (0.68 to 0.83)	1.05 (0.94 to 1.16)
Stroke	131 (0.64)	29224 (1.07)	0.6 (0.5 to 0.7)	0.87 (0.73 to 1.03)
Chronic lower respiratory disease	225 (1.09)	30401 (1.11)	0.98 (0.86 to 1.12)	1.28 (1.12 to 1.46)
Fracture	27 (0.13)	5696 (0.21)	0.63 (0.42 to 0.9)	0.92 (0.61 to 1.31)
Transport accident	7 (0.03)	1037 (0.04)	0.9 (0.39 to 1.74)	0.83 (0.36 to 1.61)

Adjusted analyses included age, sex and deprivation (SIMD quintile) as covariates in Poisson regression models. The rate ratios present the relative rate of each cause of death for people living in AQMAs compared to people living in the rest of Scotland. The adjusted rate ratios present the relative rate after adjusting for age, sex and deprivation. For all causes except chronic lower respiratory disease, rates were similar, or lower, in AQMAs than in the rest of Scotland. This was true for both unadjusted and adjusted analyses.

Morbidity

Similar results are presented in Table 4 for hospitalisations, by cause and site for people living in AQMAs and the rest of Scotland, with rate ratios adjusting for age, sex and deprivation as for the mortality analysis. For all causes of hospitalisation,

rates were lower in AQMAs than in the rest of Scotland in both unadjusted and adjusted analyses (Table 4).

Table 4 Hospitalisation in AQMAs and the rest of Scotland

	AQMA, n (rate per 1,000 person years)	Non- AQMA, n (rate per 1,000 person years)	Unadjusted rate ratio (95% CI)	Adjusted rate ratio (95% CI)
All-cause	39449 (191.81)	7029778 (256.83)	0.75 (0.74 to 0.75)	0.86 (0.85 to 0.87)
Myocardial infarction	3153 (15.33)	686196 (25.07)	0.61 (0.59 to 0.63)	0.83 (0.8 to 0.86)
Stroke	1013 (4.93)	212011 (7.75)	0.64 (0.6 to 0.68)	0.88 (0.83 to 0.94)
Chronic lower respiratory disease	2832 (13.77)	574953 (21.01)	0.66 (0.63 to 0.68)	0.78 (0.75 to 0.81)
Fracture	1395 (6.78)	231062 (8.44)	0.8 (0.76 to 0.85)	0.98 (0.93 to 1.04)
Transport accident	177 (0.86)	28775 (1.05)	0.82 (0.7 to 0.95)	0.75 (0.65 to 0.87)

Mortality and morbidity

Similar results are presented in Table 5 for the combined outcome of hospitalisations or deaths. As in the separate analyses, people living in AQMAs had better outcomes than those not living in AQMAs in unadjusted analyses and after adjusting for age, sex and deprivation.

Table 5 Combined mortality and hospitalisation in AQMAs and the rest of Scotland

	AQMA, n (rate per 1,000 person years)	Non- AQMA, n (rate per 1,000 person years)	Unadjusted rate ratio (95% CI)	Adjusted rate ratio (95% CI)
All-cause	40924 (198.98)	7299033 (266.67)	0.75 (0.74 to 0.75)	0.87 (0.86 to 0.88)
Myocardial infarction	3528 (17.15)	752701 (27.5)	0.62 (0.6 to 0.64)	0.85 (0.82 to 0.87)
Stroke	1144 (5.56)	241235 (8.81)	0.63 (0.6 to 0.67)	0.89 (0.84 to 0.94)
Chronic lower respiratory disease	3057 (14.86)	605354 (22.12)	0.67 (0.65 to 0.7)	0.81 (0.78 to 0.84)
Fracture	1422 (6.91)	236758 (8.65)	0.8 (0.76 to 0.84)	0.99 (0.94 to 1.04)
Transport accident	184 (0.89)	29812 (1.09)	0.82 (0.71 to 0.95)	0.75 (0.65 to 0.87)

Chronic lower respiratory disease

Mortality, but not hospitalisation, for chronic lower respiratory disease was higher in people resident in AQMAs. Table 6 shows a breakdown of deaths and hospitalisations stratified by deprivation quintile and gender. Counts <20 are suppressed to preserve anonymity.

The higher rates in AQMA for chronic lower respiratory disease is found only for deaths, and only in the most deprived quintile, particularly for women. The deaths occurred mainly in people over 50, but the difference in rates between AQMAs and the rest of Scotland were similar across age groups (not presented to preserve anonymity). Formal statistical tests of interaction were not significant (all p >0.05).

Table 6 Deaths and hospitalisation for chronic lower respiratory disease

	Men		Women	
	AQMA, n (rate per 1,000 person years)	**Non- AQMA, n (rate per 1,000 person years)**	**AQMA, n (rate per 1,000 person years)**	**Non- AQMA, n (rate per 1,000 person years)**
Death from chronic lower respiratory disease				
SIMD Q1 (most deprived)	63 of 21618 (2.91)	5150 of 2862472 (1.8)	48 of 24871 (1.93)	4514 of 2830309 (1.59)
SIMD Q2	31 of 27143 (1.14)	4077 of 2769627 (1.47)	28 of 34323 (0.82)	3789 of 2707957 (1.4)
SIMD Q3	(0.63)	2827 of 2740980 (1.03)	(0.75)	2922 of 2680885 (1.09)
SIMD Q4	(0.24)	2094 of 2735314 (0.77)	(0.3)	2159 of 2661814 (0.81)
SIMD Q5 (least deprived)	(0.75)	1441 of 2726122 (0.53)	(0.56)	1428 of 2655798 (0.54)
Admission from chronic lower respiratory disease				
SIMD Q1 (most deprived)	779 of 21618 (36.03)	106580 of 2862472 (37.23)	556 of 24871 (22.36)	78655 of 2830309 (27.79)
SIMD Q2	412 of 27143 (15.18)	83002 of 2769627 (29.97)	360 of 34323 (10.49)	63679 of 2707957 (23.52)
SIMD Q3	213 of 25335 (8.41)	58259 of 2740980 (21.25)	305 of 29200 (10.45)	48942 of 2680885 (18.26)
SIMD Q4	(3.86)	42407 of 2735314 (15.5)	(2.96)	37184 of 2661814

				(13.97)
SIMD Q5 (least deprived)	72 of 6658 (10.81)	30664 of 2726122 (11.25)	(5.15)	25581 of 2655798 (9.63)

Population attributable fraction

The PAFs for a 13 μgm^{-3} change in PM_{10} in AQMAs and a 1 μgm^{-3} in the rest of Scotland were 4.97% and 0.39% respectively. Table 7 shows the results obtained from applying these proportions to the total number of deaths and hospitalisations in AQMAs and the rest of Scotland n order to calculate the number of attributable deaths and hospitalisations (total number of events x PAF).

Table 7 Number of cases attributable to high PM10 in AQMAs and the rest of Scotland

	Total events AQMA	**Total events Non AQMA**	**Attributable events AQMA**	**Attributable events Non AQMA**
Deaths				
All-cause	1475	269255	73	1053
Myocardial infarction	375	66505	19	260
Stroke	131	29224	7	114
Chronic lower respiratory disease	225	30401	11	119
Hospitalisations				
All-cause	39449	7029778	1961	27517
Myocardial infarction	3153	686196	157	2686
Stroke	1013	212011	50	829
Chronic lower respiratory disease	2832	574953	141	2250

Discussion

Health in AQMAs

We found that people in AQMAs were more likely to be of working age, and male than people resident in other parts of Scotland. The relationship with deprivation was more complex. The most affluent group were under-represented in AQMAs, the proportion in most deprived quintile was similar, and people in AQMAs were more likely to be in the second most deprived quintile. We also found that people living in AQMAs were generally healthier than people not living in AQMAs, with similar rates of death and hospitalisation, and that difference persisted after adjusting for differences in age, sex and socio-economic deprivation.

It is important to note that we compared mortality and hospitalisation in people living in AQMAs and in the rest of Scotland solely for descriptive purposes, as a "benchmark" for mortality and hospitalisation rates. Numerous well-designed epidemiological studies have demonstrated that air pollution causes increased mortality. These studies made strenuous efforts to account for confounding (differences in people exposed/not exposed to air pollution which affect the outcomes) and bias (differences in measurements) including non-differential misclassification bias. It was not our intention to test the hypothesis that air pollution causes death, and no inferences about the nature of this relationship should be drawn from this report. We have, however, shown that in Scotland people who live in areas designated as having poorer air quality are generally healthier, which may have implications for targeting policy interventions aimed at improving the public health.

Speculating, it is implausible that poorer air quality is protective of health, and the most likely reason for these differences in health are unmeasured differences in the populations living in AQMAs compared to the rest of Scotland (i.e. confounding). People living in AQMAs might plausibly have moved to these areas to obtain employment, which would mean that they would tend to be healthier than the rest of the Scottish population. This would be one example of the long-established healthy worker effect which is known to affect observational research into human health.[16]

The higher rate of chronic lower respiratory diseases in AQMAs was confined to mortality and not hospitalisation, and was only evident in the most deprived quintile. Chronic lower respiratory disease includes COPD, asthma and bronchiectasis, but of these COPD is the commonest cause of death. One artefactual explanation for the findings could be that deprived people with very severe COPD are more likely to live in AQMAs than in other areas of Scotland, perhaps due to proximity to hospital. If there is a more severe spectrum of respiratory disease in AQMAs than non-AQMAs this would be consistent with the observation that mortality but not hospitalisation was higher in AQMAs. Generally, however, we would argue against speculating as to the cause of the differences in health of people living in AQMAs compared to people living in the rest of Scotland. The relevance of this comparison is to describe the health needs of these areas, not to attempt to draw causal inferences.

We did not have access to primary care data which would have allowed us to compare GP attendances, as these are not available nationally. Nor is it likely that data on sufficient numbers of people resident within AQMAs would have been collected in the Scottish Health Surveys to allow comparison of self-reported health in AQMAs to the rest of Scotland. It seems unlikely, however, that these sources of information would have led to substantially different conclusion than those drawn from hospitalisation data.

Quantitative measures of health are only one method for assessing health needs. Perceived, or felt health needs are also important. On reviewing consultation reports from AQMAs in Fife and Dundee, we did not however find that health was a major concern for most residents in AQMAs. Moreover, in the light of our quantitative findings, it is unlikely that perceptions of poor health would have a substantial effect on policy, unless there was very strong local feeling that poorer air quality was harming health.

Impact of air quality on mortality and morbidity in AQMAs and the rest of Scotland

We also considered the contribution of air quality to health in AQMAs and the rest of Scotland. We did so by calculating PAFs using published estimates of the effect of

air pollution on health. We found that, due to the low percentage of the population resident in AQMAs and, to a lesser extent, because of the low event rate in people who live in these areas, even large changes in PM_{10} in AQMAs would have very small impacts on health compared to small changes in PM_{10} across the Scottish population.

Our calculations were very simple, but we chose to compare the likely impact of a very large effect on air quality in AQMAs (taking the highest mean measurement during the recorded period) with that of a very small effect on air quality in the rest of Scotland. Consequently, it is unlikely that more complex approaches would have supported the conclusion that improving air quality in AQMAs would have a larger effect on health in Scotland than taking a population-wide approach to improving air quality.

There are, nonetheless, a number of reasons why focussing on improving air quality in AQMAs might lead to a larger improvement in health than suggested by our analyses:-

1. It may be more feasible/cost-effective to improve air quality in AQMAs than in the rest of Scotland. As such, for a given resource it may be possible to produce a greater improvement in health in AQMAs than in the rest of Scotland.
2. People not resident in AQMAs may nonetheless be exposed to PM_{10} and other pollutants because of work, recreation or travel occurring in these areas.
3. As suggested in the 2010 policy review, focussing on improving air quality in AQMAs might encourage policies which improve air quality throughout within Local Authority areas
4. If, rather than the association between the risk of death or hospitalisation and exposure to air pollution being linear, there is a plateau below which further reductions in air pollution do not improve health, improving the air quality in the rest Scotland would have smaller effect on health than suggested in our model

Summary

People living in AQMAs are more likely to be male and of working age than the general Scottish population. People living in AQMAs are also on average healthier than people living in the rest of Scotland. The small overall number and better health of people in AQMAs mean that even large improvements in the air quality in AQMAs would be unlikely to improve health substantially, compared to a small change in air quality in the whole of Scotland.

People living in AQMAs do not have greater health needs than the general Scottish population.

Recommendations

People resident in AQMAs are generally healthier than the rest of the Scottish population and therefore do not represent a high risk group from the point of view of mortality or hospitalisation.

A more in-depth health needs assessment of people living in AQMAs is probably not warranted, unless in response to specific public concerns.

Under the assumptions of our approach, even large changes in air quality in AQMAs are likely to have a smaller impact on the health of people in Scotland than small changes in air quality throughout Scotland. This relative impact of population-wide and local approaches should be considered when allocating resources to improving air quality.

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Contributions by authors:

Dr David McAllister: drafted the objectives, identified the data sources and negotiated access, prepared the data in a format suitable for analysis, reviewed and reported on the findings, wrote the final report and presented this to a national group.

Dr Jackie Hyland: proposed the subject, discussed the objectives and process, reviewed and commented on the data and presentation, contributed to the editing and facilitated and supported the presentation to a national group.

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Metadata provided by NHS Information Services Division

Hospital Admissions and Deaths by Scottish Index of Multiple Deprivation (SIMD) 2012, gender and age group for Air Quality Management Areas (AQMA) in Scotland; 2008 to 2012

The sheet behind this one contains a data table

Data in this table are potentially disclosive and shouldn't be disseminated without discussion with ISD

The data items contained in the tables are as follows:
ISD Ref: IR2013-01611

Year	Year of admission or death
Ageband	10 year age bands of individuals age as at 30th September 2012
Gender	Gender
SIMD_Quintile	Number of practice patients matched to the first quintile of deprivation (1 = most deprived).
weighted_no2	Weighted level of pollution for Nitric Oxide - data are weighted by population at postcode level
weighted_pm10	Weighted level of pollution for Particulate Matter - data are weighted by population at postcode level
population	Population based on CHI database as at 30th September 2012
death_allcauses	Number of all deaths
death_mi	Number of deaths caused by MI (ICD10 codes; I20-I25)
death_stroke	Number of deaths caused by Stroke (ICD10 codes; G45, I60-I67)
death_copd_bronch_asthma	Number of deaths caused by COPD, bronchiectasis or asthma (ICD10 codes; J40-J47)
death_fracture	Number of deaths caused by Fracture (ICD10 codes; S02,S12,S22,S32,S42,S52,S62,S72,S82,S92)
death_trans_inc	Number of deaths caused by Transport (ICD10 codes; V01-V79)
admissions_allcauses	Number of all admissions
admissions_mi	Number of admissions caused by MI (ICD10 codes; I20-I25)
admissions_stroke	Number of admissions caused by Stroke (ICD10 codes; G45, I60-I67)
admissions_copd_bronch_asthma	Number of admissions caused by COPD, bronchiectasis or asthma (ICD10 codes; J40-J47)
admissions_fracture	Number of admissions caused by Fracture (ICD10 codes; S02,S12,S22,S32,S42,S52,S62,S72,S82,S92)
admissions_trans_inc	Number of admissions caused by Transport (ICD10 codes; V01-V79)

Notes to accompany the use of these data:

1.Data sources: CHI/UPI database as at 30th September 2012.
SIMD 2012 reference files.
SMR01, ISD Scotland
GRO Deaths record, ISD Scotland

2. All patient postcodes mapped to SIMD 2012 reference files.

3. There are a number of patients where SIMD couldn't be assigned.

4. The allocation of patients into quintiles are based on the population weighted distribution of datazones. This differs slightly from methodology adopted by the Scottish Executive in that their percentile distributions tend to be based on equal numbers of datazones.

5. Quintile numbering should be interpreted on a scale where value 1 = most deprived and value 5 = least deprived.

6. Population is based on individuals registered at general practices in Scotland. This will differ from population estimates published elsewhere.

7. Number of admissions is based on episodes. An SMR01 episode is generated when a patient is discharged from hospital but also when a patient is transferred between hospitals, significant facilities, specialties or to the care of a different consultant.

9. Up to six diagnoses (the main diagnosis and five secondary diagnoses) may be recorded per hospital episode, using the International Classification of Disease Codes version 10 (ICD 10).

10. Up to ten causes of death (the main cause of death and nine secondary causes) may be recorded per death record, using the International Classification of Disease Codes version 10 (ICD 10).

11. Useful links: www.isdscotland.org/deprivation
www.scotland.gov.uk/Topics/Statistics/SIMD

Appendix 2

Electronic database search

The St Andrews online databases were searched via EBSCO

http://ehis.ebscohost.com/eds/results?sid=71e89b8c-5528-41e9-a851-14788faf0b2a%40sessionmgr10&vid=328&hid=15&bquery=traffic+AND+air+AND+pollution&bdata=JmNsaTA9RFQxJmNsdjA9MTk5OTAxLTIwMTMxMiZ0eXBlPTAmc2l0ZT1lZHMtbGl2ZQ%3d%3d

The databases included:
ERIC, ATLA Religion Database with ATLASerials, Regional Business News, PsycINFO, Psychology and Behavioural Sciences Collection, PsycARTICLES, Business Source Premier, EconLit, MEDLINE, Library, Information Science & Technology Abstracts, Film & Television Literature Index with Full Text, America: History & Life, Historical Abstracts, Philosopher's Index, GreenFILE, J-STAGE, Grove Art Online, Grove Music Online, JSTOR Arts & Sciences II, JSTOR Arts & Sciences III, JSTOR Arts & Sciences IV, JSTOR Arts & Sciences IX, JSTOR Arts & Sciences V, JSTOR Arts & Sciences VI, JSTOR Arts & Sciences VII, JSTOR Arts & Sciences VIII, JSTOR Ireland, JSTOR Life Sciences, Alexander Street Press, eBook Collection (EBSCOhost), NewsBank, British Library Document Supply Centre Inside Serials & Conference Proceedings, NewsBank - Archives, Publisher Provided Full Text Searching File, JSTOR Arts & Sciences I, Academic Search Index, Research@StAndrews:Full text, Manuscriptorium Digital Library, PsycARTICLES, SAULCAT, HeinOnline, Directory of Open Access Journals, OAPEN Library, Persée, Public Information Online, Naxos Music Library, Naxos Music Library Jazz, Bridgeman Education, British Library EThOS, World Book, ABC-CLIO Social Studies Databases, Academic Edition, Digital Access to Scholarship at Harvard (DASH), SSOAR – Social Science Open Access Repository, JSTOR 19th Century British Pamphlets, JSTOR Arts & Sciences X, JSTOR Arts & Sciences XI, Oxford Reference, Henry Stewart Talks, CogPrints, BioOne Online Journals, University Press Scholarship Online, Oxford Dictionary of National Biography, Accessible Archives, OAIster, Oxford Handbooks Online, Oxford Scholarship Online, Credo Reference Collections, arXiv, Books24x7, ScienceDirect, Anthropological Index Online, Brill Online: Encyclopaedia of Islam, Columbia International Affairs Online (CIAO), HeinOnline, Literature Online, MathSciNet, Oxford Dictionary of National Biography, Oxford English Dictionary, ProQuest Dissertations and Theses – Full Text, Scopus, Scran, The Encyclopedia of Life Sciences, The Times Digital Archive, World Shakespeare Bibliography Online, ProQuest: Aquatic Sciences and Fisheries Abstracts (ASFA), AccessAnesthesiology, AccessPediatrics, RECERCAT, AccessSurgery, SciELO, AccessEmergency Medicine, AccessPharmacy, ERIC, ATLA Religion Database with ATLASerials, Regional Business News, PsycINFO, Psychology and Behavioral Sciences Collection,

PsycARTICLES, Business Source Premier, EconLit, MEDLINE, Library, Information Science & Technology Abstracts, Film & Television Literature Index with Full Text, America: History & Life, Historical Abstracts, Philosopher's Index, GreenFILE, J-STAGE, Grove Art Online, Grove Music Online, JSTOR Arts & Sciences II, JSTOR Arts & Sciences III, JSTOR Arts & Sciences IV, JSTOR Arts & Sciences IX, JSTOR Arts & Sciences V, JSTOR Arts & Sciences VI, JSTOR Arts & Sciences VII, JSTOR Arts & Sciences VIII, JSTOR Ireland, JSTOR Life Sciences, Alexander Street Press, eBook Collection (EBSCOhost), NewsBank, British Library Document Supply Centre Inside Serials & Conference Proceedings, NewsBank - Archives, Publisher Provided Full Text Searching File, JSTOR Arts & Sciences I, Academic Search Index, Research@StAndrews:Full text, Manuscriptorium Digital Library, PsycARTICLES, SAULCAT, HeinOnline, Directory of Open Access Journals, OAPEN Library, Persée, Public Information Online, Naxos Music Library, Naxos Music Library Jazz, Bridgeman Education, British Library EThOS, World Book, ABC-CLIO Social Studies Databases, Academic Edition, Digital Access to Scholarship at Harvard (DASH), SSOAR – Social Science Open Access Repository, JSTOR 19th Century British Pamphlets, JSTOR Arts & Sciences X, JSTOR Arts & Sciences XI, Oxford Reference, Henry Stewart Talks, CogPrints, BioOne Online Journals, University Press Scholarship Online, Oxford Dictionary of National Biography, Accessible Archives, OAIster, Oxford Handbooks Online, Oxford Scholarship Online, Credo Reference Collections, arXiv, Books24x7, ScienceDirect, Anthropological Index Online, Brill Online: Encyclopaedia of Islam, Columbia International Affairs Online (CIAO), HeinOnline, Literature Online, MathSciNet, Oxford Dictionary of National Biography, Oxford English Dictionary, ProQuest Dissertations and Theses – Full Text, Scopus, Scran, The Encyclopedia of Life Sciences, The Times Digital Archive, World Shakespeare Bibliography Online, ProQuest: Aquatic Sciences and Fisheries Abstracts (ASFA), AccessAnesthesiology, AccessPediatrics, RECERCAT, AccessSurgery, SciELO, AccessEmergency Medicine, AccessPharmacy

EBESCO search for traffic-related air pollution and health studies, 1999-2013

Search Term	Result	Combination with (1) or (2)	Combination with (1) or (2) and (11)	Combination with (1) or (2) and (3) and (4) and (11)	Included after abstract review
(1)Air quality	8 884				
(2) air pollution,	59 678				
(3) emissions	36 640			4	2
(4) health	4 796 422	18 840			
(5) cardiovascular disease,	559 584	1 348	10		8
(6) respiratory disease,	339 716	2 286	16		8
(7) lung disease,	428 368	1 563	9		8
(8) cancer,	4 960 061	1 817	16		4
(9) pregnancy,	1 351 669	738	25		14
(10) newborn,	838 103	519	9		7
(11) residential distance	8 871				
(12) Scotland	323155	42	0	0	
Total			85	4	51
Total after removal of duplicates					31

Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present – edited to include only years, 1999-2013

# ▲	Searches	Results
1	((air pollut* or air quality) and health).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]	19124
2	air pollutant/ or air pollution/ or environmental exposure/	76894
3	emissions.mp.	28219
4	cardiovascular disease.mp. or cardiovascular disease/	147377
5	traffic/ or residential area/ or perinatal mortality/ or brain tumor/ or asthma/ or air pollution/ or environmental exposure/ or residential distance.mp. or demography/	322498
6	1 or 2	88031
7	5 and 6	77695
8	3 and 6 and 7	4807
9	4 and 8	118
10	respiratory tract disease/	18696
11	8 and 10	146
12	lung disease/	59854
13	8 and 12	45
14	neoplasm/	277283

☐	15	8 and 14	99
☐	16	pregnan*.mp.	788444
☐	17	8 and 16	129
☐	18	8 and 14	99
☐	19	cancer.mp. or neoplasm/	1207228
☐	20	8 and 19	327
☐	21	newborn/	497649
☐	22	8 and 21	135
☐	23	from 11 keep 1, 8, 11, 18-19, 26-28, 31-34...	46
☐	24	from 13 keep 3-4, 10-11, 15, 18-20, 27, 35...	11
☐	25	from 23 keep 1-46	46
☐	26	from 17 keep 5-6, 8, 10, 12, 16, 20...	23
☐	27	from 25 keep 1-46	46
☐	28	from 15 keep 8, 12, 19-22, 27-28, 37, 62...	14
☐	29	from 27 keep 1-46	46
☐	30	from 22 keep 1, 3, 5, 7-8, 12, 14-15...	40
☐	31	from 29 keep 1-46	46
☐	32	from 9 keep 4-5, 7, 18, 23-24, 28-29, 31-32...	27
☐	33	from 22 keep 1, 3, 6-7, 12, 14, 20...	33

☐	34	from 32 keep 1-27	27
☐	35	from 34 keep 1-27	27
☐	36	from 22 keep 1, 3, 5, 7, 12, 14-15...	28
☐	37	from 13 keep 3, 5, 15, 19-20, 26-27, 29...	9
☐	**38**	**from 36 keep 1-28**	**28**

Ovid Embase 1996 to 2013 Week 44 - edited to include only years 1999-2013

☐	35	((air pollut* or air quality) and health).mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]	16568
☐	36	air pollutant/ or air pollution/ or environmental exposure/	91530
☐	37	emissions.mp.	27140
☐	38	cardiovascular disease.mp. or cardiovascular disease/	186844
☐	39	traffic/ or residential area/ or perinatal mortality/ or brain tumor/ or asthma/ or air pollution/ or environmental exposure/ or residential distance.mp. or demography/	331274
☐	40	35 or 36	95726
☐	41	39 and 40	82491
☐	42	37 and 40 and 41	6600
☐	43	38 and 42	83
☐	44	respiratory tract disease/	28925

☐	45	42 and 44	137
☐	46	lung disease/	32396
☐	47	42 and 46	19
☐	48	neoplasm/	183520
☐	49	42 and 48	19
☐	50	pregnan*.mp.	381943
☐	51	42 and 50	70
☐	52	cancer.mp. or neoplasm/	1608796
☐	53	42 and 52	328
☐	54	newborn/	220743
☐	55	42 and 54	48
☐	56	from 43 keep 13, 16-17, 19, 33, 47, 49...	11
☐	57	from 45 keep 1, 9, 18-19, 24, 27, 39...	23
☐	58	from 47 keep 4, 6, 12, 19	4
☐	59	from 49 keep 17, 19	2
☐	60	from 51 keep 7-9, 29-31, 34, 50-51, 62	10
☐	61	from 53 keep 4, 28, 30, 51, 54, 56...	11
☐	**62**	**from 55 keep 2-3, 21, 24, 33, 40**	**6**

Internet (Google) search for traffic-related air pollution and health publications

Reports	Title	Result
Air Science (accessed 10 August 2015)	Air Science	Air pollution and health -11 of which 1 met criteria Air pollution and emissions – 120 of which 0 relevant Air pollution and residential distance – 0 Air pollution and Cardiovascular disease – 0 Air pollution and respiratory disease – 0 Air pollution and lung disease -2 but not published Air pollution and cancer – 3 but none met criteria Air pollution and pregnancy – 3 but 0 met criteria Air pollution and newborn - 0
Ayres, 2006	Cardiovascular Disease and Air Pollution. A report by the Committee on the Medical Effects of Air Pollutants	Systematic review
Barbour Index (accessed 03 January 2014)		Air pollution and health – 17 of which 5 met criteria (3 were WHO – see above) Air pollution and emissions – 3 of which 0 relevant Air pollution and residential distance – 0 Air pollution and Cardiovascular disease – 1 COMEAP Air pollution and respiratory disease – 0 Air pollution and lung disease -0 Air pollution and cancer - 0 Air pollution and pregnancy – 1 Air pollution and newborn – 0
Boulter, 2007	A review of emission factors and models for road vehicles non-	Data analysis.

	exhaust particulate matter.	
Burnett et.al., 2011	Current approaches and recent developments for estimating exposure-response functions for global application. Presentation.	Modeling method. Calculation for attributable risk.
DEFRA, (2006)	Air Quality and Social Deprivation in the UK: An Environmental Inequalities Analysis. Report to the Department for Environment, Food and Rural Affairs.	Links to deprivation.
DEFRA (accessed 10 August 2015)	About UK Air Pollution	Air pollution and health: 347 of which 2 met criteria. Public perception (Smallbone, year not recorded) Literature review of vehicle emissions.
Estarlich et. Al., 2011	Residential exposure to outdoor air pollution during pregnancy and anthropometric measures at birth in a multicenter cohort in Spain	Cohort study
Greenbaum, 2009	Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects.	Limitations of air pollution monitoring.
Gotschi et.al., 2008	Air pollution and lung function in the European Community Respiratory Health Survey.	Cross-sectional study.
HEI Panel on the Health Effects of Traffic-Related Air	Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health	Systematic review.

Pollution, 2010	Effects.	
HPA (accessed 10 August 2015)	Air	Estimated nearly 29000 deaths in 2008 attributable to long-term exposure to anthropogenic particulate emissions in the UK with 340 000 years of life lost. Air pollution – 13 publications of which 1 met criteria.
Krzyzanowski et.al., 2005	Health effects of transport-related air pollution.	Comment - Static monitoring may not reflect true population exposure. P125 health effects. Systematic literature review 2005.
Rushton, 1999	Overview and critique of the air pollution and health: a European approach (APHEA) project.	Systematic lit review of time series studies.
Scientific Committee on Health and Environmental Risks (SCHER), 2005	Opinion on “New evidence of air pollution effects on human health and the environment”	Editorial re PM 2.5
The Centre for Reviews and Dissemination, (accessed 03 January 2014)		Air pollution 20 – 0 relevant Air quality – 0
Timonen et.al., 2006	Effects of ultrafine and fine particulate and gaseous air pollution on cardiac autonomic control in subjects with coronary artery disease: the ULTRA study	Cross-sectional study – effects vary according to individual factors.

UK EA		No relevant studies
US EPA (2002)	Health assessment document for diesel engine exhaust.	Review diesel exhaust components.
WHO, 2000	Air Quality Guidelines for Europe. Second Edition	Comment - Target to have populations not exposed to unsafe levels of environmental contaminants by 2015 will not be met. Impact of the pollutants can be additive but measures are for single substances therefore only an estimate of risk. Provides background to guideline levels. Synergistic effects. Averaging of peaks. Exposure p46. All levels not in 2005 version still remain as of 2000. Excluded – references from studies before 1999.
WHO, 2003	Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide	Comment - Use of thresholds should be replaced with exposure/concentration-response relationships because there are different end points depending on susceptibility. Pollutants occur as interacting mixtures (O3, PM, NO2) so it is not possible to determine which component has the effect. Air quality guidelines for PM2.5 should be developed.
WHO, 2004	Health aspects of air quality in Europe. Results from the WHO project "Systematic review of health aspects of air pollution in Europe".	Literature review
WHO, 2005	Air quality guidelines. Global update	Comment - Update on 2000 guidelines. Covers indoor and outdoor pollution. Lower thresholds for PM and ozone not found. Monitor via hospital admission and mortality. Multiple pollutant effect. PM - recommends risk assessment in local population but locals wanted guideline values. Health effects pp 61-168.
WHO, 2008	Health risks of ozone from long range	Review based on WHO 2005 evaluation of the evidence.

	transboundary air pollution.	
WHO, 2013	Review of evidence on health aspects of air pollution –REVIHAAP Project. Technical Report.	Literature review
WHO, 2014	Ambient (outdoor) air quality and health. Factsheet N^{o} 313	Air pollution and health – 8 of which 1 met criteria Air pollution and emissions – 0 Air pollution and residential distance – 0 Air pollution and Cardiovascular disease – 0 (1 cross-over study and one statement from the American Heart Association summarising the risks and promoting further research[1] Air pollution and respiratory disease – 0 Air pollution and lung disease -0 Air pollution and cancer - 0 Air pollution and pregnancy – 0 Air pollution and newborn – 0

Appendix 3

The function of Scottish, UK and international agencies involved in air quality (September 2013)

	Organisation	*Function*
International	**WHO** http://www.who.int/topics/air_pollution/en/ (accessed 19 January 2014)	*"WHO/Europe works to make sure that the available evidence on the health risks of air pollution is used in public debate and in policy-making."*
		WHO/Europe, 2013 *http://www.euro.who.int/en/home* (accessed 19 January 2014)
	European Commission http://ec.europa.eu/environment/air/index_en.htm (accessed 19 January 2014)	*"Since the early 1970s, the EU has been working to improve air quality by controlling emissions of harmful substances into the atmosphere, improving fuel quality, and by integrating environmental protection requirements into the transport and energy sectors."*
	United Nations Environment Programme http://www.unep.org/urban_environment/issues/urban_air.asp (accessed 19 January 2014)	*"Development of international Conventions and Protocols in relation to air pollution and its impacts (e.g. CLRTAP, Stockholm Convention on POPs, etc.)"*
National	**Committee on the Medical Effects of Air Pollutants COMEAP** http://www.comeap.org.uk/ (accessed 19 January 2014)	*"COMEAP is an expert Committee that provides advice to government departments and agencies, via the Department of Health's Chief Medical Officer, on all matters concerning the effects of air pollutants on health."*
	Confederation for Passenger Transport (CPT) http://www.cpt-uk.org/ (accessed 19 January 2014)	*"The trade association representing the UK's bus, coach and light rail industries."*
	Environmental Protection Scotland (EPS) http://www.ep-scotland.org.uk/ (accessed 19 January 2014)	*"EPS is a Scottish charity supported by the Scottish Government that provides expert policy analysis and advice on air quality, land quality, waste and noise and their effects on people and communities in terms of a wide range of issues including public health, planning, transport, energy and climate.* *The air quality advisory sub group is formed of representatives of various organisations across*

		Scotland (SG, SEPA, LAs, consultants)."
	Institute of Occupational Medicine IOM http://www.iom-world.org/ (accessed 19 January 2014)	*"The Institute of Occupational Medicine (IOM) provides workplace health research and consultancy services. UK base and headquarters are in Scotland. Established in 1969 in the UK as an independent charity, with origins in occupational health research. Remit also extends into certain areas of environment and public health, and to the provision of consultancy and scientific services. The main focus of work is associated with understanding and where possible reducing the risks to health from hazards in the workplace and in the wider environment."*
	NHS Scotland	***Health Protection Scotland http://www.hps.scot.nhs.uk/*** (accessed 19 January 2014) *"The Scottish Government established health Protection Scotland (HPS) in 2005 to plan and deliver effective and specialist national services aimed at protecting all the people of Scotland from infectious and environmental hazards."* ***Scottish Environmental Public Health Practice Network (SEPHPNet)*** *"Network of Consultants in Public Health Medicine, Specialists in Environmental Health Protection and partner agencies who share expertise and provide Health Board support on environmental issues."*
		Healthy Environment Network http://www.healthscotland.com/resources/networks/healthy-environment/HEN-about.aspx (accessed 19 January 2014) *"This network provides and informal interface between organisations and professions who have the capacity to change and preserve the environment in the interests of human health, and promotes understanding of environmental influences on health, and how these can be addressed."*
		NHS Choices *http://www.nhs.uk/Livewell/weather/Pages/smog.aspx* (accessed 19 January 2014) *"NHS Choices is the UK's biggest health website. It provides a comprehensive health information service."*
		NHS Boards http://www.scotland.gov.uk/Topics/Health/NHS-Workforce/NHS-Boards (accessed 19 January 2014) *"Fourteen regional NHS Boards, which are responsible for the protection and the improvement of their population's health and for the delivery of frontline healthcare services."*

	Public Health England (PHE)	***Public Health England (PHE) (formally the Health Protection Agency HPA)*** ***https://www.gov.uk/search?q=air+quality&tab=government-results*** (accessed 19 January 2014) *"Provides health protection advice for England and Wales."* ***Air Quality Expert Group*** **(accessed 19 January 2014)** *"The AQEG provides independent scientific advice on air quality to Defra, in particular the air pollutants contained in the Air Quality Strategy (AQS) for England, Scotland, Wales and Northern Ireland and those. It does not provide advice on the health impacts of air pollution." https://www.gov.uk/government/policy-advisory-groups/air-quality-expert-group (accessed 10/01/2014)*
		Scottish (Managed) Sustainable Health Network (SMaSH) ***http://www.scotphn.net/projects/current_projects/sustainable_health_network*** (accessed 19 January 2014) *"A multiagency network, which engages in a programme of work to increase the sustainability of NHS services and partner services whose function, is to improve and protect public health and reduce inequalities."*
	Royal Town Planning Institute in Scotland (RTPI - Scotland) http://www.rtpi.org.uk/the-rtpi-near-you/rtpi-scotland/about-rtpi-scotland/ (accessed 19 January 2014)	*"RTPI Scotland works directly with the Scottish Government and the Scottish Parliament who legislate for the separate planning system in Scotland. RTPI Scotland's mission is to support people and organisations to create great places for people across Scotland."*
	Scottish Government http://www.google.com/cse?cx=007197013444011456969:ll2jctu1uq8&start=0&q=air%20quality&oe=utf-8&sort=#gsc.tab=0&gsc.q=air%20quality&gsc.page=1 (accessed 19 January 2014)	*"Andrew Taylor, Air Quality Policy Officer, leads the Air Quality agenda. The Scottish Government (SG) role is to ensure compliance with European and National legislation on air quality. The Dept. engages with national and local groups in the pursuit of its aims. It exists as a unit within the Environmental Quality Directorate (this Directorate also oversees noise and nuisance, environmental regulation, waste, water and radiation amongst other areas). Within the SG there are working links with the Health Dept., Climate Change Dept., Renewable Energy Dept., Transport Scotland (Low Carbon Unit, Sustainable Transport Unit), Planning Dept., amongst others."*

		Scottish Air Quality – Scottish Government and Ricardo AE*A* *http://www.scottishairquality.co.uk/index.php* (accessed 19 January 2014) *"The Scotland Air Quality Data and Statistics Database provides air quality statistics for Scotland from 1986 to current. The data is collected from air quality monitoring sites operated by Defra, the Scottish Government and Local Authorities. The site shows maps of AQMAs and provides information on air quality and health. Site users are invited to subscribe to the Know and Respond text-messaging service, which will send a text when air quality in a particular area is poor Air Quality Banding System* (accessed 19 January 2014)*. Estimates of emission data for a variety of sources can be obtained from http://naei.defra.gov.uk/" (*Accessed 19 January 2014)
	Scottish Environment Protection Agency (SEPA) http://www.sepa.org.uk/air.aspx (accessed 19 January 2014)	*"SEPA works to understand and improve air quality in Scotland. SEPA regulates and monitors certain industrial activities in Scotland that can generate local airborne pollution. This involves working with and directing local authorities and other partners to manage and improve air quality. SEPA provides policy and operational advice to government, industry and the public on pollution control and other environmental issues. In addition, SEPA works towards Scottish and UK objectives and targets set to address global climate change and the cross-border transfer of pollutants.* *SEPA has internal decision-making groups including air quality management groups. SEPA also sits on various stakeholder groups where sites/issues of air quality concern exist (e.g. specific regulated sites)."*
		Scottish Transport Emissions Partnership (STEP) *https://knowledgehub.local.gov.uk/web/scottishtransportemissionspartnership* (accessed 19 January 2014) *"The Scottish Transport Emissions Partnership (STEP) works with internal and external stakeholders to improve and protect Scotland's urban air quality, by communicating examples of best practice and promoting well-informed and open debate.* *Organisations in the Core Group include:* • *Scottish Environment Protection Agency (SEPA) (Chair)* • *Transport Scotland (Secretariat)* • *Road Haulage Association (RHA)* • *Royal Town Planning Institute in Scotland (RTPI – Scotland)* • *Scottish Government* • *Regional Transport Partnerships*

		• *Representative from the South West Pollution Group* • *Representative from the South East Pollution Group* • *Representative from the Central and East Pollution Group* • *Representative from the North Pollution group* • *20/20 Group – Transport sub-group* • *Confederation for Passenger Transport (CPT)* • *Society of Chief Officers of Transportation in Scotland (SCOTS)* • *National Health Service"*
	Society of Chief Officers of Transportation in Scotland (SCOTS) http://www.scotsnet.org.uk/about.php (accessed 19 January 2014)	***Society of Chief Officers of Transportation in Scotland (SCOTS)*** *"Scots is a strategic body comprising of transportation professionals from all the 32 Scottish councils and the seven Scottish regional transport partnerships. The society's work involves improving performance and innovation in the design, delivery and maintenance of transportation systems. This is done by actively influencing important aspects of transportation at the highest levels in Scottish Government by responding to consultations from Government, providing advice on legislation as it is developed or implemented, advising COSLA, local authorities and stakeholders. Another key way in which this is achieved is by communicating the important role of transportation in the current financial climate and dealing with the related issues of sustainability such as economic, environmental and social factors."*
	Transport Scotland http://www.transportscotland.gov.uk/ (accessed 19 January 2014)	*"Transport Scotland is the national transport agency for Scotland. The remit incorporates:* • *Rail and trunk road networks* • *Major public transport projects* • *Coordinating the National Transport Strategy for Scotland* • *Liaising with regional transport partnerships, including monitoring of funding* • *Sustainable transport, road safety and accessibility* • *Local roads policy* • *Aviation, bus, freight and taxi policy* • *Ferries, ports and harbours* *An agency of the Scottish Government, they are accountable to Parliament and the public through Scottish Ministers."*
	Local Authorities **http://www.scotland.gov.uk/Topics**	*Local Government Scotland* *"Scottish Local Government consists of 32 elected councils who provide services to the people of*

	/Government/local-government (accessed 19 January 2014)	*Scotland – services such as education, social care, waste management, cultural services and planning. Scottish Government works with local government and provides funding and the framework for accountability and performance.* *Scottish Pollution Control and Coordination Committee (SPCCC) acts as a co-ordinating committee in relation to pollution matters including air pollution, noise, contaminated land and waste management issues where the Local Authorities and SEPA have an interest. For each LA see http://www.cosla.gov.uk/councils "* (Accessed 19 January 2014)
	Pollution Groups – North, Central and East, South East, South West	*The four area pollution groups represent all 32 of the local authorities. The groups feed into the SPCCC.*
	Regional Transport Partnerships[2] http://www.transportscotland.gov.uk/strategy-and-research/Regional-Transport-Partnerships (accessed 19 January 2014)	*"These are 7 regional transport groups and they link with the national SPCCC. Their main function is to strengthen the planning and delivery of regional transport developments. Each RTP has prepared a regional transport strategy. This is supported by a delivery plan where RTPs set out when and how projects and proposals would be delivered.* *Some RTPs are also responsible for the delivery of transport services. In particular Strathclyde Partnership for Transport owns and operates the Glasgow subway and major bus stations across the west of Scotland."*
Environmental Campaign Groups	**Friends of the Earth Scotland** http://www.foe-scotland.org.uk/node/1556 (accessed 19 January 2014)	***Friends of the Earth Scotland*** *"They are a campaigning organisation and an independent Scottish charity forming a global "grassroots environmental network". "*
	World Wildlife Fund Scotland http://scotland.wwf.org.uk/ (accessed 19 January 2014)	*"WWF Scotland is part of the international WWF network, one of the world's most influential environmental organisations.* *Climate change, threats to natural resources and rising energy use are just some of the issues that are of growing global concern, impacting on people and wildlife right round the world. WWF Scotland works on these issues from a Scottish perspective by influencing policy, providing solutions and gaining public support and involvement."*

Appendix 4

Examples of SIGN PRISMA and COHORT assessment of studies

PRISMA Checklist[11]

Section/topic	#	Checklist item	Reported on page #
TITLE (Europe) WHO 2008 2nd edition			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	Syst rev
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	✓ VII -3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	each chapt
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	✗
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	each chapt
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	✗
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	✓
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	✗

Section/topic	*#*	*Checklist item*	*Reported on page #*
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			

Section/topic	*#*	*Checklist item*	*Reported on page #*
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers).	~
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	✓
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	✓
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	ص٤٩

SIGN Cohort Studies Checklist[1c]

SIGN

Methodology Checklist 3: Cohort studies

Study identification (*Include author, title, year of publication, journal title, pages*)

Hunter / long term exposure to NO_2 & $PM_{2.5}$ and all-cause & cause specific mortality in a prospective cohort of women 2012

Guideline topic:	Key Question No:	Reviewer:

Before completing this checklist, consider:

1. Is the paper really a cohort study? If in doubt, check the study design algorithm available from SIGN and make sure you have the correct checklist.
2. Is the paper relevant to key question? Analyse using PICO (Patient or Population Intervention Comparison Outcome). IF NO REJECT (give reason below). IF YES complete the checklist..

Reason for rejection: 1. Paper not relevant to key question ☐ 2. Other reason ☐ (please specify):

Please note that a retrospective study (ie a database or chart study) cannot be rated higher than +.

Section 1: Internal validity

	In a well conducted cohort study:	Does this study do it?
1.1	The study addresses an appropriate and clearly focused question.	Yes ☑ No ☐ Can't say ☐
	SELECTION OF SUBJECTS	
1.2	The two groups being studied are selected from source populations that are comparable in all respects other than the factor under investigation.	Yes ☑ No ☐ Can't say ☐ Does not apply ☐
1.3	The study indicates how many of the people asked to take part did so, in each of the groups being studied.	Yes ☑ No ☐ Does not apply ☐
1.4	The likelihood that some eligible subjects might have the outcome at the time of enrolment is assessed and taken into account in the analysis.	Yes ☒ No ☐ Can't say ☑ Does not apply ☐
1.5	What percentage of individuals or clusters recruited into each arm of the study dropped out before the study was completed.	
1.6	Comparison is made between full participants and those lost to follow up, by exposure status.	Yes ☑ No ☐ Can't say ☐ Does not apply ☐

ASSESSMENT		
1.7	The outcomes are clearly defined.	Yes ☑ No ☐ Can't say ☐
1.8	The assessment of outcome is made blind to exposure status. If the study is retrospective this may not be applicable.	Yes ☐ No ☐ Can't say ☐ Does not apply ☑
1.9	Where blinding was not possible, there is some recognition that knowledge of exposure status could have influenced the assessment of outcome.	Yes ☐ No ☐ Can't say ☐ ☐
1.10	The method of assessment of exposure is reliable.	Yes ☑ No ☐ Can't say ☐
1.11	Evidence from other sources is used to demonstrate that the method of outcome assessment is valid and reliable.	Yes ☐ No ☐ Can't say ☐ Does not apply ☐
1.12	Exposure level or prognostic factor is assessed more than once.	Yes ☑ No ☐ Can't say ☐ Does not apply ☐
CONFOUNDING		
1.13	The main potential confounders are identified and taken into account in the design and analysis.	Yes ☑ No ☐ Can't say ☐
STATISTICAL ANALYSIS		
1.14	Have confidence intervals been provided?	Yes ☑ No ☐
SECTION 2: OVERALL ASSESSMENT OF THE STUDY		
2.1	How well was the study done to minimise the risk of bias or confounding?	High quality (++) ☑ Acceptable (+) ☐ Unacceptable – reject 0
2.2	Taking into account clinical considerations, your evaluation of the methodology used, and the statistical power of the study, how strong do you think the association between exposure and outcome is?	
2.3	Are the results of this study directly applicable to the patient group targeted in this guideline?	Yes ☐ No ☐
2.4	**Notes.** Summarise the authors conclusions. Add any comments on your own assessment of the study, and the	

Appendix 5

Key air pollution factors reported in the literature and associated with traffic-related pollution and ill health (Step 1).

Reference	Air pollution factors
Ayres, 2006.	family Hx CVD, hypertension, active smoking, diabetes, obesity, lack of exercise, social status, lipids, outbreaks of viral respiratory illness, occupation
Greenbaum, 2009.	control for confounding consistency with other studies method to estimate exposure Analysis - • sufficient evidence • suggestive but not sufficient • inadequate and insufficient evidence • suggestive of no association
Health Effects Institute, 2010.	re-suspended dust and non-combustion vehicular emissions. stress noise
Rushton, 1999.	control condition
US EPA, 2002.	Age of vehicles
World Health Organisation, 2000.	indoor exposure occupational exposure natural air pollution tobacco smoke exposure duration of exposure concentration of pollution by time period (hourly, daily, annual) seasonal effects sources temporal variation in emissions meteorological effects

	topography monitoring method – automatic, semi-automatic, manual validation of measurements from monitors sampling techniques analytical methods data management statistical handling data validation.
World Health Organisation, 2003.	reversibility large particle monitoring adjustment pollutants monitored smoking, age, inequalities. alternative explanations for health effects exposure to passive smoking alternative sources of $PM_{2.5}$ Synergistic effects evidence of health improvements if reduction in pollution timeframe of study
World Health Organisation, 2005.	selection of monitoring sites Pollutant mixes.
World Health Organisation, 2013.	time spent indoors.

Appendix 6

Analysis of the cohort studies to assess the strength of evidence for association or causality (Step 2)

Study features and demographic factors – author, years of study, outcome, population size and age

Key

Good e.g. validated	Inadequate e.g. source of data not robust, indirect source of info, lack of expertise	Absent e.g. no evidence of factor in study	na Not applicable

Author	Population study period	Outcome	Population size	Participant age
Anderson 2011	1993-2006	hospital admission for COPD, asthma, IH, other heart disease, stroke, diabetes	57 053	50-64
Barnett 2011	Jan 2007-July 2008	negative birth outcome	970	15-47
Brauer 2007	1997-2000	development of asthmatic/allergic symptoms and respiratory infections	4,000	0-4
Brauer 2008	1999-2002	small for gestational age (SGA) birth weight, low full-term birth weight (LBW), and preterm birth	70,249	birth
Carleston 2010	birth year 1995 and at 7 years of age	asthma and bronchial hyper-reactivity	272	birth and 7 years of age
Cesonari G	1995-2007	cause-specific mortality	1,265,058	subjects ≥ 30 years of age
Chang J	1 January 2000 and 31 December 2003.	acute respiratory illnesses	3297	aged 18 years or younger;
Chen J	1982-2004	cardiovascular and cerebrovascular mortality	205 440	35-85
Cowie C	2006-2008	respiratory health	36 power effect considered - 20 took part in 2008	Details not provided

Estarlich M	2003-2008	birth weight, length and head circumference.	2505	> or = 16
Gehring U 2002	1997-1999	cough	1756	nenates, 1-2 years
Gehring, 2006	1980s and 1990s	cardiopulmonary mortality	4752	50-59 (women)
Gruzieva 2013	1994-2008	asthma	4089	0-12
Heinrich 2013	1980s and 1990s with outcome at 2008	All-cause and cause-specific mortality	4800	55
Hoffman 2009	2000 -?	systemic inflammatory markers	4814	45-75
Iniguez 2012	2003-2005	foetal and neonatal size	855	foetus and neonate
Janssen 2012	2010-2011	mitochondrial function of the placenta and foetus	178	newborn
Jerrett 2009	1992-2002	mortality	2360	median age 60
Laurent 2013	1997-2006	birth weight	70000	newborn
Medina-Ramon 2008	2000	mortality	1389	mean 76yo
Miyake 2010	Oct 2002-March 2003	allergic disorders	1002	pregnancy to 24 months
Pereira 2011	2000-2006	foetal growth	3501	
Pereira 2013	2000-2006	pre-eclampsia	23452	pregnancy
Raaschou-Nielsen 2012	1993-1997 followed up to 2009	mortality cardiovascular disease	52061	50-64
van den Hooven 2009	2002-2006	birth pregnancy outcomes	7339	median 30 yo
Wilheim 2005	1994-2000	birth outcomes	146972	<20->40
Wilheim 2012	2004-2006	low birth weight	100938	<20->35
Wu 2009	1997-2006	Pre-eclampsia and preterm delivery	81186	24-36
Yap 2012	1970-79	All-cause mortality, CVD, IHD, respiratory	22 000	45-64
Yorifuji 2010	1999-2006	All-cause and cause-specific mortality	13444	65-84

Exposure source – occupation, time indoors, residency, pollution events, source of pollution, duration and concentration

Author	occupation	time indoors	residential duration	natural air pollution events	sources/ pollutant mixes	duration of exposure	concentration of exposure µg/m^3	
							NO_2	$PM_{2.5}$
Anderson 2011							10-40	na
Barnett 2011							na	na
Brauer 2007	na						15-58	13-25
Brauer 2008							0-68	0-37

Carleston 2010	na						<28->35	<3->8
Cesonari G							IQR 11	IQR 5.8
Chang J	na						na	na
Chen J							Details not available	
Cowie C	na	na	na	na			-2 to 28	20-28
Estarlich M							18-40	na
Gehring U 2002	na						19-67	11.9-21.5
Gehring, 2006							20-60	34-52
Gruzieva 2013	na						NOx >0-135 background NOx 21	PM_{10} >0-18 background PM_{10} 4.6,
Heinrich 2013							20-60	34-52
Hoffman 2009							Na	19-26
Iniguez 2012							10-60	na
Janssen 2012							na	14-36
Jerrett 2009							Mean 10-67ppb	Details not available
Laurent 2013							Mean 25	15
Medina-Ramon 2008					na			na
Miyake 2010								na
Pereira 2011								na
Pereira 2013							IQR 5-17ppb	na
Raaschou-Nielsen 2012							10-40	na
van den Hooven 2009					na		na	na
Wilheim 2005							<3->4 pphm	<17 - >35
Wilheim 2012							mean 26-33ppb	16-20
Wu 2009							NOx 7ppb	Mean 2
Yap 2012							na	Black smoke 9-48
Yorifuji 2010							Mean -20 to 60	na

Reference levels http://ec.europa.eu/environment/air/quality/standards.htm (accessed 17 July 2015

Nitrogen dioxide (NO2)	200 µg/m3	1 hour
	40 µg/m3	1 year

Fine particles (PM2.5)	25 µg/m3***	1 year

Pathway factors– season, temperature, topography, method, validation, site, sampling, analysis and adjustments

Author	seasonal adjustment	temporal variation	topography	monitoring method	validation of monitors	monitoring site	sampling techniques	analytical methods	data management /large particle adjustment
Anderson 2011									
Barnett 2011					*na	na	na	na	na
Brauer 2007									
Brauer 2008									
Carleston 2010									
Cesonari G									
Chang J					na	na			na
Chen J									
Cowie C			na						
Estarlich M									
Gehring U 2002									
Gehring, 2006									
Gruzieva 2013									
Heinrich 2013									
Hoffman 2009									
Iniguez 2012									
Janssen 2012						na	na	na	
Jerrett 2009									
Laurent 2013									
Medina-Ramon 2008			na		na	na	na	na	na
Miyake 2010					na	na	na	na	na
Pereira 2011				na					
Pereira 2013									
Raaschou-Nielsen 2012						na	na		

van den Hooven 2009					na	na	na		na
Wilheim 2005									
Wilheim 2012									
Wu 2009					na	na			
Yap 2012									
Yorifuji 2010							na		

***** cells left blank because the variable is not applicable to this study

Human Receptor – data source, outcome, smoking, socioeconomic factors, noise, stress, CVD, HT, diabetes, respiratory disease, allergies, diet, obesity, exercise, hyperlipidaemia, viruses

Author	source of health data	outcome	smoker	passive smoking	Socioeconomic	noise	stress	control condition eg digestive disease	CVD or family Hx	HT or family Hx	diabetes	respiratory disease	asthma or family Hx	allergic conditions or family Hx	diet	obesity	lack of exercise	hyperlipideamia	viral outbreaks
Anderson 2011	questionnaire self administered	COPD, asthma, IH, other heart disease, stroke, diabetes"																	
Barnett 2011	birth data	negative birth outcome							na					na				na	
Brauer 2007	questionnaire	asthmatic/allergic symptoms and respiratory infections																	
Brauer 2008	linked health data	small for gestational age (SGA) birth weight, low full-term birth weight (LBW), and preterm birth																	
Carleston 2010	asthma was assessed by a paediatric allergist and bronchial hyper-reactivity was measured by methacholine challenge	asthma and bronchial hyper-reactivity							na	na	na	na						na	
Cesonari G	modelled	cause-specific mortality																	
Chang J	hospital admissions	respiratory illnesses, asthma.							na	na									

Chen J	Canadian Mortality Database	cardiovascular and cerebrovascular mortality										na	na	na					na			
Cowie C	spirometry and questionnaires	respiratory health							na	na	na							na				
Estarlich M	clinical measurement	birth weight, length and head circumference																na				
Gehring U 2002	questionnaires	cough	na							na							na	na				
Gehring, 2006	state agency data for deaths and questionnaire for confounders	cardiopulmonary mortality																				
Gruzieva 2013	repeated blood samples IgE and questionnaires	asthma	na				na		na	na	na				na			na				
Heinrich 2013	state agency data for deaths and questionnaire for confounders	All-cause and cause-specific mortality						na														
Hoffman 2009	self administered questionnaire, interviews, BP, anthropometric measurements, clinical and lab tests	systemic inflammatory markers																				
Iniguez 2012	INMA prospective cohort Valencia; US measurements	foetal and neonatal size																				
Janssen 2012	ENVIRONAGE birth cohort study, questionnaires, lab samples	mitochondrial function of the placenta and foetus																na				
Jerrett 2009	respiratory clinic	mortality																				
Laurent 2013	hospital based obstetric database	birth weight																				

Medina-Ramon 2008	hospital admissions	mortality in heart failure patients											na	na						
Miyake 2010	survey	allergic disorders							na	na	na					na	na	na		
Pereira 2011	midwife notifications, birth registrations, death registrations, birth defect registrations and hospital morbidity records	foetal growth											na	na			na			
Pereira 2013	birth death registrations and midwife notifications, hospital records	pre-eclampsia												na				na	na	
Raaschou-Nielsen 2012	register of causes of death, self administered questionnaire	mortality cardiovascular disease																		
van den Hooven 2009	physical examinations, hospital records and questionnaires	birth pregnancy outcomes										na	na	na			na	na		
Wilheim 2005	birth certificates	birth outcomes										na	na	na			na	na		
Wilheim 2012	birth records	low birth weight											na	na			na	na		
Wu 2009	perinatal database	Pre-eclampsia and preterm delivery											na	na			na	na	na	
Yap 2012	self administered questionnaire, medical exam	All-cause mortality, CVD, IHD, respiratory											na	na						
Yorifuji 2010	questionnaires, death register	All-cause and cause-specific mortality											na	na						

Alternative explanations and health improvements with pollution reduction

Author	alternative explanations/biotoxins	health improvements with pollution reduction
Anderson 2011		
Barnett 2011	"…chemical toxins in traffic pollutants, or because of disturbed sleep due to traffic noise."	
Brauer 2007	"…family history of allergies."	
Brauer 2008	"…alternative causes of SGA."	
Carleston 2010		
Cesonari G		
Chang J	"…family history - genetic and increased chance early response to symptoms."	
Chen J		
Cowie C		
Estarlich M	"NO_2 as marker of other pollutant?"	
Gehring U 2002	reporting bias	
Gehring, 2006	"….selective participation; mortality associated with asthma and HT at baseline, source of pollution likely to be industrial, roads and noise, mortality level low.""	
Gruzieva 2013		referred to but not measured
Heinrich 2013	"..Industry in the area"	showed decrease in effect over time and air pollution decreasing at same time
Hoffman 2009	"…exposure estimation error."	
Iniguez 2012		
Janssen 2012	"…many factors could act as confounders"	
Jerrett 2009	"..traffic noise."	
Laurent 2013	"…increase in miscarriage leading to increase mean BW. No data on height of parents, weight, smoking."	
Medina-Ramon 2008	"…comorbidities due to age."	
Miyake 2010		
Pereira 2011	"…possibility that the association observed was due to unknown factors uniquely correlated with this cohort."	
Pereira 2013	"…indoor pollution."	
Raaschou-Nielsen 2012		
van den Hooven 2009		
Wilheim 2005		
Wilheim 2012	"…pollutant mixes."	
Wu 2009	"…$PM_{2.5}$ and NOx acting as surrogates for other pollutant? E.g. ultra fine particles and PAHs."	
Yap 2012		
Yorifuji 2010		

Appendix 7

Critique of the cohort studies for association or causation (Step 3)

Author	Strength	Consistency	Specificity	Temporality	Biological gradient	Plausibility	Coherence	Experiment	Analogy	***Conclusion***
Anderson 2011			questionnaire self administered							*"Long-term exposure to traffic-related air pollution **may** contribute to the development of COPD."*
Barnett 2011			birth data							*"Results add weight to the **association** between exposure to traffic and reduced gestation time."*
Brauer 2007			questionnaire							*"Traffic-related pollution was **associated** with respiratory infections and some measures of asthma and allergy during the first 4 yrs of life."*
Brauer 2008			linked health data							***"Association** between increased risk of SGA birth weight and preterm birth with and low levels of air pollution."*
Carleston 2010			asthma assessed by a paediatric allergist; bronchial hyper-reactivity measured by methacholine challenge.							*"Modest elevations in exposure to some traffic-related air pollutants during the year of birth are **associated** with new onset asthma assessed at age 7."*
Cesonari G			modelled							*"Study **supports mortality effect** of long- term exposure to P(M.sub.2.5) and N(O.sub.2)."*
Chang J			hospital admissions							*"Exposure to traffic-related air pollution **increases asthma severity** as indicated by hospital utilisation."*
Chen J			Canadian Mortality Database							*"Traffic-related air pollution at relatively low concentrations in Ontario was **associated** with increased mortality from cardiovascular disease."*
Cowie C			spirometry and questionnaires							*"No consistent evidence of adverse respiratory effects from short-term exposures downwind of the tunnel ventilation stack, except for dry nose symptoms. increased airway inflammation and symptoms in subjects after only 2 h exposure at the heavily trafficked location, are **suggestive** of detrimental effects of short-term exposures to traffic-related air pollution."*
Estarlich M			clinical measurement							*"NO_2 exposure was **associated** with reductions in both length and weight at birth."*
Gehring U 2002			questionnaires							*"Due to the very young age of the infants, it was **too early to draw definitive conclusions** from this for the development of asthma."*

Gehring, 2006			state agency data for deaths and questionnaire for confounders							*"Living close to major roads and chronic exposure to NO2 and PM10 may be **associated** with an increased mortality due to cardiopulmonary causes."*
Gruzieva 2013			repeated blood samples IgE and questionnaires							*"Modest positive **associations** between air pollution exposure from traffic during infancy and asthma in children during the first 12 years of life, with stronger effects suggested for nonallergic asthma."*
Heinrich 2013			state agency data for deaths and questionnaire for confounders							*"Living close to a major road was **associated** with an increased relative risk for all-cause, cardiopulmonary and respiratory mortality. These associations were temporally stable."*
Hoffman 2009			"…population based prosecptive cardiovascular cohort study - self adminstered questionnaire, interviews, BP, anthropometric measurements, clin and lab tests."							*"Long-term residential exposure to high levels of PM2.5 is weakly **associated** with systemic inflammatory markers in men."*
Iniguez 2012			INMA prospective cohort Valencia; US measurements							*"Maternal exposure to NO2 is **associated** with impaired fetal growth from mid-gestation onwards."*
Janssen 2012			ENVIRONAGE birth cohort study, questionnaires, lab samples							*"Prenatal PM10 exposure was **associated** with placental mitochondrial alterations, which may both reflect and intensify oxidative stress production. "*
Jerrett 2009			respiratory clinic							*"Exposure to TRAP was significantly **associated** with increased all-cause and circulatory mortality in this cohort."*
Laurent 2013			hospital based obstetric database							*"Ambient O_3 was **associated** with a decrement in mean birth weight and significant increases in the risk of LBW were associated with traffic density, proximity to roads and ambient O_3."*
Medina-Ramon 2008			hospital admissions							*"Residential exposure to traffic-related air pollution **increases the mortality risk** after hospitalization with acute HF."*
Miyake 2010			survey							*"Intrauterine exposure to traffic-related air pollutants and/or such exposure after birth **may increase the risk** of more extreme manifestations of allergic disorders in infants."*
Pereira 2011			"Midwife notifications, birth registrations, death registrations, birth defect registrations and hospital							*"An **association** between maternal exposure to traffic emissions and reduced fetal growth."*

			morbidity records."							
Pereira 2013			birth death registrations and midwife notifications, hospital records							*"Elevated exposure to traffic-related air pollution in pregnancy was **associated** with increased risk of pre-eclampsia."*
Raaschou-Nielsen 2012			register of causes of death, self administered questionnaire							*"Traffic air pollution is **associated** with mortality from cardiovascular diseases and all causes, after adjustment for traffic noise."*
van den Hooven 2009			physical examinations, hospital records and questionnaires							*"Mothers exposed to residential traffic had **no higher risk** of adverse birth outcomes or pregnancy complications in this study."*
Wilheim 2005			birth certificates							***"Link** between CO and particle exposures to term LBW and preterm birth."*
Wilheim 2012			birth records							*"Evidence of the **potential impact** of traffic-related air pollution on fetal growth."*
Wu 2009			perinatal database							*"Exposure to local traffic-generated air pollution during pregnancy **increases the risk** of preeclampsia and preterm birth in Southern California women."*
Yap 2012			self administered questionnaire, medicaal exam							*"The **association** between mortality and long-term exposure to BS observed in the Renfrew/Paisley cohort is consistent with hypotheses of how air pollution may affect human health."*
Yorifuji 2010			questionnaires, death register							*"Long-term exposure to traffic-related air pollution, indexed by nitrogen dioxide concentration, **increases the risk** of cardiopulmonary mortality, even in a population with a relatively low body mass index and increases the risk of lung cancer mortality in non-smokers."*

Appendix 8

NHS24 Study

Caldicott Guardianship and St Andrews Ethics Committee Study Approval

Caldicott approval

From: Alexander Malcolm [Malcolm.Alexander@nhs24.scot.nhs.uk]
Sent: 18 July 2014 13:35
To: Jacqueline Hyland
Cc: Medicine Ethics
Subject: RE: air pollution events and call to NHS 24

I, Dr Malcolm Alexander, in my capacity of Caldicott Guardian (deputy) can confirm that NHS 24 are happy to release the information to Dr Jackie Hyland in the form and for the purpose stated below:

Research question: Was there evidence of an increase in health complaints during or within 2 weeks after a period of increased air pollution (20th-28th March 2012 inclusive) in the population living within 500m of air pollution monitors?

Information that will be provided:

1. Total number of calls to NHS 24 for Scotland (population 5,254,800)-
   during this period,
   one week before (control) and
   one week after

2. The total calls for
   - Edinburgh St Leonards and Glasgow Central areas (see attached sheet for postcodes and population by equivalent datazones)
   during this period,
   one week before (control) and
   one week after

3. If there was an increase in calls during the pollution period what was the nature of these calls e.g. evidence of calls relating to irritation of the eyes, nose or throat, coughing, phlegm, wheeze, breathlessness, chest tightness, chest pain or any other symptom collected by NHS 24 which would reflect air pollution affecting health.

4. Did the call type differ between the Edinburgh and Glasgow postcodes and the rest of Scotland?

Kind regards

Malcolm
Dr Malcolm Alexander
Associate Medical Director, NHS 24
Clyde Contact Centre
Beardmore Street
Clydebank, G81 4HX
Mobile 07795 603155

Ethics Committee submission

UTREC Ethical Application Form (Human)

Approval Code:
(Official Use Only)

UNIVERSITY OF ST ANDREWS
TEACHING AND RESEARCH ETHICS COMMITTEE (UTREC)

ETHICAL APPLICATION FORM

Please Tick: (*click on the box then click 'Checked' for a cross to appear in the box)*

Undergraduate ☐ Postgraduate Research X Postgraduate Taught ☐ Staff ☐

Lecturer/Course Controller on behalf of Taught module ☐ Module Code: ☐

Researchers Name(s):	Jackie Hyland		
Project Title:	The impact of traffic-related air pollution on the health of Scottish residents living adjacent to busy roads		
School/Unit: (Please indicate)	Medical School	Supervisor:	Professor Peter Donnelly
Emails	Jmh54@st-andrews.ac.uk Pdd21@st-andrews.ac.uk	Date Submitted	17th July 2014

Rationale: Please detail the project in 'lay language' addressing the reason for conduction the research; including details of participants and location. *DO NOT exceed 75 Words (for database reasons). This summary will be reviewed by UTREC and may be published as part of its reporting procedures.*

There is limited evidence of the health effects on Scottish residents from short term exposure to high air pollution levels. NHS 24 captures data on all health calls by time, place of residence and symptoms. Call statistics will be used to see if there is a link between an air pollution event in March 2012 and health based on calls to NHS 24 for specific conditions during, and for two weeks after the pollution episode.

Ethical Considerations: Please detail the Ethical issues with full seriousness addressing all issues raised by the research and explain now these issues will be addressed. *DO NOT exceed 75 words (for database reasons). This summary will be reviewed by UTREC and may be published as part of its reporting procedures.*

The data are non-identifiable statistics and will be provided with permission by Dr Malcolm Alexander, Associate Medical Director NHS 24.

APPLICATIONS MUST BE SUBMITTED TO THE RELEVANT SCHOOL ETHICS COMMITTEE
https://www.st-andrews.ac.uk/utrec/SEC/SECMembers/ PLEASE DO NOT SUBMIT DIRECTLY TO UTREC.

- Please submit an electronic copy and one hard copy (with signatures) to the Secretary/Administrator. In the absence of a Secretary please submit to the SEC Convener.
- Applicants must be accompanied by the relevant supporting documents without which a full ethical assessment cannot be made.
- Please do not type out with the text boxes provided, note that the Text Boxes are fixed in size and will not allow any viewing beyond the word limit permitted.

Ethics Committee approval

University of St Andrews

University Teaching and Research Ethics Committee
Sub-committee

17th September 2014

Dr Jackie Hyland
School of Medicine

Ethics Reference No: *Please quote this ref on all correspondence*	**MD11137**
Project Title:	**Traffic related air pollution and health**
Researchers Name(s):	**Dr Jackie Hyland**
Supervisor(s):	**Professor Peter Donnelly**

Thank you for submitting your application which was considered by the Convener of the School Ethics Committee on the 18th July 2014. The following documents were reviewed:

1. Ethical Application Form YES
2. Caldicott Approval YES

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years. Projects, which have not commenced within two years of original approval, must be re-submitted to your School Ethics Committee.

You must inform your School Ethics Committee when the research has been completed. If you are unable to complete your research within the 3 three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply.

Any serious adverse events or significant change which occurs in connection with this study and/or which may alter its ethical consideration, must be reported immediately to the School Ethics Committee, and an Ethical Amendment Form submitted where appropriate.

Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' https://www.st-andrews.ac.uk/utrec/guidelines/ are adhered to.

Yours sincerely

Dr Morven Shearer
Convener of the School Ethics Committee

UTREC Convenor, Mansefield, 3 St Mary's Place, St Andrews, KY16 9UY
Email: utrec@st-andrews.ac.uk Tel: 01334 462866

Survey Ethic Committee Submission and Approval

Approval Code:
(Official Use Only)

UNIVERSITY OF ST ANDREWS
TEACHING AND RESEARCH ETHICS COMMITTEE (UTI

ETHICAL APPLICATION FORM

Please Tick: (*click on the box then click 'Checked' for a cross to appear in the box)*

Undergraduate □ Postgraduate Research x Postgraduate Taught □ Staff □

Lecturer/Course Controller on behalf of Taught module □ Module Code:

Researchers Name(s):	Jackie Hyland		
Project Title:	The impact of traffic-related air pollution on the health of Scottish residents adjacent to busy roads		
School/Unit: (Please indicate)	Medical School	Supervisor:	Professor Peter Donnelly
Emails	Jmh54@st-andrews.ac.uk Pdd21@st-andrews.ac.uk	Date Submitted	10th March 2014

Rationale: Please detail the project in 'lay language' addressing the reason for conduction th including details of participants and location. *DO NOT exceed 75 Words (for database reasons). Tl will be reviewed by UTREC and may be published as part of its reporting procedures.*

There is evidence that air pollution from traffic has a negative impact on physic. However there is limited evidence of the effects on well being and how an underst this might influence behaviour change. The purpose of this survey is to seek the specialists on what questions we can pose in a public survey to provide evide package of developments which might encourage changes in travel behaviour.

Ethical Considerations: Please detail the Ethical issues with full seriousness addressing all issues ra research and explain now these issues will be addressed. *DO NOT exceed 75 words (for database r This summary will be reviewed by UTREC and may be published as part of its reporting procedures.*

The semi-structured interviews will be taped for later analysis. The participants will be invited for their and the findings will be anonymised so there are no ethical considerations.

APPLICATIONS MUST BE SUBMITTED TO THE RELEVANT SCHOOL ETHICS COMMI
https://www.st-andrews.ac.uk/utrec/SEC/SECMembers/ PLEASE DO NOT SUBMIT DIRECTLY TC

- Please submit an electronic copy and one hard copy (with signatures) to the Secretary/A In the absence of a Secretary please submit to the SEC Convener.
- Applicants must be accompanied by the relevant supporting documents without which assessment cannot be made.
- Please do not type out with the text boxes provided, note that the Text Boxes are fixe will not allow any viewing beyond the word limit permitted.

University of St Andrews

University Teaching and Research Ethics Committee
Sub-committee

25 April 2014

Jackie Hyland
School of Medicine

Ethics Reference No: *Please quote this ref on all correspondence*	**MD10960**
Project Title:	**The impact of traffic-related air pollution on the health of Scottish residents living adjacent to busy roads**
Researchers Name(s):	**Jackie Hyland**
Supervisor(s):	**Professor Peter Donnelly**

Thank you for submitting your application which was considered by the School of Medicine Ethics Convener on the 24th April 2014. The following documents were reviewed:

1. Ethical Application Form YES
2. Participant Information Sheet YES
3. Participant Consent Form YES
4. Participant Debriefing Form) YES

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years. Projects, which have not commenced within two years of original approval, must be re-submitted to your School Ethics Committee.

You must inform your School Ethics Committee when the research has been completed. If you are unable to complete your research within the 3 three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply.

Any serious adverse events or significant change which occurs in connection with this study and/or which may alter its ethical consideration must be reported immediately to the School Ethics Committee, and an Ethical Amendment Form submitted where appropriate.

Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' https://www.st-andrews.ac.uk/utrec/guidelines/ are adhered to.

Yours sincerely

Dr Morven Shearer
Convenor of the School Ethics Committee

UTREC Convenor, Mansefield, 3 St Mary's Place, St Andrews, KY16 9UY
Email: utrec@st-andrews.ac.uk Tel: 01334 462866