CAFS Review 2019

Health and Environment Working Group (HEWG). Final Report.

June 2019.

Summary

The Cleaner Air for Scotland (CAFS) strategy (Scottish Government, 2015) aimed to reduce air pollution and was based on the scientific consensus that exposure to air pollution is harmful to people's health and to the environment generally. Since the CAFS strategy (2015) was published, the profile of air pollution in Scotland has changed, mainly for the better. However, pollutants (e.g. ammonia) generated by the agricultural sector have not shown similar improvement. An updated analysis of trends in Scotland shows that important pollutants, including fine particulates ($PM_{2.5}$), are now mostly below recommended health based limits. However, areas of concern remain especially excess levels of nitrogen oxides in city centres.

Evidence continues to accumulate on the range and scale of impacts linked to airborne pollution, expanding our understanding of how air pollution is harmful to public health and the environment. Findings from outside the UK suggest that harmful impacts can occur at levels below currently recommended health based limits, implying that there may not be a level at which adverse effects stop occurring. More evidence is also now available on effective interventions for reducing people's exposure, especially to road traffic sourced pollution. Consequently, despite recent encouraging trends and reductions in air pollution in Scotland to date, there remains scope for further beneficial reduction.

A number of related issues that correlate closely with air pollution in terms of their impacts, have also been considered, including noise (especially transport generated noise) and airborne greenhouse gas emissions (which contribute to global warming and climate change). Increased awareness of these inter-relationships is needed, as is the potential to link co-beneficial mitigating actions. Given the close linkage between outdoor and indoor air pollution and the high proportion of time spent indoors especially by urban dwellers, indoor air quality has also been identified as an important related topic.

A range of broader policy issues that relate to improving health and environmental quality generally have also been considered. These include the public health improvement agenda focussed on promoting more active, less sedentary lifestyles and reducing health inequalities; climate change adaptation policy; planning policy and the role of placemaking; environment, agriculture and land use policies; and transport policy. Improving linkages across these policy areas, including via a future CAFS strategy, to enable better integration of policy development and implementation is identified as critical to the success of efforts to improve both public health and environmental quality.

This report considers updated scientific evidence on all of these issues, draws conclusions and proposes recommendations for further action via an updated CAFS strategy.

This updated evidence review confirms the need, as a minimum, to reduce levels of air pollution to meet existing recommended health based limits. The international evidence suggests that further reductions in air pollutants would be likely to bring additional public health and environmental benefits, with the biggest gains coming from reducing long-term exposure. Due to the relatively lower exposure levels in Scotland already and the different epidemiology of health impacts in Scotland, it is difficult to predict or quantify accurately what the scale of any such additional potential benefits would be.

Further effective reduction in pollution will require concerted action across many sectors including national and local government, the private and public sector and by the public itself. All of these stakeholders have critical roles in further reducing preventable air pollution associated with transport, domestic and industrial sources, as well as agricultural activities (a source of both primary and secondary pollutants). Increased awareness and understanding of all the relevant interlinked issues is needed. With respect to transport pollution sources, interventions need to be coupled to encouraging people to change their habitual transport choices. Achieving such public behaviour change will require facilitation by more and better coordinated government action. There needs to be more focus on inter-related interventions including: improved transport infrastructure that encourages higher levels of active travel (walking, cycling); improved access to accessible, affordable and better quality public transport offering more attractive alternatives to private vehicles; and greater encouragement to adopt less polluting private personal transport (e.g. low and zero emission vehicles).

The Human Health Impacts of exposure to air pollution.

Introduction

There is a wealth of good quality evidence linking outdoor air pollution with impacts on human health. It is now widely accepted by expert assessment groups (e.g. the World Health Organisation (WHO), the Global Burden of Disease (GBD) team, the International Agency for Research on Cancer (IARC), the (UK) Committee on Medical Effects of Air Pollutants (COMEAP), and the US Environmental Protection Agency (EPA)) that outdoor air pollution causes damage to human health across a wide range of conditions, from pre-birth to old age. Globally, air pollution is now considered the most serious of all environmental health problems. Scientifically robust conclusions on the effects of pollutants are derived from toxicology, epidemiology and experimental studies. These inform our understanding of which pollutants may be causing most damage to human health. International epidemiological studies have formed the basis for estimating the size of the impacts on populations and for quantifying the likely benefits of reducing pollutant levels. The current international consensus and evidence from more local Scottish studies have been used to interpret the significance of health impacts in Scotland.

Epidemiological Evidence Reported from International Studies.

The WHO - REVIHAAP assessment (WHO 2013a) is currently the most comprehensive review of international evidence on air pollution and health. This found significant evidence of adverse effects associated with three main pollutants: particulate matter (PM, especially $PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2) and ozone.

PM, cardiovascular and respiratory outcomes and deaths due to all causes.

REVIHAAP reviewed evidence linking PM with changes in cardiovascular (CV) (heart and circulatory system) functioning, respiratory (lung) function and premature (earlier) death. This included some long-term studies (WHO 2013a) of association between mortality and $PM_{2.5}$ at levels below the current WHO limit value ($10µgm^{-3}$). No evidence of a threshold was found (i.e. a level at which adverse effects stop occurring) leading to the conclusion that "*public health benefits will result from any reduction in $PM_{2.5}$ concentrations, whether or not the current levels are above or below the limit values"* (WHO 2013a).

The UK COMEAP (2015a) concluded that public health would benefit from reductions of both primary PM and secondary particles (produced by chemical interactions). More recently COMEAP (2018a) found additional evidence of a wider range of CV effects, concluding that the association of $PM_{2.5}$ and CV impacts, identified in epidemiological studies, is likely to be causal.

For coarse particles ($PM_{2.5-10}$), although there was less evidence than for fine particulates ($PM_{2.5}$), WHO (2013a) concluded that these are also linked to excess morbidity and mortality and therefore that it is important to control PM_{10} as well as $PM_{2.5.}$

The HRAPIE project (WHO 2013b) set out to quantify the effects of pollution on a range of health outcomes. In estimating the effects of $PM_{2.5}$ it reported the highest confidence on findings for: (i) all-cause and cause-specific mortality using cohort (long-term) studies and (ii) respiratory and CV hospital admissions from time series (short-term) studies. It reported less confidence in quantifying the effects on: infant mortality, days of restricted activity and work days lost, exacerbation of asthma in young people, and on chronic bronchitis. COMEAP (2016) later questioned if the relationships with chronic bronchitis were causal.

For all-cause mortality in adults, WHO (2013b) recommended that an estimate of a 6% increase (95% CI: 4% to 8%) for age-specific death rates per $10µgm^{-3}$ annual average $PM_{2.5}$ should be used. COMEAP endorsed this excess risk estimate for use in the UK (COMEAP 2018b). Using data from 2008 for average human sourced $PM_{2.5}$ in the UK, COMEAP (2010) had previously used the same central estimate of 6% to calculate that air pollution resulted then in a reduction in life expectancy from birth across the whole population, of approximately 6 months for the whole UK and 3-4 months for Scotland. This was also expressed as an estimate of the air pollution mortality burden in terms of as being equivalent to approximately 2000 attributable (premature) deaths in Scotland. This figure was updated (HPS 2018) using the latest annual mean concentration for human sourced $PM_{2.5}$ of $5.3µgm^{-3}$, giving an estimate of approximately 1700 attributable deaths in Scotland. It is important to note that attributable deaths are not actual recorded deaths in a particular year; the figure is a statistically derived estimate, intended to convey as faithfully as possible the amount of excess mortality caused by air pollution across the population as a whole. As explained in COMEAP (2010), this figure should not be interpreted as the number of individuals in any year where air pollution has made some contribution to earlier death; that number is unknown but is almost certainly much larger.

Research on the biological mechanisms potentially underlying the associations between particulate air pollution and cardiovascular disease also supports the case for a causal link and was assessed by WHO (2013a) as "*strongly supportive of a causal association between $PM_{2.5}$ and cardiovascular disease and mortality".* Research at the University of Edinburgh (funded by the British Heart

Foundation) examined the effects on cardiovascular function of diesel exhaust (DE), a source of particulates including ultra-fine nanoparticles. DE particulates can generate free radicals, activate inflammatory cells and directly impair vascular function, suggesting that DE particulates would be capable of promoting cardiovascular disease (Miller et al. 2009, Miller et al. 2012, Shaw et al. 2011, Shaw et al. 2016). After inhaling DE at levels resembling a heavily polluted urban environment (between 100 to 300µgm^{-3} of PM), the ability of blood vessels in healthy volunteers to relax was found to be impaired, an effect persisting for at least 24 hours (Tornqvist et al. 2007). Exposure to DE was also associated with increased arterial stiffness, a marker of vascular dysfunction (Lundback et al. 2009); with promotion of blood clotting (Lucking et al. 2008) and with reduced ability to remove blood clots (Mills et al. 2005).

Experiments in human volunteers also showed that inhaled gold nanoparticles passed into the blood circulation, supporting the previously postulated existence of a pathway to explain how inhaled PM might result in widespread effects throughout the body (Miller 2017a, Miller 2017b). This and other international mechanistic research provides evidence of a biologically plausible mechanism, whereby PM could induce cardiovascular effects; and suggests that people with existing CVD may be especially susceptible to the effects of air pollution.

Ground-level ozone, **respiratory and cardiovascular impacts.**

WHO (2013a) reviewed numerous time series (short-term exposure) studies of links between ozone, respiratory hospital admissions and deaths from respiratory causes and, less clearly, CVD causes. There was an absence of relevant powerful studies at low ozone concentrations and no specific threshold was established (i.e. a level at which adverse effects stop occurring). HRAPIE (WHO 2013b) recommended quantifying the effects of ozone on mortality and hospital admissions for respiratory (and for some CVD outcomes but not stroke) but only at levels above 70µgm^{-3} or above 20µgm^{-3} for a maximum daily 8-hr mean concentration. COMEAP (2015b) later concluded that, because there is no convincing evidence of a threshold, quantification of impacts down to zero level is reasonable. There is also some evidence of additional effects of long-term chronic exposure, especially on respiratory mortality (Jerrett et al. 2009). COMEAP (2015b) however, considered that there were too many unknowns to support quantification of these effects at that time.

NO_2, respiratory and cardiovascular impacts.

The evidence relating to NO_2 is particularly relevant to Scotland, in that most of the current Air Quality Management Areas (AQMAs) in place are because of breaches of NO_2 standards, not $PM_{2.5}$. Numerous time-series (short-term) studies have shown associations of daily concentrations of NO_2, with respiratory and CVD morbidity and mortality, on the same or immediately following days (a very short lag effect). Many cohort studies have shown associations between annual average (long-term) NO_2 and age-specific risks of death, although it is unclear if these associations are due to NO_2 itself or to co-pollutants from the same sources, especially PM from traffic.

WHO (2013a) concluded that there is some adverse effect of NO_2 acting alone, additional to that linked to PM or ozone. Although other pollutants may also be contributing, based on studies of (short-term) impacts associated with daily variations in NO_2, WHO agreed that NO_2 itself had some causal role. The evidence for causality in studies of long-term exposure was thought to be weaker (WHO 2013a). COMEAP (2015c) implicitly accepted this view but later failed to reach a consensus on whether long-term exposure to NO_2 has a causal role (COMEAP 2018c), cautioning against naively interpreting the observed health associations with NO_2 as being due to NO_2 alone.

Estimating effects due to $PM_{2.5}$ and NO_2 together

A majority of COMEAP members favoured quantifying the impact of air pollution on mortality in the UK using relationships for NO_2 as well as $PM_{2.5}$ (COMEAP 2018c). The effect associated with both $PM_{2.5}$ and NO_2 combined, was estimated to be equivalent to between about 28,000 to 36,000 attributable deaths per year UK-wide (i.e. only slightly more than the earlier estimate using $PM_{2.5}$ alone). This estimate assumed that it is valid to extrapolate effects identified at the levels studied down to lower ones not actually recorded. Alternative figures were also quoted in the report where extrapolation was not used; giving lower estimates of between 16,000 to 19,000 attributable deaths in the UK. COMEAP (2018c) did not provide results specific to Scotland. However, using the most recent estimate of 1700 attributable deaths in Scotland for $PM_{2.5}$ alone (HPS 2018) and based on internationally derived risk estimates (assuming that extrapolation to lower levels is appropriate), a combined estimate equivalent to about 2,000 attributable deaths annually may be reasonable.

Evidence of additional health effects associated with air pollution

WHO reviewed the smaller evidence base then available on other health impacts potentially associated with air pollution (WHO 2013a, WHO 2013b). Considerably more studies on non-cardiovascular, non-respiratory impacts have been published since. For this report, HPS carried out a rapid scan of international English language papers published between January 2015 to March 2019 that had reviewed primary papers on such other health effects; 31 review papers were identified that met the inclusion criteria (listed in annex A). These reviews addressed dementia and cognitive decline (3 review papers), diabetes (7), birth outcomes (7) and child development (4). Some of the reviews addressed multiple outcomes. In addition, as an update, twelve reviews of more recent studies on respiratory outcomes were also considered.

These reviews consistently reported finding associations of varying statistical significance between air pollution (generally and for individual pollutants) and dementia, Alzheimer's disease, type 2 Diabetes, preterm birth, miscarriage, and Autism Spectrum Disorder. With other outcomes (e.g. other child development outcomes, Parkinson's Disease etc.) reviews reported finding either conflicting conclusions or commented that the reviewed studies provided insufficient or inconclusive evidence of associations. In the newer respiratory outcomes reviews, associations with COPD-related morbidity, asthma development and exacerbation were consistently reported.

The review authors consistently noted limitations in the studies. Many reviews providing meta-analyses of primary study findings that had reported increased risks, gave pooled odds ratios or risk estimates that were statistically significant though often the risks were only marginally elevated. In some cases, the small margin of the increased risks meant that one additional negative study could have altered the findings to be non-significant. In terms of applicability, many of the primary studies reviewed were conducted in countries where the air pollutant concentrations were notably higher than is prevalent in Scotland, so their findings may not be directly transferable.

Epidemiological evidence on health effects specific to Scotland

There is a relatively small published literature on the effects of air pollution based on studies carried out specifically in Scotland. This evidence is important however, in developing an understanding of the local epidemiology of air pollution impacts and how this compares with the corresponding international findings. Differences in the types of study carried out in Scotland make cross comparison of their findings difficult (Lee et al. 2019). It is not therefore possible to provide pooled estimates of health effects in Scotland equivalent to those calculated in international studies. Nonetheless, valid conclusions can be drawn by assessing the balance of evidence provided by these studies of impacts on the Scottish population.

All-cause mortality. Scottish evidence linking air pollutants (NO_X, NO_2, $PM_{2.5}$, PM_{10} and black smoke) with all-cause mortality (all deaths) is inconclusive. Some studies found some significant (and some non-significant) associations (Carder et al. 2010; Beverland et al. 2012; Beverland et al. 2014; and Yap et al. 2012) but others found none (Prescott et al. 1998; and Carder et al. 2008).

Pregnancy outcomes. Evidence regarding air pollution in Scotland and pregnancy outcomes is mixed. Significant associations of NO_2 and PM_{10} with low birth weight were found using cohort data (1994 to 2008) by Dibben and Clemens (2015). Risks for very preterm birth (birth between 28-32 weeks) were raised but were non-significant. A separate individual level study in north-east Scotland (Clemens et al. 2017) reported mixed evidence linking maternal exposure to particles (PM_{10}, $PM_{2.5}$) and NO_2 with measures of foetal growth.

Respiratory disease. The evidence from Scottish studies convincingly suggests associations between air pollution and the risk of respiratory disease and respiratory mortality, consistent with the international evidence. Studies found strong and largely consistent associations across all study types and various outcomes. Statistically significant effects were found for NO_X, NO_2, $PM_{2.5}$, PM_{10} and black smoke with: (i) prescribing rates for respiratory medication (Lee 2018); (ii) respiratory hospitalisations (Lee 2012 and Huang et al. 2018); and (iii) respiratory deaths (Yap et al. 2012 and Beverland et al. 2014).

Cardiovascular disease. The evidence from Scottish studies over the years has identified no consistent association between air pollution and cardiovascular disease outcomes, such as hospital admissions or mortality (Prescott et al. 1998; Carder et al. 2010; Yap et al. 2012; Willocks et al. 2012 and Beverland et al. 2014). These studies used a variety of epidemiological methods in different time periods and considered multiple pollutants (NO_x, NO_2, $PM_{2.5}$, PM_{10} and black smoke). Occasional significant associations were found, though finding an isolated significant result in a larger set of non-significant results can result from multiple statistical testing (Catelan and Biggeri, 2010). This finding contrasts with the international evidence finding associations of air pollution (especially PM) with cardiovascular illness and deaths.

The most recent study by the Universities of Glasgow and Strathclyde (Lee et al. 2019), using Scottish data for 2015 and 2016, reinforced the main conclusions from earlier Scottish work; finding consistent significant associations of pollution (particulates and nitrogen oxides) with respiratory disease outcomes, while finding no associations with all-cause mortality or cardiovascular endpoints.

Comparison of the international and specifically Scottish evidence.

The international epidemiological evidence indicates that, all things being equal, we might expect to find some increased risk of CVD associated with exposure to air pollutants, even in Scotland. In addition to epidemiological evidence, there is good quality mechanistic evidence to support the view that (particulate) air pollutants have direct effects on the cardiovascular system, albeit at much higher levels (around 100 - 300 μgm^{-3}) than those normally prevalent in Scotland (around 10μgm^{-3}). Yet, studies in Scotland consistently fail to confirm such an association for reasons we do not understand.

Studies elsewhere in the UK have likewise failed to find evidence of association with CVD (Carey et al. 2013; Carey et al. 2016). However, other studies in non-UK countries, with similarly low levels of PM pollution to Scotland, have found such effects (State of Global Air 2019). Further analysis of such studies is needed to understand possible reasons for this variation in findings.

There are many possible factors that might contribute to the different findings in Scotland but it is not possible to investigate or eliminate all the possible explanations systematically at present. It is unlikely that one single or simple explanation exists for the Scottish CV disease findings; a combination of factors is probably responsible. Meantime, we simply do not know what the explanation is, nor how best to interpret the different findings on CV disease. More research would be needed, particularly into long-term effects of ambient pollution in Scotland (e.g. using a cohort study approach), to explore this issue further. The variation in findings is important however, in that it adds additional uncertainty to estimating and quantifying the cardiovascular impacts of air pollution in Scotland. This uncertainty also has implications for predicting the size of health benefits that would occur from future air pollution control policy in Scotland.

Interpretation of epidemiological and other evidence.

Epidemiological research requires careful interpretation due to the potential limitations of studies. Despite the best efforts of experienced research teams, individual studies are at risk of bias; the effects of confounding; limitations in exposure and outcome assessment methods and difficulty in attributing potential associations to any specific pollutant. Literature reviews need to take account of publication bias (whereby negative studies may be under-represented, leading to overestimation of positive effects) and the need to consider potential heterogeneity of studies (differences that make valid comparisons more difficult). The fact that such difficulties *can* occur should however not be taken to imply that in general (positive) results should not be accepted; the checks and balances and the transparency of epidemiology are designed to ensure that valid conclusions are drawn, despite these difficulties.

Using internationally derived data to estimate the size of impacts, by transposing epidemiological findings from other countries to Scotland, involves uncertainties and some potentially unrealistic assumptions. A study from another country may not be directly comparable to Scotland due to different levels and composition of air pollution; underlying levels of health; genetic factors; geographical and meteorological conditions; and types of confounding factors that drive ill health generally (e.g. diet, levels of activity, smoking rates, social and health inequalities).

The evidence internationally is that relationships identified between air pollution and health are remarkably robust to differences such as these: (i) they seem not to depend strongly on level or composition of pollution; (ii) typically they are represented as % effect on background rates, and so allow for differences in background rates because of genetic or other factors, including healthcare systems; (iii) the ability to adjust for meteorology in time series studies is well established and is not an issue for cohort studies; and (iv) while the available major cohort studies such as the American Cancer Society clearly show an effect of smoking, there is no clear evidence that smoking habit affects the estimated % effect of air pollution. In practice despite the limitations outlined above, all quantifications by WHO, GBD, COMEAP, US EPA and other expert groups, depend on transferability of identified relationships from one location to another.

Compared globally, air pollution levels in Scotland are relatively low. Studies in other countries are often based on levels higher than those encountered in Scotland. Applying this international evidence to Scotland therefore assumes that associations identified at higher concentrations also hold true for the lower concentrations experienced here. Such extrapolation beyond the range of reported study data is not an ideal approach, in that it introduces additional uncertainties and requires an understanding that there is no supporting data for those lower concentrations.

It is also worth noting that all attempts to set health based limit values at thresholds where no effects will occur, have in due course been amended downwards as new studies find effects at lower concentrations. Consequently, health based limits have progressively reduced over time. Also we know that if there is no pollution, then there will be no pollution associated health impacts. In reality, the lack of evidence of a no-effect threshold for exposure to $PM_{2.5}$ (a level at which there is no known excess risk) means that effects at low pollutant levels are likely to be somewhere between those reported at higher levels and no effect at all.

Conclusions on the evidence on air pollution and health.

The international epidemiological evidence convincingly shows that ambient air pollution causes serious damage to both respiratory and cardiovascular health worldwide, with wide-ranging effects including earlier death. There is no agreed level of the key pollutants (fine particles ($PM_{2.5}$), ozone and NO_2) at which adverse effects can be said with confidence, not to occur. As noted by WHO (2013b), the evidence of effects of both short-term and long-term exposure continues to grow, with the greatest public health effects being associated with long-term exposures. These findings have for many years formed the basis of air pollution control internationally, as endorsed for example by WHO, COMEAP in the UK, the EU, US EPA and many other expert groups.

There is some uncertainty from international studies about the scale of health effects associated with low pollutant concentrations typical of the average seen in Scotland now. The specifically Scottish literature, while small, has repeatedly demonstrated impacts of pollutants on respiratory illness that are consistent with international evidence. Studies in Scotland differ from the international evidence however, in not showing effects of pollution on CV disease outcomes for reasons that are unknown. The extent to which future policy making in Scotland is based on the international evidence and takes account of the specifically Scottish studies, has implications on the advice that can be given on what additional proportionate action is needed to further reduce the harm due to air pollution at current levels (and where trends in key pollutant concentrations may continue downwards in any case).

There is growing evidence from other countries showing associations of air pollution with other important health conditions including dementia, diabetes, and adverse pregnancy outcomes (low birth weight and prematurity). Collectively this constitutes good evidence that air pollution, even at the low concentrations found in much of Scotland, is linked to excess ill health that should be preventable by reducing pollution further.

Recommendations

1. The balance of evidence on adverse health impacts justifies adopting a precautionary public health approach to further air pollution reduction. As a minimum, compliance is required with internationally agreed (WHO) health based air quality limits for $PM_{2.5}$ and NO_2 particularly for long-term exposure; and practical efforts to reduce preventable air pollution further should continue.

2. Further consideration is needed of the evidence on health impacts of low level pollution in countries where levels of ambient air pollution are comparable to Scotland.

3. To aid further understanding of the human health impacts and to help explain the apparently different epidemiology in Scotland, further population based research should be carried out on the long-term effects of air pollution using cohort methods.

Air Pollution and Noise.

Noise has been shown to impact negatively on wildlife; disrupting communication, navigation, foraging, and avoidance of predators and danger. Individual studies have shown disturbed behaviours, reduced feeding and abandonment of young and depleted species richness (Curran 2019a). In humans, noise is defined as an unwanted intrusion and results in physiological (endocrine and nervous system) responses.

Noise exposure in humans is associated with annoyance and with symptoms including anxiety, high blood pressure, sleep disturbance and cardiovascular disease. An increased risk of myocardial infarction (MI) was identified associated with exposure to long-term residential road traffic noise in a Danish urban cohort study (Sørensen et al. 2012). Impairment in schoolchild academic performance has also been noted (EEA 2014).

As yet there are no fixed noise level targets in the UK. The European Union adopted a Directive on environmental noise in 2002, which stipulates that measurements must be taken of ambient noise; the results must be made publicly available and action plans for noise reduction must be agreed. WHO has published guidance on environmental noise levels taking account of existing health effects evidence (WHO 2018).

In Scotland's four major cities alone, it has been estimated that over 1 million people are exposed to noise levels in excess of the WHO guidelines during the daytime and over 0.8 million during the night, with evidence indicating that deprived communities suffer more (Scottish Government 2012). The costs of increased health impacts have not been estimated in Scotland directly but based on estimates elsewhere are potentially considerable (WHO 2015).

The major source of ambient noise is from road traffic, the same source as much ambient air pollution (Scottish Government 2012). Studies have identified links between road traffic noise and cardiovascular impacts (Halonen J, et al 2015). The adverse impacts of air pollution are closely correlated with those of noise, making it difficult to assess the impact of traffic noise on health separately. However, this also means that some interventions aimed at reducing traffic sourced air pollution are also likely to help reduce excess traffic sourced noise. These interventions range from traffic reduction in urban areas to physical responsive solutions such as green (living plant) barriers along roads, where evidence suggests these can reduce both traffic-related air pollution and noise (NICE 2017).

Recommendation

4. Local authority noise reduction plans should be closely co-ordinated with local air quality improvement plans in order to deliver co-benefits.

Air Pollution and Climate Change.

Scottish carbon emissions have reduced in the last 15 years. However, transport related carbon emissions have increased as a proportion of the Scottish total rising from 32.7% of greenhouse gases in 2015 to 37.3% in 2016 and in real terms, with transport mass emissions increasing by 2.3% between 2015 and 2016. As 68% of total transport emissions in Scotland are related to traffic, greenhouse gas emissions are therefore closely linked to road traffic sourced air pollution (Transport Scotland 2018).

The Cleaner Air For Scotland Governance Group (CAFS GG) commissioned a report from a Climate Change Sub-group to assess the likely co-benefits between climate change and air quality improvement actions (CAFS Climate Change Sub-group 2016).

This stated:

"*The findings suggest that travel choices can evolve to unlock multiple benefits, not just for climate and air quality, but also for personal health and welfare, for safety and for population health; however, the achievement of modal shifts in transport choices will require much more focus, priority and investment given to active and sustainable transport. Equally, it is found that land management can often reduce costs while maintaining productivity if appropriate climate and air quality actions are considered. It seems there may be further opportunities for modernised regulation to support industry in attaining improved carbon and other atmospheric emissions while, at the same time, encouraging economic success and community protection. A gathering momentum towards a circular economy will deliver significant co-benefits. There is evidence that we can create better civic space, buildings and homes which are more energy-efficient and use materials that embody lower resource-use. Such spaces can be more attractive as places in which to invest and in which to live and work. There are opportunities to revise Scotland's planning system to facilitate all of these beneficial changes and to grasp the available multiple benefits.*"

Of the 50 recommendations made in this report, 38 presented strong evidence of synergies between tackling climate change and improving air quality simultaneously. Only three recommendations revealed some potential for tension.

Recommendation

5. It is strongly recommended that, at all levels of governance, when actions are being taken to address air quality they should be screened to maximise the potential for co-benefits with climate change mitigation and adaptation. The reverse should also be the case. The screening should, at minimum, be against the 50 recommendations in the CAFS Climate Change Sub-group report.

6. To protect against future health and environmental impacts generally, consideration should be given to a presumption that any major new development (e.g. a new road or housing development) must not lead to a net increase in carbon emissions, must not worsen air quality, and must not exacerbate existing health inequalities.

Outdoor Air Pollution and Indoor Air Quality.

Indoor air quality is determined by multiple factors including ambient outdoor air pollution (Curran, 2019b). Unlike outdoor air quality, there are no regulated limits for indoor pollutants in domestic settings in the UK. The WHO publishes guidelines on safe concentrations of indoor air pollutants for general use (WHO 2010) and the Health and Safety Health Executive (HSE) publish occupational limits for a range of workplace air pollutants (HSE 2018).

Urban populations in the UK spend around 90% of their time indoors; the quality of the indoor air is therefore at least as important as that of outdoor air. Around 50% to 75% of the variability of indoor concentrations of common pollutants (NO_x, SO_2, O_3, and PM) is estimated to be explained by variation in outdoor pollution (Friejer and Bloemen 2000). This makes estimating the health impacts of indoor air quality alone very challenging.

The literature on indoor air pollution health effects is much less comprehensive than that for outdoor air pollution. WHO have estimated that up to 117,000 (early) deaths each year in Europe could be attributable to indoor air pollution (specifically "*cooking with polluting fuels*") (WHO 2017); including up to 3% of heart disease deaths, 3% of chronic pulmonary disease deaths, 3% of deaths from stroke and 2% of deaths due to lung cancer. New reviews of indoor air pollution and health impacts are currently under way in the UK (NICE 2019) but will not report for some time.

Sources of indoor air pollutants differ depending on the indoor setting (e.g. home, school, workplace) (WHO 2010) and include: combustion particles and gases (CO, CO_2, NOx) from burning fuels for heating and cooking and from tobacco smoke; chemicals used for cleaning and disinfection; perfumed products; chemicals, including volatile organic compounds (VOCs) released from building materials, furniture, fixtures and fittings such as carpets and wall coverings (WHO 2010). The US Environment Protection Agency (USEPA 2017) reported that, on average, the level of many VOCs is between two and five times higher inside houses compared to outdoors. Indoor pollutants can also include naturally occurring gases that accumulate inside buildings; e.g. radioactive radon gas originating in geologically sensitive areas; and CO_2 and methane migration in ex-mining areas.

The degree of correlation between indoor air and outdoor air quality depends on physical factors including the rate of air exchange. However, modern housing and other buildings are increasingly being designed to reduce active heating needs and associated carbon emissions, by making them more air tight.

Although multiple government departments have a role to play, no single Government department (in UK or Scottish Governments) has sole responsibility for indoor air quality. There is therefore a potential risk of unintended consequences for indoor air quality and health associated with policy changes promoted by unconnected Government departments (as evidenced by the increase in NO_2 emissions associated with the switch to diesel engines encouraged by Government to help reduce CO_2 emissions). Changes determined by non-health related policy drivers (e.g. the drive for energy efficiency to reduce global warming gas emissions) could have unexpected adverse health consequences, if these are not anticipated and mitigation measures identified.

As well as links to outdoor air pollution, indoor air pollution is therefore a complex issue in its own right with unique determinants. As a topic, it therefore merits more collective attention to assess its significance in relation to public health. A coordinated approach across government departments and other stakeholders is therefore needed to create a focus for a future cross-government indoor air quality strategy.

Recommendation

7. It is strongly recommended that, separately from the current CAFS strategy revision, a task group be convened to identify what, if any, actions might best be undertaken at Scottish level to address indoor air quality.

Potential Co-benefits to Public Health of Reducing Air Pollution.

Policies that improve air quality can potentially have multiple co-benefits for population health, for addressing inequality and for mitigating and adapting to climate change. A prime example is policy to promote active travel. Walking and cycling increases physical activity and significantly reduces cardiovascular incidence and mortality, and has been shown to reduce all-cause mortality even after controlling for other physical activity (Celis-Morales et al. 2017; Hamer and Chida, 2008; Kelly et al. 2014). Commuters who transitioned from using a car to active travel or public transport showed reductions in body mass (Flint et al. 2016). Substantial potential savings in health care costs have been estimated for increased levels of active travel in urban areas (Jarrett et al. 2012). Evidence shows that the physical activity benefits of active travel outweigh the harm caused by potentially more exposure to air pollution in all but the most extreme situations (Tainio et al. 2016). However, walking and cycling in places with noticeable poor air quality is a disincentive. Measures to reduce traffic sourced air pollution and to increase levels of active travel can therefore amplify benefits to public health and help to meet sustainability goals.

Evidence from NICE (2017), PHE (2019) and others has identified interventions that are effective at reducing traffic sourced air pollution as well as having co-benefits for health. Reducing emissions from existing vehicles, planning for active travel and public transport and reducing demand for polluting vehicles were all identified as effective interventions for reducing transport-related pollution.

The scale and sustainability of investment helps determine the effectiveness of interventions. In Scotland, the national budget for active travel has doubled in recent years, with widespread multi-sectoral support for prioritising walking, cycling and public transport as *"the best investment for physical activity"* (Campbell et al. 2019). Public transport investment in Edinburgh, alongside a commitment to supporting active travel, led to modal shift away from private car use and toward active and sustainable travel (Whyte and Waugh, 2015). The Dutch government invested almost €0.5 billion per year in cycling facilities over recent decades; the population level health benefits associated with their national cycling levels are estimated as equivalent to preventing 6,500 deaths per year or adding a half-a-year longer to life expectancy, with high benefit-cost ratios in the long-term (Fishman et al. 2015). Greater investment would be needed in Scotland to replicate Dutch levels of health benefit from active travel.

Air pollution and the consequent health burden demonstrate inequalities. International evidence suggests that exposure can fall disproportionately on disadvantaged or vulnerable populations; typically, people living in more deprived areas, those with pre-existing health problems, the very young and the old (Forastiere et al. 2007, Fecht et al. 2015). Few studies of interventions to reduce air pollution have assessed impacts on health equity specifically (Benmarhnia et al. 2014). Pedestrian casualties are higher in more deprived areas and higher for children than for adults (Whyte and Waugh, 2015). This suggests potential synergies between improving air quality alongside road safety to reduce inequality in the prevalence of harmful impacts; e.g. by creating more livable public spaces, reducing traffic speeds and through-flow. Placemaking is a recognised and endorsed approach to development in Scotland (Scottish Government 2014). A Place Standard tool has also been developed for use by communities, public agencies, voluntary groups and others to identify those aspects of a place that need to be targeted to improve people's health, wellbeing and quality of life (NHS Health Scotland 2019).

Recommendation

8. Action and investment to increase levels of active and sustainable travel should be prioritised along with approaches to improve air quality, to reduce carbon emissions and to reduce related health inequalities. A synergistic, holistic approach, accompanied by multiple complementary and integrated interventions, is needed to address these interlinked issues.

Public Perceptions of Air Pollution

Creating both a policy and a physical environment that encourages less polluting, more active and healthier lifestyles is essential but is not sufficient to achieve change. The perceptions and attitudes of key stakeholder groups, especially the public, to both the importance of the issues and the case for change are key factors to be addressed. There is limited research on public attitudes to air pollution as a topic.

DEFRA published qualitative research involving car users, public transport users and other identified groups, gauging levels of knowledge, public understanding and attitudes to the issues (Turner and Struthers, 2018). A wide range and a hierarchy of factors were found to determine people's beliefs and views on the issues. Environmental issues were not seen as one of the most important concerns in respondent's everyday lives. However, those who were more concerned about environmental issues in general were also more knowledgeable about air pollution and more likely to be taking action already or more willing to in future. Younger people, members of an ethnic minority group and those with higher levels of education were more likely to be concerned. Those living in urban areas, especially where air quality was known to be poorer and those living with existing health conditions (making them more susceptible to impacts) were more aware and more concerned. However, socio-economic and demographic factors had less influence in determining attitudes and levels of concern.

This DEFRA survey was restricted to England and Wales and may not be representative of the position in Scotland. Similar research to understand levels of concern and attitudes to air pollution among the general public and key stakeholder groups in Scotland, would therefore be helpful, along with research on barriers and willingness to change pollution generating behaviours.

Recommendation

9. Research should be carried out in Scotland to provide population representative information on levels of knowledge, attitudes, and levels of concern related to air pollution, as well as on barriers to changing air pollution related behaviours.

Conclusion

This report reflects discussions on evidence relating to the health impacts of air pollution in Scotland by members of the CAFS Review (2019), Health and Environment Working Group (HEWG). Members' opinions differed on some topics; e.g. on how to address scientific uncertainty associated with variation in local and international evidence on some health impacts. The report nonetheless reflects a balanced perspective on the views expressed.

The fundamental message, based on available evidence, is that air pollution is harmful to human health and the wider environment. Although difficult to predict or measure, further reductions in ambient manmade air pollution will be likely to bring additional public health gains, especially in terms of reduced long-term health impacts across a range of preventable adverse health outcomes.

International evidence on the adverse effects of air pollution is convincing and continues to grow. The evidence relating to long-term impacts associated with particulate pollution is notably strong, especially for fine particulates ($PM_{2.5}$), for which there is no agreed threshold level at which adverse effects stop occurring for the population as a whole. Reducing ambient PM levels below international health based standards must therefore remain a high priority, alongside efforts to reduce nitrogen oxides and other preventable pollutants.

Improvements in air pollution over recent decades in Scotland will have reduced the health burden associated with exposure. International evidence suggests that further reductions in human sourced air pollution would be likely to benefit public health in Scotland. However, given that key ambient pollutant levels in Scotland are now relatively low in global terms, it is difficult to predict accurately the level of additional health gain that might result from further reductions in air pollution.

The public health effects of noise pollution and climate change correlate strongly with those of outdoor air pollution; effort to address these issues in a more coordinated way offers additional potential co-benefits. Evidence based action to reduce air pollution has clear potential co-benefits in terms of supporting the aims of a range of government policies aimed at: improving public health and reducing health inequalities; environmental quality improvement, climate change mitigation and adaptation; reducing noise pollution and creating a more sustainable transport system.

Effective strategies to reduce air pollution include infrastructure support to encourage increased levels of physical activity via more active travel (walking and cycling); encouraging less reliance on private vehicles by improving access to affordable, available public transport; and improving public transport quality and choice to encourage more switching to zero and low emission vehicles. To achieve significant change in aspects of everyday business and domestic life, as well as modal shift in transport use, a better understanding is needed of current public perceptions on air pollution, as well as of motivations and barriers that impede needed changes.

Achieving these aims in a more coordinated way will also require concerted action to make health focussed policy development more of a joint priority across all relevant central and local government departments (e.g. health, environment, transport, agriculture and especially planning, placemaking and development). To achieve meaningful change, all stakeholders (e.g. government, business and industry, employers (private and public) as well as the public themselves) acting as generators of pollutant emissions generally and especially as users of transport, will need to be encouraged to play their part in helping to prevent the future health burden associated with avoidable air pollution.

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Annex A

HPS rapid review of review papers on non-cardiovascular health outcomes associated with air pollution.

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Annex B

CAFS Review 2019,

Health and Environment Working Group Members.

Chair

Colin Ramsay (NHS, Health Protection Scotland (HPS))

Members

Graham Applegate (Scottish Environment Protection Agency (SEPA)) *

James Curran (Scottish Environment Link)

Richard Dixon (Friends of the Earth Scotland (FOES))

John Howie (NHS, Health Scotland)

Fintan Hurley (Independent, formerly Institute of Occupational Medicine (IOM) and former member of the UK Committee on the Medical Effects of Air Pollutants (COMEAP)).

Duncan Lee (University of Glasgow)

David McColgan (British Heart Foundation Scotland (BHFS))

Vincent McInally (Glasgow City Council (GCC))

Robert Nicol (Confederation of Scottish Local Authorities (COSLA))

Richard Othieno (NHS Lothian)

Frank Toner (British Lung Foundation Scotland (BLFS))

Bruce Whyte (Glasgow Centre for Population Health (GCPH))

(* Secretariat)