Public Health England

Protecting and improving the nation's health

Review of interventions to improve outdoor air quality and public health

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Foreword

The case for clean air and healthy environments continues to gain momentum as our understanding of the benefits we can all gain as a result improves. We have made great strides at reducing air pollution in the UK. The London smogs of the 1950s have become a thing of the past with the reduction of burning solid fuels in homes and limits on pollution from industry. Yet the inexorable rise of road, air and sea transport, industrialisation of food production and many other factors means air quality remains a major issue for the public's health. Walking, cycling and other forms of active travel are great for improving health and reducing air pollution, but too often people are put off by the risk of exposure to high concentrations of pollutants. With an estimated effect equivalent to 28,000 – 36,000 deaths each year attributable to human-made air pollution in the UK, more action is clearly needed.

This report from Public Health England contributes by providing evidence-based advice, focused on actions available to local authorities and national actions required to support them, on the most effective practical actions to reduce air pollution and its impact on our health. This work will further support local and national government's work on improving air quality. The Clean Air Strategy, which was published in January 2019, sets out plans to meet ambitious legally-binding international targets to reduce emissions of the 5 most damaging air pollutants by 2020 and 2030. It will be followed imminently by a wider Environment Bill.

In amongst the complex wealth of evidence outlined in the report there remains a simple truth, that the evidence and technology are available to make delivery of cleaner air feasible for all of us. A key challenge to this is the commonly-held view that actions to reduce air pollution run counter to economic growth and development. In my view the evidence presented in this report highlights that this is not the case. None of us wish to put ourselves or our children at risk from the increasing number of conditions linked to poor air quality, but we do want to live, work, bring up our children and grow old in cleaner environments. This desire, coupled with the space for new technologies, is surely an opportunity for better air quality and economic prosperity to go hand in hand.

Action is needed at all levels to address this unacceptable, serious and avoidable source of harm to our health. We all have a role to play in helping to make sure that the air that we, and future generations, breathe is clean air. Please join me in this effort.

Professor Paul Cosford
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- members of our Steering Group and 5 expert Advisory Groups (Annexe A9)
- stakeholders who participated in Delphi web-surveys
- peer reviewers
- the contractors who carried out the rapid evidence assessments

Executive summary

Public Health England (PHE) was commissioned by the Department for Health and Social Care (DHSC) to review the evidence for practical interventions to reduce harm from outdoor air pollution, stratified by their health and economic impact. The focus of the review was on those actions available to local authorities and, where appropriate, the national actions needed to support them.

The threat of air pollution

The evidence is clear on the scale of harm from air pollution. It is the largest environmental risk to the public's health in the UK with:

- estimates of between 28,000 and 36,000 deaths each year attributed to human-made air pollution
- a close association with cardiovascular and respiratory disease including lung cancer
- emerging evidence that other organs may also be affected, with possible effects on dementia, low birth weight and diabetes
- emerging evidence that children in their early years are especially at risk, including asthma and poorer lung development

People are exposed to outdoor air pollution in the places where they live, work and spend their leisure time. Whilst there are opportunities for individuals to reduce their personal exposure (or that of their children) these are limited. Likewise, whilst there are opportunities for local authorities to reduce the way air pollution concentrates in certain places (such as underpasses with heavy traffic) these are also limited. The interventions that will have the greatest impact on reducing harm to people's health are, therefore, those which reduce emissions of air pollution at source and these should be the main focus of action.

The sources of outdoor air pollution are clearly understood. They include transport and the fuels used for transport, particularly road vehicles but also trains, shipping and aircraft. They also include industry, agriculture and emissions from our homes and businesses.

Given the amount of harm from air pollution and our knowledge of its sources, there is a clear need for concerted action to improve health. This report aims to support local authorities, working with partners and supported by national government, to make that action as effective as possible.

How the review was undertaken

Initial consultation with stakeholders identified 5 areas for potential action. PHE commissioned rapid assessments of the existing evidence for interventions to reduce the impact of air pollution in each area, and for any information on their economic impact. The 5 areas were:

- vehicles and fuels
- spatial planning
- industry
- agriculture
- behavioural change

Based on these rapid evidence assessments we then:

- identified high-level interventions with the potential to benefit health by reducing emissions, concentrations and exposures to the pollutants that cause harm
- identified the specific actions that appear, from the rapid evidence assessments, to be most likely to contribute to these reductions
- drew the findings together to provide information on the effective targeted approaches available to local authorities that are best supported by the evidence

A central feature of the development of this report has been the regular consultation with stakeholders. All this work has been critically appraised through expert review throughout and externally peer-reviewed.

The strength of the evidence

The evidence for effective air quality interventions is developing all the time and this report clearly articulates its challenges and limitations.

There is evidence, some of it strong, for interventions in each of the 5 areas which can reduce emissions of harmful pollutants. Few existing studies directly examine the effects of these interventions on environmental concentrations or the resulting health outcomes. The health benefits of interventions must therefore be inferred from the reductions in emissions. Whilst this is not perfect, it is reasonable to do so, given the strength of evidence supporting the links between individual pollutants and their health impacts. Studies examining the cost-benefits of interventions are unfortunately very limited.

At this stage we are, therefore, unable to stratify by cost and health benefits as the original commission envisaged. Nevertheless, despite the need for more work to understand the detailed health impact of interventions and their cost-benefits, there is sufficient evidence to recommend action. We know that air pollution has a substantial impact on health, and even where evidence of effectiveness cannot be exactly quantified; there are a wide range of interventions that can reduce emissions and reduce people's exposure and consequent health impacts.

Principles to guide action on air quality

As the evidence is examined, it becomes clear that certain principles need to guide the approach:

The different air pollutants should be considered and tackled together. They are rarely independent of each other, either in their production or resulting exposures. Interventions to reduce individual pollutants should not be considered in isolation from other pollutants, otherwise reducing harm from one may be countered by an increase in another.

Local authorities need to work together. Air pollutants don't respect borders, and there is little benefit in reducing air pollution in 1 population centre but increasing it elsewhere. Neighbouring authorities therefore need to work together, especially on interventions that apply to defined spatial areas, such as clean air zones. These can be effective in reducing harm from air pollution in cities and must be carefully designed to reduce all pollution and to avoid displacing it from one populated area to another.

Effective strategies require a coherent approach. This should be between local authority functions (such as environmental and public health, transport, and spatial planning) and between local government and local communities, as well as other public and private sector organisations.

Everyone has a role to play. Individuals need to change behaviours to reduce their exposure and their contribution to pollution. Local authorities are at the centre of local leadership and should coordinate and lead action. Employers, private and public-sector organisations should engage with local initiatives and play their part. The public sector should lead by example and national government needs to ensure a policy environment which supports local action and creates the right incentives.

It is better to reduce air pollution at source than to mitigate the consequences. There is a hierarchy of interventions with preventing, reducing or replacing polluting activities to reduce emissions as the first priority. Actions to reduce the concentration of air pollution once it has occurred is the second priority, and individual avoidance of exposure is the third. The hierarchy for the most effective approaches is to reduce emissions, then reduce concentrations then reduce exposure.

Improving air quality can go hand in hand with economic growth. A common misconception is that air pollution is a necessary consequence of economic prosperity, whereas a clean environment is increasingly understood to support, rather than hinder, economic growth. People prefer to live, and employers are likely to prefer to establish businesses, in places which are clean and support a healthy workforce. Furthermore, the UK is at the forefront of innovation and skills, including developments in clean energy and technologies, which reduce the problem of air pollution, and this technological innovation is a benefit deriving from the desire to reduce air pollution.

As action is taken some groups may need particular support. Some evidence-based actions may disproportionally affect some groups of people. For example, those whose livelihoods depend on driving but who do not have access to or the resources for cleaner vehicles may need particular support because some of the most effective interventions target road vehicle emissions. Without such support, action on air quality may have the perverse impact of increasing inequalities.

The interventions available to local authorities

This report aims to support local authorities, many of whom are already taking substantive action, by providing a broad overview of the interventions available to them.

We first identify high-level approaches that can be used across sectors to improve air quality and health. Then, we elaborate regarding interventions that tackle traffic-related air pollution, as this is a common issue that many local authorities are working to address. Most of these interventions are scalable and deliver greatest health benefits when widely implemented. For other areas, we focus on practical interventions most relevant to local authorities' roles, before outlining the supporting role of national interventions. Feasibility and cost will depend on the specific locations and context. Whilst the detail is within the report, the broad topics covered by these interventions are summarised below, divided according to the 5 areas for which rapid evidence assessments were commissioned.

Interventions and approaches that apply to all 5 areas studied

Introducing targeted interventions to address specific local sources or issues identified through local authority annual reviews and assessments. For example, anti-idling interventions can improve air quality in pollution hotspots or close to vulnerable receptors, such as schools or hospitals.

Prioritising interventions that prevent or reduce emissions over those that address pollution once it has occurred. We recommend a hierarchy of interventions that prioritises the prevention, reduction or replacement of polluting activities.

Interventions that improve local air quality for everyone, not just at pollution hotspots, will have the greatest impact on improving people's health.

Reducing the use of pollution sources in populated areas. Interventions in urban areas may target emissions from road vehicles (eg, by promotion of public transport, cycling, use of electric vehicles) or emissions from wood-burners (eg, by using cleaner fuels, or replacing old appliances).

Systematically evaluating all interventions. Evaluation should be embedded in the design and costing of all future interventions, from their outset, to systematically gather evidence to inform best practice in the future.

Interventions from the rapid evidence assessments on traffic-related pollution

Reducing emissions from existing vehicles: planning for active travel and public transport. Interventions that tackle immediate emissions from the existing vehicle fleet include driving restrictions (which have sometimes been used during episodes of high air pollution), abatement retrofit (though cost is a potential barrier, particularly for private vehicles), and anti-idling enforcement.

Promoting the uptake of low emission vehicles and reducing demand for more polluting forms of transport. Promising local interventions that can help promote a step change in the uptake of low emission vehicles include: low emissions zones, development of electric vehicle charging infrastructure, and use of alternative fuels that reduce emissions. Measures to promote a step change in the uptake of low emission vehicles (such as low emission or clean air zones) can also be used to discourage the most highly polluting vehicles from entering populated areas and reduce population exposure. Interventions with similar aims include: using cleaner buses and taxis on polluted routes, lorry restrictions in urban areas, and freight consolidation centres.

Using spatial planning to reduce sources and exposure to pollution. A joined-up spatial planning and transport strategy is one of the most effective ways of increasing public transport use and active travel and reducing emissions from existing vehicles over time – some local authorities have successfully used workplace or other levies to fund improvement and use of public transport. Spatial planning can be used to reduce the need for vehicle use by design, and has a wider role in reducing emissions from buildings through energy-efficiency measures and use of renewable energy technologies. Promising local interventions that can help reduce demand for more polluting forms of transport are associated with use of public transport and active travel and include: subsidising public transport, designating new and priority bus measures, new tram and taxi schemes, providing school buses, providing infrastructure to enable walking and cycling, and promoting walking and cycling, which provide significant health benefits associated with physical exercise. Interventions that separate people from pollution and introduce barriers can reduce people's exposure to pollutants: they include changing road and pavement layouts, well-designed urban greening schemes, and providing active travel routes through green spaces.

Interventions from the rapid evidence assessments on non-traffic sources of pollution

Reducing exposure to pollution from local airports, ports and the railway sector. Local authorities can support low-emission road transport links and cargo-handling and work with local operators towards other interventions (eg, lower-emission ships, trains, planes and supporting infrastructure).

Reducing exposure to pollution from local industry and agriculture. Local authorities can work with regulators and local operators towards site-specific interventions. For industry, technological interventions include dust abatement and primary and secondary control measures. For agriculture, interventions include livestock housing design/management, change in diet or feeding regime, changes in storage, handling and application of manure, and applying alternative fertilisation practices. In both cases, local authorities can consider inspections and enforcement actions (relating to regulatory and/or nuisance issues) and applying tighter local standards in populated and/or polluted areas.

Interventions from the rapid evidence assessments on public behaviour

Raising awareness of air pollution and health. Local interventions include: awareness campaigns, and hosting or participating in events such as Clean Air Day.

Providing information and advice to businesses and the public explaining how people can minimise their contribution to air pollution. Domestic sources of pollution include cars and solid fuel burning, and people can choose cleaner sources of transport and energy. Local interventions include eco-driving, promotion of active transport, promotion of public transport, and no-idling campaigns. There are a range of behavioural change interventions that can support these efforts; they are most effective if designed to account for models of behavioural change.

Providing information and advice to the public explaining how people can minimise their exposure to air pollution. Behavioural change interventions can include the provision of day-to-day air quality notifications and exposure reduction programmes providing information about less polluted travel routes and times of day.

How national approaches can support local action

Local interventions are most effective if underpinned by consistent and supportive national policies:

Transport. Road transport policies can lower emissions from existing vehicles or reduce long-term emissions from the vehicle fleet. The latter include interventions that reduce demand for more polluting forms of transport and interventions that promote vehicles that have low exhaust emissions. Local authorities have less direct influence over aviation, maritime and railway interventions, where local action can be supported by national policy interventions and operators taking action.

Industry and agriculture. Most industrial and agricultural interventions are dependent on national policy interventions and operators' actions. Industrial and agricultural policies to lower emissions include emission limits and specification of effective abatement techniques at farms and factories. Allowing local flexibility to require stricter controls may help local authorities tackle emissions in problem areas.

Reducing emissions. Our work showed that whilst the aim of preventing or reducing emissions underpins many existing policy interventions related to industry (such as emission limits and ceilings), more can be done to encourage emission and exposure reduction in other sectors, for which many interventions are localised and for which emission and exposure-reduction are not always such central concepts. For example, the primary aim of transport or spatial planning interventions may be to address congestion, reduce collisions, or encourage new development in an area.

Delivering a 'net health gain.' The local implementation of 'net health gain' principles can be supported by their evolution and integration within wider 'net gain' principles in national environmental and planning policies and guidance, and by using building standards' requirements to support 'healthy by design' principles.

Providing information. The effectiveness of local interventions partly depends on local factors such as urban or rural land use, sources of emissions, the nature of the local population, and presence of vulnerable groups. In all cases, they can be optimised to minimise health impacts, maximise health benefits, and address health inequalities. To inform the design and implementation of interventions and to take effective local action, local decision-makers need information, particularly about the sources of air pollution affecting their local populations.

Evaluating interventions. Development of a national framework for evaluating interventions to tackle air pollution and improve public health can support the aim of better evaluating interventions in future, as local and national government can work together to collate, evaluate and share current practices and evaluations of interventions.

The overall approach

Clean by design

This report proposes the adoption of a "net health gain" principle in any new policy or work programme which affects air pollution. If this is adopted, then any new development or proposal for change to existing developments will intend to deliver an overall benefit to people's public health. In effect this means that any new development should be clean by design. The impact would be that the considerable amount of housing and other community developments that is currently underway would by default be well designed to reduce pollution, support walking, cycling and clean public transport, as well as providing charging points for future ultra-low emission vehicles.

Such a principle would need to be built into national and local planning frameworks. It would help ensure that the role played by local authorities in shaping local places enables gradual redesign to reduce pollution and enable cleaner alternatives. Transport and urban planners will need to work together with others involved in air pollution to ensure that new initiatives have a positive impact.

For example, embedding 'net health gain' principles in local plans and reviews of applications for development consent is one way of encouraging the interventions identified in this report. For new developments, emission-lowering measures such as the use of clean energies and energy-efficiency measures (such as the use of insulation and inbuilt energy generation for electricity and water heating) alongside the provision of infrastructure to support the use of low-exhaust emission vehicles (such as electrical vehicle charging points or stations for alternative fuels) and incentives for their use (such as priority parking and reduced fees) can minimise air pollution and maximise health gains. At the planning stage, journey distances and layout need to be carefully considered to minimise driving and ensure that traffic is kept moving at optimum speed. These factors need to be built into local planning systems and supported by national planning frameworks.

Focus on children – aim for a clean air generation

Children are particulary vulnerable to the effects of air pollution. Exposure to air pollution in early life can have a long-lasting effect on lung function. There is evidence that the process of normal lung function growth in children is suppressed by long-term exposure to air pollution. Throughout childhood, there is a natural development of lung function and maximising this is important, as low lung function leads to less reserve if lung disease develops.

We therefore recommend taking a particularly focused approach on reducing the impact of air pollution on children. This would suggest that local authorities, as part of their local air quality management assessments, consider a range of interventions including working with children and their parents to implement no-idling zones outside schools, make it easy for children to walk or cycle to school and increase public awareness in relation to air pollution and children. This will reduce air pollution in the vicinity of schools and reduce children's exposure accordingly.

Next steps

For these practical interventions to deliver real and long-lasting health benefits, they are best adopted within local plans and strategies. Considerable work is already underway in many local authorities. To support local authorities and other stakeholders, our next step will be to produce additional tailored material that elaborates further upon the evidence to support reduction in air quality now and embed it in policy for the future. In the meantime, we will continue to work with colleagues in local and national government to help provide the evidence to support local initiatives and national policy, including the forthcoming Environment Bill.

Abbreviations and acronyms

Term	Explanation
AAF	Alternative Aviation Fuel
AAP	Ambient Air Pollution
ADPH	The Association of Directors of Public Health (UK)
AEI	Average Exposure Indicator
ALRI	Acute Lower Respiratory Infections
APU	Auxiliary Power Unit
AQEG	Air Quality Expert Group
AQG	WHO Air Quality Guideline
AQHI	Air Quality Health Index
AQMAs	Air Quality Management Areas
AURN	Automatic Urban and Rural Network
BAT	Best Available Techniques
BATAEL(s)	Best Available Technique-Associated Emission Level(s)
BAU	Business As Usual
BEIS	Department for Business, Energy and Industrial Strategy
BEV	Battery Electric Vehicle
BOF	Basic Oxygen Furnace
BREF	EU BAT reference document
BRT	Bus Rapid Transit
CAFE	Clean Air For Europe Programme
CAIC	Cincinnati Anti-Idling Campaign
Capex	Capital expenditures
CAS	Clean Air Strategy 2019
CAZ	Clean Air Zone
CBA	Cost-Benefit Analysis
CH_4	Methane
CI	Confidence Interval
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon dioxide
COMEAP	The Committee on the Medical Effects of Air Pollutants
COPD	Chronic Obstructive Pulmonary Disease
CRESH	Centre for Research on Environment, Society and Health
CVD	Cardiovascular Disease
DALY(s)	Disability-Adjusted Life Year(s)
DAQI	Daily Air Quality Index
Defra	Department for Environment, Food and Rural Affairs

Term	Explanation
DfT	Department for Transport
DHSC	Department of Health and Social Care
DOC	Diesel Oxidation Catalyst
DP	Decided Policies
DPF	Diesel Particulate Filter
EA	Environment Agency
EAF	Electric Arc Furnace
EC	Elemental Carbon
EEA	European Environment Agency
EHO	Environmental Health Officer
ELV	Emission Limit Values
EMEP	European Monitoring and Evaluation Programme
EPI	Electrostatic Particle Ionization
EPUK	Environment Protection UK
ESI	Electric Supply Industry
ESP	Electrostatic Precipitator
ETP	Employer Transport Plan
ETS	Emissions Trading System
EV	Electric Vehicle
FCEV	Fuel Cell EV
FGD	Flue-Gas Desulphurisation
FGR	Flue-Gas Recirculation
GAP	Global Action Plan
GDP	Gross Domestic Product
GHGs	Greenhouse Gas(es)
GP	General Practitioner
GSE	Ground Support Equipment
GTL	Gas To Liquid fuel
HAP	Household Air Pollution
HDV(s)	Heavy-Duty Vehicle(s)
HEAT	Health Economic Assessment Tools
HEV	Hybrid Electric Vehicle
HFO	Heavy Fuel Oil
HIA	Health Impact Assessment
HMT	HM Treasury
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IARC	International Agency for Research on Cancer
IAQM	Institute of Air Quality Management
IED	Directive on Industrial Emissions (2010/75/EU)
IER	Integrated Exposure-Response function

Term	Explanation
IGCB	Interdepartmental Group on Costs and Benefits
IHD	Ischaemic Heart Disease
IMD	Index of Multiple Deprivation
IMO	International Maritime Organisation
IOM	Institute of Occupational Medicine
IPPC	Directive on Integral Pollution Prevention and Control (2008/1/EC)
IQR	Inter-Quartile Range
IT-1	Interim Target-1
LA	Local Authority
LAPPC	Local Air Pollution Prevention and Control
LCPD	Large Combustion Plants Directive (2001/80/EC)
LDVs	Light Duty Vehicle
LEZ(s)	Low Emission Zone(s)
LH_2	Liquid Hydrogen
LLAQM	Mayor’s London Local Air Quality Management framework
LNB	Low-NO_x burner
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LYL	Life Years Lost
MCPD	Medium Combustion Plant Directive
MHCLG	Ministry of Housing, Communities and Local Government
MPMD	Multi-Pollutant Measures Database
MWB	Miles Walked/Biked
N	Nitrogen (fertilisers)
NAEI	The UK National Atmospheric Emissions Inventory
NECD	National Emissions Ceiling Directive (2016/2284/EU)
NERP	National Emission Reduction Plan (under the LCP Directive)
NFM	Non-Ferrous Metals industries
NGOs	Non-governmental organisations
NGT	Nominal Group Technique
NH_3	Ammonia
NH_4CO_3	Ammonium carbonate
NH_4NO_3	Ammonium nitrate
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NMHC(s)	Non-Methane Hydrocarbon(s)
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NMVOC(s)	Non-Methane Volatile Organic Compound(s)
NO_x	Nitrogen Oxides
NPPF	National Planning Policy Framework

Term	Explanation
O_3	Ozone
OLEV	Office for Low Emission Vehicles
Opex	Operating expenses
PHE	Public Health England
PHEV	Plug-in Hybrid EV
PHOF	PHE Public Health Outcomes Framework - Public Health Profiles
PICs	Products of Incomplete Combustion
PM	Particulate matter (PM_{10}, $PM_{2.5}$)
PM_{10}	Respirable Particulate Matter
$PM_{2.5}$	Fine Particulate Matter
PSS	Personal Social Services
QALY(s)	Quality Adjusted Life Year(s)
RAG	Red-Amber-Green scoring
RCP	Royal College of Physicians
RD	Respiratory Disease
REA	Rapid Evidence Assessment
RR	Relative Risk
SCR	Selective Catalytic Reduction
SEP	Socio-Economic Position
SES	Socio-Economic Status
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulphur Dioxide
SPG	Supplementary Planning Guidance
SPK	Synthetic Paraffinic Kerosene
TAN	Total Ammoniacal Nitrogen
TfL	Transport for London
TiO_2	Titanium Dioxide
TNP	Transitional National Plan
TOC	Total Organic Carbon
TSP	Total Suspended Particles
UCL	University College London
UKIAM	The UK Integrated Assessment Model
ULEZ	Ultra-Low Emission Zone
VMT	Vehicle Miles Travelled
VOC(s)	Volatile Organic Compound(s)
VSL	Value of a Statistical Life
WHO	World Health Organization
YLDs	Years Lived with Disability

Introduction

The case for action

Air pollution has a significant effect on public health, and poor air quality is the largest environmental risk to public health in the UK. Costs to society are estimated at more than 20 billion pounds every year (1). Epidemiological studies have shown that long-term exposure to air pollution (over several years) reduces life expectancy, mainly due to cardiovascular and respiratory causes and from lung cancer. The annual mortality burden of human-made air pollution in the UK is roughly equivalent to between 28,000 and 36,000 deaths (2). Short-term exposure (over hours or days) to elevated levels of air pollution can also cause a range of effects including exacerbation of asthma, effects on lung function, increases in respiratory and cardiovascular hospital admissions and mortality.

More recent research is recognising that the systemic effects of pollutants extend beyond the cardiopulmonary system to affect many other organs, increasing the risk of disease that begins from conception and persists across the life course (1), with studies showing possible effects on dementia, low birth weight, and diabetes.

National air quality objectives and European Directive limit and target values exist for the protection of human health (3). Adverse health effects from air pollutants are observed at progressively lower exposure levels than previously studied. Further action is needed to achieve ambitious, legally binding targets to reduce emissions of 5 of the most damaging air pollutants (fine particulate matter ($PM_{2.5}$), ammonia, nitrogen oxides, sulphur dioxide, non-methane volatile organic compounds), as well as achieving the government’s proposed reduction of public exposure to PM in line with the World Health Organization’s recommendations. Attributing health outcomes from exposure to individual constituent pollutants in emissions is not simple. This supports the need to tackle emissions in general and not necessarily to focus on individual pollutants (4, 5).

The aim of this report is to assist with the development and implementation of the government’s national Clean Air Strategy and the National Air Pollution Control Programme the UK is required to publish by April 2019. It will form part of government’s ongoing commitment to improve air quality and inform decision-making.

In August 2017, The Department of Health and Social Care (DHSC) requested that PHE undertake a review of the evidence for effective and cost-effective air quality interventions and provide practical recommendations for actions to improve air quality that will significantly reduce harm from air pollution, stratified by their health and economic impacts (for full details, refer to Annexe A1).

Key objectives were to provide practical recommendations for implementable local and national interventions, supplementing existing guidance. The report builds on Defra's *Air quality plan for NO_2 in UK* (2017) and the NICE guideline *Air Pollution: outdoor air quality and health* (2017), which focussed on road-traffic-related pollutants.

As a background to this report, the sections below provide short summaries of the main air pollutants of health concern and national air quality policies. In the following chapter, the methodology and approach taken by PHE and the contractors that carried out 5 rapid evidence assessments are described. The results from each of the 5 rapid evidence assessments follow, before the results of a modified Delphi process PHE carried out to rank air pollution problems and link them with interventions identified in the evidence assessments and a PHE evaluation of their potential effectiveness at improving air quality and public health. Finally, we discuss the results and make recommendations for future action to improve air quality and health.

Exposure to air pollution

The Clean Air Strategy sets out the case for action and this government's ambition for improving our air quality. The key aim of the strategy is to reduce national emissions of pollutants, background pollution concentrations, and minimise population exposure to harmful concentrations of pollution.

Figure 1 summarises the main sources of air pollution and the areas addressed by PHE's rapid evidence assessments (ie, buildings, vehicles, industry, agriculture, and people's activities). As the major sources of air pollutants have decreased since 1990, lesser more diffuse sources of air pollution, such as smaller, unregulated industrial activities, use of consumer products, open fires in homes and spreading manure on farms have increased in importance (6).

Figure 1: Sources of air pollution and pollutants of health concern (adapted from (7))

Several factors are relevant when considering the impacts of air pollution on health:

- emissions of pollutants
- environmental concentrations of pollutants
- exposure to pollutants (and susceptibility/vulnerability)

Air pollution is a local, regional and international problem caused by the emission of pollutants. Emissions, concentrations and exposures all vary temporally and spatially and, therefore, improving air quality requires a dual focus: addressing 'hotspots' (localised air pollution) and addressing background concentrations of pollutants linked to wider population exposure.

Seasonal variations and day-to-day changes in weather can have a great influence on air quality. Levels of pollutants that are relatively high on a still day when dispersion is limited can be much lower the next day, or even the next hour, if the wind direction changes or wind speeds increase (8).

Emissions and sources of pollutants

Table 1 is adapted from Table 2 of Defra's '*Emissions of air pollutants in UK, 1970-2016*' (9) and summarises the contribution of individual emission sources to the UK's total emissions of air pollutants in 2016. The table shows that industrial processes and residential and small-scale commercial combustion are the leading contributors to UK

PM_{10} (particulate matter, see Glossary) emissions, accounting for 31 and 28% in 2016, respectively. NO_x (oxides of nitrogen) emissions from transport make the largest contribution to the UK total, accounting for 34% in 2016. Emissions from energy and manufacturing industries are also major contributors to NO_x pollution. The table shows that although emissions from the agriculture sector are not significant when considering NO_x or SO_2 (sulphur dioxide), most emissions of NH_3 (ammonia) come from agriculture, with the sector accounting for 88% of total UK emissions in 2016. For NMVOCs (non-methane volatile organic compounds), the largest source is industrial processes using large amounts of solvents, accounting for 54% in 2016.

Table 1: Source emission contributions by sector for 2016 (adapted from Table 2 (9))

Sector	PHE Rapid Evidence Assessment(s)	PM_{10} ↓	$PM_{2.5}$ ↓	NO_x ↓	SO_2 ↓	NH_3 ↓	NMVOC ↓
Agriculture	Industrial Agriculture	10.0%	4.0%	0.8%	N/A	87.6%	14.4%
Energy industries	Industrial Planning	2.7%	3.3%	22.4%	37.3%	0.1%	0.5%
Fugitive emissions	All	1.1%	1.1%	0.2%	1.4%	0.1%	15.8%
Manufacturing industries and construction	Industrial Planning	10.6%	16.1%	15.6%	21.6%	0.7%	2.4%
Industrial processes[1]	Industrial Planning	31.2%	12.9%	0.1%	4.8%	1.3%	54.1%
Residential, and small-scale commercial combustion	Behavioural Industrial	27.9%	43.1%	10.3%	25.5%	0.8%	6.2%
Road transport	Vehicle Planning	11.7%	12.4%	33.6%	0.7%	1.5%	3.9%
Non- road transport[2]	Vehicle Agriculture	2.4%	3.6%	16.8%	8.3%	0.0%	1.6%
Waste	Industrial Planning	2.3%	3.3%	0.2%	0.4%	3.5%	0.8%
Other sources	All	0.1%	0.1%	0.0%	N/A	4.5%	0.4%
Total[3]	All	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[1] Note that source emission contributions presented are based on official national statistics releases and may not be directly comparable with source categories and contributions presented in the Clean Air Strategy
[2] Non-road transport also includes other mobile combustion military aircraft and naval shipping
[3] See source reference for memo items reported but excluded for protocol totals

Environmental concentrations of pollutants

The complex nature of air pollution chemistry means that air pollutant emissions reductions do not always produce a corresponding drop in atmospheric concentrations in the UK (8, 10). It is, therefore, important to measure ambient air quality as well as emissions to understand local pollution concentration levels and people's exposure. For example, from a UK perspective, only about half the exposure of the UK population to secondary inorganic aerosol pollution (see following section) is due to UK emissions, with around 33% arising from other countries and 17% from shipping in 2012. Future effects will depend on the control of emissions of SO_2, NO_x and NH_3 in other countries and from shipping, as well as sources in the UK (11).

Short-term air pollution forecasts are issued by the Met Office (Box 1). In order to monitor short and long-term air quality and help assess risks to people's health and to the environment, the concentrations of key pollutants are measured via a national network of monitoring sites – the Automatic Urban and Rural Network (AURN) – which continuously captures ambient concentrations of selected pollutants throughout the UK.

Monitoring data is combined with modelled data for annual reporting of pollutant concentrations. The UK-AIR website provides forecast information and provides the most up-to-date data for all air pollutants monitored by the Environment Agency on behalf of Defra (8).

The annual report on Air Quality Statistics in the UK (8) notes long-term decreases in PM and NO_2 concentrations:

- urban background and roadside PM_{10} has shown long-term decreases, and small decreases in concentration are observed from 2016 to 2017 for both roadside and urban background sites. A substantial network for $PM_{2.5}$ has been operational since 2009 which shows a similar trend
- urban background and roadside NO_2 pollution has shown long-term decreases and small decreases in concentration are observed from 2016 to 2017 for both roadside and urban background sites

Box 1: Air Pollution Forecast and the Daily Air Quality Index (DAQI)

Air pollution is forecast by the Met Office and presented using the Daily Air Quality Index (DAQI), which defines a scale from 1 (low) to 10 (very high). The DAQI was developed by the Committee on the Medical Effects of Air Pollutants (COMEAP) to categorise air quality levels. The DAQI air quality band is accompanied by health advice for the general population and those more likely to be affected by short-term increases in pollution, in particular those with heart and lung problems.

Defra applies the DAQI to its air quality forecasts to inform people what pollution levels are predicted over the next 5 days. The forecasts allow people to plan ahead and, where relevant, take the recommended action to reduce the effects of high levels of air pollution.

The ‘Low’ bands indicate air pollution levels where it is unlikely that anyone will suffer any adverse effects of short-term exposure, including people with lung or heart conditions who may be more susceptible to the effects of air pollution. The ‘Moderate’ band represents levels of air pollutants at which there are likely to be small effects for susceptible people only. Values for the ‘High’ bands are associated with significant health effects in susceptible people. At ‘Very High’ levels of air pollution even healthy individuals may experience adverse effects of short-term exposure (12).

An example of the DAQI banding for $PM_{2.5}$ is presented below, showing the concentration breakpoints between different levels.

$PM_{2.5}$ Particles

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
μgm^{-3}	0-11	12-23	24-35	>36-41	>42-47	>48-53	54-58	59-64	65-70	71 or more

The average number of days of moderate or higher air pollution measured at urban and rural networks (per site) in 2017 was approximately 16 days, with a gradual trend downwards since 2010 (8).

Inequalities in exposure

Those with lower socioeconomic status and those from ethnic minorities can be disproportionately exposed to environmental hazards, including proximity to industrial facilities, hazardous waste sites, air pollution, noise and occupational exposures (13). Defra has identified that the most deprived deciles were primarily located in urban areas of England (Greater London, Birmingham, Merseyside, Greater Manchester, South and West Yorkshire, and the North East) and tended to have the highest ambient levels of the 'standard' air pollutants (including fine particulate matter and NO_2) (14). Those who live, learn or work near busy roads are also likely to suffer more than others from the effects of air pollution (1).

The underlying causes of inequalities in health are multiple, complex and often entrenched. A key message of the Marmot Review on health inequalities was that focussing solely on the disadvantaged will not reduce health inequalities sufficiently. To reduce the steepness of the social gradient in health, action must be universal, but with a scale and intensity that is proportionate to the level of disadvantage (15). This is termed 'proportionate universalism'. As it requires actions *across social classes* to reduce the gap between them, this includes measures to promote changes among those who are wealthier to reduce their impacts, especially if they affect the poorest or most vulnerable groups or areas. This is relevant when considering interventions to improve air quality: for example, reducing the frequency of use of privately-owned cars leads to a reduction in air and noise pollution which can disproportionately impact deprived urban areas where fewer residents may have their own vehicles.

Vulnerable groups

During short-term high pollution episodes, children, older people, and people with chronic health problems are the most vulnerable to air pollution (1). Short-term (eg, day-to-day) peaks of elevated air pollution are associated with increases in hospital admissions, when individuals with pre-existing cardiovascular and respiratory conditions may experience worsening of symptoms (Box 2). However, because the health outcomes associated with short and long-term exposure to air pollution have many potential causes, detection and quantification of health effects due to air pollution or specific air pollutants is not straightforward.

BOX 2: Real-time syndromic surveillance systems

Real-time syndromic surveillance systems in England continuously monitor health-care-seeking behaviour from in and out-of-hours general practitioners (GP), remote health advice (through NHS 111) and sentinel emergency departments. During the course of 2 recorded episodes of poor air quality in March-April 2014, and for 2 days afterwards, there were statistically significant increases in the proportion of daily telephone calls to NHS 111 for difficulty breathing, daily consultation rates for GP in-hours for severe asthma and wheeze or breathlessness, and in the proportion of GP out-of-hours consultations for difficulty breathing or wheeze or asthma and attendances at sentinel emergency departments (16).

Syndromic surveillance is increasingly used for environmental events in order to monitor the acute impact on respiratory and other conditions during periods of poor air quality (16).

Evidence that air pollution causes Chronic Obstructive Pulmonary Disease (COPD) is not conclusive, but there is good evidence that air pollution triggers worsening of symptoms in those living with related conditions (17).

There is evidence associating exposure to air pollutants with a worsening of asthma symptoms. Traffic-related air pollution may play a role in inducing asthma in some individuals, particularly those who live near busy roads carrying high numbers of heavy goods vehicles (18). A long-term study of children's health in California reported improvements in lung development in children following a reduction in levels of air pollution (5). This study highlighted that taking action to reduce levels of air pollutants could potentially allow more young people to achieve their maximum lung function growth potential.

Contribution of outdoor air to total exposure to air pollution

Population exposure to $PM_{2.5}$, NO_2 (in places where gas appliances are infrequent), SO_2 and other pollutants comes predominantly from ambient air and outdoor sources (19). As people spend most of their time indoors, it is likely that the largest fraction of an individual's total exposure, even to pollutants generated outdoors, occurs in the indoor environment (20).

This report has not exclusively considered indoor air quality interventions in detail, as 2 organisations are currently preparing reports in this area: the Royal College of Physicians and Royal College of Paediatric and Child Health are preparing a systematic review of the evidence on indoor air (21). A NICE guideline on 'Indoor air quality at home' is also in preparation and due in September 2019 (22).

The main air pollutants of health concern

Particulate matter (PM)

Particulate matter (PM) is a generic term used to describe a complex mixture of solid and liquid particles of varying size, shape and composition (Figure 2). Sources of PM can be natural or human-made. Some particles are emitted directly (primary PM); others are formed in the atmosphere through complex chemical reactions (secondary PM).

Figure 2. Particulate matter

Particulate matter
Mass concentration of particles (µg/m^3)

Nanoparticles / ultrafine particles: smaller than 0.1 µm in diameter
Fine particles $PM_{2.5}$: with a diameter of 2.5 µm or less
Coarse particles $PM_{10-2.5}$: with a diameter 2.5 – 10 µm
PM_{10}: with a diameter of 10 µm or less
Dust: with a diameter of 75 µm or less

Sources

The composition of PM varies depending upon source contribution and geographical location. The main source of PM is the combustion of fuels (vehicle, industry and domestic) and other human-made activities such as mining, quarrying, industrial processes and tyre and brake wear. Natural sources include wind-blown soil and dust, sea spray particles, volcanos and seismic events, and fires involving burning vegetation.

Total PM emissions have decreased over recent decades, with the rate of decline being most pronounced during the 1990s. This has been achieved through a variety of mechanisms, including industrial regulation and reduction in use of solid fuels. However, this decline has slowed in recent years and the composition of PM has changed.

The Clean Air Strategy states that domestic wood and coal burning now contributes up to 38% of $PM_{2.5}$ emissions (6). As well as emissions from local and regional sources, levels of PM are also influenced by emissions from mainland Europe and further afield. Among the common air pollutants, fine particles stay in the air the longest and can, therefore, build up over days and be moved by winds over large areas.

Background $PM_{2.5}$ concentrations vary year-on-year because of variation in weather conditions. The variation in background $PM_{2.5}$ concentrations is one reason benchmarking annual PM concentrations may not give a true picture of the impact of interventions. However, this does not detract from the value of taking action and, in fact, supports the importance of measures that improve air quality across local authority boundaries. Local and national policy seeks to influence the human-made component of these concentrations, as less can be done to reduce levels from natural sources.

Secondary inorganic aerosols

Secondary particles are the predominant components of $PM_{2.5}$ in the UK, making up about 60% to the overall mass of $PM_{2.5}$ in urban areas annually (11); and even more during high pollution episodes (23). Secondary particulates (also called secondary aerosols) consist of both organic and inorganic (sulphate, nitrate, ammonium) components, which are formed in the atmosphere largely through the chemical reaction of gaseous precursors. This gas-to-particle phase conversion is not immediate and may occur over many hours or days. Thus, these particles can form at locations distant from the sources that release the precursor gases. Indeed, only about half of secondary aerosol pollution in the UK is formed from precursor species emitted in the UK, with around 33% arising from other countries and 17% from shipping (based on 2012 data) (11).

The main precursor gases for secondary inorganic aerosols are ammonia (NH_3) and oxides of nitrogen and sulphur. Volatile organic compounds (VOCs; include various groups of carbon-containing chemicals) contribute to the organic secondary PM. Sources of secondary PM precursors include gas emissions from transportation, agriculture and industry. Precursor gases may also originate naturally from, for example, trees.

Health effects

The size of particles and the duration of exposure are key determinants of potential adverse effects on health. Particles with a diameter of 10 µm or less (PM_{10}) pose a risk to health as they can penetrate and lodge inside the lungs. The strongest evidence for effects on health are associated with fine particles ($PM_{2.5}$). There is some evidence that ultrafine PM ($PM_{0.1}$) with a diameter less than 0.1 µm can penetrate deeper into lung tissue, enter the bloodstream and, therefore, pose a greater risk. However, the evidence on health effects related to exposure to ultrafine particles remains limited and inconclusive.

Short term exposure to PM may result in irritation of the eyes and respiratory symptoms, such as irritation of the nose and throat, coughing, shortness of breath and chest tightness. Individuals with existing cardiovascular and respiratory conditions, children and older adults are particularly at risk of effects when air pollution levels are elevated. Hospital admissions and deaths from these causes are also increased.

The UK experienced widespread high levels of particulate air pollution ($PM_{2.5}$ up to 83 μg/m^3 at urban background sites) over 2 ten-day periods during March and April 2014. These 2 episodes were associated with approximately 600 deaths brought forward, and around 1,570 emergency respiratory and cardiovascular hospital admissions (24).

Long-term exposure to PM reduces life expectancy, probably by contributing to the development and progression of cardiovascular and respiratory diseases, as well as exacerbation of symptoms in those who already have these diseases. It increases the risk of lung cancer, and the International Agency for Research on Cancer (IARC) has classified particulate outdoor air pollution as carcinogenic to humans (IARC Group 1).

The evidence of the public health impact of PM exposure is consistent in showing adverse health effects at exposures that are currently experienced by urban populations. There is a close relationship between exposure to high PM concentrations and increased mortality or morbidity, both daily and over time. Air pollution is considered a contributory factor rather than the sole cause of death in most cases. Cohort studies indicate that the relative risk associated with living in areas with elevated PM levels over the long term is of greater magnitude than that observed from studies of effects of daily variations in exposure.

The air pollution health indicator in the PHE Public Health Outcomes Framework (PHOF) estimates the fraction of adult mortality attributable to long-term exposure to $PM_{2.5}$ air pollution (in local authority areas) in England. It ranges from less than 3% in the least polluted rural areas to over 7% in some London boroughs (national and regional attributable fractions are shown in Table 2). The average for England is 5.1% (2017 data).

Table 2: Indicator 3.01 - Fraction of mortality attributable to particulate air pollution 2017

Area	Value %
England	5.1
East Midlands region	5.1
East of England region	5.5
London region	6.5
North East region	3.7
North West region	4.1
South East region	5.6
South West region	4.4
West Midlands region	4.9
Yorkshire and the Humber region	4.2

Nitrogen dioxide (NO_2)

Nitrogen dioxide is a gas with the chemical formula NO_2; it is produced with nitric oxide (NO) by combustion processes. Together they are often referred to as oxides of nitrogen (NO_x).

Sources

Local road traffic contributes substantially to outdoor air pollution, particularly in busy towns and cities. Defra estimates that 80% of NO_x emissions in areas where the UK is exceeding NO_2 limits are due to transport (25), with the largest source being emissions from diesel light duty vehicles (cars and vans).

These continue to be the largest sources of emissions due to significant growth in the use of diesel vehicles and the failure of the Euro standard to deliver the expected emission standards under real-world driving conditions. Emissions from industry, agriculture and commercial and domestic sources are also significant contributors.

Health effects

It is well established that NO_2, particularly at high concentrations, is a respiratory irritant that can cause inflammation of the airways (for example, cough, production of mucous and shortness of breath). Studies have shown associations of NO_2 in outdoor air with reduced lung development (lung function growth) and respiratory infections in early childhood and effects on lung function in adulthood. There are a number of studies associating NO_2 with negative health effects, including death.

Currently there is no clear evidence of a threshold concentration of NO_2 in ambient air below which there are no harmful effects for human health. Therefore, further reduction of NO_2 concentrations below the air quality standards is likely to bring additional health benefits.

Epidemiological studies have shown associations of outdoor NO_2 with adverse effects on health, including reduced life expectancy. It has been unclear whether these effects are caused by NO_2 itself or by other pollutants emitted by the same sources (such as road traffic). Evidence associating NO_2 with health effects has strengthened substantially in recent years but there is debate as to whether it is causal or a marker for other traffic-related pollutants (26).

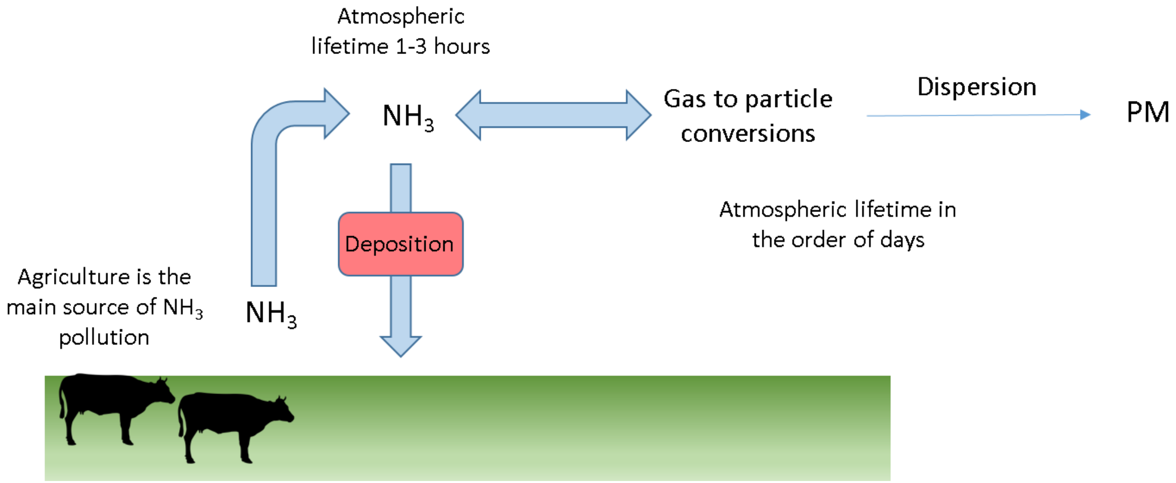
Other important pollutants included in the Clean Air Strategy

Ammonia (NH_3)

NH_3 is a gas released into the atmosphere (also called NH_3 volatilisation) from natural and anthropogenic sources. Once emitted into the atmosphere, NH_3 can be rapidly deposited over the areas near the emission source. The deposition of NH_3 can be a major source of pollution, causing nitrogen (N) enrichment (eutrophication) and acidification of soil and water sources. Atmospheric NH_3 also reacts with acid gases, such as sulphuric and nitric acid, to form secondary $PM_{2.5}$ (ie, $PM_{2.5}$ not emitted directly from sources) (Figure 3).

Thus, NH_3 not only plays a role in acidification and eutrophication but also contributes to the overall PM burden. Indeed, agricultural emissions of NH_3 have been reported to be key contributor to many high PM pollution events in recent years, such as the PM episodes across the UK in spring 2014 (23). The equilibrium between the gas and particle-phase is influenced by environmental conditions (eg, ambient temperature and relative humidity) and the physical/chemical characteristics of the aerosols and gases.

Figure 3. NH_3 release to the atmosphere, transformation to PM and removal by deposition (Adapted from Figure 2 in AQEG, *Air Pollution from Agriculture* (27))



Sources

The agricultural sector is currently responsible for the vast majority of NH_3 emissions to the atmosphere, contributing to about 88% of the total UK NH_3 emissions in 2016 (9). Primary sources of NH_3 emissions are livestock excreta (ie, urea) in livestock housing, and manure storage, processing, treatment and application to land. Emissions also occur from the application of nitrogen fertilisers to land.

From 2013 onwards, NH_3 emissions have slightly increased, driven largely by the intensification of agricultural production. This increasing emission trend may increase further due to projected increases in food demand to feed an expanding population.

Health effects

The main health impacts of NH_3 arise through its role in secondary $PM_{2.5}$ formation, known to be associated with a variety of health effects (both acute and chronic). Particles, derived from NH_3 emissions, can stay suspended in the air for long periods, depending on weather conditions and factors such as the particles' chemical and physical properties, and can be dispersed over long distances. Emissions of NH_3 also indirectly contribute to emissions of nitrous oxide– a potent greenhouse gas. Efforts to reduce agricultural NH_3 emissions have also been shown to help mitigate other pollutants, including $PM_{2.5}$. Modelled data generated using the EMEP4UK (European Monitoring and Evaluation Program Unified Model for the UK) atmospheric chemistry transport modelling system suggested that a 30% reduction in UK NH_3 emissions would reduce $PM_{2.5}$ concentrations by 0.3 to 0.5 µg/m^3 over most of England and Wales (28). It is therefore reasonable to assume that reductions in agricultural NH_3 emissions could lead to a reduction in $PM_{2.5}$-related mortality and morbidity.

An increasing population and the limited space available for urban developments has resulted in the divide between urban and rural areas becoming increasingly blurred (29), potentially increasing population-level exposures to agricultural emissions over time. A recent systematic review summarised the available evidence of health effects associated with living near intensive farms (30). The authors concluded that children living, or attending schools, close to intensive farms might be at modest increased risk of reporting asthma, or asthma-like symptoms. The authors noted, however, that further work examining exposure to bioaerosols and childhood asthma rates near intensive farms is needed to confirm the results. Incidences of zoonotic infectious diseases have also found to be increased in livestock-dense areas (31, 32).

While there tends to be a bias towards the presumption of health risks from emissions from agriculture, the converse – beneficial health effects – may also occur. The hygiene hypothesis (33, 34) states exposure to microbial agents during early life to be beneficial to later health. For example, prevalence of wheeze and asthma has been shown to be lower among adults living in close proximity of an intensive farm (35).

Sulphur dioxide (SO_2)

Sulphur dioxide is a gas that can dissolve in water and produce sulphuric acid droplets in the atmosphere. Chemical reactions of SO_2 can also produce sulphates which remain in the air as secondary particles, contributing to the PM mix (12).

Sources

Coal was once widely used for domestic heating and cooking, creating high concentrations of SO_2 and smoke in our towns and cities. Due to the increased use of gas and electricity, this is now relatively uncommon, and levels of SO_2 have steadily declined over the last 50 years. Most SO_2 in the UK now comes from industrial sources such as power stations burning fossil fuels, as well as domestic sources such as boilers and gas stoves. The introduction of low-sulphur fuels has reduced the emissions of SO_2 from motor vehicles. SO_2 is also produced naturally by active volcanoes and forest fires.

Health effects

SO_2 is produced when sulphur-containing fuels, such as coal, are burned. SO_2 has an irritant effect on the lining of the nose, throat and lungs and at high concentrations can cause coughing, tightness in the chest and narrowing of the airways of the lung. People with asthma are much more sensitive to SO_2 than non-asthmatics. When SO_2 levels are high, people with asthma may therefore find breathing more difficult and, during pollution episodes, levels of SO_2 may trigger asthma attacks.

Non-methane volatile organic compounds (NMVOCs)

Non-methane volatile organic compounds (NMVOCs) consist of a large variety of chemically different compounds, such as benzene, toluene and ethylbenzene. They are a collection of different organic compounds that display similar behaviour in the atmosphere (36).

Sources

NMVOCs in the environment come from both natural and anthropogenic sources. The total anthropogenic NMVOC emissions in the UK have decreased by 66% between 1970 and 2016. The rate of decline was most pronounced in the 1990s, largely reflecting the decline in coal mining and has slowed in recent years (9). NMVOCs are emitted from a wide variety of products and processes including industrial processes and agriculture (see Table 1) and they also form a significant component of indoor air pollution emitted from household products (out with the scope of this report) (6, 9, 37).

Health effects

In the outside atmosphere, NMVOCs react with NOx in the presence of sunlight to form tropospheric O_3, known to be harmful to health and the environment. Besides tropospheric O_3 formation, NMVOCs contribute to the formation of secondary organic aerosols that can harm human health. Certain NMVOCs, such as benzene and 1, 3-butadiene, have also been shown to be toxic, mutagenic and carcinogenic.

Ozone

O_3 is a gas and occurs both in the earth's upper atmosphere and at ground level. Ground level, or tropospheric O_3, is not emitted directly into the air, but is created by means of photochemical reactions involving the precursor pollutants NOx and VOCs. Future climate change (out with the scope of this report) is expected to increase O_3 concentrations (38). Several epidemiological studies have reported adverse associations between short-term exposure to O_3 and human health. The effects of exposure to O_3 are predominantly respiratory, but adverse effects on the cardiovascular system have also been reported (39). Less convincing evidence exists for an association between long-term exposure to O_3 and human health (39). Ground level O_3 also has negative effects on ecosystems, including loss of species diversity.

Interventions directed at reducing O_3 emissions were not within the direct scope of this rapid evidence assessment. However, interventions reducing NOx and VOC emissions could help reduce the O_3 health burden.

Air quality policies in the UK

Action on air pollution

Defra has the lead responsibility for air quality in the UK, with other departments, agencies and local authorities fulfilling important policy and regulatory roles to address emissions of air pollutants. Improving air quality is the responsibility of national and local government, and over recent years, there has been an increased focus on this work, particularly because of the UK's failure to achieve more stringent targets for the reduction of nitrogen dioxide. Air quality is a devolved policy area: Scotland, Northern Ireland and Wales lead on policy within their own territories.

PHE's role in improving air quality

PHE is the expert national public health agency that exists to protect and improve the public's health and wellbeing and reduce health inequalities. In fulfilling its role to improve the public's health, PHE will make important contributions to the development and implementation of a number of air quality-related government programmes in 2019, particularly through work to make agreed contributions to cross-government initiatives on the environment. This includes the government's Clean Air Strategy, implementation of public health recommendations in the Defra 25 Year Plan to improve the environment, and support of the revision of the National Adaptation Programme for climate change (40).

PHE's air pollution programme to support national and local government to reduce mortality and morbidity attributable to air pollution aims to provide evidence on the health effects of air pollutants and raise awareness through sustained public health engagement with local authorities and other stakeholders. Defra, PHE and DHSC are working together to provide clearer and more targeted messages about the risks of air pollution and the simple actions people can take to improve air quality and health (41).

Local authorities

Local authorities seek to develop and implement effective interventions to improve local air quality, working through public and private sector partnerships and in conjunction with local populations. Where a local authority identifies an area or areas exceeding air quality targets and there is relevant public exposure, it is required to declare an Air Quality Management Area (AQMA) and to draw up an action plan to address the problem. In July 2017, Defra and the Department for Transport (DfT) published the "*Air Quality Plan for nitrogen dioxide (NO_2) in the UK 2017*." This plan (42), and subsequent iterations, require local authorities take action to bring NO_2 air pollution levels within statutory limits in the shortest possible time.

PHE has a responsibility to provide systematic support to local authorities working on air quality plans (in relation to NO_2) and contributes to the wider air quality agenda through development of the evidence base, providing the secretariat for the Committee on the Medical Effects of Air Pollutants (COMEAP) and supporting a number of local-authority-focussed air quality networks across the country.

UK air quality plans for tackling roadside nitrogen dioxide

Under EU legislation, member states must meet air quality limits for a range of pollutants. A 2010 deadline for reducing NO_2 levels was extendable to 2015, as long as an adequate air quality plan to reduce emissions was in place. However, several countries, including the UK, failed to meet this 2015 deadline. Currently, a number of areas in the UK do not meet the NO_2 targets, especially roadsides in urban centres, and in 2016, Defra and DfT set up a joint unit specifically to deliver national plans to improve air quality and meet EU limits.

The government's Air Quality Plan for tackling NO_2, published in July 2017, aims to achieve the statutory limit values for the whole of the UK within the shortest possible time. A range of measures was proposed at a local and national level to address the link between emissions from transport – diesel emissions in particular – and NO_2 pollution. Box 3 illustrates actions being taken at city level to address local air quality.

Box 3. Examples of key actions to improve air quality taken by 2 cities

Greater London (43)

- toxicity charge
- ultra-low emission zone (ULEZ)
- retrofitting London buses and low emission bus zones
- clean vehicle checker
- air quality audits at primary schools in areas exceeding 40 µg/m^3 NO_2
- new taxis to be zero exhaust emission capable

The London Local Air Quality Management Framework (44)

The Mayor's London Local Air Quality Management (LLAQM) framework is the statutory process used by local authorities to review and improve air quality within their areas. This new framework was designed to specifically meet London's air quality needs. The framework provides templates and tools, such as air quality data, maps and graphs, to help with action planning and monitoring. Tools include an 'action matrix' to help boroughs assess and prioritise actions to improve air quality, a 'Cleaner Air Borough' accreditation scheme, better information sharing through regional annual reports, and the integration of planning into LLAQM – allowing oversight of how and where boroughs are meeting the air quality requirements found in the 'London Plan' and stressing the importance of this area of work.

This 'action matrix' outlines 38 measures (actions) for boroughs to consider delivering locally as part of their LLAQM. Whilst not an exhaustive list and not obligatory, it is a list of actions which utilise the levers that are under borough control which may be used to improve air quality. Where possible, each action includes examples/case studies, an assessment of the possible benefits, and a provisional assessment of high-level risks.

Leeds City Council (45)

- transitioning council fleet of vehicles to ultra-low or low exhaust emission vehicles
- connecting Leeds strategy – upgrading public transport and cycling infrastructure to reduce car journeys
- offering free parking for residents with ultra-low emission vehicles at council car parks
- improving traffic flow to decrease stop-start
- plans to pedestrianize more of the city centre

PHE's evidence review is likely to complement this work by providing evidence regarding interventions and strategies that will inform the options appraisals and action plans being developed by local authorities.

Government's Clean Air Strategy 2019

A Clean Air Strategy setting out how the government will meet international commitments to reduce emissions of 5 damaging air pollutants by 2020 and 2030 (nitrogen oxides, particulate matter, sulphur dioxide, non-methane volatile organic compounds and ammonia) was published on 14 January 2019. The strategy has a broader scope than the *Air Quality Plans for tackling roadside nitrogen dioxide* and covers emissions from domestic, industrial, farming and building activities. It outlines the government's ambitions relating to reducing air pollution, making air healthier to breathe, protecting nature and boosting the economy. The strategy sets out a clear direction for future air quality policies and goals.

Emissions from road transport have been in the spotlight because of their impact on local air quality, but the government is committed to cutting air pollution from all forms of transport.

The Clean Air Strategy sits alongside 3 other important UK government strategies:

- Industrial Strategy: Building a Britain fit for the future
- The Clean Growth Strategy 2017
- A Green Future: Our 25 Year Plan to Improve the Environment

National Planning Policy Framework

The revised National Planning Policy Framework (NPPF), the implementation of which, together with other planning policy and guidance, aims to align with cross-departmental work on air quality, was published in July 2018 (46). The NPPF implements the government's recent reforms to planning policy.

A good planning system could be considered an effective high-level intervention to improve air quality and health, especially as planning policy impacts across all the domains considered within this review. The NPPF states that planning policies and decisions should sustain and contribute towards compliance with relevant limit values or national objectives for air pollutants, taking into account the presence of Air Quality Management Areas and Clean Air Zones, and the cumulative impacts from individual sites in local areas. Opportunities to improve air quality or mitigate impacts should be identified, such as through traffic and travel management, and green infrastructure provision and enhancement. Insofar as possible, these opportunities should be considered at the plan-making stage to ensure a strategic approach and limit the need for issues to be reconsidered when determining individual applications for development consent. Planning decisions should ensure that any new development in Air Quality Management Areas and Clean Air Zones is consistent with the local air quality action plan.

A National Emission Control Plan for England in 2019

The UK is required to submit a national atmospheric emissions control plan to the European Commission by April 2019 under the National Emissions Ceiling Directive (47). This will set out how the UK will deliver its emissions reductions, detailing actions and proposed policies to achieve abatement of each key air pollutant in different sectors.

The PHE evidence review methodology

Steering Group

A high-level Steering Group was established, comprising representatives from the healthcare sector, government departments, local government and academia. The first meeting of the Steering Group was held in October 2017, with regular teleconferences thereafter on an approximately monthly basis. Its members were consulted regarding the commission and subsequent tender specification, rapid evidence assessments and PHE report. The Steering Group's terms of reference and membership is described in Annexe A9.

Rapid evidence assessments

As the commission sought to inform developing government work on air quality, PHE's work programme was subject to tight deadlines and required a balance between gathering and refining evidence and maximising its potential contribution to evolving policy. A rapid evidence assessment methodology (described below) was adopted as a proven approach to gather and summarise evidence and provide an overview within a short time period.

PHE invited tender applications for rapid evidence assessment(s) across 5 categories of interventions to reduce air pollution: industrial/regulatory (Lot 1), planning (Lot 2), vehicle/fuel (Lot 3), agricultural/rural (Lot 4), and social science/behavioural (Lot 5). An open tender was issued for all 5 lots that closed in January 2018. PHE subsequently issued contracts to 2 consortia: Lot 1 was awarded to a consortium led by the environmental consultancy Wood Plc. Lots 2-5 were awarded to a consortium led by the Institute of Occupational Medicine (IOM). The reviews commenced in February 2018 and final reports (Annexes A2-A6) were submitted to PHE in June 2018 and subsequently peer reviewed by external academic reviewers unconnected to the project.

Rapid evidence assessments: scope

The full tender specification for the rapid evidence assessments is provided in Annexe A1. Notable components included:

- focussing on local interventions insofar as possible but including relevant national interventions if supported by evidence
- focussing on UK evidence, but including other sources if the interventions they described could be used in the UK

- focussing on the effect of interventions on air pollution and health effects, but also considering associated co-benefits and impacts such as effects on green space and mental health, where possible

Within the scope of the rapid evidence assessments, health economic, financial and social/societal impacts and benefits were to be considered. The list of health outcomes listed in the tender specification was not considered exhaustive. The rapid evidence assessments were limited to critical assessments of available evidence: the primary aim was to focus on collecting and summarising existing evidence in enough detail to inform any more detailed health or health economic evaluations that could be carried out at a later stage.

Rapid evidence assessments: methodology

The reviews were carried out in parallel across all 5 lots. A ‘rapid evidence assessment methodology’ was used for each lot to search and evaluate available evidence, including publications from universities, UK government departments and allied agencies.

Definitions, methods and applications of rapid evidence assessment vary from traditional systematic review methods by utilising more stringent search strategies with stricter eligibility criteria centring around year of publication, search databases, language, and sources beyond electronic searches (48, 49). Rapid reviews involve the same level of rigour employed for a systematic review, but by agreeing sharply focused search parameters and limiting the searches and databases used, the process can be accelerated to deliver robust results within a limited time or resource framework (49).

The contractors searched targeted electronic databases using lot-specific search strings, which included terms for pollutants, interventions and health outcomes. Search strings were developed with input from PHE, the Steering Group and 5 lot-specific technical Advisory Groups. Papers were then screened for adequacy and relevance. Data were extracted using a uniform template, and quality of evidence was assessed. A detailed overview of the methodology used by the contractors for each of the 5 lots to derive the evidence in this report is provided in Annexes A2-A6.

Rapid evidence assessments: expert input

For each of the 5 topic-areas, PHE setup an Advisory Group to provide technical input, chaired by PHE and involving wider external stakeholders such as government departments and subject-matter-expert academics. Recommendations were sought from Steering Group members for external experts. Advisory Group members were consulted regarding the contractors' search strategies, key references, assessment methodologies, and interim and final reports.

The Advisory Groups provided peer input and subject-matter-expert review of the content and process of the rapid evidence assessments. Their terms of reference and membership are described in Annexe A9.

The contractors carried out targeted calls for evidence as part of their rapid evidence assessments. These are described in Annexes A2-A6.

PHE's annual review meeting on outdoor and indoor air pollution was organised in May 2018, at which interventions to improve air quality and health were a focus. PHE also held a stakeholder seminar in May 2018 to inform the PHE report.

PHE report methodology

PHE received the contractors' 5 rapid evidence assessments in mid-June 2018 and carried out 2 pieces of follow-on work between June and July 2018: a modified Delphi stakeholder survey, and further assessments of interventions' potential effectiveness at improving air quality and public health. Each piece of work is described below.

Using a modified Delphi to rank air pollution problems

A modified Delphi process was used to elicit multiple views from a broad range of academics, practitioners, policy-makers, elected members and members of the public regarding the relative importance of different air quality issues. Stakeholders were selected because of being active in the field of air quality, a subject matter expert or wider stakeholders with a relevant role. Members of the public were canvassed via PHE's public involvement team. Prospective Delphi panellists represented a heterogeneous and geographically dispersed group of 1,176 candidates from different disciplines.

The methodology is fully detailed in Annexe A7. Over 2 iterative survey rounds, Delphi panellists rated air quality problems suggested by stakeholders or associated with interventions identified by the 5 rapid evidence assessments. Panellists scored a collated list of air quality problems for each rapid evidence assessment topic area using a 5-point Likert scale: 5 ('extremely important'), 4 ('very important'), 3 ('quite important'), 2 ('somewhat important') or 1 ('unimportant').

Descriptive statistics (median and inter-quartile range) were used to assess consensus of the results, which are described in the results chapters and Annexe A7. Due to the rapid nature of the Delphi study timelines; there was potential selection bias, as it was not possible to collect detailed demographic information from responders to refine invitations or to profile respondents.

Evaluating interventions' public health effectiveness

The rapid evidence assessments summarised existing evidence of past evaluations, which could be used to inform an estimate of the potential *future* benefits these interventions could have for public health if implemented. PHE reviewed this information and undertook an evaluation of the future public health benefits of introducing different interventions to improve air quality (see Annexe A8 for full details). The PHE evaluation considered each intervention's future potential to improve air quality and public health, primarily through impacts on sources (emissions), pathways (the location of pollutants), and receptors (individual and population level exposures). The interventions PHE evaluated were based on the definitions and descriptions of interventions within the rapid evidence assessments. In some cases, closely related interventions were evaluated from different rapid evidence assessments.

A scoring criteria and overall methodology were produced which considered public health air quality outcomes, wider public health co-benefits, and factors related to implementation. Proposals were refined using feedback from stakeholders at PHE's *2018 Air Quality and Public Health Stakeholder Seminar* on 24 May 2018, in London.

The evaluation of intervention effectiveness was subsequently undertaken for each of 5 rapid evidence assessment areas, and considered:

- potential to improve air quality public health outcomes nationally
- potential to improve air quality public health outcomes locally (eg, to address pollution hotspots / single sites)
- potential for health co-benefits
- potential to address or improve health inequalities (eg, if an intervention could benefit particular subgroups, such as vulnerable groups, or specific locations)
- feasibility of implementation
- timescale to benefit (speed of impact): immediate, short or long-term

Interventions were also categorised according to PHE's air pollution intervention hierarchy (refer to Discussion, Figure 19):

Prevention:
Intervention prevents or reduces emissions.

Mitigation:
Intervention reduces environmental concentrations once emissions have occurred.

Avoidance:
Intervention reduces personal or population exposure to environmental pollutants.

Other:
Where the intervention could not be categorised into the 3 categories above or was a combination of the 3 intervention types.

Illustrative examples of the factors considered during the assessment are provided in Table 3 below (and fully detailed in Annexe A8).

Table 3: Examples of factors considered during public health assessment of interventions

Assessment of interventions in terms of potential impact on public health		
Effectiveness	Potential to improve air quality public health outcomes nationally	- impact on respiratory mortality/morbidity, cardiovascular mortality/morbidity, cancer, emerging outcomes - hospital admission and attendance at primary care - disability-adjusted life-years (DALYs), quality-adjusted life-years (QALYs)
	Potential to improve air quality public health outcomes locally (eg, hotspots/ single sites / defined populations)	- impact on respiratory mortality/morbidity, cardiovascular mortality/morbidity, cancer, emerging outcomes, hospital admission and attendance at primary care - disability-adjusted life-years (DALYs), quality-adjusted life-years (QALYs) - Impact on vulnerable groups (eg, elderly, children, those with pre-existing conditions, hospitals, schools, care homes) - Local factors, hotspots (eg, Air Quality Management Areas (AQMAs), Clean Air Zones (CAZs), industrial sites, schools)
Wider public health aspects	Potential for public health co-benefits	- potential impact on obesity, increased physical activity, access to green spaces - encouragement of active travel (eg, cycling, walking) - encouragement of behavioural change - impact on wider health and wellbeing - support of sustainable development or sustainability goals
	Potential impact on improving health inequalities	- potential for a positive or negative impact on geographic distribution of pollutant concentrations and subsequent health inequalities in population exposure - wider potential for health inequality (eg, fuel poverty in population subsets)
Feasibility and timescale to benefit	Feasibility	- ease of implementation, timescale of implementation - replicability (can the intervention be replicated elsewhere) and scalability geographically (national to local, national to regional) - longevity and persistence of the intervention - proven approach (practice vs hypothetical)
	Timescale to benefit	- time to observe public health effect intervention has on its target: immediate or months/years

Five PHE reviewers evaluated each of the 5 rapid evidence assessments' interventions. Annexe A8 details the evaluation guidance provided to reviewers regarding intervention categories, the evaluation process, and consideration of health outcomes. Scoring of each criterion was according to set criteria, as illustrated in Table 4 below.

Table 4: Scoring criteria used when evaluating interventions

Scoring criteria			
Effectiveness scoring: National and local	**Co-benefits and health inequalities scoring**	**Feasibility scoring**	**Timescale to benefit scoring**
No/ little evidence	No/ little evidence	No/ little evidence	No/ little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long-term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (Months to years)
Fully effective	Fully effective	Feasible	Immediate to short-term

Individual scoring, supported by the evaluation guidance, was based on expert opinion, informed by the rapid evidence assessments and the 5 PHE reviewers' personal knowledge. Interventions in which reviewers had strongest views as to interventions' effectiveness were assigned 'limited effectiveness' or 'fully effective', whereas 'potentially effective' interventions were associated with more uncertainty. Evaluation of effectiveness focussed on whether there was evidence that the intervention worked (ie, that it could reduce local or national emissions, concentrations or exposures), and not the relative level of effect, which was typically uncertain or presented using outcome measures that could not be directly compared across interventions.

Following collation of the 5 individual scores for each set of interventions in each rapid evidence assessment, the group of experts were presented with a collation of individual group results, and teleconferences took place to discuss and agree overall final PHE scores. Where reviewers concluded that there was a high degree of uncertainty or insufficient information was available to support an evaluation of effectiveness for an intervention, it was scored 'No/ little evidence'. Reviewers noted that for many interventions there was little evidence available to support a public health evaluation: consequently, it was seen as a general impression of the potential effectiveness that could be used to distinguish interventions that seemed more likely to benefit public health from those that seemed less likely to benefit public health. The evaluations were dynamic, to be updated over time to reflect new and emerging evidence and new evaluations. The results are presented in the results section for each of the 5 rapid evidence assessments and then summarised across all 5 domains.

Matching air pollution problems with available interventions

Using the universal median scores from the second round of the Delphi study previously described, air quality problems suggested by stakeholders or associated with interventions identified by the rapid evidence assessments were categorised as either ‘extremely important’, ‘very important’, ‘quite important’, ‘somewhat important’ or ‘unimportant’ according to stakeholders’ responses.

The evaluation process described above assigned a rating to each intervention for its potential to benefit local air quality and health.

The strength of evidence associated with each intervention was identified in the corresponding rapid evidence assessment[4]. For the rapid evidence assessments related to planning, vehicle/fuel, agriculture and behavioural interventions the uncertainty range, which considers the number and quality of studies on each intervention and the consistency of the study results, was used to represent the strength of evidence.

For each of the rapid evidence assessment areas, the compiled list of air quality problems was used to diagrammatically match each individual problem to a related intervention (or interventions), with the connecting line indicating the strength of evidence. The diagrams presented the Delphi importance rating of each problem and the PHE evaluation score of each intervention’s potential benefit to local air quality and health. *Local* effectiveness was chosen as the evaluation category outcome most relevant to the scope of PHE’s evidence review and to local decision-makers.

External peer review

The contractors’ rapid evidence assessments and the final PHE report underwent external peer review. Peer reviewing of the final evidence assessments was co-ordinated by PHE’s research department and involved 2 to 4 anonymous peer

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[4] For the industrial rapid evidence assessment, strength of evidence was termed as such within the report (Annexe 2). For the other 4 rapid evidence assessments (Annexes 3-6: planning, vehicle/fuel, agriculture, and behavioural / social science interventions) it was defined as the ‘uncertainty range’ (based on the number and quality of studies related to each intervention and the consistency of the study results)

reviewers per evidence review, with desk-based reviews carried out over a period of 2 to 3 weeks.

The processes were approved by Steering Group members and are described, together with their outcomes, in Annexes A2-A6 (rapid evidence assessments and peer reviews) and Appendix A9 (PHE report peer review).

Results: Vehicle/fuel interventions

Key messages

This chapter discusses the effectiveness of 7 categories of interventions to reduce harm from transport-related air pollution, based on the rapid evidence assessment (Annexe A4.1). The main points are summarised as follows:

- air quality within urban areas is likely to be improved by any intervention that promotes the uptake of low and zero-exhaust emission vehicles, particularly electric vehicles. There is a lack of evidence of the generation and health impact of non-exhaust particulate matter (PM) emissions, which remain a potential issue
- the effectiveness of Low Emission Zones (LEZs) can be improved if combined with the newer emission standards of road vehicles (Euro 6)
- traffic management interventions, such as road pricing and access restrictions, have the potential to improve air quality and encourage the public to consider travel behaviour change and active travel options
- active travel interventions at a limited scale do not generally improve air quality significantly, but the added physical exercise benefit makes them very effective transport interventions for improving public health outcomes
- in general, road transport interventions need to be combined to achieve a greater impact, as most existing measures on their own may only generate a small reduction in road vehicle emissions
- in the aviation sector effective actions identified include the electrification of Ground Support Equipment, reduction in Auxiliary Power Units, pushback control, take-off thrust reduction and alternative aviation jet fuels
- in the maritime sector, few evaluated interventions were identified but regulation of the sulphur content in marine fuels can lead to sulphur dioxide (SO_2) emission reduction, and fuel-based interventions have the potential to reduce other pollutants
- in the rail sector, the introduction of bi-mode trains (ie diesel/electric hybrid) and the electrification of the fleet would be effective measures at reducing emissions, but cost and operational limitations are potential barriers to electrification of the rail network

Research questions

What evidence is there for vehicle design and fuel interventions, which reduce harm from air pollution?

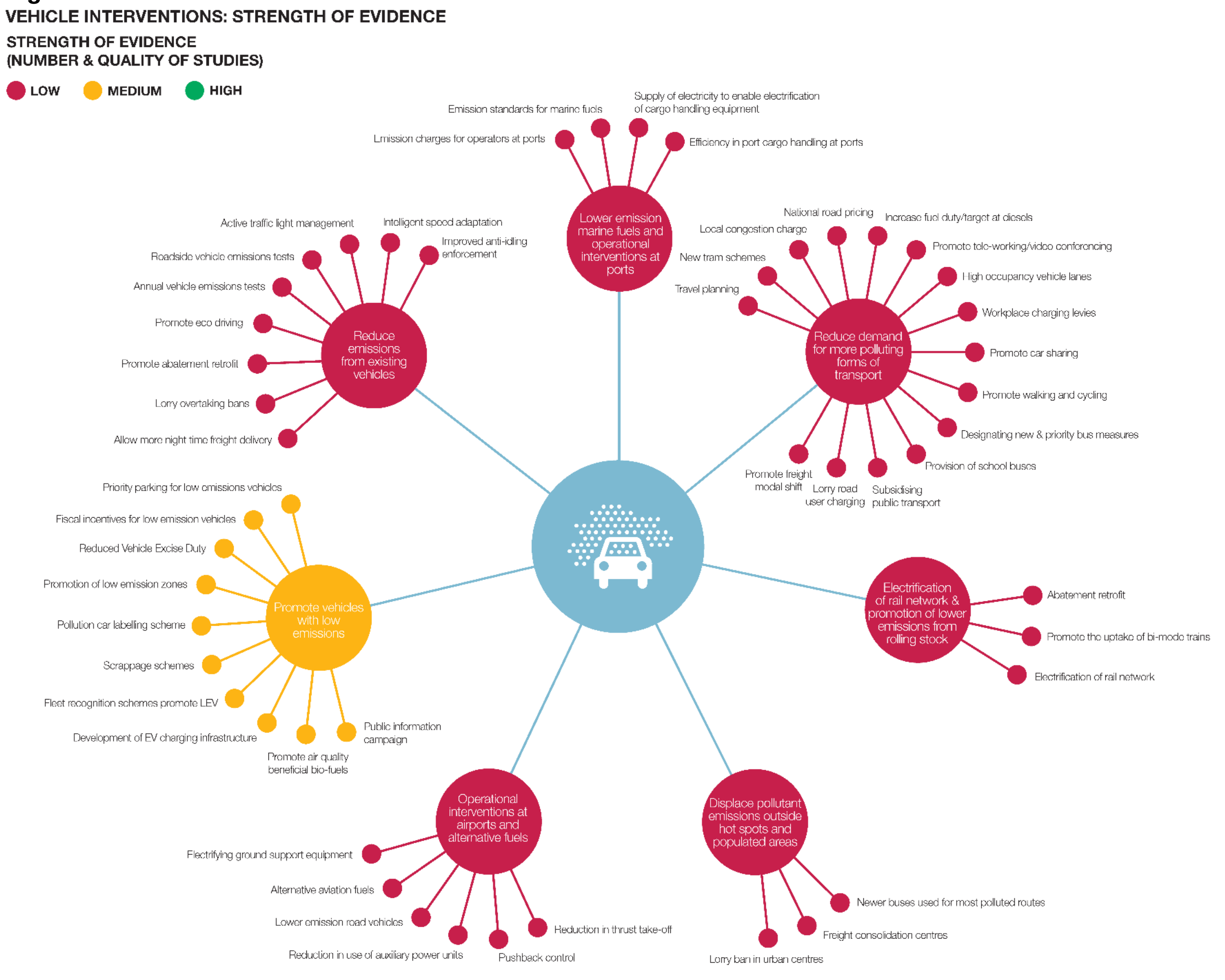
The vehicle/fuel interventions identified in the rapid evidence assessment were categorised in themes, as summarised in Table 5 and Figure 4. Many of these interventions considered under these themes may not be primarily focused at reducing air pollution, such as traffic management interventions and actions for reducing road traffic collisions, but will have an impact on air quality.

Table 5: Vehicle/fuel interventions

Key intervention types	Type of Intervention	Sub-intervention
Road transport 1: reduce demand for more polluting forms of transport	Prevention	Promote freight modal shift
		Lorry road user charging
		Subsidising public transport
		Provision of school buses
		Designating new and priority bus measures
		Promote walking and cycling
		Promote car sharing
		Workplace charging levies
		High-occupancy vehicle lanes
		National road pricing
		Local congestion charging
		Promote tele-working/video conferencing
		Increase fuel duty/target at diesels
		New tram schemes
		Travel planning
Road transport 2: reduce emissions from existing vehicles	Prevention / Mitigation	Allow more night time freight delivery
		Lorry overtaking bans
		Promote abatement retrofit
		Promote eco driving
		Annual vehicle emissions tests
		Roadside vehicle emissions tests
		Designating new and priority bus measures
		Active traffic light management
		Intelligent speed adaptation
		Improved anti-idling enforcement
Road transport 3: promote	Prevention	Scrappage schemes

Key intervention types	Type of Intervention	Sub-intervention
vehicles with low emissions		Fleet recognition schemes that promote low emission vehicles
		Reduced Vehicle Excise Duty for early purchase of new vehicles
		Promotion of low emission zones
		Priority parking for low emissions vehicles
		Pollution car labelling scheme
		Fiscal incentives for low emission vehicles
		Development of electric vehicle charging infrastructure
		Promote air quality beneficial bio-fuels
		Public information campaign to promote cleaner vehicles
Road transport 4: displace pollutant sources outside hotspots and populated areas	Mitigation / Prevention	Lorry ban in urban centres
		Freight consolidation centres
		Newer buses used for most polluted routes
Aviation: operational interventions at airports and alternative fuels	Prevention	Electrifying ground support equipment
		Reduction in thrust take-off
		Pushback control
		Reduction in use of auxiliary power units
		Lower emission road vehicles
		Alternative aviation fuels
Maritime sector: lower emission marine fuels and operational interventions at ports	Prevention	Emission standards for marine fuels
		Emission charges for operators at ports
		Supply of electricity to enable electrification of cargo handling equipment
		Efficiency in port cargo handling at ports
Rail sector: electrification of the rail network and promotion of lower emissions from rolling stock	Prevention	Electrification of rail network
		Promote the uptake of bi-mode trains
		Abatement retrofit

Figure 4. Vehicle/fuel interventions



Identify and prioritise implementable interventions or groups of interventions related to vehicle design and fuel technology etc.

For road transport, interventions that aim to reduce the use of polluting forms of transport, such as road pricing (ie, increasing the cost of polluting vehicles via tax or fuel tariffs) and low emission zones, may improve health through better air quality. Price increases may cause the public to consider travel behaviour change; this has a higher effectiveness in larger cities where alternative lower emission travel modes such as public transport and active travel options are more prevalent.

Active travel interventions, such as promoting walking and cycling, on a small scale do not generally improve air quality significantly. However, the added physical exercise, noise reduction, climate change mitigation, road safety and community cohesion benefits make these efficient transport interventions to improve public health and make urban environments more sustainable.

The interventions that promote the uptake of low emission vehicles, such as electric vehicles, scrappage schemes and promotion of beneficial biofuels, have the potential to improve air quality. In particular, the increase in electric vehicles has shown a high impact on emission reduction of PM, SO_2, oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and carbon monoxide (CO). It is also clear from the evidence that vehicle regulation standards based on Euro 6 have shown significant emission reductions of NO_x compared to previous Euro standards. Selective Catalytic Reduction abatement technology is helping to achieve these standards. Alternative fuels, such as biofuels, bring reductions in PM emissions compared to conventional diesel and are regularly used in blends of petrol and diesel.

Synthetic/paraffinic fuels are reported to have low NO_x, PM, CO and hydrocarbon carbon emissions. Interventions that aim at reducing emissions from existing vehicles, such as the promotion of eco-driving (also identified as a behavioural intervention) and anti-idling enforcement, were deemed to have low costs of implementation. However, their overall effectiveness at improving air quality was found to be low, though clearly they are an important part of the package of interventions.

Interventions aiming to reduce emissions over the short term, for example during an episodic event of high pollution, help raise public awareness of air pollution, but drastic emission reductions are needed to achieve measurable effects on ambient air concentrations. The effectiveness of such approaches in the longer term remains unproven. This supports the importance of designing and applying permanent abatement interventions.

In the aviation sector, electrifying Ground Support Equipment, reduction in thrust take-off, pushback control and reduction in use of Auxiliary Power Units and/or use of desulphurising jet fuel can reduce emissions at airports, as well as interventions that reduce emissions from road vehicles, both airside and landside, and interventions that consider alternative aviation fuels. The government published a consultation on a new aviation strategy, Aviation 2050, on 17 December 2018, which considers air pollutant emissions from flight and non-flight sources associated with airport operations and passanger travel (50).

In the maritime sector, the regulation of the sulphur content in marine fuels led to a reduction in ambient SO_2 at a European large port. Discussion of other possible interventions can be found in Annexe A4.1. The UK government will publish guidelines to advise all major ports in England on how to develop effective and targeted Air Quality Strategies by spring 2019.

In the rail sector, the electrification of the fleet or the introduction of bi-mode trains, ie diesel/electric hybrid would be effective measures at reducing emissions, but cost and operational limitations are potential barriers to electrification of the rail network. The Clean Air Strategy sets out a requirement for the rail industry to produce a road map to phase out diesel-only trains by 2040.

How are these interventions implemented?

Use of taxation is one of the most cost-effective measures and typically straightforward as it is implemented within an existing system. The literature is clear that any pricing mechanism scheme, whether it is a national tax duty or local road toll, should be designed with care as the unintended social inequality impacts of increased cost of transport affects the most deprived in society (51).

Scrappage actions have most impact when combined with appropriate taxation/incentives mechanisms that encourage the uptake of alternative fuel or smaller-capacity vehicles (downsizing).

Development of effective charging infrastructures is required for promoting the increase of electric vehicles. The use of alternative fuels would also require significant investment in recharging/refuelling infrastructure by individuals, businesses and developers, as well as grants and subsidies from local authorities and government.

Some public transport is currently subsidised for example, free bus travel is offered to all people over the age of 60 years in England; however, many public transport routes to rural communities have been reduced (52). In addition, the rapid evidence assessment highlighted that the de-regulated bus market creates difficulties in investing in cleaner buses due to state-aid rules and the need to operate in a competitive market. The Bus *Service Operators Grant* refunds a proportion of fuel duty incurred by operators of registered local bus services in the UK, based on their annual fuel consumption and creates a low-emission dis-incentive by rewarding higher fuel consumption.

Promote walking and cycling: Uptake is low in many UK cities, but many initiatives are on-going to promote uptake, such as bike hire schemes in London (53). In September 2018, the government announced £2 million in funding to support the uptake of e-bikes. Barriers to implementation include limited dedicated cycle lanes, road safety and weather conditions.

Promote eco driving: Training is often limited to the transport delivery and freight sector. There is also a requirement to frequently provide refresher training to drivers to maintain fuel efficiency savings.

Improved anti-idling enforcement: Local authorities can implement no-idling zones in areas with vulnerable population (for example, schools, hospitals, care homes). A novel regenerative auxiliary power system is available on freight vehicles, which does not require the engine to run for temperature control of the refrigeration units.

Aviation: A significant reduction in airport emissions could be achieved through electrification of ground support equipment, although this does not take into account potential additional emissions from increased electricity generation using fossil fuel technologies. The Clean Air Strategy sets out plans for reducing air pollution from aviation.

Maritime: A significant reduction in SO_2 could be attributed to a number of interventions including the use of lower sulphur content in marine fuels, and enforcement of emission control area regulations (as demonstrated at the port of Rotterdam (54)). By spring 2019, the government will consult on options for extending the current Emissions Control Areas (ECAs) in UK waters.

Rail: Extend the operation in electric compared to diesel mode trains. The Clean Air Strategy sets out a requirement for the rail industry to produce a road map to phase out diesel-only trains by 2040.

Based on the evidence, how effective are these interventions in reducing air pollution source emissions/environmental concentrations/exposure and affecting health outcomes? What is the strength of evidence regarding effects?

Evidence on the effectiveness of vehicle/fuel interventions to improve air quality and reduce harm from air pollution is limited. However, packaging a number of interventions together is considered to have potential to reduce emissions and improve health.

The effectiveness of LEZs has been investigated; LEZs have tended to focus on reduction of PM_{10} emissions and many LEZs were established before 2010 across Europe. In the Netherlands, traffic flows and the air pollution at street level before and after implementation of LEZs targeted at heavy goods vehicles (HGVs) were measured. It was found that, on average, daily traffic flows in the LEZs reduced by 9.8% 2 years after implementation, resulting in a 6.2% reduction in NO_2 concentrations (55).

The effectiveness of LEZs across 5 member states in Europe (Denmark, Germany, Netherlands, Italy and UK) was reviewed and mixed results were reported. In German cities, reductions in annual mean PM_{10} and NO_2 concentrations (up to 7% and 4% respectively) due to the implementation of a LEZ were reported, whereas in other countries no effects were generally observed. This may be explained by the German LEZs restricting passenger cars, particularly diesel cars as well as heavy duty vehicles (56).

Levels of restriction in LEZs was compared with cities without LEZs in Germany; the decrease in urban PM_{10} levels found could be attributed to the introduction of LEZs. It was also found that more stringent stage 2 zones showed a threefold reduction in PM_{10} concentrations compared to stage 1 zones (57).

In Lisbon, Portugal, a LEZ has been implemented in different phases, progressively expanding its area, including more vehicle types, and adopting more stringent requirements in terms of minimum emission standards required to access the LEZ. In particular, phase 1 began in 2011, where circulation of pre-Euro vehicles in zone 1 (at the Marques of Pombal/Terreiro do Paço axis) was banned on weekdays between 08:00 and 20:00. Phase 2 began almost a year afterwards, encompassing a much broader area of about one-third of the city of Lisbon where circulation of pre-Euro vehicles was banned, while in zone 1 the minimum standard was increased to Euro 2 and the operative hours of the LEZ were extended (weekdays from 07:00 to 21:00).

The analysis of air quality data before and after phase 2 showed a positive impact on air quality improvement compared to the period between 2011 (before measures) and 2013 (after measures) (58). In 2013, there was a reduction in PM_{10} annual average concentration of 23% and NO_2 annual average concentrations of 12%, compared with the year 2011. Although PM_{10} reductions were more significant inside the LEZ area, the same was not true for NO_2, suggesting that the implementation of these measures was not as effective in reducing NO_2 levels. The results from road traffic characterization indicate a relevant effect on fleet renewal, with an overall decrease in the relative weight of pre-Euro 2 vehicles in 2012/2013, compared with data from 2011. An important increase in the share of Euro 4 and Euro 5 vehicles was also observed. The main conclusion of the study was that stricter restriction standards should be enforced in the future stages of the Lisbon LEZ in conjunction with greater effort and investment in LEZ enforcement to achieve further improvement in air quality (58).

In London, the introduction of the LEZ in 2008, which banned the most polluting diesel HGVs and light goods vehicles, may have contributed to the general reduction in NO_X and NO_2 across London, along with the general decrease in total vehicles since 2010 and the retrofitting of Euro 3 buses with selective catalytic reduction abatement technology (59). Also in October 2008, Euro 5 was introduced for HGVs, which tightened NO_X emissions by 42% compared to Euro 4 standards.

The effectiveness of electric vehicles was assessed (60), in this case to include the following types of electric vehicles: Hybrid (HEV), Plug-in Hybrid (PHEV), Battery (BEV) and Fuel Cell (FCEV). The 65 studies reviewed consistently showed reductions in greenhouse gas emissions and emissions of some criteria pollutants, particularly PM and SO_2, although the increases or decreases were very dependent on the context. The Requia et al (60) study cites several examples to demonstrate that the energy grid and location of emissions (on road or power plant) are key aspects in the consideration of impact of EV technology on air quality. In the US grid market, which has a high proportion of coal power generation, a higher life cycle PM emission from PHEVs and some BEVs compared to HEVs was demonstrated (61). The impacts of electric vehicles in 8 countries were reviewed and an increase in SO_2 was found due to increased electricity generation from coal fired plants (62). In the UK, where the energy generation sector does not heavily rely on coal power plants, this is less of a concern, but many commentators have queried the energy supply chain, suggesting a needed policy focus on an increased supply to meet the demand from electrification of the transport sector. There is a lack of evidence of the generation and health impact of non-exhaust emissions and this remains a potential issue. Although there is some evidence that brake wear emissions from EVs can be lower than internal combustion vehicles, as 95% of braking is provided by regenerative braking (reducing brake wear emissions by 25% relative to conventional vehicles (63)), the use of regen braking in practice and variability of vehicle and driving scenarios require further investigation. The government is committed to building and using evidence to inform the development of policies to reduce non-exhaust emissions, and published a call for evidence on tyre and brake wear, which closed in September 2018.

Of the gaseous pollutants, electric vehicles were linked to potentially large reductions of NO_x, VOC and CO concentrations, although many of these studies were based on predictive modelling (64, 65). Modest decreases in ambient ozone (O_3) concentrations have been associated with electric vehicle uptake, although this is mixed depending on spatial variability and atmospheric conditions (66, 67). Electrification of vehicles and off-road equipment across the USA was associated with reductions in O_3 concentrations by 1 ppb and $PM_{2.5}$ by 0.5 µg/m^3 when 17% of light duty, 8% of heavy duty vehicles and 79% of off-road vehicles were electrified (60). Overall, the benefits of electric vehicles for reducing air pollutants depends on the following factors: (i) type of electric vehicles, (ii) source of energy generation, (iii) driving conditions, (iv) charging patterns, (v) availability of charging infrastructure, (vi) government policies and (vii) climate of regions.

Very effective interventions for enhancing public health were road pricing measures, particularly in the case of low and integrated fares (for more than one public transport mode) which facilitate greater public transport use and help reduce social exclusion, and congestion and parking charges, which can help reduce car use (68). A study focusing on the Republic of Ireland highlighted that increases in car taxation to drive decarbonisation of fleets reduced NO_x emissions (69). In Australia, higher diesel prices were associated with statistically significant short-term reductions in NO_x (up to 30%) and CO (up to 70%) (70). The scale of the public health impacts was not quantified due to the current small evidence base.

The most recently introduced Euro 6 standards aim to make all diesel vehicles, and particularly HGVs, emit lower NO_x. Under real-world operating conditions, current diesel vehicles emit far more NO_x than during laboratory certification testing; however, Anenber et al showed that adopting and enforcing next-generation standards (more stringent than Euro 6) could potentially eliminate real-world diesel related NO_x emissions (71). Most of these emission reductions leading to public health benefits can be achieved by implementing Euro 4 standards where they have not yet been adopted for HGVs. Diesel-powered engines are used in the vast majority of the world's heavy-duty trucks, buses and off-road vehicles. They are easy to repair, extremely durable and estimated to last 15-20 years and achieve a 1 million mile life or more (72). Emission retrofit abatement, although potentially costly, is, therefore, an important intervention for existing vehicles of this type.

The effectiveness of using alternative fuels, such as Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Liquid Petroleum Gas (LPG), biofuels and synthetic/paraffinic fuels in reducing emissions has been investigated. Worldwide the environmental benefits of CNG vehicle technologies is well established, as they result in low PM emissions and many studies have shown significant reductions in NO_x (73, 74). An environmental issue has been methane slippage, but with more stringent emission controls, CNG vehicles are now fitted with appropriate methane clean-up catalysts to oxidise hydrocarbons. LPG is particularly clean-burning and produces low PM; LPG cars produce 50% fewer nitrogen oxides than petrol, and 20 times fewer than diesel (75).

Biofuels, which include bioethanol, biodiesel and biogas, can have an impact on reducing PM emissions. Petrol and diesel sold in the UK already contain biofuels; E5 petrol can contain up to 5% of ethanol and B7 diesel can contain up to 7% of biodiesel (driven by the UK's Renewable Transport Fuel Obligation – RTFO) (72).

Synthetic/paraffinic fuels are free of unwanted components such as sulphur, metals and VOCs and can reduce air pollutants when used in a standard diesel engine. Gas-to-Liquid (GTL) from a specific manufacturer was tested as a drop-in fuel for existing and for new commercial diesel vehicles, inland ships and non-road mobile machinery and showed a reduction in all regulated pollutant emissions (NOx, PM, CO and VOCs) compared to regular diesel (EN590) (76). For relatively simple systems such as Euro 3 engines, measurements showed NOx reductions in the range of 5% to 19% and PM reductions in the range of 10 – 34%. For engines with more advanced emission control systems, the relative variations in NOx and PM can be larger; for Euro 5 SCR engines, measurements showed NOx reductions in the range of 5% to 37% and PM reductions up to 33%, depending on engine type and test cycle (no information was presented for Euro 6 engines).

An evidence assessment of short-term action plans (77) (measures taken to reduce the risk of exceedance of pollutant levels or the duration of the exceedance) concluded that there is little or no evidence that such measures will be effective in reducing the intensity, extent or duration of pollution events. A recent study evaluated the effectiveness of a short-term action plan, which included 4 action stages dependent on the pollutant concentration levels for Madrid (78): the study concluded that drastic emission reductions are needed to achieve measurable effects on ambient air concentrations. This supports the importance of designing and applying permanent interventions rather than relying on time-limited measures. The average daily pollution levels in Mexico during 1986–2005 showed no apparent improvement after the introduction of an access restriction programme, which led to an increase in total numbers of vehicles and an increase in high emission vehicles (79).

A more recent analysis of behavioural response to such an intervention concluded the unintended consequence of most households changing their travel behaviour from restricted days to unrestricted days, which was less costly than the purchase of a second car (80). A similar behaviour change response to road access restriction based on the licence plate last digits was reported for Lanzhou, a polluted city in China (81). A driving restriction on certain days, based on last digits of licence plates, had the potential to significantly *increase* NO_2, NO_x and O_3 concentrations from empirical evidence from Bogota, Colombia (82). In addition, a similar licence plate circulatory restriction had limitations in Sao Paulo due to the fore-mentioned behavioural responses, and there was no quantified evidence of its impact (83). In Paris, city authorities introduced a similar intervention in 2015, due to episodic events in 2014. However, this was accompanied by a package of interventions based on purchasing hybrid and EVs, increasing pedestrianisation, bicycle and EV sharing schemes and financial incentives to encourage use. Despite this wider set of measures, these were insufficient to improve air quality as they were not developed at the federal level, and, most importantly, the package of measures did not include fleet renewal (81). No significant effect of an odd-even licence plate access restriction was found in Delhi on $PM_{2.5}$ concentrations (84).

In general, although these short-term interventions during episodes of elevated pollution help raise public awareness of air pollution, there is little quantitative evidence of their impact on air quality or cost-effectiveness. Driving restrictions for reasons other than elevated air pollution, such as during sporting events, are considered in the planning chapter.

An impact assessment of UK aviation on air quality and health estimated that up to 65% of the health impacts of UK airports could be mitigated by desulphurising jet fuel, electrifying ground supply equipment, avoiding use of auxiliary power units and use of single engine taxiing (85). Similar interventions were assessed for southern Californian airports (86), where it was estimated that reducing taxi-out time, electrifying ground supply equipment and use of alternative aviation fuels (aviation biofuels from the AAFEX study by Moore et al (87)) reduced the aviation-attributable population weighted ground level $PM_{2.5}$ by 36% in summer and 32% in winter. A study of over 3,000 flights from London Heathrow showed that reduced thrust can reduce NO_x by 11-48% and black carbon by 49-71%, depending on aircraft-engine combinations relative to 100% thrust take-off (88). A reduced (75%) thrust take-off resulted in a reduction in $PM_{2.5}$ emissions of 18% relative to 100% thrust take-off at Detroit airport (89). Optimizing gate hold by implementing pushback control can reduce $PM_{2.5}$ by 36% and O_3 by 35% relative to no control. The replacement of conventional (oil-kerosene) Jet A1/8 fuel with alternative synthetic and biomass derived fuels: Synthetic Paraffinic Kerosene (SPK) and LH_2 (Liquid Hydrogen) was found to be beneficial for air quality (90, 91). SPK fuels have substantially lower NO_x emission (by 11-22%) PMs (by 97.5-99.9%), and NMHCs (by 18-25%) than convention Jet A1/8 fuels, and they are free from sulphur.

In the maritime sector, there was little evidence of the effectiveness of interventions to reduce emissions. The most robust study was an ex-post evaluation of interventions in Rotterdam that found that SO_2 concentrations decreased rapidly from 2007 to 2010, which was attributed to changes in emission from refineries, sea shipping in the North Sea, nearby inland shipping and within port emissions (54). The reduction in sea shipping emissions resulted from the use of fuel with low sulphur content due to the sulphur emission control area regulations in the North Sea.

Health outcomes

Air quality has been considered in the literature as one of the assessment criteria for interventions, among other criteria such as noise, heat and access to green space (92-94). In the Mueller et al study, annual preventable morbidity and disability adjusted life years (DALYs) were estimated for Barcelona under compliance with exposure recommendations; exposures over the recommended levels resulted in an estimated loss of 52,000 DALYs each year in Barcelona (13% of all annual DALYs) and non-compliance was estimated to result in direct health costs of 20m Euros. The authors identified that a reduction in motor traffic with the promotion of active transport and the provision of green infrastructure would result in a considerable reduction in the burden of disease and substantial savings to the health care system, but none of these were quantified.

The effectiveness of active transport interventions on health has been assessed in the literature (92, 95, 96). Almost all studies reported positive results linked to increasing physical activity and active travel. In Brown et al study, the health benefits of increased physical activity included positive impacts on health outcomes such as obesity, coronary heart disease, stroke, cancer, diabetes and dementia. However, there appears to be a significant degree of uncertainty regarding the effectiveness and impact of these interventions linked to the reduction of air pollution, and this is reflected in the wider variety of economic assessments (for example, cost benefit and cost-effectiveness assessments). In addition, the quality of these assessments was not always adequate, and the descriptions of intervention characteristics were incomplete.

Health inequalities

The promotion of EVs can be associated with social inequality, as most private EV owners in the UK are currently affluent, live in urban areas with households containing 2 or more cars, and have the ability to charge their cars at home (97). Based on insights from more developed EV markets, the basic socio-demographic profile of EV owners in the UK is not likely to change significantly. The health effects associated with electric mobility in USA or China, where the electricity generation sector is quite different to the UK, were investigated (60). In the USA and China, population exposure to air pollution was considered lower with increasing EV penetration, as the majority of the population resides in urban centres subject to vehicle traffic. But there is an environmental justice issue with this intervention, as air pollution was thought to increase in more rural areas in the vicinity of coal-fired power stations, where exposure to air pollutants would rise (98, 99). Evidence is needed from other international regions, especially from the UK, as there is a significant spatial variation regarding potential EV impacts and benefits to air quality and public health when energy generation is also considered. The use of non-polluting energy sources has the potential to mitigate this risk.

The introduction of any transport pricing action may have social inequality consequences, if the more deprived in society are equally targeted. Some studies have shown taxation is a socially inequitable solution to manage emissions, with those in socially deprived or rural areas particularly disadvantaged by the increased cost of transport.

Interventions such as regulatory restrictions, low emission zones, parking controls, new rail services, and freight bans may increase inequalities if not properly designed (68). Unintended consequences resulting from schemes such as LEZs and road tolls include pollutant emission displacement where drivers use alternative routes to avoid tolls. On the other hand, interventions such as bus and public transport services, bus priorities, and concessionary fares may decrease inequalities. In addition, community severance can result from infrastructure policies (particularly new road and rail lines) and from heavy traffic. Conversely, community severance can be reduced if heavy traffic flows are reduced, which can result from some traffic reduction policies, such as access restrictions and road pricing.

There is a more extensive evidence base on the accessibility of transport interventions for different socio-economic and community groups, and on the impact of such measures on health inequalities. However, these studies do not typically associate such interventions with changes in air quality. While this is a limitation in the context of this report, it does demonstrate that research focussed on air quality interventions and inequality in the field of transportation is feasible and should be recommended.

What is the cost, and how cost-effective are these interventions? What is the strength of evidence regarding effects?

In the UK, the design of the transport appraisal process (webTAG) (100) is underpinned by HMT Green Book principles, which advocates the use of cost-benefit (welfare) analysis to determine value for money. Welfare analysis is used as it captures a broad range of impacts, such as economic, environmental and social. A broad range of options is considered in the early stages; these are then sifted against a set of criteria to a shortlist of preferred options, which then undergoes comprehensive evaluation. However, while this intervention appraisal process is used extensively, there have been few appraisals of interventions primarily aimed at improving air quality. It tends to be used in schemes that are typically designed to improve traffic management and reduce congestion.

The economic impacts of interventions encompassed in a clean air plan for the Lausanne-Morges area of Switzerland were estimated (101). The plan included measures to reduce air pollution in different sectors, such as transport, energy, and industry, and resulted in a decrease in PM_{10} and NO_2 exposures. Monetised health impacts of the reduction of PM_{10} exposure were valued at approximately CHF 36 million annually (equivalent to £28 million). Immaterial costs, mainly related to the economic valuation of years of life lost, dominated the monetised health impacts (90% of total value), while savings at the workplace (net loss in production and re-occupation costs) amounted to about CHF 1.9 million (equivalent to £ 1.5 million), and savings in health care costs to about CHF 0.5 million (equivalent to £0.4 million).

The economic impacts from walking and cycling can be quantified using a newly developed model from Sustrans (102). This is based on Defra's damage costs (103) and includes the impact of emissions avoided due to reduced car journeys and impacts due to changes in pollution exposure across the cycle/walking routes.

Other studies provide evidence that the most cost-effective single intervention is road pricing. This was evidenced in both Europe and the USA. A cost-benefit analysis of the 'Ecopass' road pricing access restriction in Milan, Italy showed that this measure has been effective in curbing not only pollution emissions, but also congestion (104). The cost-benefit-analysis presented an overall net benefit, as the implementation costs for the scheme were low. A cost-effectiveness study of interventions to reduce congestion and simultaneously improve air quality was undertaken for the Phoenix and Tucson areas, USA, comprising approximately 60 million and 15 million miles of road per weekday, respectively. A comparison of interventions found that the most cost-effective intervention was congestion pricing, followed by various bus interventions, including an improved bus service and increase in CNG buses. Parking management (involves reducing or removing the free parking for employees on-site) was also found to be cost-effective at reducing trips to work (105).

A method to value health impacts resulting from exposure to poor air quality was applied to 1 intervention being considered within the West Yorkshire Low Emission Zone feasibility study (106). Estimates of pre-Euro 4 buses and HGVs being upgraded to Euro 6 by 2016 generated an annual benefit of £2.08 million and a one-off benefit of £3.3 million for the National Health Service (NHS)/Personal Social Services (PSS) in the West Yorkshire region, compared with a net present value cost of implementation of £6.3 million.

In the maritime sector, port authorities in the UK are investigating infrastructure to supply electricity to ships at berth (Policy Exchange, 2016) and to support off-road vehicle movements on the dock. LNG fuel meets all International Maritime Organisation (IMO) emission standards and could be significantly cheaper than Heavy Fuel Oil. However, as the cost of retrofitting a vessel with LNG is very large, it is more likely to be seen as an alternative fuel for new ships. It has been noted that investment in purpose-built infrastructure to support refuelling ships, and regulations for the handling of LNG, will be required (107). The UK government has introduced a new government-led Clean Maritime Council to bring together different parts of the maritime sector to drive uptake of cleaner technologies and greener fuels.

What interventions are under development, and what is their potential impact?"

The UK government's 'Road to Zero Strategy' (108), states that £1.5 billion will be invested in ultra-low emission vehicles by 2020. The measures will include:

- installation of charge points in newly built homes, and inclusion of charging points in new lampposts
- launch of a Charging Infrastructure Investment Fund that will fund new and existing companies that produce and install charge points
- development of a low-cost wireless and on-street charging technology
- funding the installation of charge points at home for EV owners and workplace extension of grants that will allow consumers to make significant savings when purchasing a new electric vehicle
- the launch of an Electric Vehicle Energy Taskforce to bring together the energy and automotive industries to plan for the increase in demand on energy infrastructure that will result from a rise in the use of electric vehicles

Freight access restrictions are commonplace in urban areas of the UK, particularly in main retail streets in town and city centres, which are often pedestrianised.
Euro 6 standards are expected to significantly reduce real-world diesel-related NO_x emissions from the transport sector; however, they have not yet been adopted for HGVs.

CNG has been adopted as a transport fuel in various countries. The potential methane slippage (leakage of unburned methane emitted from the vehicle) associated with this fuel arises principally because the dual-fuel vehicles currently in use are from after-market adaptations of originally diesel-only vehicles, rather than of new engine manufacture design. Now, with more stringent emissions control legislation, virtually all the CNG fleet being manufactured use solely CNG fuel, with fuelling carefully controlled and vehicles fitted with appropriate methane clean-up catalysts to oxidise hydrocarbons.

LPG remains a niche transport fuel, with only about 43,000 LPG cars on the road in Great Britain (0.1% of the total fleet) and 10,000 LPG vans (0.3% of the fleet). Most petrol cars can be fitted with an LPG conversion, turning them into 'dual-fuel cars' that can run on LPG as well as petrol. However, in the UK there is a lack of incentives to encourage this, for example, through vehicle excise duty. In mainland Europe, LPG is far more common, with 46,436 filling stations and 8 million LPG vehicles across Europe as a whole, representing about 3% of the car fleet (109).

In terms of biofuels, the UK is looking to introduce E10 (10% bioethanol blended with petrol) in the near future. It is estimated that in 2015 more than 92% of petrol cars were suitable to use E10 petrol (110). The Defra Air Quality Expert Group considered the impact on air quality of road transport biofuels and concluded that the evidence suggests the increased use of bioethanol by replacing E5 with E10 petrol will have no change in NO_x emissions but would lead to a reduction in the other regulated pollutant emissions including CO, HC, and PM. The Air Quality Expert Group also concluded that the reductions in emissions might be more apparent for older vehicles.

In the aviation sector, the electrification of ground supply electrification, a reduction in auxiliary power units, pushback control and take-off thrust reduction are considered as effective operational practices. However, it is not clear from the evidence to what extent these practices are already in day-to-day operation at UK airports, and it is most likely that their use is affected by many other airport operational issues, including the aircraft movement schedule, meteorological and safety conditions. Emission contributions from transport to airports, which include passenger, employee and fleet operator vehicles, are also important. The government published a consultation on a new aviation strategy, Aviation 2050, on 17 December 2018, which considers air pollutant emissions from flight and non-flight sources associated with airport operations and passanger travel (50). Many airports are working on encouraging cleaner vehicles, for example, Clean Vehicle Partnership at Heathrow airport. Alternative aviation jet fuels, such as synthetic paraffinic kerosene, aim to reduce emissions, but it is not clear from the literature what the uptake levels are. Liquid Hydrogen (LH_2) is at the research and conceptual stage for the industry: research projects on aircraft design to use LH_2 are underway, with cryogenic aircraft expected to be fully developed by 2020 and enter commercial service by around 2040.

In April 2018, the International Maritime Organization (IMO) agreed an Initial IMO Strategy to reduce greenhouse gas emissions from international shipping by at least 50% by 2050 (111). In the maritime sector, LNG will not be available at scale by 2020, due to the high cost of retrofitting vessels, a lack of infrastructure to support refuelling ships and lack of regulations on handling LNG.

In the rail sector, industry's Long-Term Passenger Rolling Stock Strategy (112) states that pure electric vehicles now comprise 72% of the national fleet, but their use is limited due to the partial electrification of the national rail network. Interest in vehicles of other traction types including bi-mode trains is rising rapidly. Bi-mode trains are capable of operating using more than 1 source of power. Currently, all 1,030 bi-mode trains operating in the UK have diesel generators as their on-board power source, but they have drawbacks in terms of less power when in diesel mode, increased weight, increased complexity and maintenance and they are less environmentally sustainable.

Of the current diesel rail fleet in the UK, none has an engine that is compliant with EU legislation Stage IIIB emissions limits for diesel engines for new rail vehicles. Existing EU and UK legislation does not prevent the continued operation of any of the present vehicles due to an amendment agreed in 2011. The rail strategy states it is unlikely that a business case can be made at present to retrofit a Stage IIIB compliant diesel engine to any of the existing British diesel-powered passenger vehicles. The UK government announced on 12 October 2017 that around £47.9 billion is expected to be spent on the railway during 2019-2024; this spend covers England and Wales and includes electrification, as well as station upgrades (113). The UK government is committed to cutting air pollution from all forms of transport and has asked the rail industry by spring

2019 to produce recommendations and a route map to phase out diesel-only trains by 2040.

Principles: maximising benefits to public health

When assessing interventions, consideration should also be given to wider public health criteria as well as air pollution, such as noise, traffic congestion, and associated co-benefits, such as increased physical activity. Multiple interventions, each producing a small benefit, are likely to act cumulatively to produce significant change, and this aspiration should be recognised in overall strategies.

In Barcelona, Mueller et al (93) predicted that a reduction in motor traffic with the promotion of active transport and the provision of green infrastructure would result in a considerable burden of disease avoided and substantial savings to the health care system.

A good public transport system needs to be designed in order to encourage modal shift from car to public transport as a part of a package of interventions to reduce emissions (114). Evidence showed people who took up a free bus pass were more likely to use public transport and, therefore, less likely to use their car and contribute to air pollution. Subsidised public transport schemes have the potential to increase physical activity. In addition, the provision of school buses is likely to reduce term-time peak-hour traffic, and thus decrease traffic congestion if implemented as part of an overall package.

The NICE review (115) of traffic-related interventions to reduce NO_2 recommended taking a number of actions in combination, such as local planning, clean air zones, measures to reduce emissions from public sector transport services and taxis, smooth driving and speed reduction, active travel and awareness-raising. These actions are likely to bring multiple public health benefits, in addition to air quality improvements, such as prevention of traffic collisions, reduction of carbon emissions, increased physical activity, enhanced neighbourhood appearance and community cohesion (116).

Strategies emerging from the assessment

For road transport, interventions that aim to reduce the use of polluting forms of transport, such as national road pricing, increased fuel duty and LEZs, can be effective at reducing traffic emissions. This is mainly at local level, but they can also have national benefits if implemented at many areas across the country. However, such measures can be unpopular because of their restrictive nature, if not handled sensitively with considerable prior consultation and engagement.

The promotion of abatement technologies can be a highly effective mitigation action in road transport, as well as in the rail sector; however, the retrofit of emission abatement in trains in particular has been deemed particularly expensive.

Alternative energy use in the transport sector, such as electric vehicles, electrification of ground support equipment at airports and electrification of the rail network, have shown to have a high potential to reduce pollutant emissions and impacts. Cost appears to be the main barrier, particularly in the rail sector, alongside the operational limitations of implementation. Therefore, the introduction of bi-mode trains that can operate using more than 1 source of electrical power has been rising rapidly. There may also be an environmental justice issue associated with increased use of electric vehicles, depending on the electricity source, as air pollution has been predicted to increase near coal-fired power stations in rural areas in some studies. It is also important to note that electric vehicles retain some impacts associated with PM from brake/tyre wear; thus, it remains important to promote use of public and active transport, particularly when considering short journeys.

Alternative fuels, such as biofuels, bring reductions in PM emissions compared to conventional diesel, and biofuels are already regularly used in blends of petrol and diesel. Alternative aviation fuels, such as synthetic paraffinic kerosene, can lead to significant emission reduction at and around airports.

The promotion of walking and cycling, as well as subsidising public transport, have the greatest overall health benefits, providing flexibility to select routes away from heavily trafficked main roads whilst active travelling. Furthermore, these transport modes increase physical activity that leads to multiple health co-benefits. They also have potential to improve health inequalities, as they can be made equally accessible to all population categories.

An important point that affects the effectiveness of the interventions in the transport sector is the trade-off between time-limited air quality and climate change mitigation policies. For the assessment of the direct and indirect impacts of interventions (air pollutant emissions, greenhouse gas emissions, physical activity, noise, congestion, road collisions, and so on), the design of methodologies at different spatial and temporal scales is recommended. Another issue is the complexity of behavioural pathway mechanisms, as it can be difficult to predict how people travelling will respond to interventions, which can vary over time and location. In addition, it can be very challenging to predict the unintended consequences of transport interventions. For example, interventions can reduce congestion and increase speeds, which can be counter-acted by increased traffic volumes through increased demand.

Overall, the evidence suggested that the greatest impact on reducing emissions from road transport and improving public health outcomes associated with interventions identified by the rapid evidence assessment was associated with the co-implementation of a package of intervention measures designed according to each local area's requirements and supported by overarching national policies. For example, a LEZ can be co-implemented with retrofit or scrappage schemes to meet vehicle emission compliance, as well as actions promoting active travel and subsidising public transport. Additional measures could help to improve the public acceptability of nationally significant measures such as pricing policies, and they would offer various public health and well-being co-benefits, including increases in physical activity, noise reduction and improved neighbourhood cohesion. In parallel, the promotion of eco-driving through smooth driving, speed reduction and anti-idling could reduce traffic emissions and support improvements in other areas, such as fewer traffic collisions and economic savings in fuel consumption. Transport interventions should be complemented by planning interventions, such as the development of green spaces in urban areas, and behavioural interventions and promotion campaigns, in order to improve their effectiveness to improve public health.

Limitations

The strength of the evidence for transport interventions to improve air quality remains weak. In addition, the rapid evidence assessment identified important studies, but other relevant studies may have been missed and may require a systematic review approach.

The evidence to support the selection of traffic interventions to improve air quality and health is limited by:

- lack of implementation and ex post evaluation. Transportation studies are most often ex ante assessments for proposed interventions and often rely on modelling to forecast the impact. The majority of studies use average-speed emission factors that only capture limited aspects of the influence of traffic dynamics on emissions. Ex post evaluations are required to build the evidence base for air quality benefits of traffic interventions in practice. Monitoring of the observed impact (and range of outcome measures) is needed as many traffic interventions have an associated complex array of travel behaviours
- lack of exposure and health assessment. There has been little measurement of exposure or health impacts associated with transport interventions. There are ex ante studies, such as the Ultra-Low Emission Zone for London (117), but the detection of traffic related health impacts following implementation is complex
- small recorded intervention effects due to the influence of confounding factors. Large confounding factors include emissions from non-traffic sources, meteorology and vehicle fleet variability amongst many more. The small effect of transport interventions on air quality is likely to be the cause by the low strength of evidence

- uncertain long-term effects when considering the evolving vehicle fleet mix, technology and urban systems. Many health effects from exposure to air pollution are long-term outcomes. Evidence of air quality and health impacts from past interventions may not be representative of future performance due to new iterations of vehicle fleet changes, particularly the introduction of hybrids and electrification of the fleet. Higher-performing vehicle types have a lower response to interventions that focusses on congestion reduction as a means of improving air quality (ie, once the fleet is lower-emission, these measures are less effective and other approaches are needed). The introduction of autonomous vehicles would also alter the potential impacts of traffic management interventions, such as variable speed limits and eco-driving, on air quality improvements

Further work emerging from the assessment

Following up on the current limitations to support the selection of interventions to improve air quality and health, a number of priorities are summarised below:

- monitoring of the observed impact and multiple outcome measures for traffic intervention studies is needed
- development/utilisation of source apportionment techniques in order to estimate the air quality impacts of the interventions; there are large confounding factors that affect the evaluation of interventions, such as emissions from non-traffic sources, meteorology and vehicle fleet variability amongst many more
- more evidence on interventions for the aviation, rail and maritime sectors

Results: Planning/structural design interventions

Key messages

This chapter discusses the effectiveness of 9 interventions to reduce harm from air pollution, based on the rapid evidence assessment (Annexe A3.1). The main points are summarised as follows:

- the interventions with the highest potential to be effective both at national but mainly at local level are related to traffic. Driving restrictions produced the largest scale and most consistent reductions in air pollution levels
- for all the interventions, the effectiveness strength was low, and the uncertainty range was high, with only 1 exception: driving restrictions. However, the paucity of evidence of effectiveness should not be confused with or assumed to be evidence of ineffectiveness
- interventions comprise structural and planning measures. In this review, the former referred to road and green infrastructure and the latter referred to traffic-related measures, as well as to the promotion of active travel
- measures, such as Low Emission Zone (LEZ) and road pricing, produced reductions in traffic, but not necessarily great improvements in air quality, perhaps due to localisation of emissions, for example by displacement. LEZ are potentially effective at reducing air pollutant levels (more effective for particulate matter, PM_{10} than for nitrogen dioxide, NO_2) in cities. They are expected to work better for NO_2, if combined with interventions that incentivise the use of Euro 6 standards for both heavy and light duty vehicles
- potential to improve air quality and public health outcomes is associated with the co-implementation of a mix of various measures that provide/improve green and active travel infrastructure, prioritise road safety, provide public transport and discourage travel in private cars, together with policies focussing on reducing the emissions of vehicles
- green infrastructure is potentially effective not only to improve air quality related public health outcomes, but also to improve health inequalities in urban areas and promote our health and well-being. Green infrastructure has also the potential to impact positively on urban heat islands and reduce the negative impacts of flooding
- for speed limitations (traffic calming measures) and encouraging active transport, the public health ‘co-benefits’ outweigh benefits associated with reduction of exposure to air pollution alone, as speed limitations are associated with a reduced risk of pedestrian injury and traffic collisions, and increased physical activity is associated with multiple public health benefits (improved

cardiovascular outcomes and improved weight status among children, adults and older adults)

Research questions

What evidence is there for planning/structural development control interventions and decisions which reduce harm from air pollution?

The scope of the rapid evidence assessment encompassed structural and planning interventions and their impact on air pollution and public health. Structural measures refer to infrastructure, whereas planning interventions routinely encompass land use designation, spatial planning (from neighbourhood master plan to city-region scale and beyond), pricing (road user charging, parking), regulation (of traffic speeds), investment (for example in clean technology, car share promotion) and public education (of impacts, opportunities).

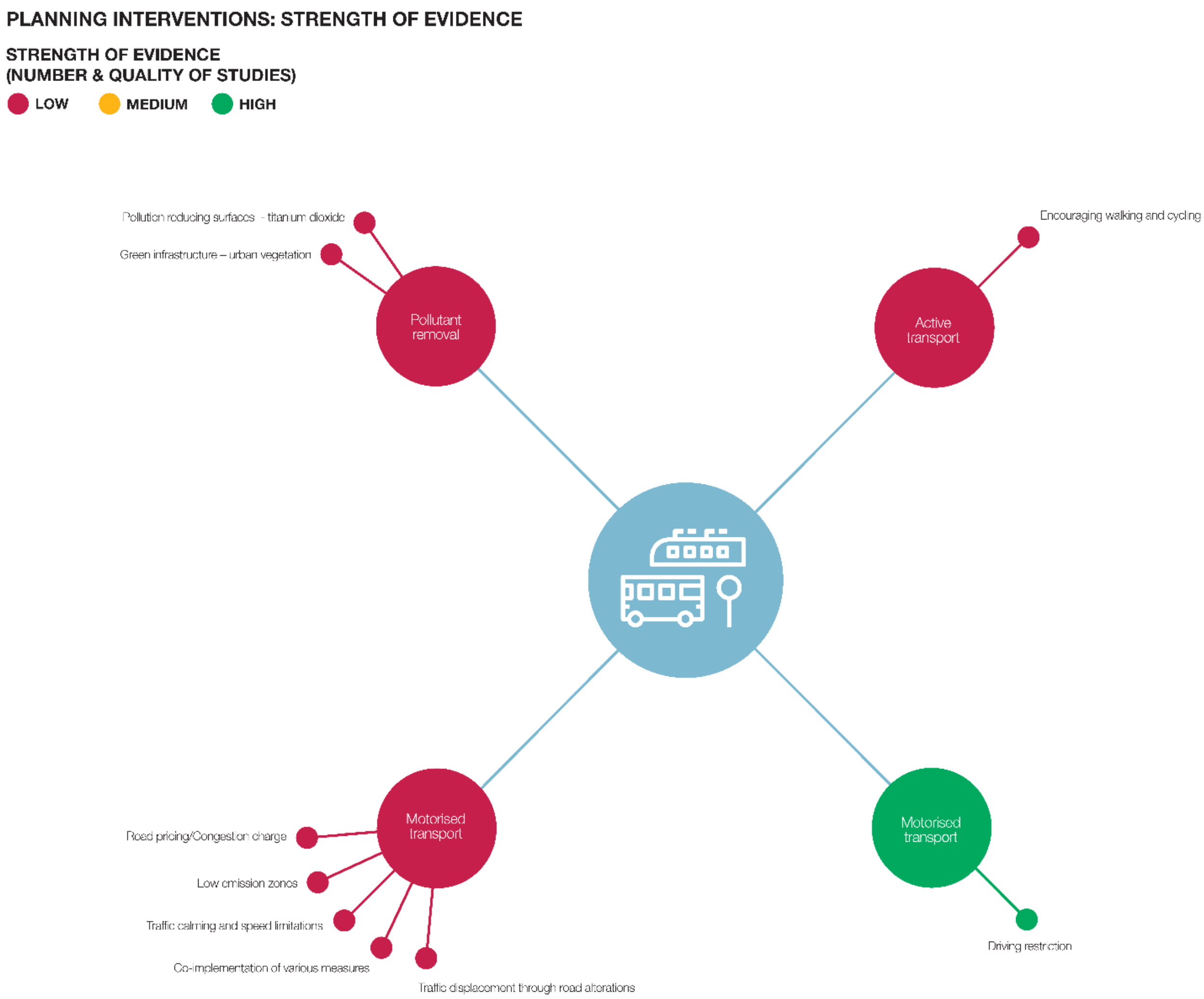
The rapid evidence assessment identified the following planning/structural interventions, which are presented in Figure 5 and Table 6, together with their principles.

Table 6: Planning/structural interventions

Intervention	Type of intervention	Description/principles
1. Green infrastructure – urban vegetation	Mitigation	This intervention uses vegetation to reduce ambient air pollution concentrations. NO_2 and PM are deposited, Volatile Organic Compounds (VOCs) are adsorbed. Gases can be removed by stomatal intake, adsorption to plant surfaces, and absorption to leaves
2. Pollution reducing surfaces - titanium dioxide	Mitigation	This intervention aims to use outdoor photocatalytic surfaces with titanium dioxide (TiO_2) to promote catalytic reactions when exposed to light, as a means of reducing concentrations of various pollutants, particularly NO_2. VOCs can also be oxidised by TiO_2 surfaces
3. Encouraging cycling and walking	Prevention	This intervention encourages active transport, such as walking and cycling to reduce the number of vehicle miles travelled or cars being used
4. Road pricing/ Congestion charge	Prevention	This intervention may require only certain types of vehicles, or all vehicles, to pay a charge to use certain roads
5. Driving restrictions	Prevention	Various measures put into place to restrict the number and type of vehicles at certain times and in certain areas (eg, restrictions based on license plates and meeting Euro emission standards)

Intervention	Type of intervention	Description/principles
6. Low emission zones (LEZs)	Prevention	LEZs follow a similar philosophy as driving restrictions and road pricing; certain classes of vehicles are restricted from entering a zone based on emissions. This may be a complete ban or a charge. LEZs target particulate matter and nitrogen oxides
7. Traffic calming and speed limits	Prevention	With this intervention, vehicles pass through an area to reduce their speed. Pollutant emissions vary with vehicle speed. PM, CO, and hydrocarbon emissions are higher at lower speeds, while NOx emissions tend to be higher at higher speeds
8. Traffic displacement through road alterations	Prevention	This intervention includes road alterations to accommodate traffic or public transit routes
9. Co-implementation of various measures	Other	Combinations of the measures above. Case studies exist from various countries, where the health impacts, cost benefit or cost effectiveness of city-wide air quality programmes were evaluated

Figure 5. Planning/structural design interventions



Identify and prioritise implementable interventions or groups of interventions related to spatial/transport planning and management/structural development control, land use planning, and building design

From the interventions identified for spatial/transport planning, driving restrictions produced the largest scale and most consistent reductions in air pollution levels at a city level, and seem to be an effective way to both reduce air pollution and improve public health. However, these restrictions may require changes in the political thinking and practice in the UK, and their longer-term effectiveness is not well evidenced. Green infrastructure – urban vegetation, if carefully designed, can also successfully remove air pollutants at a local scale and bring additional social, environmental, ecological and hydrologic co-benefits that can promote health and wellbeing.

Interventions such as LEZs, road pricing and traffic calming were shown to reduce traffic, but not necessarily greatly improve air quality. LEZs may have positive impacts on NO_2 levels in the UK, but they need to be considered together with other interventions to reduce traffic emissions (see conclusions from the rapid evidence assessment of vehicle/fuel design intervention). Furthermore, changes to road infrastructure, even if they are related to public transportation, do not particularly improve air quality.

Schemes such as bicycle sharing or implementation of bicycle lanes are unlikely to have large impacts on air quality in the UK, unless a large percentage of car travel is replaced with active transport (>50%).

Finally, there is insufficient evidence that interventions such as pollution reducing surfaces – titanium dioxide (TiO_2) are an effective means of reducing NO_2 levels in ambient air on a city or neighbourhood level. The review suggested that there is numerous laboratory-based evidence only. There are also some field trials in Belgium (118); however, the translation from laboratory results to real life applications is still difficult due to the great number of parameters involved and the lack of large scale projects to assess the effectiveness of photocatalytic materials.

How are these interventions implemented?

The measures for driving restrictions limit the number and type of vehicles at certain times and in certain areas. They were implemented for international athletic events (eg, Beijing 2008 Olympics, Guangzhou 2010 Asian Games). This was temporary (before, during and after the event), rather than on a permanent basis, and in cities with generally higher levels of air pollution than the UK.

There are various options for new green infrastructure, which include:

- smaller green space features (such as street trees and roadside vegetation)
- green spaces not available for public access or recreational use (such as green roofs and facades, or green space on private grounds)
- larger green spaces that provide various social and recreational functions (such as parks, playgrounds or greenways) (119)

A WHO report (119) includes an overview of case studies implemented in the UK, Europe and Turkey, together with the estimated impact and effectiveness of urban green space interventions on health and wellbeing. These have mainly been implemented in small-scale studies and are yet unproven at a relatively larger scale. The type of vegetation is important: trees that release allergenic pollens should be avoided and high-density vegetation should be preferred as barriers (particularly hedges, compared to trees), so deciduous trees may not be a good choice in some areas. Where there is little room for dense hedges or trees, green walls and roofs could be useful on urban structures. In street canyons, the spacing of trees should be considered to allow for effective air circulation and to avoid inadvertently concentrating pollutants in some areas and increasing exposure.

Existing LEZs are generally implemented in Europe (for example, in Germany and Italy). Some target heavy goods vehicles and buses only, but some also target light duty vehicles. In Germany, there are 3 stages of LEZs (Table 7 below): Stage 1 LEZs only ban very high-emitting ('non-sticker') vehicles from entering the defined zone. Stage 2 LEZs ban non-sticker and red-sticker vehicles. Stage 3 LEZs only grant access to low-emitting vehicles with a green sticker.

Table 7. Four different LEZ emission classifications and associated minimum emission levels required to obtain a certain sticker (120)

	Emissions required for each sticker category			
	No sticker	Red sticker	Yellow sticker	Green sticker
Diesel vehicles	Euro 1 or older	Euro 2 or Euro 1 + particle filter	Euro 3 or Euro 2 + particle filter	Euro 4 or better, or Euro 3 + particle filter
Gasoline vehicles	Without catalytic converter	-	-	Euro 1 with catalytic converter or better

Road pricing interventions apply a charge for use of certain roads and may require only certain types of vehicles to pay the charge, or all vehicles that wish to use the roads. Examples include the London congestion charge, a congestion tax in Stockholm, the Ecopass scheme in Milan and a high occupancy toll (HOT) lane in Miami, USA.

Speed limitations can be applied both by implementing 20mph zones with physical limitations such as speed humps or cushions and by reducing the higher speed limit highways (for example from 100km/h to 80km/h).

Specific interventions related to changes to road infrastructure may include road widening to reduce traffic congestion, road narrowing to create room for a tramline, dedicated bus lanes and placement of major roads underground as tunnels.

Active travel relies on infrastructural changes that will consider road safety issues and avoid road collisions. Methods for encouraging cycling and walking include siting of bicycle lanes, bicycle sharing schemes (as in London, Barcelona), and workplace financial commuting incentives.

Based on the evidence, how effective are these interventions in reducing air pollution source emissions/environmental concentrations/exposure and affecting health outcomes? What is the strength of evidence regarding effects?

The rapid evidence assessment showed that for the all interventions identified, the effectiveness strength was low and the uncertainty range was high. The only exception was driving restrictions. However, it is important not to confuse the lack of evidence of effectiveness of the other interventions with evidence of ineffectiveness – they may still have an important role to play in reducing exposure to air pollution, which is the overall objective.

As discussed above, driving restrictions have been effective interventions to reduce air pollutant levels and improve health at a local/city scale, when applied around international athletic events. In terms of health outcomes, during the Olympic Games of Atlanta, reported acute asthma events (daily events and hospitalisation) were drastically decreased, whereas statistically significant effects were found for asthma hospitalisations and paediatric asthma, but not for other respiratory or cardiovascular admissions. For the Beijing Olympics, the largest decrease (47%) was observed in respiratory outpatient visits, with a 10.8% decrease in respiratory hospital admissions and a 26.4% decrease for overall emergency room visits. The effectiveness of these measures, both in terms of air quality and public health outcomes, have only been demonstrated for short-term occasions, while the restrictions were applied (several weeks before the event, ending soon after the event). The rapid evidence assessment found no information regarding their impact on health inequalities. The strength of evidence of effectiveness of this intervention was high, whereas the uncertainty range was low.

There is evidence that appropriately designed urban green infrastructure can improve air quality and reduce exposure to noise on a local scale but should not be used in isolation to address air pollution (121). The results from the current assessment were consistent with those from the WHO on the health effects of green space in urban areas (122, 123). There is significant and growing evidence of the health benefits of access to good-quality green spaces. These include better self-rated health, lower body mass index, overweight and obesity levels, improved mental health and wellbeing and increased longevity. These positive health, social and environmental outcomes are relevant to all population groups. In particular, the positive effects of green spaces on physical activity could reduce health inequalities among lower socioeconomic status groups, where physical activity levels are lowest (124, 125).

Although health impact assessment studies indicate that LEZs may be effective in reducing air pollutant levels and improving health, there are few evaluation studies to support this. For instance, dispersion modelling studies showed that PM_{10} concentrations decreased up to 10% as a result of the implementation of LEZs in

Germany, and agreed with data from monitoring stations, which showed a relative decrease of PM_{10} levels in the range of 5–12% at traffic-related monitoring sites, compared to reference urban air quality background levels (126). It has also been reported than more stringent zones in German LEZs (stage 2 zones, as detailed in Table 7 in the previous section) reduce PM_{10} concentrations 3 times more compared to stage 1 zones. However, the large impact of meteorology on the year-to-year variation of PM mass concentrations at any given location needs to be considered, as most of these studies were applied over short periods of time and used rather simple statistical approaches (57).

Although the implementation of LEZs seems to be effective at reducing PM_{10} levels, there is less evidence that LEZs are effective at reducing NO_x. A 5-year analysis of the London LEZ found that PM_{10} levels decreased by 2.5-3.1% within the zone compared to 1% elsewhere, but that NO_x concentrations remained unchanged. The reasons for these small effects may be the relatively small percentage of vehicles affected, the small LEZ areas, or that reductions in NO_x emissions between newer standard classes and old were not, in practice, as great as predicted (127). LEZs generally can have positive impacts on NO_2 in the UK, especially if applying a Euro 6 entry standard to low duty vehicle (LDV) and high duty vehicles (HDV), which will be required for the London Ultra Low Emission Zones (ULEZ).

In terms of exposure reduction and health benefits (regarding an adverse outcome), in Rome, lower socio-economic status (SES) residents benefited less than higher SES residents. The premature mortalities due to LEZ-attributable changes in long-term exposure to $PM_{2.5}$ were estimated to be reduced by 3, as a result of the introduction of the more stringent stage 2 zones, compared to the introduction of stage 1 zones (57).

Although road pricing (congestion charge) is an effective mean of controlling traffic and reducing emissions (eg, in Stockholm), the impact on air quality is not always clear. Modelling studies show the effectiveness of the intervention in terms of air pollution reduction and health, providing estimates of premature deaths to be avoided and years of life to be gained. However, monitoring data in London a couple of years before and after the implementation of this intervention led to conflicting messages (decreases in nitrogen oxide but increases in NO_2 and ozone in the congestion charge zone relative to the control zone). It is estimated that greater reductions in air pollution in more deprived areas are likely to make a small contribution to reducing socioeconomic inequalities in terms of air pollution.

Health benefits from speed limits that slow down traffic mainly derive from the need to prevent fatalities and serious injuries to motorists, cyclists and pedestrians, and promote active travel. However, this measure does not necessarily result in significant decreases in ambient air pollution levels, even within the intervention zone. A negligible impact on air pollution related illnesses is expected due to the limited impact of this intervention on emissions. There was no evidence of this intervention improving health inequalities.

Traffic displacement through road alterations should be undertaken with caution: road widening may increase traffic and, hence, may deteriorate air quality, whereas road narrowing does not necessarily result in decreased NO_2 levels, and displacement of traffic and new public transportation lines may shift emissions elsewhere. Implementing better public transport and active transport infrastructure in the longer term may lead to potential benefits in terms of air pollution and public health, as long as it does not cause more congestion or move traffic hotspots to other areas (a potential unintended consequence). Co-benefits may be achieved from reduced noise pollution and increased green space. There was no evidence of the impact of this intervention on health inequalities.

Bicycle sharing or implementation of bicycle lanes may offer benefits to society from a health perspective; these are primarily associated with improved physical activity, which improves multiple health endpoints (cardiovascular and respiratory health, diabetes and obesity, mental health and wellbeing), rather than with improvements in air quality. Road safety issues also need to be considered. The effectiveness of this intervention depends on people’s proximity and access to such infrastructure (pavements and cycle lanes).

Although, not explicitly mentioned in the review, there are 2 modelling tools that can be used for health impact assessments (HIA) related to traffic interventions: the ITHIM modelling tool (128, 129) and the UTOPHIA tool (130). These are integrated tools, since they address all 3 pathways (physical activity, road traffic injuries and air pollution). Furthermore, the World Health Organization's Health Economic Assessment Tool (HEAT) (131) is widely used to evaluate the benefits of physical activity and analyses the health benefits of walking and cycling by estimating the effects on mortality. These tools are discussed further in a separate PHE review of HIA tools for active travel/local travel plans (132).

Based on the results from ex-ante health impact assessments, the implementation of multiple traffic-related and infrastructure interventions is more likely to produce benefits for air quality and population than single interventions. The most effective combinations of these interventions depend on the issues and contexts of each local area.

What is the cost, and how cost-effective are these interventions? What is the strength of evidence regarding effects?

The rapid evidence assessment concluded that evidence of economic impact, in terms of either cost-effectiveness or cost-benefit of planning and structural interventions to improve air quality, is very limited and related mainly to traffic interventions.

At national level, implementing, for instance, more stringent LEZs in Germany was estimated to increase the benefits from the total health-related costs by a factor of 3. It was also estimated that benefits from health-related costs were double the cost of upgrading the fleet from dirty to green vehicles (133).

At local level, limited evidence from a cost-benefit-analysis of a road pricing intervention in Milan showed an overall net benefit, as the implementation costs for the scheme were low. Speed limitations can prevent traffic collisions and save costs in medical payments and working days lost, which far outweighs any costs or benefits from air pollution impacts

The 2008 NICE guidance on physical activity and the environment (134) stated that the long-term health and economic benefits associated with increases in cycling and walking would “neutralise any initial (infrastructure) costs”. PHE's review of active travel states that investment in walking and cycling infrastructure or behaviour change programmes can be expected to deliver low cost, high-value dividends for individual health, the NHS, the transport system and the economy as a whole (135). A cost-benefit analysis in the USA showed that building more sidewalks would encourage more walking and cycling and have a positive impact on air pollution. The overall benefit-cost ratio was 1.87 over 10 years. The total health benefit from physical activity was 10 times higher than the air pollution savings.

The previously mentioned HEAT (Health Economic Assessment Tools) have been widely applied in a number of European countries and the USA when planning new cycling or walking infrastructure, reflecting their availability and ease of use (136). In the UK, the Transport Action Plan by the Mayor of London in 2014 on “improving the health of Londoners” recommended these tools be used by public health specialists from London Boroughs to quantify and monetise the health impacts of projects and policies.

Furthermore, the economic impacts from walking and cycling may be quantified when evaluating new interventions using a newly-developed model from Sustrans (102). This is based on Defra’s damage costs (103) and includes the benefits of emissions reduction due to fewer car journeys and lower air pollution exposures for users of cycle/walking routes.

What interventions are under development, and what is their potential impact?

There was no information in the rapid evidence assessment about planning/structural design interventions that are under development.

Principles: maximising benefits to public health

The PHE *Spatial Planning for Health* report (137), based on a rapid assessment commissioned by PHE from the University of the West of England, concluded that the 5 aspects of the built and natural environment that are associated, or thought to have an association with, health outcomes and can be influenced by local planning policy are:

- neighbourhood design
    - enhance neighbourhood walkability
    - build complete and compact neighbourhoods
    - enhance connectivity with safe and efficient infrastructure
- housing
    - improve quality of housing
    - increase provision of affordable and diverse housing
    - increase provision of affordable housing for groups with specific needs
- healthier food
    - healthy, affordable food for the general population
    - enhance community food infrastructure
- natural and sustainable environment
    - reduce exposure to environmental hazards, such as air pollution
    - access to and engagement with the natural environment
    - adaptation to climate change
- transport
    - provision of active travel infrastructure
    - provision of public transport
    - prioritise active travel and road safety
    - enable mobility for all ages and activities

Focussing on transport, the NICE (2017) *Air pollution: outdoor air quality and health* guideline (115) evaluated the effectiveness and cost effectiveness of the following interventions to reduce people's exposure to and health impact from traffic-related air pollution:

- planning development control decisions and interventions
- interventions to develop public transport routes and services
- interventions to develop routes and infrastructure to support low emission modes of transport
- measures to promote absorption, adsorption, or impingement deposition and catalytic action

According to this guideline, air pollution should be included in 'plan making' by all tiers of local government, in line with the Ministry for Housing, Communities and local government's National Planning Policy Framework (138), including county, district and unitary authorities, as well as regional bodies and transport authorities. The Local Plan (139) and other strategic planning processes (such as the core strategy, local transport plan, environment and health and wellbeing strategies) should include zero- and low-emission travel.

Supplementary Planning Documents (SPD) build upon and provide more detailed guidance about policies in the Local Plan. Legally, they do not form part of the Local Plan itself and they are not subject to independent examination, but they are material considerations in determining planning applications. SPDs should only be prepared where they are necessary. SPDs may relate to the development of certain types of buildings (such as food outlets), certain locations within the local authority area (such as town centres), or may relate to wider issues of concern to all developments (such as air quality).

Strategies emerging from the rapid evidence assessment

Transport is a significant source of emissions of air pollution. The government is committed to tackling poor air quality and reduce emissions of nitrogen oxides in the areas where their concentrations currently exceed legal limits. Through cleaner road transport and is working closely with local authorities and Local Economic Partnerships to make progress.

The evidence from this rapid evidence assessment suggested that planning interventions are crucial for improving air quality and reducing population exposure to air pollution. The interventions with the highest potential to be effective both at national but mainly at local scale are related to traffic.

This review showed that driving restrictions produced the largest scale and most consistent reductions in air pollution levels, with the most robust studies. This measure has been effective for short-term actions in cities around athletic events and over specified time periods. It could have national benefits if implemented widely by cities; however, feasibility is an issue, as efforts would be required to maintain benefits in the longer term and it requires a change in political and economic thinking before it could become accepted in practice.

Schemes such as LEZs and road pricing produced reductions in traffic, but not necessarily great improvements in air quality, perhaps due to localisation of emissions. LEZs are potentially effective at reducing air pollutant levels (more effective for PM_{10} than for NO_2) within cities. They are expected to work best if combined with interventions that incentivise the use of both heavy and light duty vehicles with the most recent Euro 6 standards, which have a greater impact than earlier emission standards.

The practical feasibility of this intervention should not be an issue, as it is mainly a matter of political will.

Green infrastructure is an intervention potentially effective at not only improving air quality related public health outcomes, but also in improving health inequalities in urban areas as well as improving health and well-being by enabling stress alleviation and relaxation, physical activity, improved social interaction and community cohesiveness. Further evaluations of large-scale use and guidance on optimising scheme design are needed. Green infrastructural changes did not produce notable improvements in air quality, partially due to the limited spatial coverage, though, as with driving restrictions, it is likely that this was due to a lack of large-scale projects.

For some interventions, public health ‘co-benefits’ outweigh benefits of reduction of exposure to air pollution. This is the case for speed limitations (traffic calming measures) that have limited effectiveness at improving air quality, either nationally or locally; however, they are associated with increased walking and a reduced risk of pedestrian injury and traffic collisions. Equally, encouraging active transport may have limited effectiveness in terms of air quality public health outcomes if modal shift does not occur on an unprecedented scale. But, there is a wealth of high-quality evidence showing that investing in infrastructure to support walking and cycling can increase physical activity, leading to multiple public health benefits, such as improved cardiovascular outcomes and improved weight status among children, adults and older adults (137). These are convincing reasons to promote these interventions.

The highest potential to improve air quality and public health outcomes is associated with the co-implementation of various measures, which allow policies to be tailored to local contexts (for example, packages of multiple traffic management and green/road infrastructure measures). Policies and planning approaches that aim to reduce air pollution and improve public health outcomes will vary from region to region to accommodate differences in terrain and land use characteristics and environmental conditions.

Policies to improve/provide green and active travel infrastructure, prioritise road safety, provide public transport and encourage active travel and appropriate use of cars, together with policies focussing on reducing the emissions of vehicles, can have the highest potential to fully realise health benefits. This finding is in agreement with the outcome of large EU-funded projects such as PROPOLIS (140), which concluded that planning measures have synergistic effects; when applied in combination, the outcome is more substantial than the sum of individual interventions. Congestion charges and LEZs may also benefit from additional interventions that help people move through the zones, including low emitting public transport.

The rapid evidence assessment concluded that the evidence of economic impacts, either in terms of cost-effectiveness or cost-benefit, for interventions to improve air quality is very limited and related mainly to traffic interventions. At national level, implementing more stringent LEZs has the potential to increase the total health-cost benefits, even when accounting for the cost of upgrading the fleet with cleaner vehicles. At local level, speed limitations can prevent traffic collisions and save costs in medical payments and workdays lost. Finally, the long-term health and economic benefits associated with increases in cycling and walking have the potential to outweigh any initial infrastructure costs.

Limitations

There were some limitations regarding the effectiveness of the various interventions, which related to their assessment, feasibility and timescale to benefit. The review concluded that the effectiveness of various interventions depends on various factors, such as the local geography and meteorology, as well as on the environmental, social and political situation. Studies of interventions to reduce impacts on air quality are difficult to set up (given the several confounding factors), are costly, and consequently, are rare. Furthermore, studies on the health impacts of planning interventions become very complex and hence expensive and less in number.

The rapid evidence assessment emphasised that a limitation was not being able to identify high-quality empirical evidence for each intervention group. There were a limited number of studies evaluating interventions, and most of them relied on either environmental or health impact assessments, which estimated the changes in exposure or health outcomes based on deterministic modelling. This does not mean that the interventions were not successful, but this prospective assessment of their effectiveness was inherently more uncertain.

Additionally, most interventions were evaluated for only a short period; however, due to meteorology and atmospheric variability, a long time series (for example 10 years) is recommended for detecting whether interventions have a significant effect on air quality. Furthermore, most interventions do not occur alone; therefore, it is not simple to determine the impact of a single intervention on air quality in isolation from many other outcome determinants.

Co-implementation of various measures cannot always be evaluated in a complex system such as the built and natural environment, due to difficulties using experimental approaches, such as randomised controlled trials and natural experiments, to assess causality.

Finally, the rapid evidence assessment focused on spatial and planning interventions and did not review the role of strategic land use (such as restricting residential development in areas of high air pollution) and transport planning in modifying emissions, air quality and health, which is very relevant for new developments.

Further work emerging from the assessment

This rapid evidence assessment identified gaps in the literature, suggesting further research is required to be able to fully evaluate the impacts of structural/planning interventions on air pollution and public health. These are summarised below:

- review the evidence of how urban form (the physical characteristics of the built environment, including shapes, size, density and configuration) may influence local air quality and public health
- evaluate the impact of strategic land use and transport planning on modifying emissions, air quality and health, as strategic planning sets the framework for local interventions
- there is a need for longitudinal studies of green infrastructure interventions (not just green space studies), on a relatively large scale, together with controlled, long-term, measurements of changes in air concentration of pollutants
- there is a need for better inclusion of health and equity outcomes in studies on green space interventions, through improved monitoring of local green space management and related health and equity impacts
- for traffic-related interventions, such as road pricing/congestion charge and speed limitations, there is a need to evaluate other potential sources of air pollution or simultaneous interventions as well as a need for longer-term monitoring
- specifically for LEZs**,** monitoring other PM metrics, such as black smoke or elemental carbon, may be more useful in determining their traffic-specific impacts
- studies should be done of the impact of road infrastructure changes on a wider area, to account for traffic displacement. A longer period of evaluation is needed to tease out impacts of weather and other potentially confounding variables
- given the difficulty in evaluating the co-implementation of various measures in the complex systems of the built and natural environment, there is need to develop further research methodologies, which could follow a complex, whole-systems approach to examine causality

Results: Industrial interventions

Key messages

This chapter discusses the effectiveness of 18 categories of intervention used to reduce harm from air pollution, based on the rapid evidence assessment (Annexe A2.1). The main points are summarised as follows:

- there was a clear distinction between policy-level interventions that set overarching targets and have the potential to widely reduce industrial air pollutants, and technological interventions implemented at the individual installation level (to meet policy-level intervention targets) that have potential benefits for local air quality and national air quality if implemented at scale
- evaluations of policy interventions were generally based on evaluating specific existing or prospective policy options, whilst evidence of technological interventions was primarily based on European evaluations of best available (industrial) techniques (BAT)
- the evidence found primarily related to evaluations of interventions' effects on emissions (sources), from which consequent benefits to air quality and health are inferred. Few interventions directly evaluated effects on environmental concentrations, and fewer still directly evaluated health outcomes. Therefore, more evidence is needed to identify the links between specific interventions, air quality and improved health outcomes
- for some aspects of interventions, little or no evidence was found. For example, there was little evidence of industrial interventions' effects on health inequalities or of co-benefits
- for technological interventions, each had a range of potential cost: benefit ratios, which could be estimated using Defra's established damage costs methodology
- for policy interventions to be effective, proven technological interventions are required to be able to implement them

Research questions

What evidence is there for legislative interventions which reduce harm from air pollution?

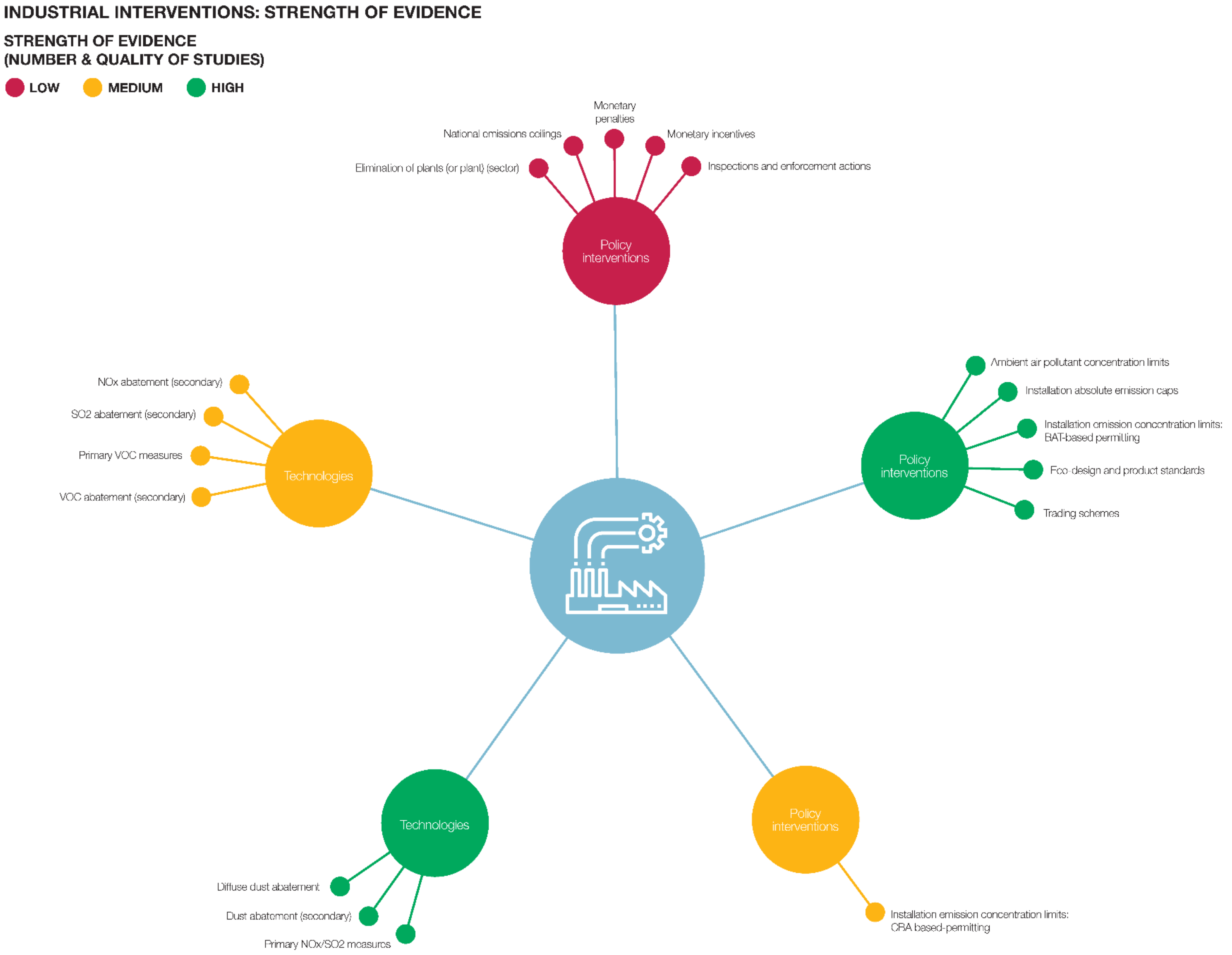
Approximately 120 individual interventions were identified in the rapid evidence assessment, covering technical, legislative and other policy measures across a range of industries. Many of these interventions involved similar types of techniques applied in different industry sectors, or a variant of a similar type of policy approach (for example setting emission limit values, emission caps, cost-benefit-analysis based permitting). The assessment grouped interventions into 18 categories, with 11 being categorised as policy measures and 7 categorised as technologies (Table 8 and Figure 6):

Table 8: Industrial interventions

#	Intervention category	Type of intervention	Description/principles
Policy measures			
1	Ambient air pollutant concentration limits	Prevention	This intervention involves the setting of ambient air quality standards for various pollutants. Emissions from all sources, including industry, contribute to ambient concentrations and additional measures are required to reduce emissions if these pollutant concentration limits are exceeded
2	National emissions ceilings	Prevention	Setting national-level absolute (mass) emission ceilings for various pollutants. Emissions from all sources, including industry, contribute to the ceilings and additional measures are required to reduce emissions if these pollutant limits are exceeded
3	Installation absolute emission caps	Prevention	Setting emission caps at installation level in the form of absolute emission limits (mass based)
4	Installation emission concentration limits: Best Available Technique (BAT) based permitting	Prevention	Setting emission concentration limits which installations must comply with to receive a permit to operate
5	Installation emission concentration limits: Cost-Benefit-Analysis (CBA) based permitting	Prevention	CBAs are carried out to set permit conditions, including emission limit values, for industrial installations. Such CBAs consider the cost of implementing a technique and compare this with the environmental benefits
6	Eco-design and product standards	Prevention	Policy measure implemented at product level by setting specific eco-design requirements for emission concentrations (eg, of boilers)
7	Elimination of plants	Prevention	Policy measure to shut down plants, eliminating all emissions
8	Inspections and enforcement actions	Prevention	Measures to increase the number of inspections and enforcement actions
9	Monetary incentives	Prevention	Providing industries and companies with an incentive or the means to reduce industrial pollution by adopting air pollution prevention and control technologies and to undertake research into process and product efficiency

#	Intervention category	Type of intervention	Description/principles
10	Monetary penalties	Prevention	Penalising polluters for negative environmental impacts at company/industry level
11	Trading schemes	Prevention	Market-based measure for reducing emissions of pollutants through emissions trading
Technologies: Split between **primary** and **secondary** control measures. Primary control measures are those that prevent the formation of the pollutant during the industrial process, for example low NO_x burners. Secondary control measures are those that can be termed 'end of pipe' technologies that capture or treat a pollutant at the point of emission to atmosphere, such as a thermal oxidiser to combust VOCs			
12	Diffuse dust abatement	Prevention	Measures to prevent and control diffuse dust emissions from industrial activities
13	Dust abatement (secondary)	Prevention	Abatement measures to control dust emissions (combustion and process emissions) from industrial activities
14	Primary NO_X/SO_2/PM measures	Prevention	Primary measures to prevent formation of NO_X, SO_2 and PM from industrial activities
15	NO_X abatement (secondary)	Prevention	Abatement measures to control NO_X emissions (secondary techniques) from industrial activities
16	SO_2 abatement (secondary)	Prevention	Abatement measures to control SO_2 emissions (secondary techniques) from industrial activities
17	Primary VOC measures	Prevention	Primary measures to remove sources of VOC emissions from a range of sectors applying surface treatment (eg cleaning, coating processes or printing)
18	VOC abatement (secondary)		Abatement measures to control VOC emissions (secondary techniques) from industrial activities

Figure 6. Industrial interventions



The evidence mainly covered national interventions (legislation, regulations, policy actions and so on). Despite this, documents such as the BAT Reference documents (BREFs) (141), while developed to support an international policy approach, are implemented at a local (installation-specific) level and contain plant-specific information and examples. Similarly, the multiple pollutant measures database (MPMD), developed to support national policy, and contains information on specific techniques that are applied in a range of industrial installations and sectors. It can inform evaluation of measures of abating industrial pollution, and its use continues to be refined by Defra with input from stakeholders.

Identify and prioritise implementable interventions or groups of interventions related to industrial regulation/legislation/factory design/abatement technologies/location/enforcement etc.

The rapid evidence assessment concluded that there are a wide range of industrial sectors, processes, pollutants, geographical locations or levels to which the interventions can be implemented. Therefore, it would require further analysis to prioritise the interventions in any way. It further recommended that prioritisation be best performed on a case-by-case basis; spatial planning considerations are also relevant when carrying out such interventions.

The review applied a methodology to rank technology interventions (Section 4.1.2 of the rapid evidence assessment, Annexe A2.1), based on calculated cost-benefit ratios. In order to calculate cost-benefit ratios, the cost to implement a technique (expressed as cost per tonne of pollutant abated) was divided by a Defra damage cost (103) for the specific pollutant, reflecting the monetised cost to society of impacts (including health outcomes). Many of the abatement measures had a cost several times higher than the benefit. The measures were not ranked by cost-effectiveness, as both the costs and the benefits can be expected to change when site specific factors are accounted for and additional benefits are reflected.

How are these interventions implemented?

Policy interventions are generally implemented through top-down imposition of standards, limits and practices at installation or sector level. Monetary incentives and penalties generally supplement other policy interventions by encouraging behaviour change to meet targets and criteria. Several policy measures identified by the assessment are implemented at present through national or European Union-wide (EU) legislation (such as the industrial emissions directive (IED), national emissions ceiling directive (NECD), air quality strategies (AQSs)). However, the assessment concluded that policy interventions currently implemented at national level could be applied at different geographical scales if there was flexibility and authority to use knowledge of local situations to consider appropriate concepts to implement, though capacity and consistency are likely to be issues if considering this in practice. Again, it is worth emphasising that industrial policy measures should seek to tie in with spatial planning considerations, though investigating the combination of the 2 was outside the scope of this assessment.

With reference to the technology measures (including performance levels), the assessment concluded that implementation of these will generally be done by the operator of a particular installation, mandated or governed through regulation (environmental permitting for instance). The effectiveness of technological interventions must be considered in relation to the policy framework, for example, through setting technological standards, regulating, and enforcing them.

The assessment identified that overall approaches to the implementation of identified interventions was not significantly different across industrial sectors, and that many of the interventions identified (both policy and technological) were already commonplace.

Based on the evidence, how effective are these interventions in reducing air pollution source emissions/environmental concentrations/exposure and affecting health outcomes? What is the strength of evidence regarding effects?

The rapid evidence assessment concluded that the effects of interventions on reducing emissions of air pollutants ranged from significant reductions of multiple pollutants (such as a policy intervention to eliminate, for example, power plants) to addressing the emissions of a single pollutant arising from a specific industrial activity (such as reducing VOC emissions by substituting cleaning agents in offset printing). For some of the interventions, such as emission concentration limits as set out in BAT-based permitting, emissions trading schemes and ambient air pollutant concentration limits at the policy level, and dust abatement technologies and primary NO_x and SO_2 control measures, evidence of effectiveness was very strong. These were derived from extensive reviews, stakeholder consultations or information exchange processes between industry and government experts. However, there were a number of aspects of interventions (such as their effects on exposure or costs) regarding which the rapid evidence assessment found a single source or where little or no information was found.

What is the cost and how cost-effective are these interventions?

The review identified a wide range of costs and information on cost-effectiveness of interventions. Costs were broadly split across costs at a national level (for example, the implementation of a European Directive has costs to the state, in terms of its implementation and associated administrative burden, and to industry in terms of its compliance costs and costs to the regulators in administering the regulatory framework, which are then passed on to operators). Regulatory impact assessments (RIA) of specific policy options evaluate these different costs; costs and benefits of large-scale national industrial policy interventions range from hundreds of millions to billions of pounds.

Technological interventions' implementation and operating costs are borne by individual operators or industrial sectors, and capital costs depend on the size of the installation and technological intervention in question. Again, there is a large, context-dependent, range from thousands to millions of pounds at the installation level. Economic costs are not the only consideration when evaluating an intervention's viability and due consideration is needed of other factors, such as the local environment, background air quality concentrations, and health profile of the local population. Further consideration of how best to account for these factors within economic appraisals could help to optimise health and health economic benefits of interventions in future, and the Environment Agency (EA) and local authority regulators have a potentially important role.

Health outcomes

The rapid evidence assessment found that most of the evidence describing interventions addressed their effects on emissions, with little discussion or data on potential exposure and/or health issues. Existing EU-level legislation includes estimates of tonnes of pollution abated, which can be used to estimate population-level monetised health impact through the application of the Defra damage costs (103). However, case-specific impact assessments of regulatory frameworks such as the IED and MCPD are not necessarily applicable to the same intervention types if implemented under different assumptions and contexts.

Evidence of the health impacts of other interventions was limited. The review concluded that direct assessment of health impacts were not well considered when the use of specific technologies, such as abatement equipment, was being evaluated. This reflects the need to consider public health impacts and benefits in more detail within the various frameworks and methodologies used in industrial regulation, as well as spatial plans and development consents (which apply to both large scale industry subject to formal environmental permitting requirements and regulation, and smaller scale industrial processes subject to light-touch or no regulation).

Damage costs

The rapid evidence assessment identified the use of damage costs as an established economic approach to value impacts and benefits associated with changes in air pollution. Damage costs include impacts associated with morbidity and mortality and are published by Defra for various pollutants, 'activity categories' and locations (103), and further detailed consideration of local and regional conditions would require bespoke approaches.

As these values indicate the marginal external costs caused by each additional tonne of pollutant emitted, or conversely the benefits of reducing the amount of a pollutant emitted by 1 tonne, they can be used to value the benefits of air quality impacts of certain policies or projects if the only information available is the amount (in tonnes) of pollutant that is reduced.

The rapid evidence assessment concluded that, due to limited information available in the literature regarding the potential 'tonnes abated' of different industrial interventions, it was not possible to calculate and compare their potential benefits using damage costs.

Damage costs are relevant to industrial and non-industrial activities, and their potential use to prioritise interventions based on the impacts associated with different activities, pollutants and locations of interest is discussed in the 'Intervention strategies' chapter.

Health inequalities

The rapid evidence assessment considered how the location of industry might influence spatial distribution of impacts. It concluded that there was a limited amount of information available regarding variation in impacts of industrial emissions in different regions of the UK, but that variation will exist as the locations of industries and people do vary. This was thought to be of a lower order of magnitude in comparison with releases from domestic and road traffic sources, though evidence to support this conclusion was not strong. No evidence was found in relation to the variation in impact of different processes or interventions at more local scales.

In terms of populations at risk, the rapid evidence assessment concluded that interventions that led to greater emissions reductions and improvements to air quality also tended to be associated with larger reductions in spatial inequality of health impacts (as they reduced impacts in worst affected areas). One study concluded that in general, population in lower income households live in wards with worse air quality, hence there is environmental inequity. However, the limited evidence was variable, and this generalisation was not true for all areas, as more rural households showed the opposite relationship (that is, slightly better air quality in more deprived, potentially more remote, rural areas). Therefore, whilst there is some evidence of a link between poor air quality and deprivation, the relationship is inconsistent.

The review concluded that there was no systematic relationship between people working in or living near industry and their exposure to outdoor air pollution. However, this was based on limited evidence. Furthermore, industrial impacts cannot be considered in isolation from spatial planning. As with health outcomes, there are opportunities for considering and addressing industrial impacts on health inequalities in more detail within current and future industrial and spatial planning consent frameworks.

Economic impact

The technological interventions considered in the rapid evidence assessment are already considered to be best available techniques (BAT); thus, are already applied and considered economical for implementation by industrial sectors and installations within the environmental permitting regulatory framework. Economic costs of implementing BAT are considered at an international or national level using agreed understanding of what is technologically feasible. The economics of the implementation of technologies set out in BAT Reference Notes (BREF) is then considered by an operator for specific installations, and should the cost be considered prohibitive, the operator can enter into discussions with the regulator to potentially agree a derogation from implementation, usually time-bound, to lessen the economic impact to the business.

Evidence of the cost effectiveness of interventions with respect to health economic outcomes is limited. When cost-benefit assessments of interventions to be implemented at the installation level are undertaken, they sometimes focus on the costs of meeting standards rather than the potential monetised health benefits in going beyond the standards. To maximise health benefits, it is also important to consider population exposure, as the larger the population, the greater the impact per unit of pollutant, and, conversely, the greater the benefit should effective interventions be implemented.

To inform cost-benefit-analyses, Defra has calculated monetised health impacts for different air pollutants, polluting activities and locations. These can inform national prioritisation of action on health grounds, because they indicate where health impacts may be highest and where targeted action may be most cost-effective. Polluting activities in urban areas are associated with higher damage costs, due to the number of people exposed. At a national level, a range of interventions is required to reduce cross-sector emissions and population-level exposure to air pollutants.

Can differences be identified in approach for different types of emissions, sources or industry sectors?

The rapid evidence assessment found the overall approach to implementing the identified interventions was not significantly different across industry sectors. Many of the policy intervention concepts and technological measures are already (or have the potential to be) implemented in a range of industry sectors.

When identifying the most effective or cost-effective intervention for a particular sector or type of emission source, economically viable conditions must be considered. For industry sectors with typically smaller installations (such as printing or paint shops and industrial processes not subject to environmental permitting regulations), techniques or interventions associated with high implementation costs may not be as viable as for sectors with larger installations.

What new innovations in abatement technology or elsewhere are under development, and what is their potential impact?

Limited evidence was found regarding emerging or innovative interventions. The European best available techniques reference documents (BREFs) reviewed during the rapid evidence assessment list some emerging or innovative interventions for each sector they relate to; however, little information is included regarding their effects on air pollution, costs and health impacts and evidence was limited to estimates, modelling, laboratory tests or pilot studies. The rapid evidence assessment commented that:

- information is not reported or publicly available, as emerging techniques and new innovations are still being developed or tested
- some of the emerging techniques and innovations with a potential impact on air quality may be driven by other initiatives, such as reducing greenhouse gases (GHG), instead of air quality or health

Strategies emerging from the rapid evidence assessment

There was little direct evidence linking health outcomes with interventions or groups of interventions. Evidence found by the rapid evidence assessment predominantly relates to the wider environmental or economic benefits of interventions to emission reduction. Nevertheless, benefits to air quality and health can be inferred by emission reductions, overall strategies that reduce pollutants (eg, ammonia, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs) and metals), will also be associated with inferred health benefits. However, this was outside the industrial rapid evidence assessment search scope.

The government’s Clean Air Strategy (6) notes a variety of actions are needed to fill the gap between where we are now and what we want the quality of our air to be like in 10 years’ time and beyond. Many technologies and solutions already exist to support the move towards a clean economy, and this is true of industrial interventions. However, in some cases readily available technologies and solutions to air quality challenges are not yet taken up at scale. In these cases, levers such as incentives, disincentives, behaviour change and regulation may help overcome barriers such as a lack of information or awareness, or access to finance. They should be considered as part of overall approaches that comprise both industrial and behavioural interventions.

From the interventions identified, it is clear that the maximum population-level health benefit is associated with effective national policy interventions, such as regulatory frameworks (for example, Industrial Emissions Directive (IED), National Emissions Ceilings Directive (NECD) etc.), whereas local, smaller-scale, benefits can be achieved through local policy decisions underpinned by effective technological interventions at installation level. These provide a means of both meeting population-exposure reduction aspirations and addressing hotspots of poor air quality, through technological interventions, such as abatement measures and eco-design that can improve process efficiency, product quality and reduce emissions to air.

It is important to consider how to maximise co-benefits at both local and national level when considering approaches at the installation, local or national level, including the role of local officials responsible for permitting and enforcement. Though little evidence was found in the rapid evidence assessment of co-benefits to wider health outcomes, they are associated with some interventions. For example, regulation and enforcement has a role in addressing problematic sites, and technological interventions can potentially reduce the likelihood of nuisance noise, dust and odour in proximity to the installations implementing them. A wider co-benefit of many of the industrial interventions is associated with their potential contribution to climate change mitigation through reduced emissions of greenhouse gases, though interventions primarily directed at reducing such emissions were not within the direct scope of the rapid evidence assessment.

Evidence of interventions' effectiveness at addressing health inequalities was lacking, but here, too, there is potential to embed consideration of location-specific spatial and population impacts and benefits, rather than limiting approaches to wider environmental or economic considerations. As there might still be groups in the UK who are affected disproportionately by industrial emissions, regulators must be aware of the potential for such issues when making decisions regarding emission permits.

The policy and technological industrial interventions have clear potential in reducing emissions at local and national level. Broadly speaking, policy interventions have greatest potential to improve public health outcomes at a national level, and technological interventions have the potential to improve local air quality around installations, though local or regional implementation of some of the policy interventions (or parts of their approaches) is possible. When designing strategies at a high level and to ensure that proposals are feasible, it is important to consider current uptake within industry, and the current technological interventions to help sectors meet policy intervention objectives. At a more local level, consideration of the most appropriate interventions may extend to site-specific assessments of their potential to deliver not only benefits to air quality, but also potential health co-benefits and their potential to address health inequalities. Particularly when considering installations in areas already subject to high levels of pollution or rates of ill health, or in proximity to known sensitive populations such as children or the elderly.

Differential application of regulatory controls at local levels based on existing background concentrations of air pollutants or the health profile of the nearby population exists to some extent already, in that the environmental permitting regime gives discretion to the regulator to consider whether installations should go beyond BAT due to the nature of the local area. The extent to which this is applied in practice is worth further consideration. Adopting new approaches in future would require consideration of viability, and consistency and equity in implementation. When considering any intervention at the installation level, the balance between the health benefits of pollution reduction and the potential impacts associated with installation closure or relocation, remain an important consideration.

Combinations of industrial and spatial planning intervention have the potential to enhance one another's impact, and this should be considered in any overall approach in order to maximise synergies between them. This also applies when considering agricultural interventions: the policy-level interventions found in the industrial rapid evidence assessment are applicable higher-level interventions that can facilitate the technological interventions and specific abatement technologies related to agriculture and found by that rapid evidence assessment.

Limitations

The rapid evidence assessment identified limitations not discussed above that noted:

- the list of industrial interventions was not considered prescriptive nor exhaustive and only presents an overview and discussion of possible options. Interventions must be assessed on a case-by-case basis
- there are a wide range of metrics used for effects of industrial (and other) interventions on air pollution and how emissions are expressed; thus, it is difficult to compare (groups of) interventions
- there is a limited amount of information available on variation in damage from industrial emissions for different regions of the UK. It is acknowledged that there will still be groups in the UK who are affected disproportionately by industrial emissions. However, there is no systematic relationship between people working in or living near industry and their exposure to outdoor air pollution. With this in mind, it was not possible to factor equity or distributional issues into the present work

The review sought to examine interventions in a representative sample of different industrial sectors, and not every industrial sector could be examined in detail, rather, the aim was to seek generalisable interventions. As discussed earlier in this chapter, due to this focus on the broad rather than specific picture, some pollutants were not considered within the scope of the rapid evidence assessment. These gaps may bear closer examination if a pollutant-specific or sector-specific focus is required. Aside from the agricultural sector (described in the following chapter), 4% of ammonia emissions come from the waste sector (6), and searches for interventions specifically related to the waste sector or abatement of wider industrial sources of ammonia were outside the direct scope of this review. The same is true of interventions to reduce greenhouse gases (GHG), which may have a positive or negative impact upon air pollution. Interventions found by this review remain relevant across sectors and to industrial processes that produce other pollutants, and anaerobic digestion processes are particularly relevant to both considerations. The role of biomass in providing industrial electricity and heat also bears further consideration, and is recognised in Defra’s Clean Air Strategy (6).

One area that could be extended is consideration of smaller local authority air pollution control (LAPPC) regulated processes and processes not subject to environmental permit requirements. These make a potentially significant contribution to local and wider emissions. Addressing industrial processes without environmental permits is a challenge, as, by their nature, they are exempt from some or all of industrial policy interventions’ requirements and tend to be small-scale and less able to implement costly technological solutions.

Under “inspections and enforcement” the review does not identify evidence in relation to the importance of inclusion of public health considerations in inspection criteria nor ensuring that staff are well trained in public health risk assessment to undertake inspections with due consideration of public health outcomes.

The review found few studies that had assessed the effectiveness of regulation and enforcement; it is important that this not be taken as evidence of its ineffectiveness. This bears further consideration. For example, there is a role in preventing health impacts and nuisance through enforcement of standards, but public health considerations can also be addressed through methodologies and recognition of public health considerations by officials involved in permit writing, determination, and subsequent regulation and inspection. There are clear synergies with interventions related to agriculture and spatial planning.

Further work emerging from the assessment

The rapid evidence assessment, and external peer review comments (see Annexe A2.1), identified areas for further work that could be carried out relatively quickly, including carrying out additional searches for evidence of interventions that could address other pollutants and benefits to ambient air quality. Focuses suggested in the rapid evidence assessment included:

- review permitting approaches to ensure they maximise potential benefits to public health outcomes and account for local health profiles and health inequalities when evaluating applications for installations' environmental permits at installation level (including the possibility of local approaches which impose tighter controls in certain areas or circumstances)
- evaluate the contribution of smaller LAPPC-regulated processes and processes not subject to environmental permit requirements to population-level exposures to air pollution (ie, their cumulative impact)
- innovations with a potential impact of improving air pollution and health
- applicability of interventions given the variability in existing industrial equipment, performance and installation location
- specific consideration of the relationship between industry and spatial planning
- improving consideration of public health outcomes in the regulation of industrial emissions and choice and implementation of associated interventions

The review identified cost-benefit-analysis-based permitting as a policy intervention. There is potential to adapt this approach further to evaluate benefits to health at different scales and to specifically address local costs and impacts; this should be considered as part of any wider use of damage costs to move beyond impact assessment and mitigation to option appraisal and intervention design, with the aim of maximising health gains.

Results: Agricultural interventions

Key messages

This chapter discusses the effectiveness of 6 categories of intervention used to reduce harm from air pollution, based on the rapid evidence assessment (Annexe A5.1). The main points are summarised as follows:

- several promising opportunities for reducing ammonia (NH_3) emissions at farm-level were identified: urease inhibitors and slow-release nitrogen (N) fertilisers, slurry acidification, low NH_3 emission storage and spreading, air filtration systems, and low protein feeding
- the actual impact of such interventions, however, will depend on the extent of uptake on farms as current mitigation strategies rely on voluntary uptake. Understanding the current level of uptake of mitigation measures will be necessary for monitoring progress in reducing emissions against emission targets
- it has not been possible to evaluate the interventions' potential impact at a national scale. This was primarily because limited information was available on the existing uptake of these measures
- a combination of regulations, incentives, and awareness-raising measures will be needed to overcome the barriers to widespread adoption
- no studies evaluated the health and cost impacts related to these interventions. We are therefore unable to advise on which intervention has the highest health and economic impact – this is an area requiring further work
- to maximise co-benefits and minimise negative trade-offs, it will be important to align agricultural interventions with other sector strategies and policies

Background and rationale

The agricultural sector is an important source of air pollution: it is responsible for 88% of the total UK NH_3 emissions (9). Primary sources of NH_3 emissions are livestock excreta (ie, urea) in livestock housing, and manure storage, processing, treatment and application to land. Emissions also occur from the application of nitrogen (N) fertilisers to land.

NH_3 loss to the atmosphere is called NH_3 volatilisation. As pH or temperature increases, more NH_3 is produced. NH_3 can react with atmospheric nitric and sulphuric acids to form fine PM ($PM_{2.5}$), known to cause adverse health effects. It is clear from the foregoing discussion that agricultural emissions include a number of air pollutants that also have potential negative effects on both human and animal health. These emissions have wide-ranging environmental effects, including acidification, eutrophication and climate change, across different geographical scales (ie, local, national and global).

Overview of interventions

Based on the methodology described in Annexe A5.1, a total of 161 papers were identified. To summarise these studies further, 6 major intervention categories were identified, all considered relevant for reducing agricultural emissions to air. These intervention types were then further divided into 35 subcategories of mitigation actions. The categories of interventions and a description of each mitigation action are presented in Table 9 and Figure 7.

Table 9: Categories of interventions and evidence strength

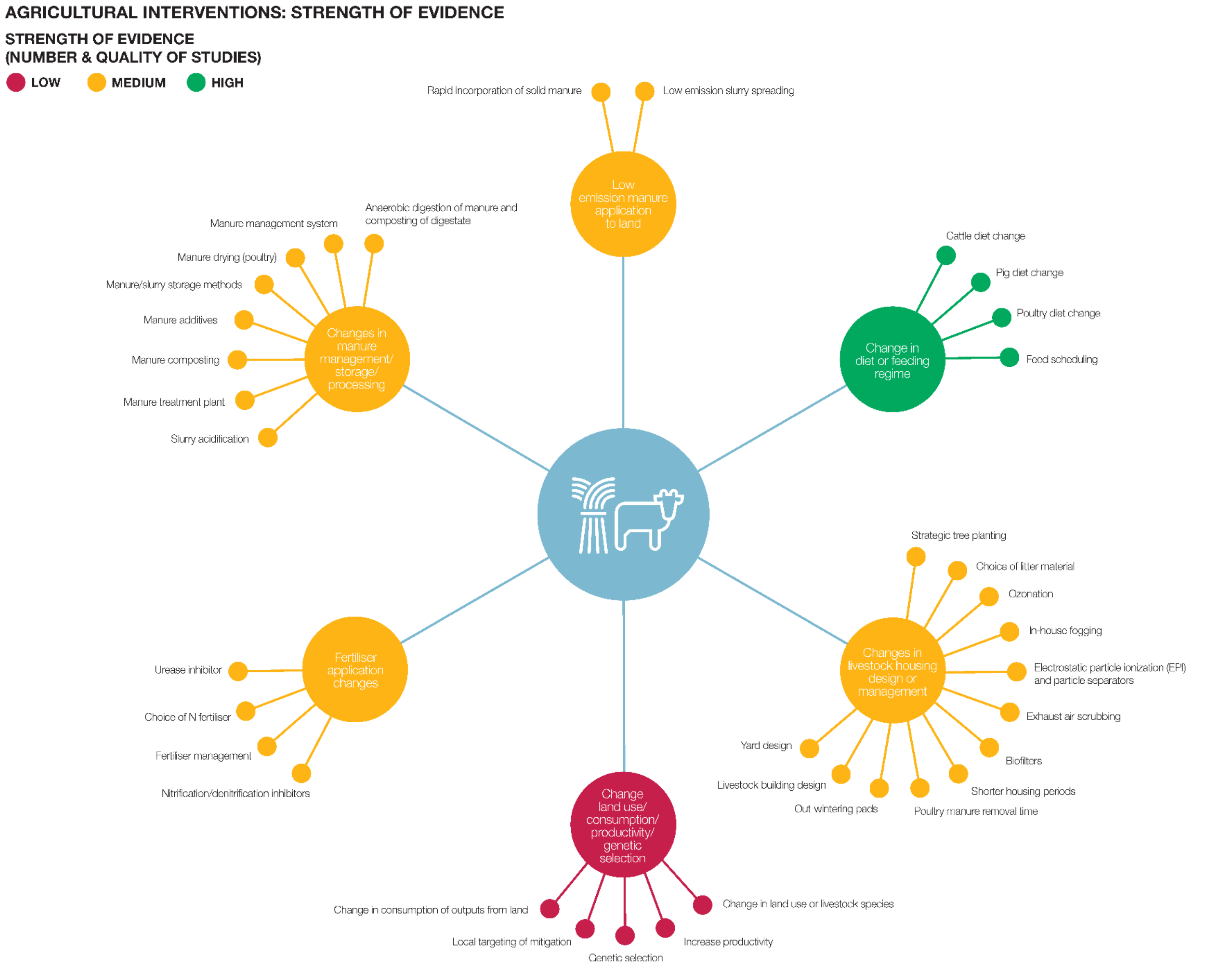
#	Intervention	Mitigation action	Type of intervention	Description/rationale
1	Change in livestock housing design or management	Livestock building design	Prevention	Installation design and flooring which lead to reduced NH_3 emissions
		Out-wintering pads	Prevention	Alternative housing system for winter cattle. The increased filtration and absorption of urine by woodchips, compared with concrete and wooden flooring, increases the physical barrier to volatilisation of NH_3
		Yard design	Prevention	Pressure-washing to remove the urine deposited on the collecting yard surface; thereby reducing NH_3 emissions
		Shorter housing periods for cattle	Mitigation	Urine deposition by cattle at grazing rapidly infiltrates into the soil and is therefore associated with low NH_3 emissions
		Bio-filters	Prevention	Exhaust air from mechanically-ventilated livestock housing is treated by bio-filters to remove NH_3
		Exhaust air scrubbing	Prevention	Exhaust air from mechanically ventilated livestock housing is treated by acid scrubbers to remove NH_3
		Electrostatic particle ionisation (EPI) and Particle separators	Prevention	Induces an electric field that negatively charges air ion, which are then attracted to ground surface and thereby reducing emissions of PM, odours, NH_3 etc.
		In-house fogging	Prevention	Use of fine liquid droplets (eg, oil) to remove pollutants within livestock houses
		Ozonation	Prevention	Ozone application to reduce internal air pollutant concentrations in livestock buildings

#	Intervention	Mitigation action	Type of intervention	Description/rationale
		Choice of litter manure	Prevention	Act as a physical barrier between urine and air above the bedding; thereby reducing NH_3 emissions
		Poultry manure removal time	Prevention	More frequent removal aims to reduce the overall emitting surface of the manure, thereby reducing NH_3 volatilisation
		Strategic tree-planting	Mitigation	Reduce volatilisation of NH_3 by affecting dispersion and also acting as a permeable filter
2	Change in diet or feeding regime	Cattle diet change	Prevention	Reducing the N surplus in the diet while ensuring the requirement of essential amino acids or changing the proportion of dietary N utilised by the animal can reduce the amount of N excreted, thereby reducing the potential for NH_3 volatilisation losses
		Pig diet change	Prevention	In the same way as described above
		Poultry diet change	Prevention	In the same way as described above
		Feed scheduling (or phase feeding)	Prevention	Livestock have different optimum feed requirements at different stages of the life cycle. Phase feeding allows more precise matching of the ration of the individual animal's nutritional requirements. Nutrients are utilised more efficiently and less of the dietary N is excreted, thereby reducing the potential for NH_3 volatilisation losses
3	Change in manure management/storage/ processing	Anaerobic digestion of manure and composting digestate	Prevention	Microbial process that degrades manure in absence of oxygen producing biogas

#	Intervention	Mitigation action	Type of intervention	Description/rationale
		Manure additives	Prevention	Reduce NH_3 volatilisation into the atmosphere
		Manure composting	Prevention	Converts the N present in the raw manure into a more stable form and thereby reducing losses of N to the environment
		Manure drying (poultry)	Prevention	Drying will inhibit the hydrolysis of the uric acid content of manure to NH_3
		Manure management system	Prevention	Includes range of emission control options (eg, more frequent removal of manure)
		Manure treatment plant	Prevention	Includes range of emission control options
		Manure/slurry storage methods	Prevention	Covering stored manure (natural crusts or artificial covers) slows the release of NH_3 into the atmosphere
		Slurry acidification	Prevention	Lowering the pH in slurry with acids inhibits urease activity in bacteria. This in turn, shifts the NH_3/NH_4^+ equilibrium to favour NH_4^+ formation and consequently lowering NH_3 emissions
4	Low emission manure application to land	Rapid incorporation of solid manure	Prevention	Reduces the exposed surface area of the manure from which NH_3 emissions can occur
		Low emission slurry spreading	Prevention	Reduces the overall surface area of the applied slurry, thereby reducing NH_3 emissions
5	Fertiliser application changes	Urease inhibitor	Prevention	Reduces urea hydrolysis and NH_3 volatilisation.
		Choice of N fertiliser	Prevention	Switch from urea-based fertilisers to lower emission fertilisers
		Fertiliser management	Prevention	Careful planning (eg, time, weather conditions) that maximises the efficiency of fertiliser use and reduce the amount of N lost as NH_3

#	Intervention	Mitigation action	Type of intervention	Description/rationale
		Nitrification/denitrification	Prevention	Use of inhibitors of microbial nitrification/denitrification
6	Change land use/consumption/productivity/ genetic selection/other	Change in consumption	Prevention	Change in general consumption pattern of agriculture outputs
		Change in land use or livestock species	Prevention	Strategic land use to mitigate emissions
		Local targeting of mitigation	Prevention	Targeting of mitigation actions in localities where impacts are greatest
		Genetic selection	Prevention	Use of genetic tools to reduce emissions
		Other	Prevention	eg, glasshouse heating

Figure 7. Agricultural interventions



General observations relevant to all intervention categories

Most studies assessing the impact of interventions to reduce exposure have been conducted over short-time periods, and therefore little is known on the potential long-term effects and sustainability of the interventions. Research has mostly focussed on interventions aimed at reducing NH_3 emissions, with little emphasis on other pollutants.

Research outcomes on sources of emissions and emission quantification were the main types of evidence. Air pollutant concentration data were scarce and tended to be local and site-specific.

Changes in livestock housing design or management

A large number of studies fell under this category (52 in total) and encompassed a wide range of mitigation actions. For some of the mitigation actions, there was very little research identified (for example, out-wintering pads and yard design). If properly designed and operated, high removal efficiencies (as great as 100%) of NH_3 and H_2S can be achieved by treating exhaust air in livestock operations with acid scrubbers or bio-filters(142, 143). Though somewhat variable, reductions have also been observed for PM, VOCs, bacteria and odours. These technologies have been adopted with great success in a number of large-scale operations in Denmark, Germany, France and the Netherlands (144, 145). There are a number of considerations that must be taken into account when designing a system to maximise removal efficiency, including, but not limited to, the pH of the bio-filter or scrubbing liquid, system volume and moisture content (145-147). The high retrofitting and maintenance costs are likely to be a significant barrier to the widespread adoption of these technologies in the UK. Abatement systems are, therefore, perhaps most suited to purpose-built new installations.

Creating tree belts downwind from emission sources can act as natural filters for both gases and PM. Indeed, reductions in downwind particulate, odour and NH_3 have been reported (148-150). Estimates of emission reductions varied widely depending on factors, such as tree species, canopy structure and planting area. Tree planting can also have a myriad of other benefits including: 1) visibility screening around housing units; 2) reduced noise emissions; 3) climate change mitigation; and 4) water pollution mitigation. Mitigating agricultural emissions by planting trees also fits well with national afforestation policies, however, if planted on farms this is likely to be a costly abatement option for farmers through the cost of losing productive agriculture land.

Changes in diet or feeding regime

Less than half of the N consumed is retained by the animal and the rest is excreted (often lost as NH_3). Dietary manipulation of animal diets by reducing crude protein intake has successfully been shown to lower NH_3 emissions without affecting livestock performance (151). Reducing crude protein intake is a key NH_3 abatement as it reduces the overall N input at the very beginning of the manure management chain. Most studies have focussed on feeding less protein to cattle and pigs.

The extent to which these methods can be applied depends on the proportion of farms currently feeding excess N and the proportion of forage in diets. Within the pig and poultry sector, there is already a focus on lowering total diet crude protein, and therefore there is limited scope for further reduction. The largest NH_3 reductions are likely to be for housed beef cattle. For dairy cattle, where a large part of the diet is likely to be forage based, emission reductions are likely to be difficult to deliver.

Changes in manure management/storage/processing

Sixty-seven papers were identified that addressed mitigation strategies to reduce emissions during the management, storage and processing of manure. Some of these mitigation measures could be implemented in the UK immediately. This includes:

- more frequent manure removal from laying hen housing with belt clean systems
- installing covers on slurry and manure storage

Covers provide a physical barrier between the solid manure or liquid slurry and the surrounding air. A number of covering techniques are available, including permeable floating covers (eg, straw), natural crusts and impermeable plastic covers. The rapid evidence assessment identified a consistent and reliable body of evidence showing reduced NH_3 and odour emissions following the use of covers for manure and slurry storage facilities.

The increased nutrient retention in the manure may also mean less N fertiliser is needed to maintain or increase crop yields, in turn reducing NH_3 emissions during fertiliser application. Having the capacity to store manure may also allow farmers greater flexibility to time the application of manure to help maximise the efficiency of N use from manures and minimise emissions.

The Nitrate Directive (152) has regulations on the timing of manure application to land, for example during wet conditions. However, this may have a negative knock-on effect on NH_3 emissions with greater manure application during dry and warm conditions, when risk of NH_3 loss is increased. This mitigation measure is best used when combined with reduced emission slurry and manure spreading techniques.

The acidification of slurry can significantly reduce NH_3 emissions during housing and storage, and further downstream during the application of slurry to land. In February 2017, slurry acidification was approved as a Best Available Technology (BAT) (153), as a potential NH_3 mitigation measure for pig farms. Acidification of slurry has proved to be effective in reducing NH_3 emissions in Denmark, where acidification of slurry has become increasingly popular (154). However, there has been low uptake in other countries: this is partly due to cost and safety concerns with the handling of acid. Further research is also needed to assess the effectiveness and applicability to the UK pig sector.

Low emission manure application to land

Manure incorporation into the soil reduces the exposed surface area of the manure from which NH_3 emissions can occur. There was generally consistent reporting of decreases in NH_3 emissions when applied slurries or solid manures are rapidly incorporated into the soil by ploughing or injected deeply (154-156). From 2020, it will be compulsory for German farmers using a urea fertiliser to wither use urease inhibitors or to incorporate urea fertiliser into the soil immediately after application. The evidence was much less consistent when spreading anaerobic digestate (157). The size of emission reductions is largely dependent on the time period between application and soil incorporation. Therefore, precise synchronisation of spreading and rapid incorporation is important to minimise or even negate adverse impacts, whilst maximising the beneficial effects. Incorporation is restricted to land that is cultivated. The high N content in the soil also means that under anaerobic condition this could be emitted as N_2O.

Fertiliser application changes

Urea is the world's most commonly used N fertiliser. Following application, there is an increase in the pH around the urea fertiliser granule, leading to a large potential for NH_3 emission. Indeed, fertiliser application contributes to about 23% of the total agricultural NH_3 emissions in the UK (6). A number of studies have reported the addition of a urease inhibitor into urea fertiliser or switching to a lower release fertiliser (eg, ammonium nitrate (NH_4NO_3)) to be effective in reducing NH_3 emissions (156).

In theory, there should be no practical reasons why these mitigation measures could not be applied across the UK. However, one of the most difficult implementing challenges will be motivating farmers to make the change. Compared with other fertilisers, urea fertilisers are cheaper per unit of N. Therefore, regulatory measures are likely to be needed to facilitate the widespread adoption of actions needed to reduce N fertiliser-related emissions.

Change land use/consumption/productivity/genetic selection

Current evidence is too sparse and inconsistent to permit any conclusions to be drawn.

Overview of interventions

In considering the results of the rapid evidence assessment, together with expert judgement, the contractors assigned the 35 interventions as High, Medium or Low Priority. Below is a list of the High and Medium Priorities, with the highest priority first:

- choice of N fertiliser and/or urease inhibitor (High Priority)
- slurry acidification (High Priority)
- low emission slurry spreading (High Priority)
- manure/slurry storage methods (High Priority)
- bio-filters and exhaust air scrubbers (Medium Priority)
- cattle diet changes (Medium Priority)

This list of priorities is focussed on NH_3 emission and mitigation for 2 reasons: 1) agriculture dominates the emission of NH_3 in the UK, and 2) there is an urgent need to mitigate NH_3 emissions to avoid exceeding internationally-agreed emission ceilings for 2020 and 2030 (158). The level of priority was based on the size of the source of emissions mitigated, the effectiveness for NH_3 mitigation, an expert view of the extent of further uptake, and the practicality of implementation. For more details, please see Table 9 in Annexe A5.1.

Health outcomes

Evidence only addressing the links between air pollution and health impacts without a link to agricultural interventions was not included in the rapid evidence assessment. Whilst many studies looked at the impact of agricultural interventions on emissions, no studies assessed the resultant impacts on health.

Health inequalities

The rapid evidence assessment identified no papers, which contained information on the impact of agricultural/rural interventions on inequality. This lack of an evidence base is clearly a gap, which should be addressed.

Economic impact

The papers assessed were focussed on emissions reductions, and generally lacked information on economic impacts. Few papers contained any economic data, and where data was available, the information was on implementation costs of interventions; generally, this was not current and was in non-UK currency. Most interventions and more specific mitigation actions have implementation costs relating to multiple variables, such as costs of equipment, materials and labour.

What interventions are under development, and what is their potential impact?

There is currently no agricultural policy in the UK specifically targeted at mitigating agricultural pollutants. The Environmental Permitting (England and Wales) Regulations 2016 (159) extend the pollution control regime to the UK agriculture sector by covering intensive pig and poultry installations. These installations must hold an environmental permit, which requires adoption of BAT for their production processes to reduce emissions to air, land and water. Therefore, industrial interventions (refer to industrial interventions listed in the earlier chapter) have significant scope to influence emissions from agricultural buildings. Policies aimed at other objectives, such as nitrate pollution and manure management, can also have some impact on agricultural emissions. A strict regulatory framework has already proven to be effective in reducing NH_3 emissions in Denmark and the Netherlands.

Although there was relatively robust, if at times wide ranging, evidence for the NH_3 emission reduction potential of the mitigation measures at farm (installation) level, it has not been possible to evaluate their potential impact at a national scale. This was primarily because limited information was available on the existing uptake of these measures. Despite the presence of a wide variety of mitigation options in the UK agriculture industry, their adoption is voluntary. For most farmers, changing practice to reduce emissions will incur some cost. Widespread adoption requires an understanding of the factors that motivate farmers and barriers to the adoption and implementation in the UK. Financial schemes, including the Manure Efficiency Technology Scheme, the Farming Ammonia Reduction Grant Scheme (160) and the Countryside Productivity Small Grant Scheme (161), have been effective in achieving some behavioural change among UK farmers.

The degree to which the mitigation measures are already adopted in the UK agriculture industry will influence the overall impact, which might be expected. For some mitigation measures current adoption is expected to be low or non-existent (eg, pig slurry acidification and acid scrubbers), whereas for others they are already widely used (eg, reduced crude protein levels in pig and poultry feeds). However, information available on the existing uptake of the mitigation measures was limited and more detailed data is required to assess the level of implementation as part of any future policy evaluations. Understanding the current level of uptake of mitigation measures is necessary for tracking the progress in reducing emissions against emission targets. This will also help in ensuring that any necessary corrections are made quickly, that unwanted trade-offs do not result and help to understand where activities can have the best impact to promote long-term improvements. For example, despite technologies available to reduce N fertiliser based emissions, barriers remain to widespread adoption. Perhaps one of the biggest challenges is motivating farmers to make the change because of the additional costs involved. Regulatory measures are likely to be needed to facilitate the widespread adoption of actions needed to reduce N fertiliser-related emissions, ensuring slurry stores are covered and that manure is applied using low-emission spreading equipment.

The behavioural interventions discussed in the following chapter are also relevant when considering how to raise-awareness of and encourage practices that are not yet in widespread use within the sector.

Principles: maximising benefits to public health

As noted above, mitigation actions in agriculture rely on voluntary uptake by farmers. Information, awareness-raising and training activities aimed at promoting adoption of mitigation measures will be essential in delivering a range of positive environmental and health benefits. The code of Good Agricultural Practice for reducing ammonia emissions identifies appropriate actions for individual situations and directs farmers to support resources (162).

While many studies have considered the impact of agricultural interventions on emissions, none has followed this up to see the resultant impacts on health. Studies evaluating the costs and health benefits of interventions aimed at reducing agricultural-related air pollution will be important for prioritising measures, which have the greatest public health benefit. It is clear from this rapid evidence assessment that measures to improve agricultural emissions do not always go hand-in-hand with the resolution of other environmental problems, such as nitrate pollution to groundwater and climate change. Therefore, to maximise co-benefits and minimise negative trade-offs, it will be important that agricultural interventions to reduce air pollution are aligned with other sector strategies and policies, including, for example, those aimed at water and climate change.

Consideration should also be given to the mitigation measures already been taken up by an increasing number of farms, namely low protein feeding and covered manure storage. Dietary manipulation of animal diets by reducing crude protein intake has successfully been shown to lower NH_3 emissions without affecting livestock performance. Reducing crude protein intake is a strategic NH_3 abatement as it reduces the overall N input at the very beginning of the manure management chain.

Within the pig and poultry sector, there is already a focus on lowering total diet crude protein, and therefore there is limited scope for further reducing the N content of diets. It is likely that the greatest potential to reduce feed N excretion is in housed beef cattle, which represent the largest livestock NH_3 emissions.

There is a consistent body of evidence at farm-level reporting reduced NH_3 and odour emissions following installation of covers for manure and slurry storage facilities. Reducing odour emissions may have the co-benefit of improving the quality of life of the populations surrounding farms. However, this may have a negative knock-on effect on NH_3 emissions with greater manure application during dry and warm conditions, when risk of NH_3 loss is increased and has the potential to lead to greater NH_3 volatilisation losses during the spreading of manure and slurry to the land. Therefore, this mitigation measure is best used when combined with reduced emission slurry and manure spreading techniques.

Limitations

Some common limitations in the evidence base are listed below:

- there have been no studies evaluating the costs and health effects of interventions. Therefore, the conclusions in the review have not been able to directly answer the review question
- although there was relatively robust, if at times wide ranging, evidence for the NH_3 emission reduction potential of the mitigation measures at farm (installation) level, it has not been possible to evaluate their potential impact at a national scale. This was primarily because limited information was available on the existing uptake of these measures. Understanding the current level of uptake of mitigation measures is necessary for the tracking and monitoring of interventions. This will help to ensure any necessary corrections are made quickly, that unwanted trade-offs do not result and help to understand where activities can have the best impact to promote long-term improvements
- data on costs or intervention implementation were scarce and generally not useful (eg, cost data was out of date or considered not relevant to the UK). No studies attempted to bring together cost and effectiveness data, and therefore it is extremely difficult to estimate even roughly the set of measures needed to reach the emission targets
- most studies assessing the impact of interventions to reduce exposure have been conducted over short-time periods, and therefore little is known on the potential long-term effects, sustainability and cost-effectiveness of the interventions
- the focus of a few pollutants (primarily NH_3) might omit other important pollutants, such as NOx, H_2S and biological pollutants (also called bio-aerosols)
- the interventions identified in this evidence review were mainly changes in agricultural practices and/or use of technical equipment. The literature searches did not identify evidence about effectiveness of legislation or incentives that might require, promote or restrict interventions
- a further gap is work on acidification of slurry in the context of the UK livestock industry. This mitigation action has been adopted in Denmark, but there are many barriers to adoption in the UK, including the need for more research to understand the efficacy of slurry acidification in reducing NH_3 emissions in the UK, as well as concerns in the agriculture sector over safety and costs

Further work emerging from the rapid evidence assessment

Keeping these limitations in mind, there is the need to:

- review the factors that motivate farmers and barriers to the adoption and implementation of mitigation measures (interventions) in the UK and monitor the current level of uptake. This will help to identify and secure ‘quick wins’, identify and avoid unwanted trade-offs, and help to understand where long-term improvements can be made
- evaluate the agricultural sources, distribution and impact of other pollutants (besides ammonia), such as oxides of nitrogen and bio-aerosols
- within the context of UK-wide emissions, NH_3 abatement by slurry acidification needs further study
- characterise how agricultural mitigation measures can be aligned with other sector strategies and policies (eg, water and climate change) to maximise co-benefits and minimise negative trade-offs
- conduct studies which also consider the impact of agricultural/rural interventions on inequality

Results: Behavioural interventions

Key messages

This chapter discusses the effectiveness of 9 categories of behavioural interventions to reduce harm from air pollution, based on the rapid evidence assessment (Annexe A6.1). The main points are summarised as follows:

- behavioural interventions comprised educational or awareness-raising initiatives. Other approaches highlighted in the studies included incentivisation and training
- the highest potential to improve air quality and public health outcomes is associated with combining behavioural interventions with other policy or infrastructure-based interventions (eg, improving public transport or cycling infrastructure and then using behavioural interventions to maximise its use). In this way, behavioural interventions can be used in parallel with other interventions and maximise their potential effectiveness
- for all the behavioural interventions identified, the effectiveness to reduce emissions of air pollution was low and the uncertainty range was high, except for 2 interventions (eco-driving training and large-scale national events, which the rapid evidence assessment considered of medium effectiveness strength and uncertainty range). However, the paucity of evidence of the behavioural interventions' effectiveness should not be taken as evidence of ineffectiveness
- little evidence was identified of behavioural interventions that promote alternative methods of transport as having a direct impact on air pollution or health outcomes. However, they should not be discounted, as there is a wealth of evidence showing that removing vehicles from the road can reduce emissions. There is also strong evidence for the health benefits of physical activity associated with active travel, such as walking and cycling
- raising awareness in itself is not enough to effect change: it must be done in conjunction with other behavioural and non-behavioural interventions

Research questions

What evidence is there for interventions which raise-awareness, promote behavioural change and reduce harm from air pollution?

Twenty-five documents, identifying 23 individual interventions, were shortlisted for inclusion in the rapid evidence assessment. Many of the studies focused on educational or awareness-raising initiatives. Other ‘intervention functions’ highlighted in the studies included incentivisation and training initiatives.

The rapid evidence assessment identified the following behavioural interventions, which are presented in Figure 8 and Table 10, together with their principles.

Table 10: Behavioural interventions

Intervention	Type of intervention	Description/principles
1.Promotion of walking and cycling	Prevention	To encourage a move away from polluting forms of transport
2. Public engagement	Prevention/ Mitigation/ Avoidance	To involve the public in understanding the issues, for example citizen science initiatives to measure air pollution
3.Investment in public transport	Mitigation	To increase public transport use
4. Eco-driver training	Prevention	Eco-driving is a way of driving that increase fuel efficiency, speed and safety
5. No idling campaigns	Prevention	Idling is when a vehicle’s engine is left running while parked or stationary
6. Eco-travel co-ordination programmes	Prevention	Education to encourage changes in travel behaviours including raising awareness of impact and encouragement to use other methods
7. Air quality messages/alerts/indices	Avoidance	Information on current or forecast levels of air pollution communicated to the public
8. Personal exposure-reduction programmes	Mitigation/ Avoidance	Actions to reduce health risks from personal exposure to air pollutants
9. Clean air days	Prevention/ Mitigation/ Avoidance	Awareness days

Figure 8. Behavioural interventions

Identify and prioritise implementable behavioural interventions or groups of interventions

The evidence presented in the rapid evidence assessment mainly related to smaller-scale local awareness-raising interventions. However, national clean air days were also included within the assessment and public engagement was considered a scalable intervention that could be implemented locally or nationally.

Most of the interventions identified were considered to have low effectiveness strength and a high uncertainty range, except for eco-driving training and large-scale national events, such as the Global Action Plan National 'Clean Air Day'. These 2 interventions were considered to have the potential to have medium effectiveness strength and uncertainty range, although the latter is based on a single paper.

The evidence for eco-driving training found by the rapid evidence assessment was assessed to be of medium effectiveness strength and uncertainty range. However, the NICE guidelines on outdoor air pollution (115) recognised their potential impact, promoting a smoother driving style by using speed limits and average speed technology could help reduce emissions of air pollutants. Real-time feedback of information to drivers could also encourage smoother driving style. Such approaches, as well as signs that display a driver's current speed (discussed in the vehicle/fuel chapter), may reduce overall speeds in urban areas without requiring physical measures such as traffic humps and bumps that may inadvertently cause acceleration and deceleration.

Clean Air Day is a national awareness campaign run by the charity Global Action Plan as an annual event. In 2018, it raised awareness of sources of both outdoor and indoor pollutants and tips for reducing pollution. The evidence cited, from a single paper, suggested that this type of intervention could have a moderate impact on health, due to its medium effectiveness strength and uncertainty range. Large-scale events have the potential to reach a large audience and reach can be increased through collaborative working and national and social media. The Trans Theoretical Model (TTM) (163) posits that health behaviour change involves progress through 6 stages of change: precontemplation, contemplation, preparation, action, maintenance, and termination. Based on this, a successful awareness campaign tailored to the context, values, language, and resources available to local audiences can move people to different stages of change, for example, from contemplation to determination or determination to action. However, annual or one-off events can soon be forgotten, and evidence of their effects’ persistence is limited. Following the event, people may return to their old behaviours.

How are these interventions implemented?

Raising awareness of air pollution was implemented by alerting systems and campaigns, providing advice on actions to reduce emissions of, and exposure to, air pollution. Interventions to influence travel related behaviours were implemented via training, awareness-raising, campaigns and incentivisation.

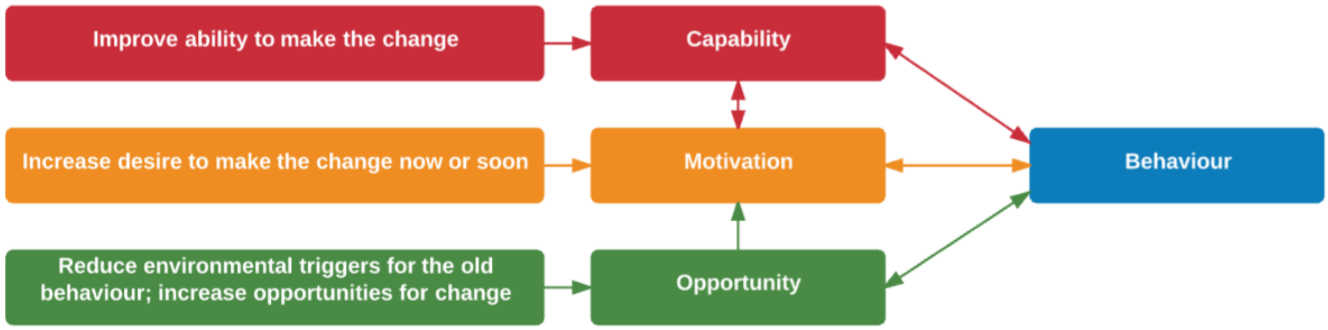
The intervention case studies assessed by the rapid evidence assessment were implemented at a local or regional scale, apart from National Clean Air Day. The rapid evidence assessment noted that achieving significant changes in behaviour and reducing road transport demand and traffic emissions required combination of a wider range of soft and hard measures to boost the effectiveness of the overall approach (164). For example, the provision of public transport information and marketing, including advertising campaigns and simplified ticket schemes – ‘soft measures’ – alongside ‘hard’ policies aiming to decrease the attractiveness of car use by introducing economic disincentives, laws and regulations, as well as modifying physical environments (eg, through road closures, road tolls, congestion charging, traffic calming, increased prices of fuel and vehicle ownership, and reduction of road capacity).

Behaviour change interventions can have a broad reach across the whole population, thereby having potential to lead to population-level exposure reduction. This supports implementation of awareness-raising interventions at the national scale (such as Clean Air Day or the recent “wood sure” campaign by Defra (165) to encourage the burning of dry wood in domestic heating stoves) conducted in parallel with other national-level policy interventions. Behavioural interventions also have potential longer-term benefits, if beliefs and attitudes change over time and become normalised. This may require sustained awareness-raising strategies.

Unintended consequences must also be considered. For instance, any intervention that reduces congestion on the roads, such as by taking steps to increase car occupancy, could have the unintended side effect of making car travel more attractive because of the reduced congestion; hence creating a negative feedback loop, increasing emissions from traffic after an initial decrease.

The evidence assessment concluded that behavioural frameworks were not always used when interventions or evaluations of interventions were designed, confirming the perception of Michie et al (166) that few interventions identified in the rapid evidence assessment were based on a recognised behavioural framework. The Michie et al study demonstrated that for behaviour change interventions to be effective, it is essential to ensure that people have the capability, opportunity and motivation to change. All 3 of these need to be in place for a successful intervention. This broad principle has been captured by the ‘COM-B’ model of behaviour (Figure 9).

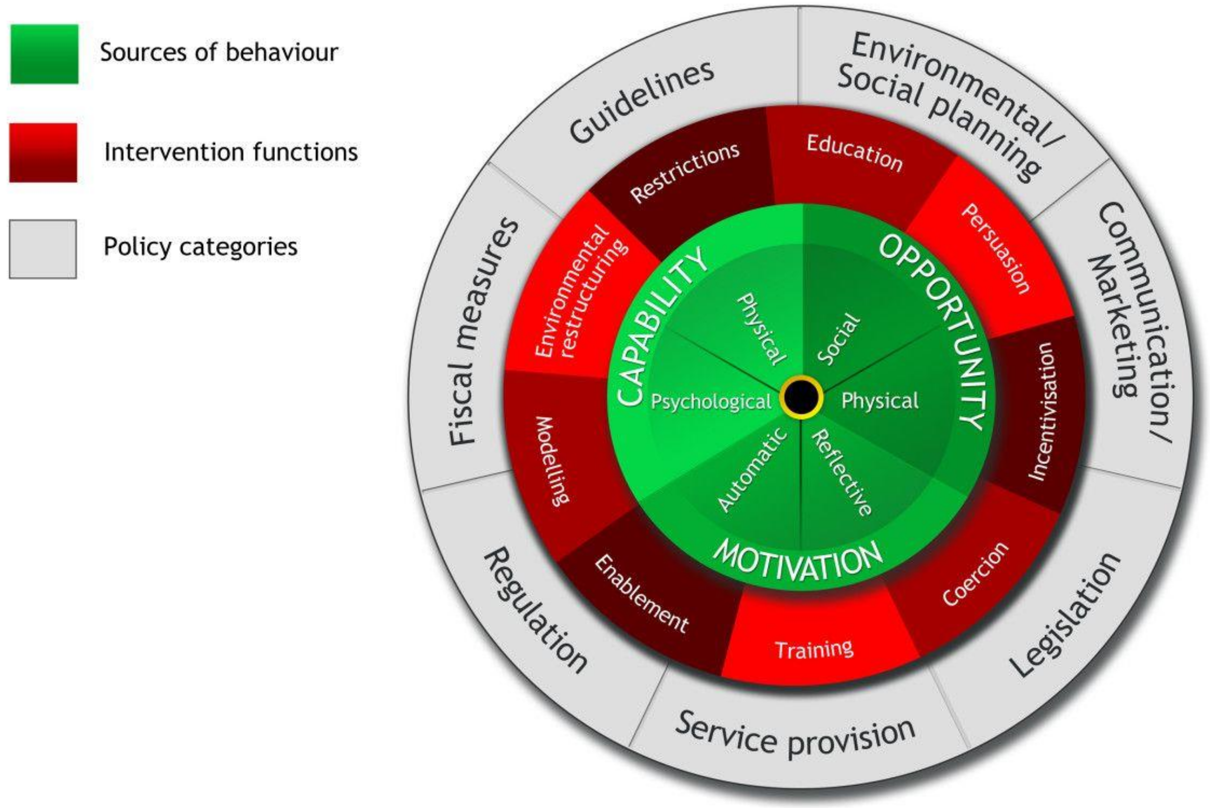
Figure 9: The COM-B model of behaviour change (from (167))



The COM-B model underpins the 'behaviour change wheel' (BCW) (166) (Figure 10), around which are positioned the 9 intervention functions aimed at addressing deficits in 1 or more of these conditions (capability, motivation and opportunity, in red shading); around this are placed 7 categories of policy (in grey shading) that could be potential targets for behaviour change initiatives.

The “behaviour change wheel” in Figure 10 presents different categories of behavioural interventions.

Figure 10: The behaviour change wheel (166)



The COM-B model has been effectively applied to encourage smoking cessation in a given population or sub-population (for example, low-income smokers, smokers with mental health problems or pregnant smokers) (167). Examples of successful behaviour change interventions in relation to smoking-cessation include:

- social marketing via mass media, social media and other promotional platforms. This was seen as a key driver of motivation to change behaviour (quit smoking) through calls to action and reminding smokers about quitting and the best ways to do it
- brief advice from a healthcare professional was still one of the most important triggers to behaviour change (quitting), especially if it involved the offer of support

Based on the evidence, how effective are these interventions in reducing air pollution source emissions/environmental concentrations/exposure and affecting health outcomes? What is the strength of evidence regarding effects?

The rapid evidence assessment found no evidence of health benefits or impacts being directly linked with behavioural interventions relating to air pollution reduction. However, many of the interventions were focussed on changing behaviours and not the consequences/impacts of the change in behaviour (eg, reductions in environmental concentrations of pollutants).

As a standalone intervention, the interventions related to the promotion of walking and cycling and of the use of public transport had no or limited effect on environmental concentrations. However, targeted communications can encourage defined population groups to adopt active and sustainable transportation modes, reaping multiple co-benefits in the form of increased physical activity and reduced body mass. For example, Mutrie et al (168) showed that the implementation of the “Walk in to Work Out" information pack to a randomised intervention group increased the uptake of walking to work nearly 2 fold compared to the control group after 6 months (odds ratio of 1.93, 95% confidence intervals 1.06 to 3.52). Of the intervention group who received the pack at the start of the study, 25% were regularly actively commuting at the 12-month follow up stage. Whilst no effect on environmental concentrations was measured as part of this study, the uptake of alternative methods of travel reduced car journeys. This may be inferred to have reduced local concentrations of pollutants. There would also be health benefits from physical exercise of those who were walking to work.

Public engagement is a process that brings people together to address issues of common importance, to solve shared problems, and to bring about positive social change. Effective public engagement invites citizens to get involved in deliberation, dialogue and action on public issues that they care about. Public engagement can take many forms: the rapid evidence assessment found studies demonstrating the use of citizen science to educate different public groups, and scheduled events in which streets were closed to motorised vehicles and opened for recreational activities. Despite the diversity in the identified interventions, they all aimed to raise awareness of how individuals’ behaviours can affect emissions or exposures, with the aim of changing polluting behaviours to reduce air pollution.

Whilst the rapid evidence assessment found no evidence that public engagement alone led to a positive reduction in air pollution, a notable TTM finding over the past 30 years has been that moving people forward by 1 stage will roughly double the odds that they will ultimately take action and change their behaviour (169). Therefore, public engagement can been seen as a simple, potentially low-cost incremental process, particularly useful for moving those at the earliest stages of change (170). Whilst Clean Air Days were distinguished in the rapid evidence assessment as a separate intervention type, the general principles of the intervention are similar in nature to public engagement/awareness raising events. It is therefore more helpful to consider Clean Air Day as a public engagement event of limited time (a single day), scaled for national coverage, resulting in similar effects. Direct evidence of the effects of public engagement interventions on air quality and health outcomes remains limited.

The NICE guidance on general approaches to behaviour change (171) concluded that actions to bring about behaviour change might be delivered at individual, household, community or population levels using a variety of means or techniques. Outcomes do not necessarily occur at the same level as the intervention itself. For example, population-level interventions may affect individuals, and community and family-level interventions may affect whole populations. This poses a challenge regarding the choice of metrics with which to evaluate such interventions, particularly those related to air quality and health.

Whilst not highlighted in the rapid evidence assessment, vehicle choice (ie, the impact of consumer choice) can reduce air pollution if it leads to the removal of the most polluting vehicles from the roads or the replacement of one vehicle with another, less polluting, vehicle. Increased public concern regarding air pollution from diesel cars has been cited as a reason for the current downward trend in their sales reported by the Society of Motor Manufacturers and Traders (SMMT) (172).

Eco-driving (including improved driving behaviour and reduced engine idling time), smooth driving and speed reduction can reduce fuel consumption and potentially pollutant emissions. Ensuring motorists drive steadily at an optimum speed can help reduce stop-go driving and so reduce exhaust emissions, as well as particles emitted from brake wear. Furthermore, reducing traffic speed in residential areas can help encourage walking and cycling and reduce traffic-related injuries.

Sharing common themes with eco-driving interventions, the rapid evidence assessment identified anti-idling campaigns as a type of behavioural intervention. These interventions included awareness-raising sessions and training across 3 separate intervention studies, and the assessment concluded that the interventions had a medium effectiveness but a high uncertainty range, due to the nature of the studies. The study by Xu et al (173) fitted an idle detection system to 480 buses in the Cobb County (Georgia) School District to track vehicle activity and provide notification of idling events exceeding 5 minutes. Emissions and fuel savings were evaluated with the US Environmental Protection Agency's MOVES (Motor Vehicle Emission Simulator) model (174). The reduction in idling that resulted was statistically significant: more than 6 minutes fewer idling per bus per day. The anti-idling program reduced total annual emissions of criteria pollutants (oxides of nitrogen, particulate matter, and carbon monoxide) by 1.82 tons (3.43 kg per bus per year) and annual emissions of carbon dioxide by 53.3 tons (100.74 kg per bus per year). The paper estimated that approximately 41,100 children riding the buses or attending schools served by the buses were positively affected by the idle-reduction system.

Whilst this paper was from the US study, and the bus fleet composition would differ from the UK, such approaches could be implemented in this country. In 2017, there were 34,900 buses registered in England (DfT) (175). Following the approach above and assumptions regarding fleet composition and similar reductions in idling, this could result in an approximate reduction of 120 tonnes of air pollution. However, the number of local bus passenger journeys in England decreased by 1.4% between March 2017 to March 2018 (176). Understanding the reasons for this will be important if the public are to be encouraged to take public transport to reduce emissions of air pollution.

A second US study identified review also showed a reduction in idling of over 50% following an anti-idling initiative; however, the associated reduction in emissions was not estimated. An additional study in the US by Ryan et al (177) that was not highlighted in the rapid evidence assessment demonstrated that following an anti-idling campaign at 4 schools there were reductions in $PM_{2.5}$, elemental carbon and particle number concentration.

The rapid evidence assessment identified several studies in the category of ‘exposure reduction’. All the studies identified related to encouraging peoples’ avoidance of high-polluted areas. They particularly aimed to reduce exposure to high air pollution for vulnerable groups, through awareness-raising. The nature of the intervention was such that there was unlikely to be an effect on emissions or environmental concentrations of pollutants.

Whilst defined in the rapid evidence assessment as a separate intervention type, the use of air quality messages/alerts/indices is in essence an exposure reduction programme. Participants typically receive personalised alerts regarding air quality at regular intervals (usually daily). Whilst not addressed in the evidence review, 2 studies reviewed the impact of air pollution personal alert systems on health. A feasibility study by King’s College, London, (178) indicated that if the ‘airAlert’ (Sussex-air) developed as part of a forecast service provided by the Sussex Air Quality Partnership (179) were provided to the whole of the Sussex population, and 67% of people took action that was 100% effective, around 250 respiratory hospital admissions could potentially be avoided over a 6 year period. Increased benefits were predicted if the service were expanded to increased numbers of asthmatics (though statistically, tens of thousands would need to receive the service to avoid 1 asthma admission). Targeting the service at patients with chronic obstructive pulmonary disease (COPD) could also have small benefits. They estimated that 850 COPD patients would need to receive the service to avoid 1 COPD admission over 6 years), with increasing benefits for larger numbers, assuming the actions were effective.

A similar study by Lyons et al (180) concluded that personalised air quality alerts were associated with *increased* emergency admissions for respiratory conditions and questioned the benefits of implementing near real-time personal pollution alert systems. One concern is the increase in ‘worried well’ seeking health care advice, and highlights the importance of appropriate messaging with clear actions and advice. The evaluation by King's College noted that focus group research showed that the service was valued by carers and relatives in addition to the affected individuals.

A single paper was identified on the introduction of an eco-travel co-ordination programme in Japan. The rapid evidence assessment indicated that though this intervention was associated with a high uncertainty range, mileage was reduced and attitudes changed within the participant group versus the non-participant group following the intervention. Whilst no effect on environmental concentrations was measured in the study, reductions in mileage may lead to benefits for air quality and health.

Health outcomes

Two papers examined the health effects of the alternative transportation strategy implemented during the 1996 Olympic Games in Atlanta (USA). These looked at a package of interventions that were implemented to reduce traffic density in the city centre during the event. Part of the package of intervention measures included public engagement interventions such as awareness-raising to suggest alternative work hours and tele-commuting and public warnings of potential traffic and air quality problems. Friedman et al (181) showed that introduction of this package of intervention measures decreased traffic density in the city centre during the Olympic Games, with an associated reduction in O_3 levels and significantly lower rates of acute care visits and hospitalisations for childhood asthma. However, Peel et al (182) observed little or no evidence of reduced emergency department visits for respiratory and cardiovascular conditions during the Olympic Games, despite O_3 concentrations being approximately 30% lower during the Games compared with the baseline periods. The meteorological conditions at that time, along with reductions in O_3 levels observed in cities near Atlanta, which were not impacted by the Games, suggested that both meteorology and reduced traffic might have played a role in the observed reduction in O_3 concentrations and childhood asthma hospitalisations in Atlanta over that period. This demonstrated the difficulty in evaluating the effects of interventions on air quality, particularly in the short-term.

There is strong evidence that increasing the uptake of active transport and replacing car journeys can lead to public health benefits associated with increased levels of physical activity. For society as a whole, the benefits of increased use of active transport (cycling and walking) can be even larger if enough modal shift is achieved to secure reduced emissions of air pollutants and fewer traffic collisions. Behavioural interventions that promote cycling are likely to have net beneficial effects on public health only if accompanied by suitable transport planning and safety measures (183).

Health inequalities

The rapid evidence assessment did not identify any papers that contained information on the impact of behavioural interventions on health inequalities. However, 2 of the studies identified during the review related to exposure-reduction programmes specifically targeted vulnerable or susceptible groups. A study by Araban et al (184) focussed on the education of pregnant women and a study by Spurr et al (185) evaluated the effectiveness of the Canadian air quality health index (AQHI) in informing vulnerable groups. Whilst there was limited or no evidence of the impact of these interventions on health inequalities, in principle they have the potential to be effective. This was reflected in PHE's public health evaluation of behavioural interventions (Table 22), which indicated that exposure-reduction programmes are potentially effective at addressing health inequalities.

The strength of evidence of benefits associated with the use of health indices or pollution-event messages was similarly limited. However, the use of personalised messaging systems can help to minimise the exposure of the most vulnerable in society (eg, to warn people with pre-existing respiratory conditions of high levels of air pollution so that they are able to reduce their exposure or moderate their activity levels), as well as influencing the behaviour of the general public.

Reducing strenuous physical exertion outdoors is recommended on days of high air pollution, particularly for at-risk individuals (eg, adults and children with heart or lung problems (186)). There is anecdotal evidence that this advice is sometimes misinterpreted as advice to stay indoors, illustrating the importance of careful messaging to avoid unintended consequences. In the longer-term, the benefits of reducing exposure to pollution must be balanced against the physical and mental health benefits of outdoor activity; this is a consideration both when designing interventions based on alerts or longer-term exposure reduction.

What is the cost, and how cost-effective are these interventions? What is the strength of evidence regarding effects?

The rapid evidence assessment found no substantive evidence of economic costs and benefits associated with behavioural interventions in any of the papers identified.

What interventions are under development, and what is their potential impact?

The PASTA project (Physical Activity Through Sustainable Transport Approaches) (187), which has recently been completed (October 2017), was identified as developing intervention. This project focuses on increasing the physical activity of European citizens in the urban environment using a mixed-method and multi-level approach that is consistently applied in 7 case study EU cities. Determinants of active mobility (walking and cycling for transport) and the evaluation of measures to increase active mobility are investigated through a large-scale longitudinal survey involving 14,000 respondents. The project aims to use the empirical findings to improve health impact assessment for active mobility, for example, with estimates of crash risks, factors for active mobility/physical activity substitution and carbon emissions savings from mode shifts. This will inform the WHO's online Health Economic Assessment Tool for the health benefits of cycling and/or walking (131). This study's wide scope, the combination of qualitative and quantitative methods and health and transport outcomes, the innovative survey design, the general and city-specific analyses, and the transdisciplinary composition of the consortium and the wider network of partners may produce relevant insights for research and practice.

Peer review comments of the rapid evidence assessment noted that multiple interventions that fulfilled the search scope may have been been carried out over the last 5 years, but may not (as yet) have resulted in being published in peer-reviewed literature.

Principles: maximising benefits to public health

Behavioural interventions were defined by Michie et al (166) as “co-ordinated sets of activities designed to change specified behaviour patterns”. The authors indicated that interventions were commonly designed without reference to a behavioural framework (model of behaviour). This suggests that there are opportunities to do so when considering the design of future interventions and overall strategies to maximise the impact of behavioural interventions and effectively supplement other interventions, such as transport or spatial planning interventions associated with new infrastructure or policy incentives to use lower emissions vehicles.

Strategies emerging from the rapid evidence assessment

The rapid evidence assessment of behavioural interventions found little direct evidence of public health benefits from any individual intervention or group of interventions. To achieve significant changes in behaviour (and associated reductions in emissions), a wide range of soft and hard measures need to be combined to maximise the effectiveness of the overall package of interventions.

Hard policy measures modify the objective environment. There may be changes in the mode of travel if car users perceive any changes in the environment (eg, blocked highway lanes) and deliberately reflect on the consequences it may have for the possible set of travel options (eg, resulting in increased travel time by car). They may judge that these consequences provide sufficient reasons to change current car travel (eg, public transport may provide a faster service). In contrast, soft policy measures directly influence car users' decision-making by altering their perceptions of the objective environment, by altering their judgements of the consequences associated with the use of different travel options, and by motivating and empowering them to switch to alternative travel options (188).

The limited evidence of behaviour change interventions benefiting air pollution and health outcomes provides some support to the view that raising awareness in itself is not enough to effect change: it must be done in conjunction with other interventions. Behaviour change interventions should, therefore, be implemented alongside wider policy, planning, and transport interventions and designed in from the start.

Successful large-scale campaigns, such as smoking cessation, use the principles and frameworks of behavioural change theory (167, 189). The rapid evidence assessment indicated that behaviour change interventions should address the following points during the design phase of an intervention:

- involve the stakeholders as early as possible
- ensure the intervention has visibility
- raise awareness using good communicators and accurate, clear messaging
- reward behaviour change or intention to change (provide reasonable incentives)
- work with other specialists, such as healthcare practitioners or public health practitioners, to co-design materials
- use trusted messengers
- encourage social norming of desired behaviours
- understand that raising awareness in itself is not enough to effect change: it must be done in conjunction with other interventions
- work with local groups (eg, local authority and community groups)

Consideration must also be given to work-based behaviour change and (locally-led) staff engagement with broader community approaches.

There is a broader need to raise awareness of the impact of air pollution on health to change people's behaviour (ie, explain the problem, then provide and direct people to the solutions). Whilst evidence indicated limited evidence of benefits to air quality and health from awareness-raising alone, it can be used to increase public awareness and galvanise support for action. This has the potential to have a synergetic effect and increase the potential feasibility and effectiveness of interventions to improve air quality and health.

Limitations

The limited number of studies highlighted by the rapid evidence assessment were assessed as having low confidence in strength of effectiveness and uncertainty.

However, for some behavioural interventions, other evidence exists that was not within the search scope (as it may not have made direct links between interventions and air pollution and health). For example, a study by Moser and Bamberg (190) reported on a meta-analysis of 141 studies evaluating the car-use reduction effects of workplace travel plans (44 studies), school travel plans (25 studies), and travel awareness campaigns/marketing of public transport (72 studies). Inclusion of these latter studies may have provided additional detail on which to base evaluations of the promotion of public transport.

The scope of the rapid evidence assessment focussed on interventions linked to effects on air pollution and health, of which there was limited evidence. Extending the search to standalone behavioural interventions (ie, those relating to behavioural outcomes such as use of public transport from which emission or exposure reduction would have to be inferred) could have greatly broadened the scope of the review and evidence considered, though drawing conclusions as to interventions' potential benefits for air quality and health would remain a challenge. For example, research co-ordinated by the Economic and Social Research Council has addressed social research and this wider behavioural research is relevant to consideration of behavioural interventions related to air pollution. There is also a relevant body of scientific research examining decision-making in general.

Behaviour change interventions are often combined with other interventions and it is difficult, therefore, to separate their effects. For example, the rapid evidence assessment highlighted papers by Brand et al (191) and Sahlqvist et al (192), which focussed on the promotion of cycling, and walking infrastructure installed and/or upgraded following the large nationwide intervention, Connect2 (193), implemented by Sustrans. Behaviour change studies, specifically those that are combined with other interventions, require a clear approach to disentangle the effect of the separate parts of the intervention package.

Studies tend to focus on the uptake of behaviour: for instance, the outcome measured for 'promotion of public transport' interventions tended to be uptake or use of public transport. Stronger links between these changes in behaviour and consequent effects on air pollution and health are needed.

Other known behavioural interventions involve awareness-raising of personal exposure through the use of low-cost sensors and personal monitoring equipment – whilst the potential of citizen science initiatives to effect wider behaviour change was not well evidenced in this rapid evidence assessment, it is worth further consideration.

The specific role of different forms and routes of communication was not considered in detail within the rapid evidence assessment. The role of the media, for example, TV

and radio news, social campaigns, website information, newsletters, social media all bear closer evaluation when designing specific behavioural interventions
formal evaluations of the DAQI and air-text messaging services have taken place (178, 180); wider evidence not found within the evidence assessment may inform future reappraisal of the effectiveness of some of the interventions found.

Further work emerging from the rapid evidence assessment

The rapid evidence assessment concluded that there were 4 broad areas to consider for future research:

- development of interventions using a behavioural framework (such as the COM-B model and Behavioural Change Wheel (166)) to better identify facilitators, barriers and levers to behaviour change
- more work is required to identify how various behaviours might differ from each other and which tools might best be used for understanding causal processes or for effectively achieving change
- researchers need to consider longer-term follow up of behavioural interventions, which are required to establish if behaviour change and benefits can be sustained
- evaluation of the effectiveness of social marketing, particularly in transport planning and travel behaviour (194)

Results: Using a modified Delphi to rank air pollution problems

Following receipt of the 5 rapid evidence assessments and use of the large scale modified nominal group technique (NGT) at PHE’s May 2018 air quality stakeholder event, 87 unique air quality problems were identified across the 5 topic areas (industry, spatial planning, vehicles / fuels, agriculture, and behavioural). Eleven of these problems were deemed relevant to all rapid evidence assessment topic areas and were presented in all 5 topic areas of the survey, leading to a total of 101 problems presented for scoring (see Annexe 7 for full details).

During round 1 of the Delphi process, 135 participants (12% of invitees) completed the survey. For 63 out of 101 (62%) of the air quality problems consensus was achieved, and 6 additional problems were suggested by respondents.

During round 2, 84 participants (7% of invitees) completed the survey. For 65 out of 107 (60%) of the air quality problems consensus was achieved.

The results from the Delphi study informed understanding of the perception of different groups of the relative importance of different problems, and the potential prioritisation of air quality problems. The results did not necessarily indicate an acceptance or willingness to act on a problem. By the nature of the Delphi study, the air quality problems with in a single domain (eg, transport, industry etc.) were compared, and the relative importance of different domains was not explored. Consideration of the heterogeneous nature of the Delphi sub-panels for each domain and different numbers of respondents within them is necessary when comparing sub-panel views across different domains (limitations of the Delphi study are discussed in more detail in in Annexe A7).

During both rounds the median response value across the whole Delphi panel for each individual air quality problem was at least 3 (‘quite important’) for all of the problems but 1: Problem 1.3 (There is too much industry in the UK) scored a universal median of 1 (‘unimportant’) during both rounds of the Delphi process.

Table 11 to Table 15 below show the final stakeholders’ importance ratings for each of the air quality problems across the 5 separate evidence review domains.

Likert scale: 5 (‘extremely important’), 4 (‘very important’), 3 (‘quite important’), 2 (‘somewhat important’) or 1 (‘unimportant’).

Table 11: Delphi results (5: Extremely important)

Score	Industry	Spatial planning	Vehicle/fuel	Agriculture	Behaviour
Extremely Important ('5')		There is too much congestion and traffic flow is very slow, leading to increased air pollution	People rely on the convenience of their cars for short journeys (for example the school run or local shops) instead of considering alternatives		There is too much congestion and traffic flow is very slow, leading to increased air pollution
		When new developments are designed and constructed, access to green space, active travel and social interaction (to increase self-sufficiency) are not fully addressed	There are too many vehicles in urban centres		There is a lack of public transport use
		There are too many vehicles in urban centres	There are too many vehicles on the roads		People rely on the convenience of their cars for short journeys (for example the school run or local shops) instead of considering alternatives
		There is a lack of public transport use	There is too much congestion and traffic flow is very slow, leading to increased air pollution		There is a lack of consistent messaging due to shifting priorities and competition between health, environment and economic growth
		There are too many vehicles on the roads	The uptake of low emission vehicles/electric vehicles is low as they are not affordable/desirable and have a limited mileage range		There are too many vehicles in urban centres
			There is a lack of public transport use		

Table 12: Delphi results (4: Very important, Table 1 of 3)

Score	Industry	Spatial planning	Vehicle/fuel	Agriculture	Behaviour
Very Important ('4')	The current regulations allow too much air pollution to be emitted	Mitigation of air pollution exposure from traffic is not included in the design of new developments (eg Green infrastructure, abatement technologies)	Emissions from existing vehicles, in particular commercial vehicles	Housing livestock indoors for too long leads to increased emissions to atmosphere	There is a lack of public awareness of active travel infrastructure (eg cycle lanes, pedestrian walkways etc.)
	Some industrial processes, such as heating and cooling, lead to too much pollution due to a lack of environmental standards and guidance	There is a lack of clean energy technology incorporated in the design and construction of new developments	There is a lack of transparency from vehicle manufacturers regards vehicle emissions standards and engine performance	Air pollution is not factored in during the design phase of new farms	There is a lack of public awareness of the impacts air pollution can have on health
	It's too difficult to enforce available legislation following breaches of the emission limits	There is a lack of awareness of the environmental benefits of working from home	There are too many old and heavily polluting commercial vehicles on the road and fleets are not updated fast enough	Livestock being fed poor quality feed for economic reasons can increase emissions	There is a lack of public awareness of eco-driving techniques and the positive impacts it can have on the environment
	Not enough is being done to educate and influence and incentivise the industrial sector to address the impacts of air pollution	Emissions from existing vehicles in general	There are too many old and heavily polluting buses on the road and fleets are not updated fast enough	Manure from agricultural sites leads to direct emissions to atmosphere	People leave their vehicles running when stationary for a long period of time (Idling)
	Industrial sites lead to fugitive emissions including dusts and Volatile Organic Compounds (VOCs)	The impact a development has on air quality is not seen as important as its impact on the economy	It is too difficult for people to start active travel	Slurry from agricultural sites leads to direct emissions to atmosphere	There is a lack of awareness about the impact on health from air pollution amongst frontline health professionals which can limit the advice they can give
	Industrial sites emit pollutants directly to atmosphere	It's too difficult to enforce planning conditions relating to air pollution on a new development	People do not car share	The spreading practices within the agricultural sector leads to direct emissions to atmosphere	There is a lack of awareness about the impact on health from air pollution within vulnerable groups (school children, the elderly, people with pre-existing health conditions) which can limit informed decision making

Table 13: Delphi results (4: Very important, Table 2 of 3)

Score	Industry	Spatial planning	Vehicle/fuel	Agriculture	Behaviour
Very Important ('4')	Use of diesel generators to generate power at industrial sites which increases emissions	The quantification of the cumulative impacts on air quality of a development including domestic energy and heating sources are not considered at a planning stage	There is a lack of public awareness of eco-driving techniques and the positive impacts it can have on the environment	The current high supply and demand of food production leads to farming practices which are associated with high levels of air pollution	There is a lack of awareness of the impacts of air quality and health amongst the general public
	Increasing use of biomass as a fuel within the industrial sector which increases emissions	There is no quantification of the cumulative impact on air quality a number of small developments can have within the same location	Mitigation of air pollution exposure from traffic is not included in the design of new developments (eg Green infrastructure, abatement technologies)	Air pollution emitted from large farms can lead to local or regional air pollution hotspots	There is a lack of public messaging and alerts during air pollution events
	Small polluters have a different regulatory regime which is harder to enforce	Environmental impacts including impacts on air quality are not fully taken into account within the current UK building regulations	People leave their vehicles running when stationary for a long period of time (idling)	Not enough is being done to educate and influence the agricultural sector to address the impacts of air pollution	There is not enough joint working in local government to fully address air pollution issues
	Some stacks do not disperse pollution enough	There is a lack of awareness regarding the impacts a new development can have on air quality and health from those within the planning profession	There are still incentives to buy polluting diesel vehicles	The use of diesel arrays, backup generators and subsidies from National Grid for diesel farms (to provide a short-term operating reserve) on agricultural land is increasing the amount of air pollution from the agricultural sector	There is a lack of awareness about the impact on health from air pollution amongst local elected members and councillors
	Some abatement techniques do not remove enough pollution	There is no requirement for consultation with professionals responsible for air quality at the design stage of new developments	The deregulation of taxi fleets leading to an increase in emissions to atmosphere (3.79)	The transition from traditional farming methods to large/super farms is increasing the amount of air pollution emitted from the agricultural sector	Not enough is done to assess the impact of plans and policies on air quality and health. This is required to allow people to be able to make better informed choices

Table 14: Delphi results (4: Very important, Table 3 of 3)

Score	Industry	Spatial planning	Vehicle/fuel	Agriculture	Behaviour
Very Important ('4')	The current rise of 'convenience one-day delivery' is leading to increased emissions to atmosphere	There is a lack of good local authority planning guidance related to air quality impacts from new developments	Wear from vehicle tyres and brakes emit pollutants such as particulate matter	Agricultural sites lead to fugitive emissions including dusts and bioaerosols	There is a lack of awareness of the impacts that domestic burning of solid fuel (eg coal, wood) has on air quality
	There is not enough being invested in renewable energy generation to reduce reliance on fossil fuel sources	The current national planning guidance could be improved and sometimes there are high emissions from new developments		There is too much old and heavily polluting machinery within the agricultural sector	There is a lack of awareness of the environmental benefits of working from home
		When master plans and strategic plans are prepared for an area the location specific effects on local and regional air quality are not fully addressed		Agricultural sites burn some materials on site producing smoke	People do not car share
		It's too difficult to enforce the conditions related to the construction emissions management plans for developments		Economic prosperity and survival is seen as more important within the agricultural sector than reducing air pollution	There is a lack of information about the co-benefits of interventions that can improve air quality (eg benefits for climate change, ecology, physical exercise etc.)
		The risk of planning appeals stops air quality considerations being addressed within planning			There is a lack of awareness of the exposure from air pollution inside vehicles
		The increased air pollution and public exposure related to travel due to new developments, is not fully considered during the planning process			
	Spatial planning: Local authority planners do not have enough resources to fully consider air quality during planning	The design of road networks favours the use of traffic light junctions rather than consideration of free flow alternatives	**Spatial planning:** Travel plans are sometimes not enforced which can lead to increased emissions		

Table 15: Delphi results (3: Quite important, 2: Somewhat important, 1: Unimportant)

Score	Industry	Spatial planning	Vehicle/fuel	Agriculture	Behaviour
Quite Important ('3')	The current permitting system for the UK is not the best option and leads to high emissions from the industrial sector	The construction of new developments lead to emissions of dust	Emissions from existing vehicles, in particular the rail fleet	Livestock emit pollutants directly to atmosphere	
	Small businesses burning waste and producing smoke		Emissions from existing vehicles, in particular the shipping industry	There is an increasing use of biomass as a fuel within the agricultural sector which increases emissions	
	There is too many industrial sites located in close proximity to residential areas		Emissions from existing vehicles, in particular from the aviation industry	The increased use of anaerobic digestion to generate power within the agricultural sector is leading to increase air pollution	
Somewhat Important ('2')					
Unimportant ('1')	There is too much industry in the UK				

Annexe A7 provides full details of sub-panel scoring (ie, how scores varied between groups of panellists), which is summarised below.

Following round 1 the policy-makers and advisers sub-panel scored Problem 2.11 (it's too difficult to enforce planning conditions relating to air pollution on a new development) as '3' (quite important), compared to '5' (extremely important) from the health sub-panel. The practitioners and implementers sub-panel, which included spatial planners, scored this problem in between the disagreeing sub-panels with a median of '4' (very important). Following round 2 the differences in scoring were no longer as large, but there were not enough responses from the policy-maker and adviser sub-panel in round 2 for valid comparison.

The final median scores for Problem 1.11 (increasing use of biomass as a fuel within the industrial sector which increases emissions) was lower for members of the public ('quite important') and the rest of the sub-panels (either 'very important' or 'extremely important'). Following round 2, after being shown the group scores for round 1, members of the public rated this problem as extremely important.

For agricultural problems, there was a low response rate to both Delphi rounds: only the members of the public sub-panel had greater than 10 participants. The sub-panel results for agricultural problems were, therefore, difficult to interpret and compare.

There were some disagreements between specific sub-panels and the remaining groups when scoring air quality problems related to behaviour. The policy-makers and advisers sub-panel gave lower scores than other sub-panels: ‘3’ (quite important) for Problem 5.10 (there is a lack of awareness of day to day air quality and local pollution levels) and ‘2’ (somewhat important) for 5.12 (there is a lack of public messaging and alerts during air pollution events). The advocacy sub-panel gave a lower score than other sub-panels of ‘3’ (quite important) for Problems 5.4 (there is a lack of public transport use) and 5.6 (there is a lack of public awareness of eco-driving techniques and the positive impacts it can have on the environment). However, in round 2 there were a low number of responses from the policy-makers and advisers sub-panel (n=3) and advocacy sub-panel (n=4), making these results difficult to compare to others.

The locally elected members sub-panel scored problem 5.16 (there is a lack of awareness of the impacts that domestic burning of solid fuel (eg, coal, wood) has on air quality) lower than other sub-panels. However, there were a low number of responses (n=2) from locally elected members, making these results difficult to compare to the higher scores from other sub-panels.

Overall scoring of the problems in each rapid evidence assessment area are summarised in a later section in Figure 12 to Figure 18, with full scoring breakdowns in Annexe A7.

Results: Evaluating interventions' effectiveness

Overview

PHE evaluations were carried out to give a general impression of interventions that could be used to distinguish interventions that seemed more likely to benefit public health from those that seemed less likely to benefit public health.

The PHE public health evaluation of the interventions identified by the 5 rapid evidence reviews considered these interventions' effectiveness in improving local and national air quality and public health, wider public health aspects, and factors influencing implementation.

Due to the limited timescale to undertake evaluations, they were carried out by PHE based on the 5 rapid evidence assessments and reviewers' personal knowledge.

The evaluations identified promising interventions considered to be fully and potentially effective in terms of their potential impact on air quality and public health outcomes locally and nationally.

Wider public health benefits to co-benefits and health inequalities were assessed, and overall favoured interventions identified.

The evaluations also considered some implementation considerations: feasibility and timescale to benefit. There was insufficient information on which to compare cost or return on investment across interventions.

Currently, as highlighted by the rapid evidence assessments, there is a lack of formal evaluation of interventions, and few evaluations consider direct impacts or benefits to public health. As a consequence, few interventions were evaluated as fully effective, with interventions often classified as 'potentially effective' due to the limited supporting information.

Interventions in which reviewers had strongest views as to interventions' effectiveness were assigned 'limited effectiveness' or 'fully effective', whereas 'potentially effective' interventions were associated with more uncertainty.

Evaluation of effectiveness focussed on whether there was evidence that the intervention worked (ie, that it could reduce local or national emissions, concentrations or exposures), and not the relative level of effect, which was typically uncertain.

Scoring of each rapid evidence assessment's interventions is summarised in Table 16 and Table 17 (vehicle/fuel interventions), Table 18 (planning/structural design interventions), Table 19 (industrial interventions), Table 20 and Table 21 (agricultural interventions), and Table 22 (behavioural interventions) and fully detailed in Annexe A8.

Promising interventions across the 5 rapid evidence assessment domains are shown in concluding tables Table 23 and Table 24.

The evaluations were dynamic, to be updated to reflect new and emerging evidence and new evaluations.

The evaluations were generalisations; further detailed assessments and cost-benefit-analyses are required to inform options appraisals of national and local interventions.

Table 16: PHE public health evaluation of transport: vehicle/fuel interventions (Table 1 of 2)

REA intervention strength of evidence		Intervention		Sub-intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
Effectiveness strength	Uncertainty range					Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
		Road transport intervention 1	Reduce demand for more polluting forms of transport	Promote freight modal shift	Prevention						Long
				Lorry road user charging	Prevention						Medium
				Subsidising public transport	Prevention						Medium
				Provision of school buses	Prevention						Long
				Designating new & priority bus measures	Prevention						Long
				Promote walking and cycling	Prevention						Medium
				Promote car sharing	Prevention				Negative?		Medium
				Workplace charging levies	Prevention				Negative?		Medium
				High occupancy vehicle lanes	Prevention						Long
				National road pricing	Prevention				Negative?		Medium
				Local congestion charge	Prevention				Negative?		Medium
				Promote tele-working/video conferencing	Prevention						Medium
				Increase fuel duty/target at diesels	Prevention				Negative?		Medium
				New tram schemes	Prevention						Long
				Travel planning	Prevention						No/little evidence
		Road transport intervention 2	Reduce emissions from existing vehicles	Allow more night time freight delivery	Mitigation						No/little evidence
				Lorry overtaking bans	Prevention						No/little evidence
				Promote abatement retrofit	Prevention						Medium
				Promote eco driving	Prevention						Medium
				Annual vehicle emissions tests	Prevention						No/little evidence
				Roadside vehicle emissions tests	Prevention						No/little evidence
				Active traffic light management	Prevention						Medium
				Intelligent speed adaptation	Prevention						No/little evidence
				Improved anti-idling enforcement	Prevention						Medium

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Table 17: PHE public health evaluation of transport: vehicle/fuel interventions (Table 2 of 2)

REA intervention strength of evidence: Effectiveness strength	REA intervention strength of evidence: Uncertainty range	Intervention		Sub-intervention	Intervention type	Effectiveness: Potential to improve AQ public health outcomes nationally	Effectiveness: Potential to improve AQ public health outcomes locally	Wider public health benefits: Potential for public health co-benefits	Wider public health benefits: Potential impact on improving inequalites	Feasibility	Timescale to benefit
		Road transport intervention 3	Promote vehicles with low emissions	Scrappage schemes	Prevention				Negative?		Long
				Fleet recognition schemes promote LEV	Prevention						Long
				Reduced Vehicle Excise Duty	Prevention				Negative?		No/little evidence
				Promotion of low emission zones	Prevention				Negative?		Medium
				Priority parking for low emissions vehicles	Prevention						No/little evidence
				Pollution car labelling scheme	Prevention						No/little evidence
				Fiscal incentives for low emission vehicles	Prevention						No/little evidence
				Development of EV charging infrastructure	Prevention						No/little evidence
				Promote air quality beneficial bio-fuels	Prevention						No/little evidence
				Public information campaign	Prevention						No/little evidence
		Road transport intervention 4	Displace pollutant emissions outside hot spots and populated areas	Lorry ban in urban centres	Prevention						Immediate-short
				Freight consolidation centres	Mitigation						No/little evidence
				Newer buses used for most polluted routes	Prevention						Medium
		Aviation interventions	Operational interventions at airports and alternative fuels	Electrifying ground support equipment	Prevention						Long
				Reduction in thrust take-off	Prevention						Immediate-short
				Pushback control	Prevention						Immediate-short
				Reduction in use of auxiliary power units	Prevention						Long
				Lower emission road vehicles	Prevention						No/little evidence
				Alternative aviation fuels	Prevention						No/little evidence
		Marine interventions	Lower emission marine fuels and operational interventions at ports	Emission standards for marine fuels	Prevention						No/little evidence
				Emission charges for operators at ports	Prevention						No/little evidence
				Supply of electricity to enable electrification of cargo handling equipment	Prevention						No/little evidence
				Efficiency in port cargo handling at ports	Prevention						No/little evidence
		Rail interventions	Electrification of rail network & promotion of lower emissions from rolling stock	Electrification of rail network	Prevention						Long
				Promote the uptake of bi-mode trains	Prevention						No/little evidence
				Abatement retrofit	Prevention						No/little evidence

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Table 18: PHE public health evaluation of planning interventions

REA intervention strength of evidence: Effectiveness strength	REA intervention strength of evidence: Uncertainty range	Intervention		Intervention type	Effectiveness: Potential to improve AQ public health outcomes nationally	Effectiveness: Potential to improve AQ public health outcomes locally	Wider public health benefits: Potential for public health co-benefits	Wider public health benefits: Potential impact on improving inequalites	Feasibility	Timescale to benefit
(red)	(red)	Pollutant removal	Green infrastructure - urban vegetation	Mitigation	(orange)	(light green)	(light green)	(light green)	(light green)	Medium
(red)	(red)		Pollution reducing surfaces - titanium dioxide	Mitigation					(orange)	No/little evidence
(red)	(red)	Active transport	Encouraging walking and cycling	Prevention	(orange)	(orange)	(dark green)		(dark green)	Medium
(red)	(red)	Motorised transport	Road pricing / Congestion charge	Prevention	(light green)	(light green)		Negative?	(light green)	Medium
(light green)	(light green)		Driving restriction	Prevention	(light green)	(dark green)		Negative?	(light green)	Immediate-short
(red)	(red)		Low emission zones	Prevention	(light green)	(light green)		Negative?	(dark green)	Medium
(red)	(red)		Traffic calming and speed limitations	Prevention	(orange)	(orange)	(light green)		(light green)	Medium
(red)	(red)		Traffic displacement through road alterations	Prevention		(orange)	(light green)		(light green)	Long
(red)	(red)		Co-implementation of various measures	Other	(light green)	(dark green)	(light green)	(light green)	(light green)	Medium

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness (orange)	Limited effectiveness (orange)	Limited feasibility (orange)	Long term (years +)
Potentially effective (light green)	Potentially effective (light green)	Potentially feasible (light green)	Medium (months-yr)
Fully effective (dark green)	Fully effective (dark green)	Fully feasible (dark green)	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention (red)	High uncertainty based on number and quality of studies (red)
Medium (amber)	Medium (amber)
High magnitude and consistency of the impact of the intervention (dark green)	Low uncertainty (dark green)

Table 19: PHE public health evaluation of industrial interventions

REA intervention strength of evidence		Intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
				Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
	Policy interventions	Ambient air pollutant concentration limits	Prevention						Long
	Policy interventions	National emissions ceilings	Prevention						Long
	Policy interventions	Installation absolute emission caps	Prevention						Long
	Policy interventions	Installation emission concentration limits: BAT-based permitting	Prevention						Long
	Policy interventions	Installation emission concentration limits: CBA based-permitting	Prevention						Long
	Policy interventions	Eco-design and product standards	Prevention						Long
	Policy interventions	Elimination of plants (or plant) (sector)	Prevention				Negative?		Long
	Policy interventions	Inspections and enforcement actions	Prevention						Long
	Policy interventions	Monetary incentives	Prevention						Long
	Policy interventions	Monetary penalties	Prevention						Long
	Policy interventions	Trading schemes	Prevention						Long
	Technologies	Diffuse dust abatement	Prevention						Medium
	Technologies	Dust abatement (secondary)	Prevention						Long
	Technologies	Primary NOx/SO2 measures	Prevention						Long
	Technologies	NOx abatement (secondary)	Prevention						Long
	Technologies	SO2 abatement (secondary)	Prevention						Long
	Technologies	Primary VOC measures	Prevention						Long
	Technologies	VOC abatement (secondary)	Prevention						Long

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Table 20: Public health assessment of agricultural interventions (Table 1 of 2)

REA intervention strength of evidence			Intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
Effectiveness strength	Uncertainty range				Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
		Changes in livestock housing design or management	Livestock building design	Prevention						Long
			Out-wintering pads	Prevention						No/little evidence
			Yard design	Prevention						No/little evidence
			Shorter housing periods	Mitigation						No/little evidence
			Biofilters	Prevention						Medium
			Exhaust air scrubbing	Prevention						Medium
			Electrostatic particle ionization (EPI) and particle separators	Prevention						Medium
			In-house fogging	Prevention						Medium
			Ozonation	Prevention						No/little evidence
			Choice of litter material	Prevention						Immediate-short
			Poultry manure removal time	Prevention						Immediate-short
			Strategic tree planting	Mitigation						Long
		Change in diet or feeding regime	Cattle diet change	Prevention						Immediate-short
			Pig diet change	Prevention						No/little evidence
			Poultry diet change	Prevention						No/little evidence
			Feed scheduling	Prevention						No/little evidence

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Table 21: Public health assessment of agricultural interventions (Table 2 of 2)

REA intervention strength of evidence		Intervention		Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
Effectiveness strength	Uncertainty range				Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
		Changes in manure management/ storage/ processing	Anaerobic digestion of manure and composting of digestate	Prevention						No/little evidence
			Manure additives	Prevention						No/little evidence
			Manure composting	Prevention						No/little evidence
			Manure drying (poultry)	Prevention						No/little evidence
			Manure management system	Prevention						No/little evidence
			Manure treatment plant	Prevention						No/little evidence
			Manure/slurry storage methods	Prevention						Medium
			Slurry acidification	Prevention						Long
		Low emission manure application to land	Rapid incorporation of solid manure	Prevention						Medium
			Low emission slurry spreading	Prevention						Medium
		Fertiliser application changes	Urease inhibitor	Prevention						Medium
			Choice of N fertiliser	Prevention						Medium
			Fertiliser management	Prevention						Medium
			Nitrification/denitrification inhibitors	Other						No/little evidence
		Change land use/ consumption/ productivity/ genetic selection	Change in consumption of outputs from land	Prevention						No/little evidence
			Change in land use or livestock species	Prevention						No/little evidence
			Increase productivity	Other						No/little evidence
			Local targeting of mitigation	Other						No/little evidence
			Genetic selection	Other						No/little evidence

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Table 22: PHE public health evaluation of behavioural interventions

REA intervention strength of evidence		Intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
Effectiveness strength	Uncertainty range			Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
		Cycle and walking pathways (Encouraging)	Prevention						Medium
		Public engagement	Other						Medium
		Investment in public transport (Encouraging)	Prevention						Medium
		Eco-driver training	Prevention						Medium
		No idling campaigns	Prevention						Medium
		Exposure reduction programmes	Avoidance						Medium
		Ecotravel coordination programmes	Prevention						No/little evidence
		Clean air day	Other						Medium
		Air quality messages/alerts/indices	Avoidance						Immediate-short

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Rapid Evidence Assessment (REA) strength of evidence key	
Effectiveness	Uncertainty
Low magnitude and consistency of the impact of intervention	High uncertainty based on number and quality of studies
Medium	Medium
High magnitude and consistency of the impact of the intervention	Low uncertainty

Public health evaluation: cross-domain interventions with multiple potential public health benefits

Some similar interventions were evaluated favourably across different domains (eg, green infrastructure and cycling and walking interventions identified by the planning, vehicle/fuel and behavioural rapid evidence assessments); however, care should be taken to refer to the precise definitions of the interventions given in the rapid evidence assessments (Annexes A2-A6), where full intervention summaries and narratives are given, along with more nuanced descriptions of the intervention types (eg, 'promotion of walking and cycling' versus 'encouraging use of cycle and walking pathways').

Due to the scarcity of evidence of direct impacts or benefits to public health outcomes associated with interventions, few interventions across the 5 domains (transport, planning, industry, agricultural, and behavioural) were considered 'fully effective' (ie, felt most likely to lead to public health benefits). When designing interventions, further case-specific assessment is required to examine the likely level of effect (for which there was insufficient evidence to make general comparisons between interventions that were considered by the PHE evaluations). Other important considerations to be addressed on a case-by-case, rather than generalised, basis include cost, cost-effectiveness and feasibility.

Evidence of benefits to co-benefits and health inequalities was also scarce. When designing and implementing packages of interventions, it is important to maximise co-benefits and address health inequalities, and to use behaviour change interventions to maximise the impacts of interventions in other domains.

There are clear opportunities to improve air quality and achieve greater public health benefits when interventions are combined, introduced and implemented together as a package of interventions, as highlighted by the high potential effectiveness of the planning intervention 'co-implementation of various measures'. This is considered further in the '*Intervention strategies'* chapter and recommendations of this report. Further case-specific evaluation of specific packages of interventions is desirable, particularly to address synergies and antagonisms, but the tables below provide an indication of which interventions seem most promising for addressing air quality and public health outcomes, distinguishing between local and national levels and intervention types of note due to their effect on wider public health outcomes (such as physical exercise) or health inequalities.

The review process is dynamic, to be updated to reflect new and emerging evidence and new evaluations, and it remains important to note that absence of evidence of effectiveness (ie, outcomes assigned 'no / little evidence') is not evidence of ineffectiveness. In such cases interventions may prove to be effective at delivering benefits to air quality and public health outcomes as new evaluations are carried out.

Table 23: PHE public health evaluation – interventions with multiple potential benefits for air quality and public health outcomes (Table 1 of 2)

Intervention category	Intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
			Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
Planning	Co-implementation of various measures	Other						Medium
Planning	Green infrastructure - urban vegetation	Mitigation						Long
Transport	Subsidising public transport	Prevention						Medium
Agricultural	Strategic tree planting	Mitigation						Long
Agricultural	Biofilters	Prevention						Medium
Agricultural	Exhaust air scrubbing	Prevention						Medium
Behavioural	Exposure reduction programmes	Avoidance						Medium
Industry	Dust abatement (secondary)	Prevention						Long
Industry	Diffuse dust abatement	Prevention						Medium
Transport	Provision of school buses	Prevention						Long
Transport	National road pricing	Prevention				Negative?		Medium
Transport	Promote abatement retrofit	Prevention						Medium
Behavioural	Eco-driver training	Prevention						Medium
Behavioural	Public engagement	Avoidance						Medium
Industry	Inspections and enforcement actions	Prevention						Long
Industry	Installation concentration limits: BAT	Prevention						Long
Industry	Primary NOx/SO2 measures	Prevention						Long

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Table 24: PHE public health evaluation – interventions with multiple potential benefits for air quality and public health outcomes (Table 2 of 2)

Intervention category	Intervention	Intervention type	Effectiveness		Wider public health benefits		Feasibility	Timescale to benefit
			Potential to improve AQ public health outcomes nationally	Potential to improve AQ public health outcomes locally	Potential for public health co-benefits	Potential impact on improving inequalites		
Industry	NOx abatement (secondary)	Prevention						Long
Industry	SO2 abatement (secondary)	Prevention						Long
Planning	Encouraging walking and cycling	Prevention						Medium
Transport	Promote walking and cycling	Prevention						Medium
Planning	Road pricing / Congestion charge	Prevention				Negative?		Medium
Planning	Driving restriction	Prevention				Negative?		Immediate-short
Transport	Increase fuel duty/target at diesels	Prevention				Negative?		Medium
Transport	Promotion of low emission zones	Prevention				Negative?		Medium
Agricultural	Manure additives	Prevention						No/little evidence
Agricultural	Livestock building design	Prevention						Long
Agricultural	Rapid incorporation of solid manure	Prevention						Medium
Agricultural	Manure/slurry storage methods	Prevention						Medium
Agricultural	Low emission slurry spreading	Prevention						Medium
Agricultural	Poultry manure removal time	Prevention						Immediate-short
Agricultural	Cattle diet change	Prevention						Immediate-short
Agricultural	Choice of litter material	Prevention						Immediate-short
Behavioural	Investment in public transport	Prevention						Medium

PHE evaluation key			
Effectiveness (national & local)	**Impact on co-benefits & inequalities**	**Feasibility**	**Timescale to benefit**
No/little evidence	No/little evidence	No/little evidence	No/little evidence
Limited effectiveness	Limited effectiveness	Limited feasibility	Long term (years +)
Potentially effective	Potentially effective	Potentially feasible	Medium (months-yr)
Fully effective	Fully effective	Fully feasible	Imm.-short (weeks)
	Negative?		

Results: Matching air pollution problems with available interventions

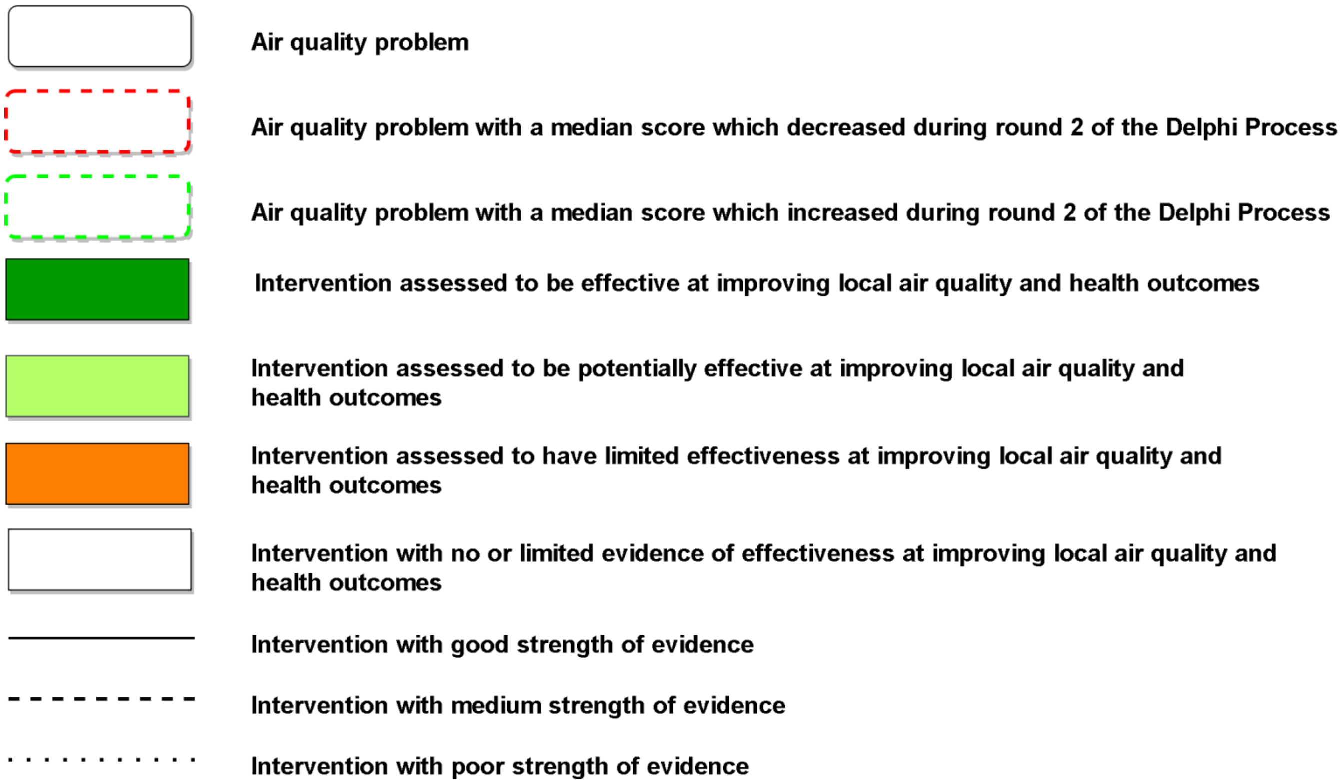
We aim to provide information in a format that can be acted on by practitioners. Steering Group members supported the provision by PHE of recommendations that dealt with specific local issues and clearly identified which interventions (and packages of interventions) can be used to address them.

The results of the Delphi surveys informed understanding of the perception of different groups of the relative importance of different problems, and the potential prioritisation of air quality problems by stakeholders. In this section we match air quality issues identified and ranked by stakeholders with the evidence, or lack of evidence, of interventions identified in the rapid evidence assessments that could address them. Full details of the Delphi and intervention evaluation methodologies that informed this work and their results are found in Annexes A7 and A8.

Local authorities and policy-makers can use this chapter to identify whether the rapid evidence assessments identified interventions that might address their own local problems or issues of interest, and the local effectiveness and strength of evidence regarding each intervention. Further detailed information about each of the specific interventions, and their associated health impacts and benefits, are contained in the rapid evidence assessments in Annexes A2-A6).

Comparison of the list of problems collated for the Delphi process and the individual interventions identified in the rapid evidence assessments indicated that 49 air quality problems did **not** have corresponding interventions. Perceived problems that are not addressed by interventions identified in the rapid evidence assessments, and for which there may be other solutions, are discussed in detail in Annexe A7.

Figure 11. Legend for Figure 12 to Figure 18



For each figure that follows, problems were listed in number order (ie, the same order in which they were presented to stakeholders during the Delphi surveys described above and in Annexe A7). The only exception to this was problems whose median score changed following round 2 of the Delphi process. If the median score decreased (ie, if stakeholders considered them less important after reflection), they were highlighted with a red dashed border (see legend above) and then placed at the top of each score category (to show they had previously had a higher score in round 1 of the Delphi). Conversely, if the median score had increased following round 2 (ie, if stakeholders considered them more important after reflection), the problems were highlighted with a green dashed border and placed at the bottom of the score category (to show they had previously had a lower score in round 1 of the Delphi).

To show the potential effectiveness of interventions, individual interventions' PHE evaluation score for *potential to benefit local air quality and health* was indicated (see earlier methodology section and Annexe A8 for full details of the evaluation process). The local effectiveness categories were 'fully effective' (dark green), 'potentially effective' (light green), 'limited effectiveness' (orange) and 'limited or no evidence of effectiveness' (white).

Good strength of evidence (as defined in the related rapid evidence assessment) was represented by a solid line, medium strength of evidence by a dashed line and poor strength of evidence by a dotted line.

Figure 12: Stakeholders' air quality problems associated with industry and matching interventions

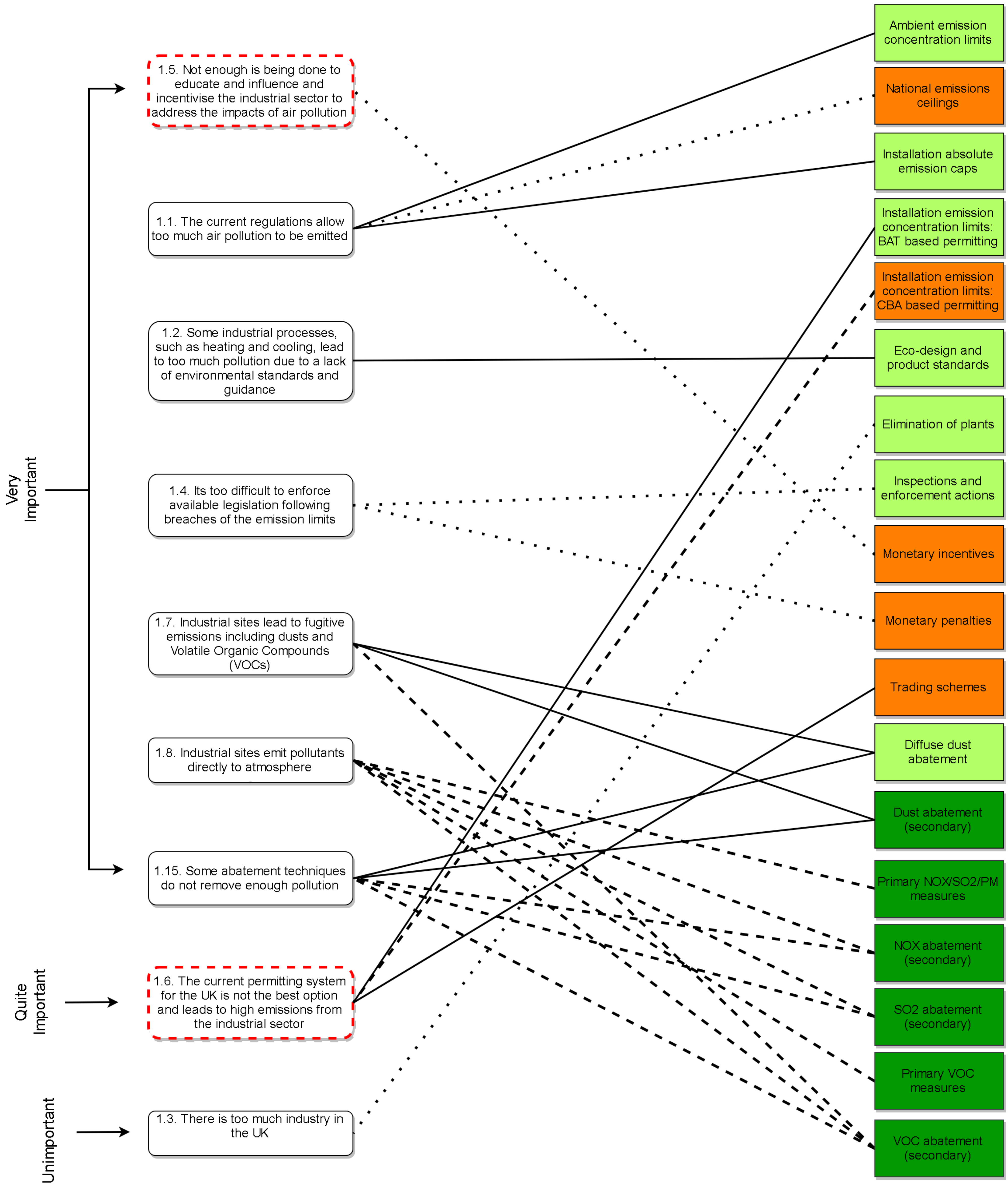


Figure 12 showed that all but 1 matched **industrial** problem (see below) had at least 1 matched intervention that was at least potentially effective at improving local air quality and health.

Of the 7 ‘very important’ problems with matched interventions, only 2 problems had single matched interventions. Both were specific problems with specific solutions: heating and cooling processes (Problem 1.2) could be addressed by eco-design and product standards (with strong strength of evidence); a lack of incentivisation to address pollution (Problem 1.5) could be addressed by monetary incentives; however, it is notable that this was the only matched problem whose only potential solution was judged to be of potential limited effectiveness (at improving local air quality and health) – it was also associated with poor strength of evidence. Of the remaining problems, the general problem of “too much pollution” (Problem 1.1) was addressed by a mix of ambient concentration limits, emissions ceilings and installation emission caps. The problem of enforcement (Problem 1.4) could be addressed by inspections and enforcement actions or monetary penalties, though the strength of evidence associated with both interventions was poor. The technological intervention types were matched with Problems 1.7, 1.8 and 1.15, which related to fugitive and point source emissions to air from industrial sites and insufficient abatement. There were judged to be several fully effective potential interventions that could address each of these problems.

Three potential solutions were identified by the rapid evidence assessment as potentially relevant to ‘quite important’ Problem 1.6 (the current permitting system…): they comprised variants of the current Best Available Techniques (BAT) permitting approach and alternative cost-benefit-analysis based approach or emissions trading schemes.

Problem 1.3 (there is too much industry in the UK) was judged ‘unimportant’ by stakeholders. It was matched with the ‘elimination of plants’ intervention, which was considered potentially effective but was an intervention that reviewers judged unlikely to be feasible in practice and which had a poor strength of evidence.

There were 9 industrial problems unmatched to interventions found by the rapid evidence assessment: they are discussed in Annexe A7.

Figure 13: Stakeholders' air quality problems associated with spatial planning and matching interventions

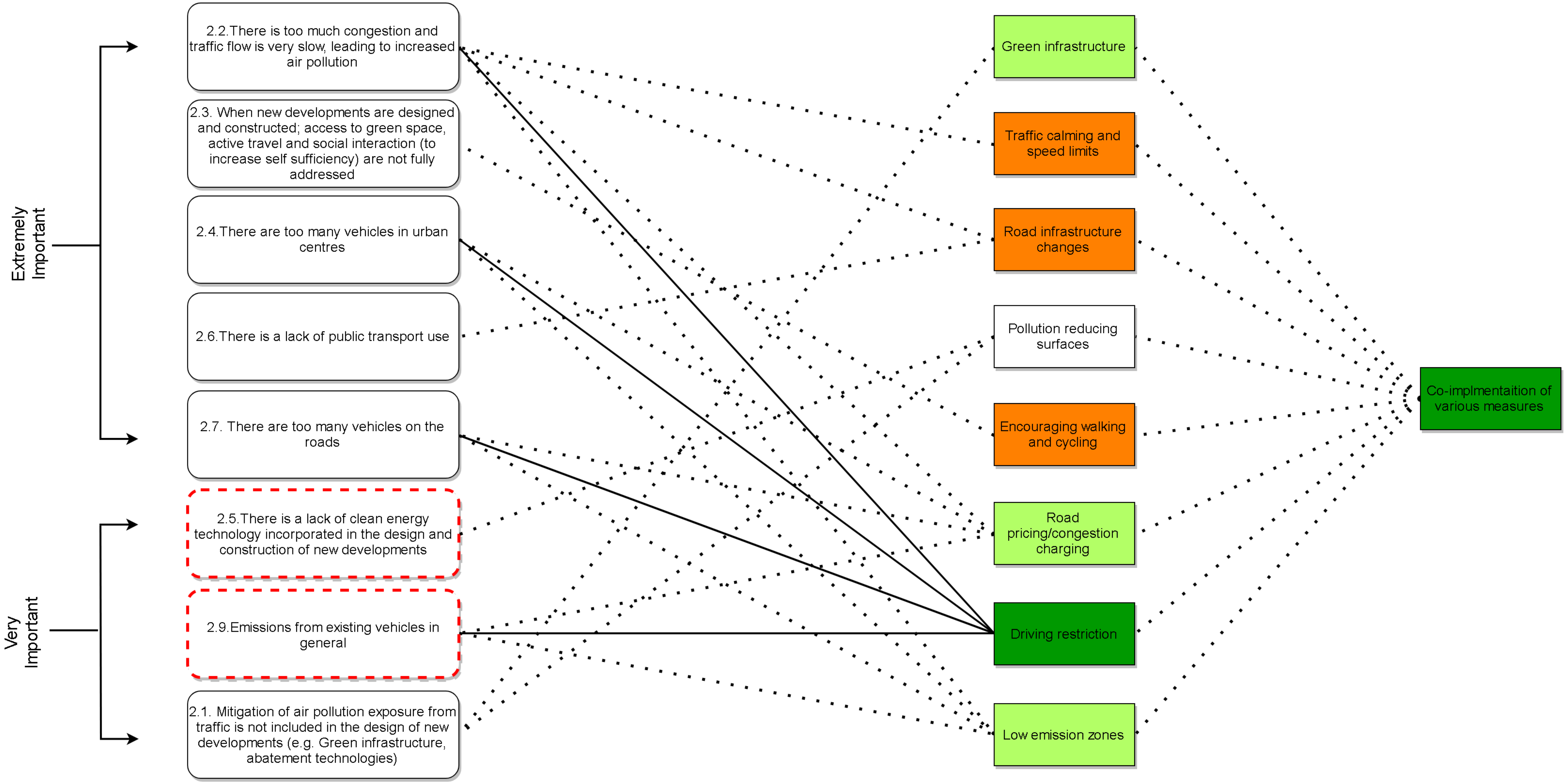


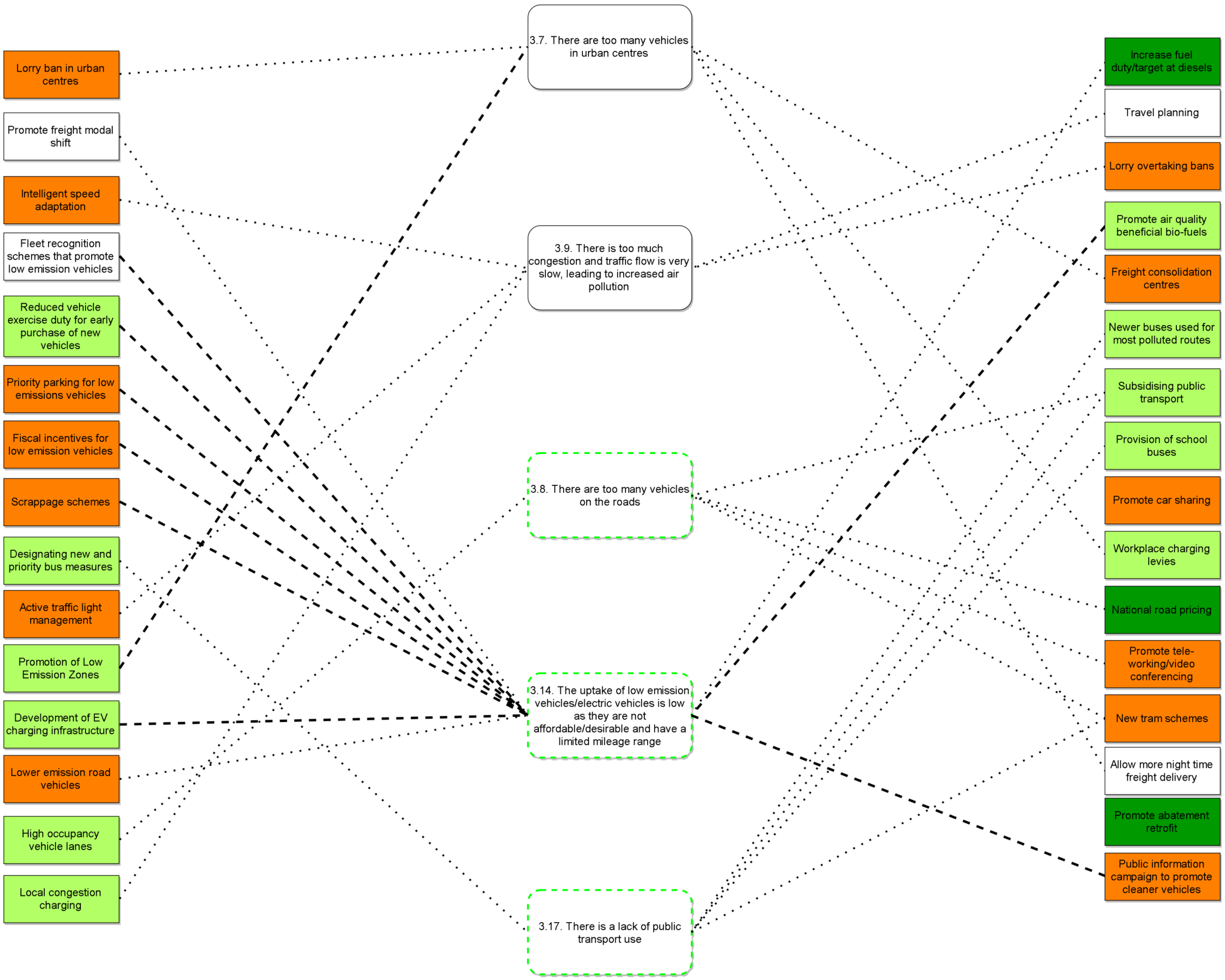
Figure 13 illustrated the finding that whilst individual **planning** interventions may be of uncertain or limited effectiveness, co-implementation of various measures was a fully-effective intervention that could be used to address a number of problems at once.

Of the 5 ‘extremely important’ problems, 3 (Problems 2.2, 2.4 and 2.7) related to road vehicles had several interventions that could address them that were potentially or fully effective at improving local air quality and health, with driving restrictions potentially addressing all 3 problems and being the only intervention found by the rapid evidence assessment to have strong strength of evidence (others were generally poor). Road infrastructure changes were the single intervention matched with Problem 2.6 (A lack of public transport use); whilst this intervention was regarding as having limited effectiveness at addressing local air quality and health, it is worth noting that interventions in other rapid evidence assessment areas (such as subsidising public transport (vehicle/fuel) or promotion of public transport use (behavioural)) well address this problem. A lack of access to green space and active travel in new developments (Problem 2.3) was linked to encouraging walking and cycling, though the wider effect on local air quality and health of this solution was judged limited.

Three matched problems were judged ‘very important’; 1 was a general problem related to vehicle emissions (Problem 2.9) for which there were 3 potentially or fully effective interventions at improving local air quality and health, including road pricing, congestion charging and driving restrictions. The other 2 problems related to the design of new developments: a lack of use of clean energy technology (Problem 2.5) was linked to pollution-reducing surfaces whose effectiveness was judged unevidenced. This would be a mitigation intervention designed to reduce environmental concentrations of pollutants, and when considered ‘clean energy technology’ – a somewhat open-ended concept – there may be other options that could prevent or reduce emissions at source, such as the use of renewable and battery power or heating sources rather than building new developments entirely reliant on non-renewable fuels. The unmet potential of urban design and new developments to mitigate exposure to traffic pollutants (Problem 2.1) was also matched to the uncertain pollution-reducing-surface interventions; however, it was also matched with use of green infrastructure, a solution thought to have higher potential to benefit local air quality and health.

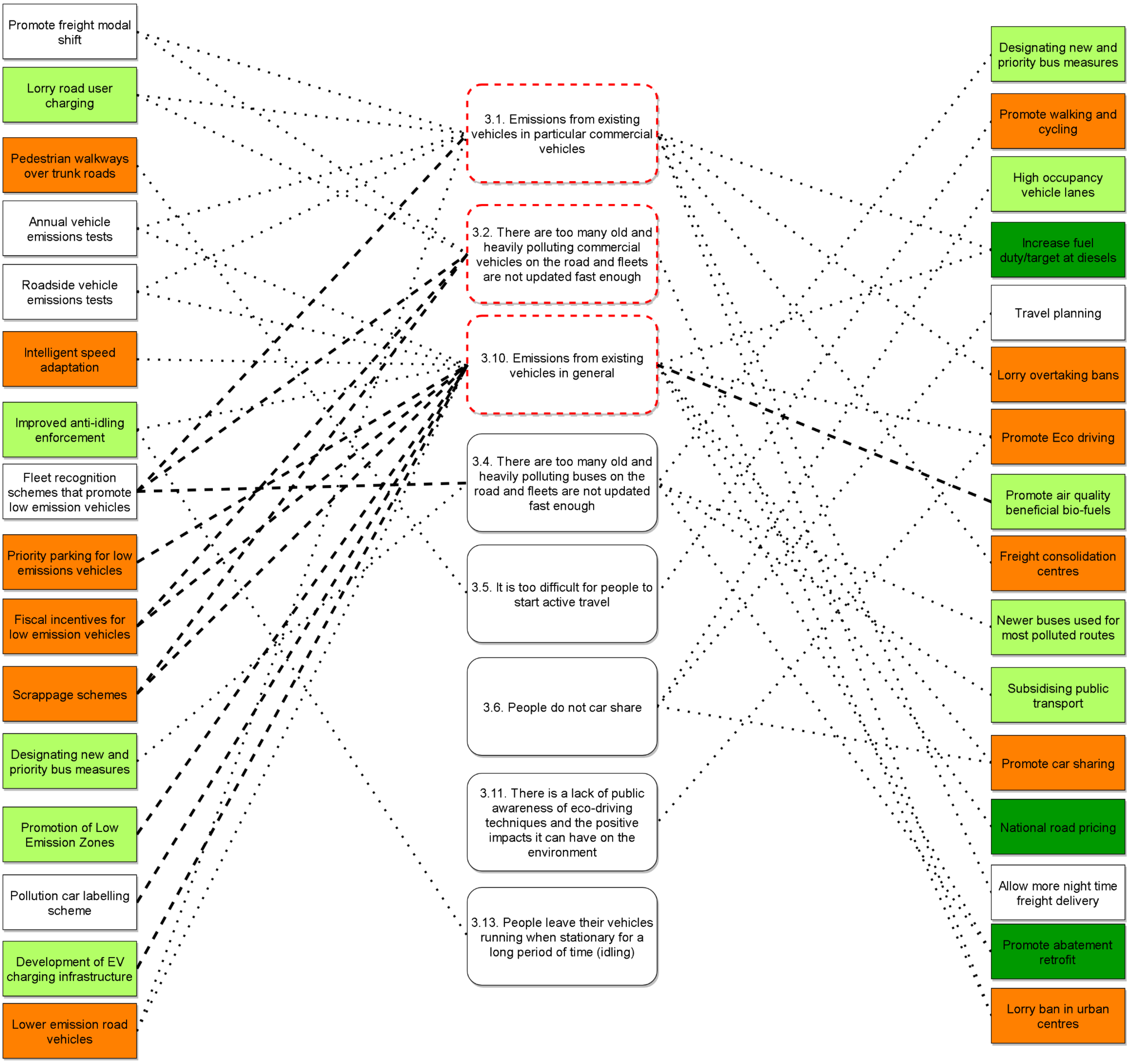
There were 19 planning problems unmatched to interventions found by the rapid evidence assessment: they are discussed in Annexe A7.

Figure 14: Stakeholders' "extremely important" air quality problems associated with vehicles / fuels and matching interventions



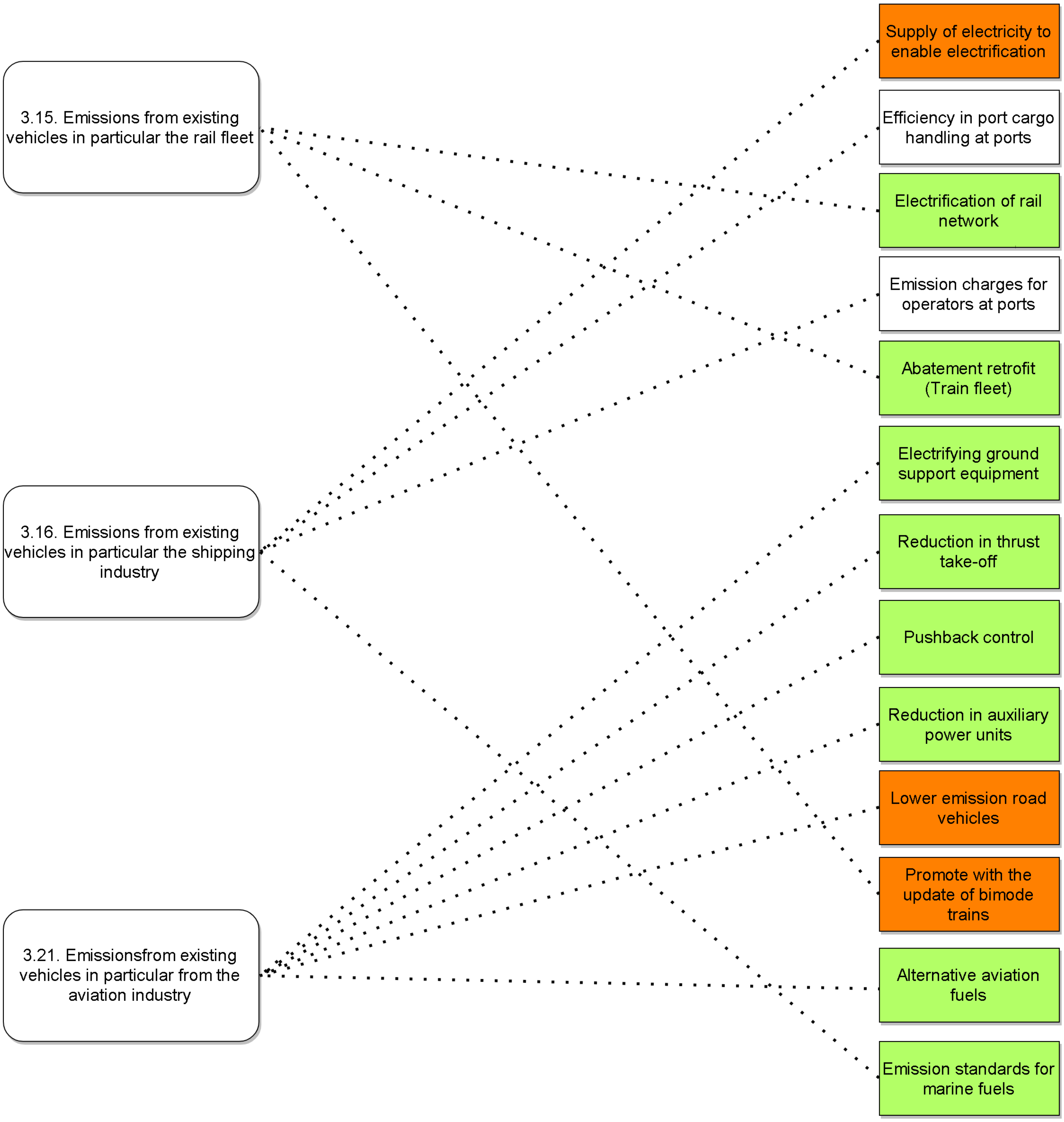
A large number of problems and interventions were identified by the **vehicle/fuel** rapid evidence assessment, and 'extremely important' problems were listed in Figure 14. The 'lack of public transport use' (Problem 3.17), that had a single planning intervention solution had 5 matched vehicle/fuel interventions of limited or potential effectiveness in improving local air quality and health, though the strength of evidence associated with all of them was poor. There were 11 interventions matched with limited uptake of low emission and electric vehicles (Problem 3.14); they ranged from unproven to fully effective at improving local air quality and health, and increasing fuel duty / targeting diesels as part of a mix of transport interventions to increase use of electric vehicles may be one means of delivering local benefits, though the strength of evidence with that intervention was poor. Promotion of alternative fuels, development of charging infrastructure and reduced vehicle excise duty for early purchase of new vehicles were judged potentially effective (locally) with a medium strength of evidence. A mix of public transport, road pricing and high-occupancy vehicle lanes offered potential benefits for local air quality and health if aiming to reduce the number of vehicles on the road (Problem 3.8), though strength of evidence was poor, and when considering vehicles in urban centres specifically (Problem 3.7) low emission zones also had potential, with medium strength of evidence, along with workplace parking levies (poor strength of evidence), and options with lesser judged potential to improve local air quality and health such as lorry bans, night-time freight deliveries, and freight consolidation centres. The problem of congestion (Problem 3.9) had 6 matched interventions, all of poor strength of evidence; local congestion charging was through to have highest potential to improve local air quality and health over traffic management options (limited effectiveness), whilst traffic planning was a potential solution that was unproven.

Figure 15: Stakeholders' "very important" air quality problems associated with vehicles / fuels and matching interventions



'Very important' **vehicle/fuel** problems identified by stakeholders, Figure 15, include several problems related to emissions from vehicles (Problem 3.10), particularly commercial and old commercial vehicles (Problems 3.1 and 3.2), that decreased in perceived importance during the second round of the Delphi process. All 3 were associated with at least 6 potential matched interventions, and at least 1 that had medium strength of evidence (Problem 3.1, with 3 or more medium strength of evidence solutions for the other 2 problems). As an intervention addressing both commercial vehicle problems (and buses, Problem 3.4), fleet recognition schemes that promote low emission vehicles had a medium strength of evidence but their potential to improve air quality and health was uncertain, indicating that further review of this particular solution could be valuable. Potential benefits to air quality and health were perceived for interventions with poorer strength of evidence, such as increasing fuel duty, lorry road-user charging, abatement retrofit and national road pricing, and it is clear that related solutions include several options that have potential benefits for local air quality and health. The remaining problems were more specific and were matched with fewer potential interventions. Difficulties starting active travel (Problem 3.5) was matched with promoting walking and cycling: planning and behavioural interventions related to providing and promoting related infrastructure are also potential solutions. A lack of car-sharing (Problem 3.6) could be addressed by its promotion, but creation of high-occupancy vehicle lanes was considered potentially more effective at leading to local air quality and health benefits; travel planning was also considered relevant but of uncertain effectiveness at delivering such benefits. A lack of awareness of eco-driving (Problem 3.11) was matched with its promotion (which was also identified as a behavioural intervention), whilst stationary vehicle idling could be addressed by enforcement, with potential benefits for local air quality and health, though it is also clear that this can be addressed over time by technological improvements to newer vehicles (such as engine auto-cut-out).

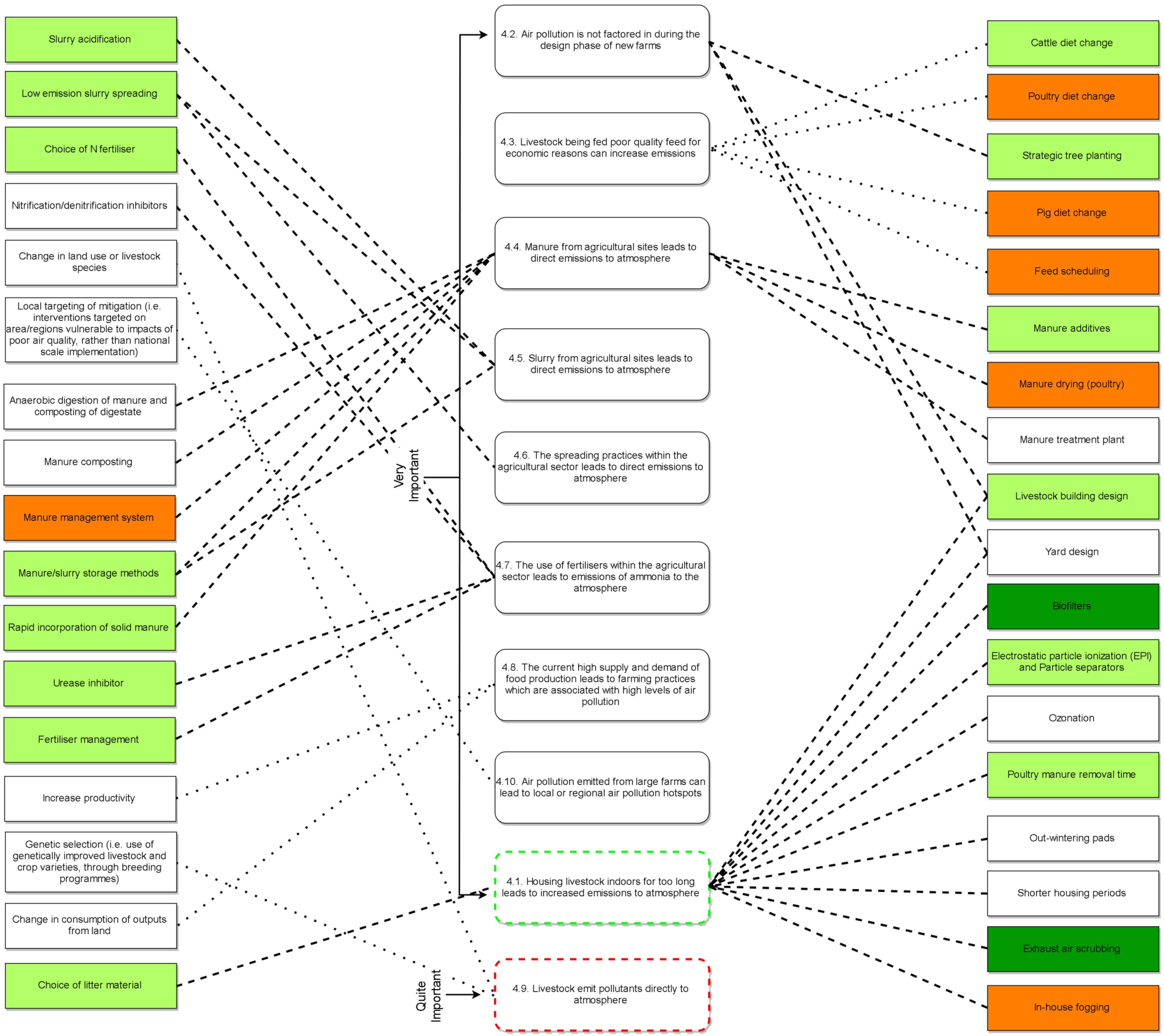
Figure 16: Stakeholders' "quite important" air quality problems associated with vehicles / fuels and matching interventions



Rail, shipping and aviation emissions were scored by stakeholders as ‘quite important’, indicating that stakeholders thought road-vehicle emissions were more important **vehicle/fuel** problems to address. Figure 16 shows that the strength of evidence of all of the related interventions (3 to 6 per source) was poor. However, all but 1 of the 6 aviation interventions were thought potentially effective at improving local air quality and health (they ranged from alternative fuels to electrification of ground equipment). Interventions for shipping were associated with most uncertainty regarding potential local benefits – port emissions charges and cargo handling efficiency had insufficient information, whilst provision of electricity was thought of limited effectiveness based on the rapid evidence assessment, though it is of increasing interest (195). Emissions standards for marine fuels were thought to offer the highest potential for local benefits (as they would reduce emissions of all shipping whilst at berth and at sea). For rail, electrification and abatement retrofit were both thought potentially effective at improving local air quality and health, and a combined approach to rail emissions involving a mix of both, though costlier, may have greater potential for local benefits than the current trend towards use of bi-mode trains.

There were 6 vehicle/fuel problems unmatched to interventions found by the rapid evidence assessment: they are discussed in Annexe A7.

Figure 17: Stakeholders' air quality problems associated with agriculture and matching interventions



Stakeholders judged almost all of the **agricultural** problems to be ‘very important’ (Figure 17); only emissions from livestock (Problem 4.9) were considered ‘quite important’, after falling in scored importance in the second stage of the Delphi. The 2 matched interventions, genetic selection and changes in land use or species, were both uncertain in terms of their potential effect on local air quality and health.

Of the ‘very important’ agricultural problems, it was clear that when livestock are housed indoors (Problem 4.1), there were a large number of potential interventions that could address emissions, all of which had medium strength of evidence, and 2 of which were judged fully effective at improving local air quality and health: bio-filters and exhaust air scrubbing. Other potentially effective options related to litter, manure, and other abatement technologies. The interventions matched with emissions due to livestock feed (Problem 4.3) all had poor strength of evidence, but of the 4 matched interventions, cattle diet change had potential to improve local air quality and health; pig and poultry diet change and feed scheduling were judged to have limited potential effectiveness.

There were also many potential interventions with medium strength of evidence matched with emissions associated with manure (Problem 4.4), of which those thought to have most potential to improve local air quality and health were manure additives, manure/slurry storage methods, and rapid incorporation of solid manure. Emissions from slurry (Problem 4.5) was matched with 3 interventions, all of which had potential to improve air quality and health: slurry acidification, low emission slurry spreading, and manure/slurry storage. Low emissions slurry spreading was the only matched intervention thought to directly address Problem 4.6: emissions from the spreading practice itself.

Emissions associated with fertilisers (Problem 4.7) had 4 matched interventions, of which 3 – choice of N fertiliser, urease inhibitor, and fertiliser management – were all thought potentially effective at improving local air quality and health; thus, a mixed approach may deliver local benefits. Whilst nitrification/denitrification inhibitors were matched to this intervention, the evidence indicated they could actually worsen local air quality by increasing emissions of ammonia.

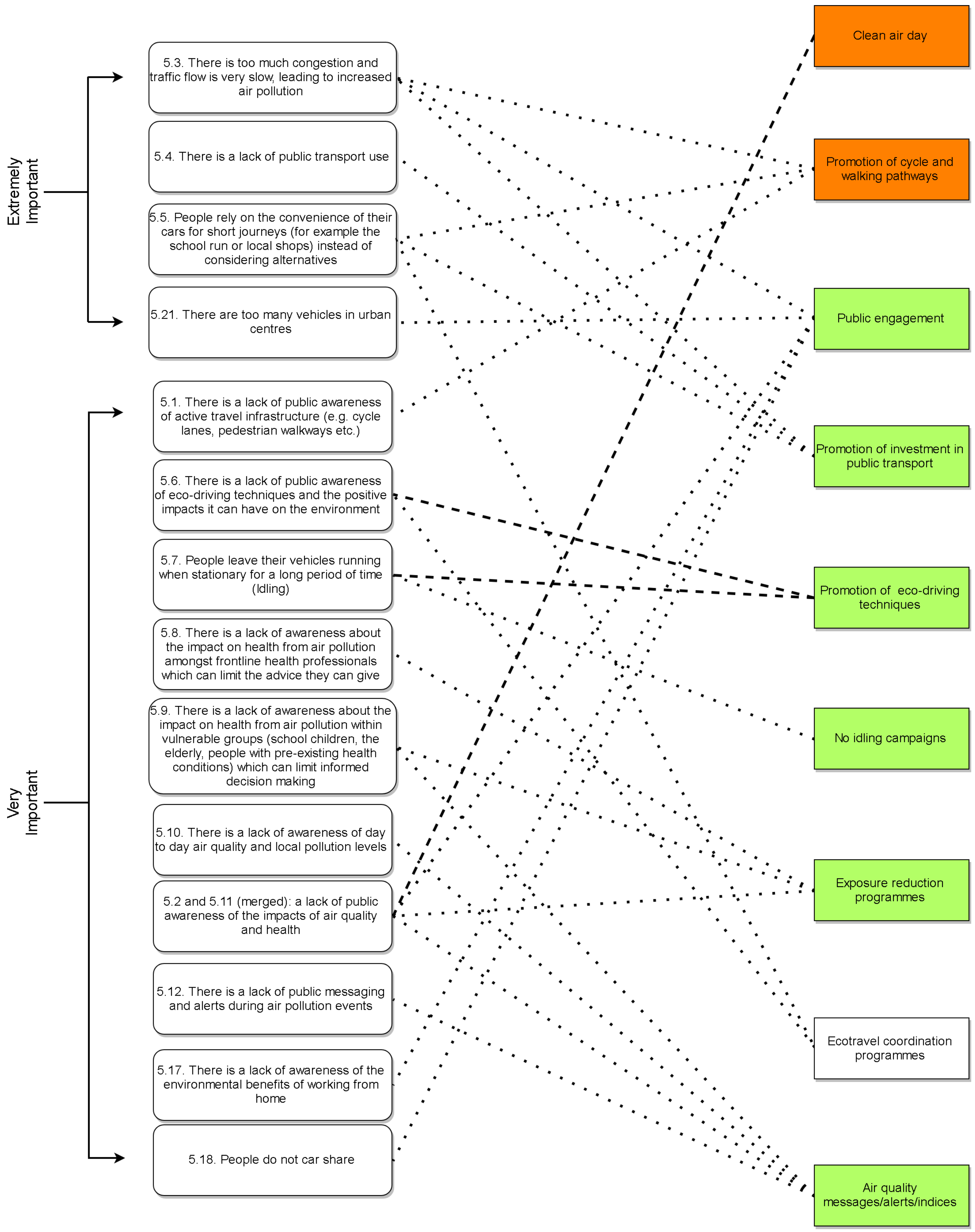
A lack of emission minimisation when designing new farms (Problem 4.2) had 3 potential solutions, of which building design (including incorporation of abatement technologies) and strategic tree-planting had the potential to improve local air quality and health, the former through reducing emissions and the latter through mitigating them by affecting dispersion around farms.

Two problems had matched interventions that had uncertain benefits for local air quality and health. One (Problem 4.8) related to pressure for high-intensity farming due to demand for food products: increasing productivity or changing consumption patterns were potential solutions. Sector-level pressures and demand and supply are potentially important determinants of emissions from the agricultural sector, and the uncertainty regarding the effectiveness of matched interventions indicates that this is an area to consider in future when considering longer-term approaches and emission and exposure trends.

Local or regional pollution hotspots associated with large farms (particularly intensive farms, Problem 4.10) was matched with local targeting of mitigation (ie, use of locally specified approaches). This intervention had little evidence of effectiveness, and further case-studies where local approaches have been taken to address such problems are required. In common with other rapid evidence assessment areas, it is the case that combinations of interventions could address such issues: in this case policy and technological interventions identified in the industrial rapid evidence assessment are also relevant as potential solutions.

There were 9 agricultural problems unmatched to interventions found by the rapid evidence assessment: they are discussed in Annexe A7.

Figure 18: Stakeholders' air quality problems associated with behaviour / social science and matching interventions[5]



[5] Problems 5.2 and 5.11 (insufficient awareness of air pollution and health) were presented as one problem in Figure 8 and separately in Annexe A7

Four **behavioural** problems were judged by stakeholders as ‘extremely important’: all 4 related to traffic in some way. Two had single matched interventions as solutions, both with weak strength of evidence: a lack of public transport use (Problem 5.4) was matched with promotion of public transport (potentially effective in improving local air quality and health); too many vehicles in urban centres (Problem 5.21) was matched with public engagement (potentially effective). Other interventions identified in the spatial planning and vehicle/fuel rapid evidence assessments are also potential solutions (this applies to many of the traffic-related behavioural problems identified). Congestion (Problem 5.3) was addressed by promotion of public transport, public engagement and promotion of cycling and walking, though the latter was considered of limited effectiveness in improving local air quality and health (due to the limited number of additional people that may take up active travel); a combined approach is necessary. Promotion of cycling and walking pathways, though potentially limited in terms of effects on air quality and health, was the only intervention matched with the ‘very important’ problem of a lack of public awareness of active travel infrastructure (Problem 5.1). Reliance on cars for short journeys (Problem 5.5) was matched with promotion of cycling and walking, though the impacts of that on local air quality were thought limited due to the limited effect of promotion alone, and promotion of investment in public transport (thought to have a potentially higher local benefit) and eco-travel co-ordination programmes (considered unproven).

A lack of public awareness of health impacts associated with air pollution (Problem 5.2), decreased from ‘extremely’ to ‘very important’ in the second round of the Delphi. It was matched with Clean Air Day (or similar initiatives), which was 1 of only 2 interventions across the review area with medium strength of evidence attributed by the rapid evidence assessment, though its effects on air quality and health were thought limited, and the other matched intervention, public engagement, was thought to have the potential for more persistent local benefits; although both short and long-term awareness-raising activities have their roles. As a general intervention that could be applied to address specific problems, public engagement was the only intervention matched with Problem 5.17 (a lack of awareness of the benefits of working from home) and Problem 5.18 (People do not car share), though it is clear that other behavioural interventions could be adapted to address these specific issues; there are also vehicle/fuel and spatial planning interventions (such as multiple-occupancy lanes) that are relevant, as previously discussed.

The other behavioural intervention with medium strength of evidence was eco-driving, which was thought to have potential effectiveness as improving local air quality and health. It addressed 2 ‘very important’ problems: a lack of awareness of eco-driving (Problem 5.6) and people running their engines in stationary vehicles (Problem 5.7). Engine idling was a recognised problem in the vehicle/fuel rapid evidence assessment too, and a mix of interventions that include enforcement (vehicle/fuel), eco-driving and no-idling campaigns (behavioural), may be a useful combined approach that could address hotspots of air pollution related to idling traffic, such as outside schools.

The remaining ‘very important’ air quality problems related to a lack of awareness of air pollution and health effects, and measures that could be taken to avoid or reduce exposure to air pollution (Problems 5.9, 5.11) or to a lack of information or awareness about real-time air pollution levels (Problem 5.10) both day-to-day and during short-term episodes of poor air quality (Problem 5.12). Air quality messages / alerts / indices were matched with all 4 problems, and thought potentially effective at improving local health, though as with many interventions in this rapid evidence assessment area, the strength of evidence was poor. Exposure-reduction programmes were matched with problems that required longer-term awareness-raising (Problem 5.11, public awareness of air quality and health impacts) but also had the potential to address specific groups, such as raising awareness among health professionals by involving them (addressing Problem 5.8) and raising awareness and prompting action by vulnerable groups with pre-existing health conditions who might not otherwise be prompted to minimise their exposure (Problem 5.9) and reduce their individual risk of adverse health outcomes. In this case, it is clear that these 2 interventions are related: awareness of the health effects of air pollution requires distinction between short-term and long-term exposures and effects. A combination of alerts (short-term) and messages and information (long-term), combined with advice on what actions can be taken (exposure reduction), together have the potential to improve local health by providing locally-tailored messages sensitive to exposure concentration and the nature of the target audience (eg, professionals, public, or vulnerable groups).

There were 7 behavioural problems unmatched to interventions found by the rapid evidence assessment: they are discussed in Annexe A7.

Discussion

Taking effective action to improve air quality and health

There is clear evidence of the health harms caused by a variety of pollutants in the air. The Committee on the Medical Effects of Air Pollutants (COMEAP) has highlighted that exposure to air pollution contributes to many thousands of deaths in the UK by increasing the risks of cardiovascular disease, respiratory disease and cancers. We know that air pollution disproportionately impacts those who live in less affluent areas, broadening health inequalities. There is also emerging evidence that suggests links between air pollution and conditions like diabetes, the underdevelopment of infant lungs and cognitive decline. All of these factors contribute to the case for action to tackle air pollution and improve the public's health.

The UK government requested PHE review the evidence for effective interventions and provide practical recommendations for any actions not currently included in the *UK's (2017) plan for reducing roadside nitrogen dioxide (NO_2) concentrations* which will significantly reduce harm from air pollution and should build on the NICE guidelines *Air pollution: outdoor air quality and health*. PHE was required to stratify any recommendations by their health and economic impacts. The recommendations were to be focused on the practical interventions available to local authorities, appreciating and making explicit the limits of the evidence available, whilst also making recommendations for further developing this evidence. This would form part of the government's ongoing commitment to improve air quality and inform future decision-making on the issue.

Much of the contributing evidence to substantiate interventions to improve air quality has been focussed on emission sources and reductions. Emission reduction is a primary aim of the government's Clean Air Strategy to reduce background pollution and minimise human exposure to harmful concentrations of pollutants. As such, PHE's review focussed on the 5 key air pollutants contained within the Clean Air Strategy.

PHE supports measures to reduce sources of air pollution and people's exposure. Health inequalities can be reduced if interventions account for exposure and vulnerability. As well as targeting 'hotspots' of air pollution that show an exceedance of an air quality objective, health outcomes can be improved if local and national approaches include interventions that improve air quality as a whole. There are no thresholds of effect at a population level identified for pollutants such as PM and NO_2, so there are health benefits to be gained from improving air quality even below concentrations stipulated by EU and UK standards. By implementing the policies set out in the Clean Air Strategy, Defra proposes to reduce $PM_{2.5}$ concentrations across the

UK so that the number of people living in locations above the WHO guideline level of 10 µg/m^3 is reduced by 50% by 2025.

From the outset, it is important to recognise that not all air pollution in the UK is generated within the UK. Future reductions will depend on the control of emissions of SO_2, NO_x and NH_3 in other countries and from shipping, as well as in the UK (11). The potential health benefits of reducing trans-boundary pollution are significant: non-UK sources contribute an estimated population-weighted contribution of approximately 25% of background $PM_{2.5}$ via primary PM and secondary inorganic aerosol (SIA), whilst 35-55% of population exposure to $PM_{2.5}$ arising from UK nitrate and sulphate is incurred outside of the UK (11). We should continue collaborative working to reduce trans-boundary air pollution and international engagement to share evidence and experience to improve air quality. One example of how this can be done is the Transport, Health and Environment Pan-European Programme, which aims to drive an integrated policy approach for developing sustainable and healthy transport and mobility (196); this is linked to the WHO Sustainable Development Goals (197).

Emission sources are not usually spread uniformly and where they cluster, for example, near busy roads, industrial areas or large intensive farming operations, these emissions contribute more to local concentrations of pollutants. The health impact of pollution depends on how much is emitted, how harmful it is and how it interacts with other substances in the air. It also depends on where it is emitted and how sensitive the exposed population is.

An understanding of emission sources and air pollution chemistry is key to determining and implementing effective national and local strategies, which can impact air pollution or reduce concentrations and public exposure. For example, in their report on mitigation of UK $PM_{2.5}$ concentrations, AQEG concluded that reductions of primary $PM_{2.5}$ emissions in the UK deliver reductions in $PM_{2.5}$ mass predominantly in areas of higher population density, while ammonia reductions lead to decreases in $PM_{2.5}$ concentrations mainly in non-urban areas (198). This observation suggests that if the aim is to reduce the impacts of $PM_{2.5}$ on public health, as indicated by the Average Exposure Index (AEI) (199), reducing primary PM emissions is likely to be an effective strategy. If the focus is on ecosystem damage and reducing spatially-averaged $PM_{2.5}$ concentrations across the UK, then ammonia reduction would be a more effective approach.

Emission reduction is an important step in reducing air pollution; however, it is not the only factor that determines the concentration of a pollutant. Factors such as weather, chemical transformation in the air and transport of pollutants all have a bearing. This means that the reduction in emissions of a pollutant do not always translate to an equivalent reduction in concentration or people’s exposure.

Studies have generally found that a large reduction in emissions (in the order of 50%) is needed for a relatively large decrease in air pollution concentrations (200, 201). This is partly due to the various factors such as meteorology (especially wind speed, precipitation and mixing height) which has a large impact on air pollution concentrations. When considering large-emitting sectors, these may not have the highest local impact, as this depends on location, dispersion characteristics and population exposure (for instance, the 6 refineries in the UK, are not relevant to most local authorities), so prioritising interventions needs to be considered in determining the right policy measures at both local level and national. Most of the studies that evaluated interventions associated with transport found that single interventions rarely have a significant impact on air pollution concentrations by more than a few percent.

Spatial scale of an intervention is an important factor in determining attributable health improvements. It is often difficult to demonstrate the health improvements from some interventions such as low emission zones, where the scale of the intervention is not large enough to overcome confounders on the data used to evaluate the health improvement. This does not necessary mean there is no improvement in health from such interventions (especially if implemented in many cities), it just means that quantifying the health benefit can be much more difficult. Needless to say, there are direct, additional beneficial health gains from interventions such as active travel at a local level, since they promote and improve physical activity. The NHS Sustainable Development Unit found that a 3% increase in uptake of active travel by NHS staff in England would lead to healthier staff, saving over £265m in avoided health treatment costs and improving health by 114,000 Quality Adjusted Life Years (QALYs) (202).

Some interventions may result in unintended consequences, and it can be difficult to predict what these might be. For example, commuters can respond in many ways to interventions which could vary over time. Traffic interventions designed to reduce congestion and decrease the speed of traffic could be counter-acted by increasing demand, leading to increased traffic volumes. The possibility of unintended consequences needs to be carefully accounted for when formulating effective strategies and policies. Behavioural insight research will help predict how the public may respond to specific interventions, and it can feed back into their design.

Having the evidence to be able to implement the most appropriate intervention strategies is important in achieving the greatest impact on public health. The lack of apposite evaluation has led to a paucity of evidence on the impact on health, health economic outcomes and health inequalities. This evidence is crucial to be able to justify the large investment in air quality interventions to ensure that the most effective and cost-effective interventions are implemented now and in the future.

Balancing the costs and the benefits of interventions to improve air quality is essential to assess the policies available and implement effective and efficient interventions. The rapid evidence assessments found few evaluated studies with information regarding costs (details of which can be found in Annexes A2 to A6). Taking into account all the possible impacts of improving air quality is challenging, as it involves considering a vast number of health, societal, environmental and economic outputs falling on different parts of society. For example, an economic evaluation of interventions to improve air quality should compare the cost of implementation of the interventions and the value of the impacts of the interventions. This is likely to include measuring and valuing the health benefits of the reduced exposure and the impact on healthcare costs, as well as the impact on buildings and the environment, or indirect effects such as, impacts on productivity.

The cumulative effect of a range of interventions to improve air quality has greater potential to reduce the associated burden of disease than any one intervention alone. Evidence considered by PHE's evaluation of interventions showed the '*co-implementation of various measures*', especially targeting the whole air pollutant mixture, as the intervention with the most potential to improve air quality and public health outcomes. There is evidence that national and local interventions in each domain (transport, planning, industrial and agricultural interventions) can be optimised if they are supplemented by behavioural interventions such as awareness-raising and behaviour change initiatives, particularly if they are based on behavioural change models. Adopting a package of interventions allows policies to be tailored to local and national contexts. The cumulative effect of effective long-term local approaches and incremental gains can build a critical mass: shifting to active travel, improving and creating sustainable environments, and leading to improvement in air quality and health at scale.

This is in line with the NICE review of outdoor air quality and health (115), which made recommendations for taking a number of actions in combination, because multiple interventions, each producing a small benefit, are likely to act cumulatively to produce significant change. These actions are likely to bring other public health benefits, in addition to air quality improvements (116).

Within the Mayor's LLAQM framework and evaluation (see Box 3, Introduction) 5 interventions from the 38 recommended were categorised as high priority. The results of the rapid evidence assessments generally support these findings in that the highest scored interventions include measures which reduce emissions through better technology (new boilers), reduce emissions through restrictive measures by introducing 'Low Emission Neighbourhoods' and virtual loading bays, encouraging the uptake of electric vehicles and encouraging the provision of infrastructure to support walking and cycling.

In this report PHE recommends a hierarchy of interventions that prioritises prevention or reduction of polluting activities (emission reduction) as preferable to taking steps to reduce air pollution once it has occurred (concentration reduction) or relying on avoidance (exposure reduction). However, concentration and exposure reduction measures can be cost-effective, and still have a critical role to play to supplement emission reduction interventions.

An air pollution intervention hierarchy

One way of considering a systems or model approach is a hierarchy of measures, as illustrated by Figure 19 below. The hierarchy provides a simple way of prioritising interventions to address air pollution problems from the **polluting activities**, to the **environment**, to the **people** who are exposed to the pollution:

1) **Prevention**	Reduce / eliminate emissions
2) **Mitigation**	Reduce concentrations
3) **Avoidance**	Avoid individual exposure

Figure 19: Air pollution intervention hierarchy

Pollution is a consequence of the modern society we live in: everything we manufacture will generate some form of waste (pollution), for example, combustion by-products that contaminate our air. There will inevitably be trade-offs between what we are willing to accept as a society and what we are prepared to do as individuals (such as ride our bikes or use public transport rather than drive our cars).

PHE's proposed air pollution hierarchy is a similar concept to the waste management hierarchy, which is well established in the waste industry (203). A similar principle for air pollution could be adopted across industry, business and government.

The first priority in any action to improve air quality is to consider whether air pollution can be removed or reduced at source – 'Prevention' – see Figure 20.

For example, implementing interventions which remove or reduce polluting sources such as emissions from cars (eg, by promotion of public transport, cycling, use of electric vehicles) or emissions from wood-burners (cleaner fuels, removing old appliances).

Figure 20: 'Prevention'

Prevention is not a binary choice between clean air and economic prosperity. Importantly, 'Prevention' applies to *emissions* of pollutants rather than *activities*. There is not necessarily any need to stop or reduce activities, if they can be carried out in a way that is less polluting. The global shift to clean growth and development of clean energy and innovative technologies offers future economic opportunities, and the principle of inclusive economic growth and environmental improvement is embedded in government's long-term industrial strategy, clean growth and sustainable development agendas (204-206).

Actively seeking less harmful alternatives to activities that cause increases in air pollution fits within the aspiration to develop a 'culture of clean air'. It also supports the potential adoption of a 'net health gain' within plans and policies that could affect air quality and health to prioritise the protection (and improvement) of public health. This is discussed in more detail in a later section of this report.

The air pollution intervention hierarchy recognises that it is not always possible to prevent or reduce emissions of pollutants to air. If emissions cannot be fully eliminated, then the next step is to consider how environmental pollution could be reduced. Examples are keeping sources of pollution away from people, redesigning spaces to introduce barriers to separate people from pollution, and displacing pollutant emissions outside hotspots and populated areas to reduce population exposure (Figure 21).

Figure 21: 'Mitigation'

Finally, if environmental pollution cannot be reduced or displaced, the last step is to consider how people can avoid exposure: setting out interventions to support exposure reduction (such as using travel plans based on less polluted routes) (Figure 22).

Figure 22: 'Avoidance'

Within this air pollution hierarchy, the least preferable interventions when implemented in isolation, at a population level, relate to exposure reduction (avoidance of pollution); ideally, interventions based on avoidance should be used to supplement, not replace, wider packages of interventions that prevent or mitigate air pollution.

At each level of this hierarchy, interventions need to be appropriately evaluated to ensure they are proportionate and deliver overall benefits to public health. There are considerations beyond air quality and health. For example, even though an intervention might be entirely effective in preventing air pollution (such as closing a local industrial site), it could lead to a worse overall outcome for the local population if they were reliant on the plant as their major employer.

Promising intervention strategies

A key aspect of the review was to provide practical recommendations for local actions that will significantly reduce harm from air pollution, stratifying these according to their health and economic impact.

The rapid evidence assessments were undertaken across the 5 domains of transport, planning, industry, agriculture and behaviour. They summarised existing evidence to inform an estimate of the potential future benefits effective interventions could have on public health.

This evidence, combined with eliciting multiple viewpoints from a range of stakeholders and members of the public through a Delphi process, helped generate an impression of air quality problems to be tackled and the priorities for action. The assessments also highlighted the evidence, or lack of evidence, which supported different interventions and where problems exist that might have no evidence-based effective intervention to help solve or abate the problem.

When assessing the effectiveness of an intervention we considered its potential to improve public health outcomes locally (in terms of pollution reduction at hotspots / single sites) and 'nationally' (in terms of its potential to lead to a wider reduction in population exposure across wider spatial areas). As well as its potential for public health co-benefits, potential impact on improving health inequalities, feasibility of implementation, and timescale to benefit. Effectiveness depends greatly on the circumstances and context of an intervention: in some cases interventions may be effective, in others they may have to be applied in combinations to be effective. The aim is to find combinations that have synergies and for which the effect is greater than if the interventions were implemented independently.

Our evaluations of all the interventions across the 5 domains is brought together below to discuss strategies and actions in each domain that seem most promising for deliverng the highest overall public health benefit. These evaluations are subjective and it is important to note the specific context and refer back to the source material in the rapid evidence assessments in Annexes A2-A6. Whilst the rapid evidence assessments found little in terms of economic evidence, where information was found, it has been incorporated. PHE's findings are based on interventions' generalised potential benefits to public health and provide an impression of the available evidence based on rapid evidence assessments. Policy-makers must carry out detailed options appraisals of case-specific interventions when developing future approaches. These must consider health and non-health outcomes and address practical considerations, such as cost and synergies and antagonisms with wider policy objectives.

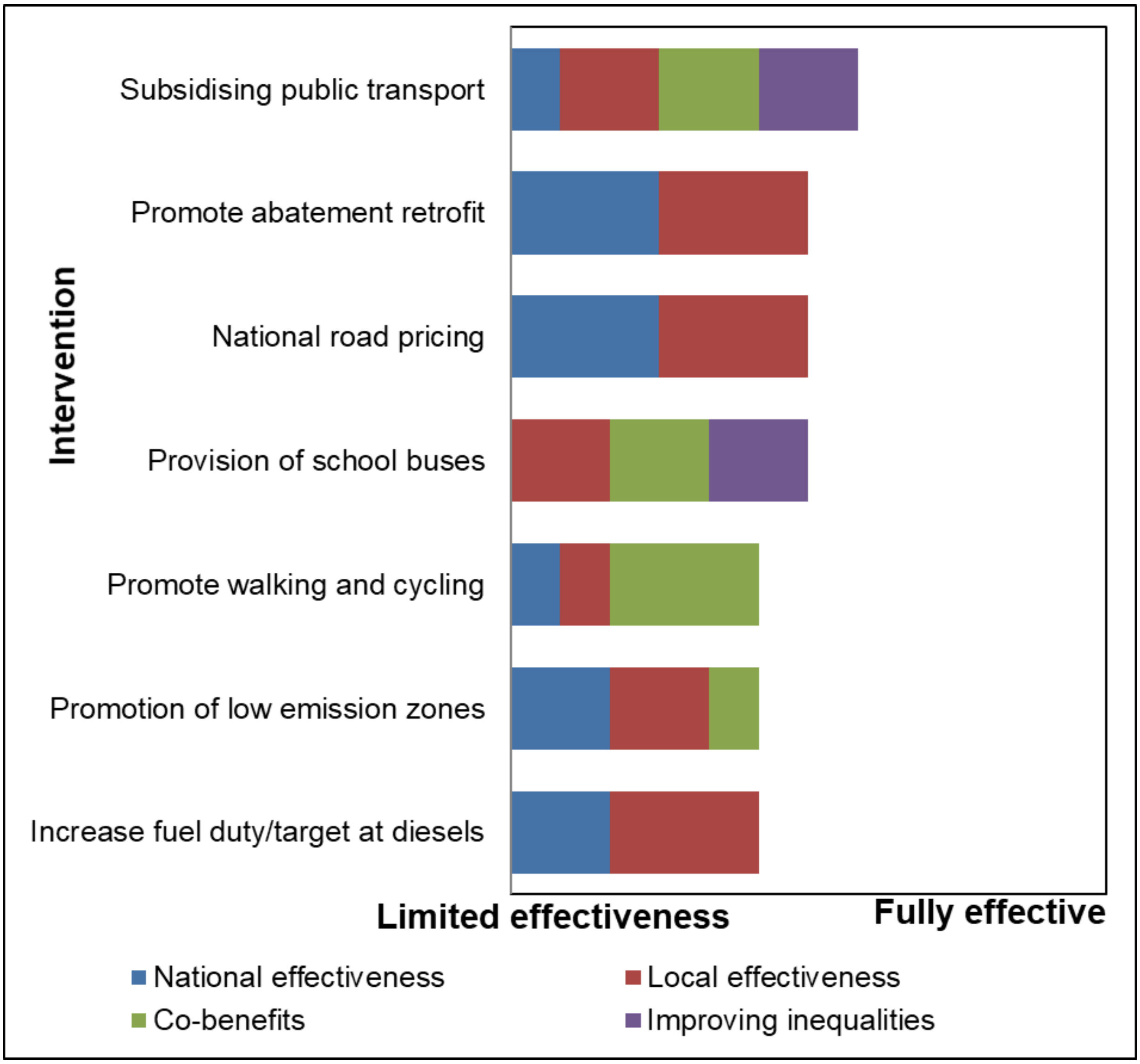
Transport interventions

Reducing emissions at a local level is important. Local measures proposed by local authority air quality action plans often include traffic-related measures such as promoting a modal shift from private cars to active travel, and reducing congestion.

Strategies that deliver the highest public health benefit relative to transport are actions or interventions aimed at reducing the use of polluting forms of transport, such as low emission zones and road pricing. The DfT's British Social Attitudes Survey 2017 (207) indicated there is a strong majority agreeing that car use should be reduced, but almost half of respondents indicated they felt there was no point in reducing their own car use unless others did the same. Pricing measures are effective, particularly in the case of low and integrated fares, which facilitate greater public transport use and help reduce social exclusion, and congestion and parking charges, which can help reduce car use. Active travel interventions, such as promoting walking and cycling at limited scale, do not generally improve air quality significantly; however, there are proven public health and environmental benefits from the added physical exercise, noise reduction, climate change mitigation and greater road safety and community cohesion.

Interventions within the transport domain assessed by the public health evaluation to have higher potential to deliver overall health benefits are presented in Figure 23.

Figure 23: Selected transport interventions' evaluated public health impact



There were also a number of transport-related interventions within the *planning* rapid evidence assessment which scored highly in terms of local or national effectiveness, and overlap with the interventions above. They include driving restrictions, co-implementation of various measures and road pricing /congestion charges, encouraging walking and cycling, and speed limitations (see next section, Figure 24).

Within the transport domain, the evidence suggests that the greatest impact on reducing emissions from road transport and improvement in public health outcomes is from the co-implementation of a package of policy measures (transport and non-transport related interventions) designed according to the local area's requirements. For example, a low emission zone can be co-implemented with appropriate retrofit or scrappage schemes (though noting cost and potential misuse of the schemes as potential barriers) to meet vehicle emission compliance, as well as with actions investing in and promoting active travel and public transport. The additional measures could help to improve the public acceptability of pricing policies, and they would offer various public health and well-being co-benefits, including increases in physical activity, noise reduction and improved neighbourhood cohesion. As the more stringent stages of Euro6/VI come into play, their adoption could potentially improve the effectiveness of LEZs. Following consultation in 2018, the government will introduce additional offences and penalties for manufacturers who fit defeat devices to vehicles (208).

In parallel, the promotion of eco-driving through smooth driving, speed reduction and anti-idling could contribute to the reduction of traffic emissions, although the evidence appears weaker than other interventions. This could support improvements in other areas, such as decreased traffic collisions and economic savings in fuel consumption.

Evidence suggests promoting abatement retrofit implementation has the potential to have a significant impact on air quality. However, it is likely to be costly to fit and maintain, especially for private cars. For larger vehicles it may sometimes prove cheaper to upgrade to a newer, more environmental friendly vehicle than retrofit an older vehicle (209) albeit this may not be affordable for everyone.

Air quality within urban areas is likely to be improved by any intervention that promotes the uptake of low and zero-exhaust emission vehicles, particularly electric vehicles. The Automated and Electric Vehicles Act 2018 came into law on 19 July 2018 and imposes requirements on large fuel retailers and service area operators to provide public charging points (210). Defra's funded work on public attitudes to air quality found that tax breaks for lower emitting vehicles were considered reasonable by 45% of the survey respondents (211). It is clear that any incentives for uptake of electric vehicles need to encourage those with the more polluting vehicles to change vehicles, but research has shown that people who tend to buy them are those who already have less-polluting vehicles (212).

The results from the rapid evidence assessment of transport interventions noted the use of LEVs should be combined with an energy policy that does not increase the use of fossil fuels from electricity generation. Another wider consideration is potential environmental concerns regarding the full life-cycle of electric vehicles and manufacture of batteries.

The Office for Low Emission Vehicles (OLEV) notes that studies suggest current reserves of rare earth metals are sufficient for the increased production of electric vehicles, but recycling and alternative battery compositions still need further research. While LEVs have reduced exhaust emissions, they will still produce some PM emissions from brake and tyre wear.

Scrappage actions have most impact when combined with appropriate taxation/incentive mechanisms that encourage the uptake of alternative fuel or smaller-capacity vehicles (downsizing). Cost-effectiveness and feasibility are potential barriers. The rapid evidence assessment noted that scrappage schemes are perceived as expensive, have the potential to break state-aid rules (due to supporting the motor industry) and may be cost-effective only in the short-term.

Government has an important role in regulating markets and incentivising investment in new infrastructure. De-regulation of the bus market and investment in clean buses was identified in the rapid evidence assessment: there will be a continued role for targeted market-based schemes to incentivise interventions in other transport and non-transport sectors.

Transport policies could also complement planning interventions, such as the development of green spaces in urban areas, and behavioural interventions and promotion campaigns, in order to improve their effectiveness to benefit public health.

Traffic management interventions, such as road pricing and access restrictions, have the potential to improve air quality. The public should be encouraged to consider their travel choices and active travel options (which would need a large proportion of the population to take up to have a notable effect on air quality). Road pricing and increasing fuel duty/targeting diesels were assessed to be potentially feasible, with a timescale to benefit of medium term. Interventions which target fuels can also reduce emissions from other non-road sources, such as the use of red diesel, which was subject to a Defra call for evidence in 2018 (213).

Other modes of transport

Within the Delphi survey, stakeholders scored road vehicle emissions as a ‘very important’ problem to address, and they thought rail, shipping and aviation emissions only ‘quite important’, indicating that road vehicles are recognised as a universal issue, whereas emissions from other modes of transport may be less recognised or more of a local issue if such infrastructure is nearby. For these other modes of transport, some effective actions were identified, which are outlined in the transport priorities below.

Economics

The rapid evidence assessment concluded that evidence of economic impact, either in terms of cost-effectiveness or cost-benefit of transport interventions to improve air quality, was limited.

A cost-benefit analysis of the ‘Ecopass’, a road pricing access restriction in Milan, Italy, showed that this measure has been effective in curbing not only pollution emissions, but also congestion (104). The cost benefit analysis presented an overall net benefit, as the implementation costs for the scheme were low.

One comparison of interventions found that the most cost-effective intervention was congestion pricing, followed by various bus interventions, including an improved bus service and increase in compressed natural gas buses. Parking management was also found to be cost-effective (105).

Use of taxation is one of the most cost-effective measures as the implementation is typically straightforward in an existing system. Public acceptability of taxing is low, and there is much opposition to adopting tax-related measures, which require political commitment from decision-makers. The DfT's British Social Attitudes Survey 2017 (207) indicated that disagreement with higher car taxes for the sake of the environment was the most common position.

Health inequalities relating to transport

Many of the interventions such as regulatory restrictions, increases in taxes/charging, low emission zones, parking controls, new rail services, and freight bans may increase inequalities if not properly designed (68). When implementing local interventions to prevent or restrict traffic in a defined area, the displacement of activity and pollution elsewhere nearby is a potential unintended consequence. On the other hand, interventions such as bus and public transport services, provision of school buses and subsidising public buses, and concessionary fares may decrease inequalities.

Community severance can result from infrastructure policies (particularly new road and rail lines) and from heavy traffic, which can arise from conventional traffic management. Conversely, community severance can be reduced if heavy traffic flows are reduced, which can result from some traffic reduction policies, such as access restrictions and road pricing.

The introduction of any transport pricing action may have social inequality consequences if the more deprived in society are equally targeted. Some studies have shown taxation to manage emissions is a socially inequitable solution, with those in socially deprived or rural areas particularly disadvantaged by the increased cost of transport. Any pricing mechanism scheme should be designed with care to avoid any social inequality impacts on society (51).

The promotion of EVs can be associated with social inequality, as most private EV owners in the UK are currently affluent, and live in urban areas with households containing 2 or more cars and have the ability to charge their cars at home (97). Based on insights from more developed EV markets, the basic socio-demographic profile of EV owners in the UK is not likely to change significantly (97). Cost was the most frequently cited barrier to switching to less polluting cars for 63% of respondents to Defra's *attitudes to air quality* survey (211).

Transport priorities

Strategies that deliver the highest public health benefit relative to transport are interventions aimed at reducing the use of polluting forms of transport, such as low emission zones, road pricing and low emission modes of transport. Investment in infrastructure and public transport is required along with the promotion of active travel and complementary behavioural interventions at the design stage:

- for the aviation sector the electrification of ground support equipment, reduction in auxiliary power units, pushback control and take-off thrust reduction (evaluated as providing an immediate time to benefit) and alternative aviation jet fuels should be considered
- for the maritime sector, regulation of the sulphur content of fuels can lead to SO2 emission reduction, and fuel regulations have the potential to reduce other pollutants
- in the rail sector, one of the most effective interventions is the electrification of the rail network, if cost and operational barriers can be overcome

Local authorities would benefit from guidance on options and protocols for reducing the use of vehicles or using low emission vehicles (LEVs).

In order to make an informed choice, consumers would need access to up-to-date information on vehicles (such as emissions, alternative fuels, battery recycling).

Planning interventions

The rationale for local government's role in reducing air pollution and its health effects is evident: air pollution is, primarily, an issue experienced locally. As improvements are made in air quality nationally, air pollution hotspots will become even more localised and the importance of action at a local level will increase (42). Planning is a domain where local government has a significant role to play. However, local authorities face a significant challenge in relation to air quality and planning. Firstly, planning lies outside of the direct oversight of public health teams and, therefore, action depends on strong working relationships between local authority public health and planning departments. Secondly, planning decisions are based on a complex and often competing mix of factors, with air quality being just 1. Thirdly, published high-quality evidence of which activities are effective at reducing the health impacts of air pollution at a local level is limited. The Delphi survey raised the problem that planning officers sometimes struggled to enforce planning conditions; therefore, when problems arise which create local pollution, mitigating them can be difficult.

At the local level, PHE supports local authorities with matters such as the development of Local Plans and Clean Air Zones (CAZs), the review of local air quality strategies and action plans. PHE also provides information and advice on the public health impacts of new and existing industrial and commercial developments regulated under the Environmental Permitting regime and is a statutory consultee for Nationally Significant Infrastructure Project applications. We also provide evidence on the links between spatial planning issues and health outcomes and provide advice to local planning authorities on how the planning system can be used to address local concerns with air pollution.

PHE has been working with government departments, namely Ministry of Housing, Communities & Local Government (MHCLG), but also Defra, DfT and Business, Energy & Industrial Strategy (BEIS), to ensure that the impacts of air pollution on health are taken into consideration as part of the spatial planning system and as part of a whole system approach which aims to reduce overall emissions and increase sustainability.

With regard to air quality, the National Planning Policy Framework (NPPF) (138) states that planning policies and decisions should sustain and contribute towards compliance with relevant limit values or national objectives for pollutants, taking into account the presence of Air Quality Management Areas and CAZs, and the cumulative impacts from individual sites in local areas.

Planning policy focuses on ensuring air quality standards are achieved, rather than reducing emissions to as low as possible. Much of the infrastructure in the UK is already built, and the quality of new development is dictated largely by private sector investment. There is a debate as to what constitutes 'good density' of urban form to reduce vehicle emissions. Similarly, certain street configurations can improve pollutant dispersion, while siting residential buildings, schools, nurseries and care homes away from areas of high air pollution can reduce population exposure. There is a considerable amount of research ongoing in this area, though much more work is needed given its complexity.

In addition, local supplementary planning documents may cover more specific aspects; they should build upon and provide more detailed advice or guidance on the policies in the Local Plan (139).

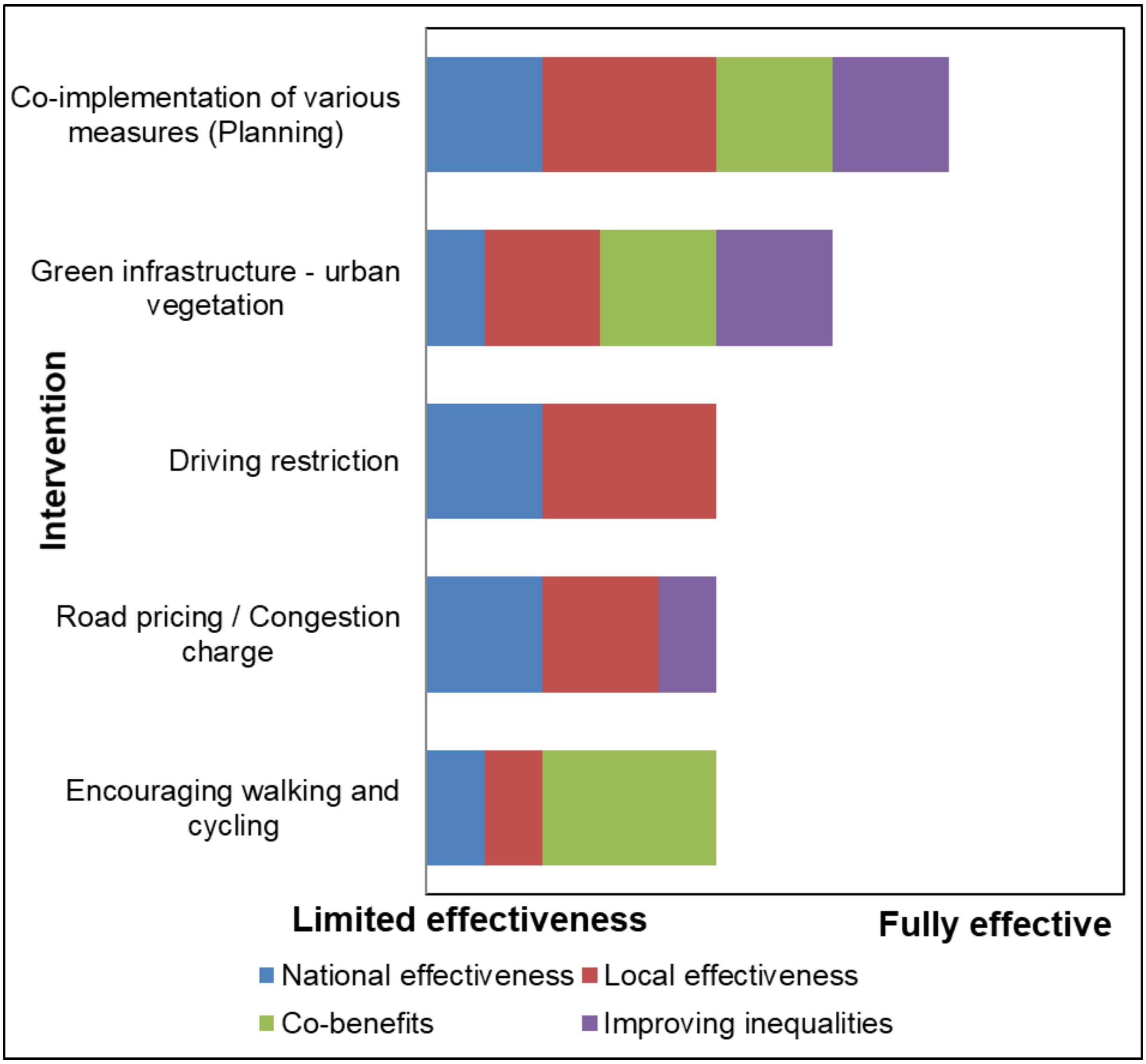
NICE recommended the following things to consider in 'plan-making':

- design and site new developments such that the need for motorised travel is reduced
- minimise exposure to vulnerable groups
- site residences away from roadsides
- avoid street and building configurations that may enhance pollution
- include green infrastructure, keeping in mind that it should be designed to encourage pollution dispersion and removal
- include information about how structures will affect the distribution of pollutants

Considering the merits of individual development proposals in isolation is less likely to produce a pattern of land use that reduces the demand for polluting car journeys. Local Transport Plans are required to consider mechanisms for reducing the need for travel. In addition, policies that promote low energy use in buildings can help reduce local emissions of air pollutants. These also align with other policies aimed at climate change mitigation.

Interventions within the planning domain assessed by the public health evaluation to have higher potential to deliver overall health benefits are presented in Figure 24. The planning interventions determined to be the most effective in terms of their impact on health locally and nationally were complementary to the transport domain interventions above (eg, co-implementation of various measures, driving restrictions and road pricing / congestion charges).

Figure 24: Selected planning interventions' evaluated public health impact



Due to the potential for public health co-benefits and the potential to improve inequalities (such as wider environmental quality and access to green spaces) the benefit of green infrastructure scored highly; however, there is significant uncertainty and multiple variables influencing this intervention's effectiveness. There are feasibility issues associated with the length of time for growth and the need for ongoing maintenance. Whilst there is a lack of evaluation of the air quality and health impacts of interventions related to urban green infrastructure, there is evidence through smaller-scale studies and observational studies linking vegetation and improvement of air pollution that indicates certain species of plants can successfully remove air pollutants from the air (with greater effects reported using high density vegetation, particularly hedges, compared to trees).

Green infrastructure intervention case studies highlight the need for careful planning and consideration of tree placement and vegetation type. There can be a number of unintended adverse consequences if the wrong species of plants or location are chosen, such as increased releases of VOCs or pollen that may affect people with respiratory illness or pollen allergies and impacts on pollutant dispersion (214).

Co-benefits associated with greening infrastructure include social, environmental, ecological and hydrological aspects. They include mitigation of the urban heat island effect, carbon sequestration, and enhancement of mental health, well-being, social cohesion and possibly encouragement of physical activity. A tool to estimate how much pollution is removed by vegetation and the associated damage costs (ie, monetised health and environmental impacts) suggests that the pollution removed by vegetation in the UK in 2015 saved £1 billion in avoided damage costs (215). Vegetation can benefit reclaimed or derelict land and control floods. However, use of green infrastructure is not a single solution for improving air quality and should only be used as part of a package of solutions.

The rapid evidence assessment found that measures such as LEZs and road pricing/ congestion charges (ie, requiring only certain types of vehicles, or all vehicles, to pay a charge to use certain roads) produced reductions in traffic, but not necessarily great improvements in air quality, perhaps due to the scale of intervention and localisation of emissions (eg, displacement of the pollutant elsewhere). LEZs could have primarily local impacts if implemented in certain ‘local’ zones; however, there could be national effects if road pricing is implemented through national policy. Driving restrictions implemented across many cities could have a national effect and were evaluated as having an immediate timescale to benefit; reflecting the fact that they are typically used to address short-term episodes of poor air quality. As such, these interventions have the potential to improve health locally, but may also have effects at larger spatial scales, especially if implemented via national measures. The public acceptance and feasibility of outright or long-term restrictions on driving is likely to preclude their use in practice.

For speed limitations (traffic calming measures) and encouraging active transport (walking and cycling), the public health ‘co-benefits’ were thought to outweigh benefits associated with reduction of air pollution. The co-benefits of implementing speed limits are associated with a reduced risk of pedestrian injury and traffic collisions. There are convincing reasons to promote these kinds of measures via behaviour change initiatives when multiple public health benefits (improved cardiovascular outcomes and improved weight status among children, adults and older adults) are also considered.

Economics

The rapid evidence assessment concluded that evidence of economic impact, either in terms of cost-effectiveness or cost-benefit of planning and structural interventions to improve air quality, was very limited and related mainly to traffic interventions.

The 2008 NICE guidance on physical activity and the environment (134) stated that the long-term health and economic benefits associated with increases in cycling and walking would "neutralise any initial (infrastructure) costs". PHE's review of active travel states that investment in walking and cycling infrastructure or behaviour change programmes can be expected to deliver low cost, high-value dividends for individual health, the NHS, the transport system and the economy as a whole (135).

Health inequalities

The benefit of good quality, green infrastructure was shown to improve health inequalities. In particular, the positive effects of green spaces on physical activity could reduce health inequalities among lower socioeconomic status groups, where physical activity levels are the lowest (124, 125). As discussed in the section on transport, other interventions such as road pricing and low emission zones may have negative effects on health inequalities, depending on how they are implemented.

Planning priorities

At a local level, opportunities to improve air quality or mitigate impacts should be identified as part of existing and new developments, such as through traffic and travel management, and green infrastructure provision and enhancement. Insofar as possible, these opportunities should be considered at the planning stage to ensure a strategic approach is taken and limit the need for issues to be reconsidered when determining individual applications. Planning decisions should ensure that any new development in an AQMA or CAZ is consistent with the local air quality action plan.

At both local and national level, policy makers and local decision-makers need to give consideration to tree placement and vegetation type in order to maximise their potential to mitigate exposures to air pollution (whether or not these are part of dedicated 'green infrastrucutre' schemes).

Further academic research, including longer-timescale and larger-scale studies, is required to evaluate the use and types of vegetation to reduce air pollution and ensure that these interventions are aligned with other sector strategies and policies.

At a local level, Town & Country and transport planners have a crucial role to play in designing healthy environments; therefore, a cross sectoral-approach bringing in planners, environmental and public health professionals is critical to the design of the optimum intervention package for a given locality.

At the planning stage, new developments, both at national and local level, must include air quality impact assessments. These should provide options for low-emission mobility and active travel options and plans for improving active travel such as cycle lanes.

At national level, there is a potential need to develop training packages to raise spatial and transport planners' awareness of the air quality impacts of existing and new developments – and how their potential benefits for local air quality and public health outcomes can be maximised.

Industrial and regulatory interventions

Emission reduction and controls within industrial processes, such as those regulated by Environmental Permitting Regulations, have played a significant role, both locally and nationally, in controlling and driving down emissions from industrial and certain commercial sectors through establishing emission limits and assessing abatement technologies. The rapid evidence assessment identified that the overall approaches to the implementation of identified interventions were not significantly different across industrial sectors, and, indeed, many of the interventions identified (both policy and technological) are already commonplace across sectors.

The potential effectiveness of technological measures needs to be considered in relation to the adequacy of supporting policy measures, which may improve or support their success, for instance, through financial incentives or sanctions if standards are not met. There is a well-established relationship between industry and government through industrial sounding boards, with information exchange and stakeholder consultation processes in place, at which potential strategies' feasibility can be discussed.

Spatial planning and permitting guidance currently dictates that if a proposed installation meets the requirements of industrial legislation (such as the Industrial Emissions Directive) and emissions from it will not lead to local exceedances of air quality standards, the proposed installation is not regarded as having prohibitively adverse impacts on health. Whilst this regime helps to ensure health-based standards are not exceeded, it does not incentivise realisation of proven potential public health gains associated with further reducing exposure to non-threshold pollutants.

The benefits to public health of improved air quality occur even when ambient air pollutants are reduced below air quality standards and can benefit the entire affected area. For overall pollution improvement, action to improve air quality is not just about dealing with areas where there are exceedances of air quality standards and should not be focused solely on local areas with AQMAs. For example, there is no regulatory standard for local authorities in England with respect to action to reduce emissions or concentrations of $PM_{2.5}$ pollution, although action to tackle PM_{10}/NO_x would usually contribute to this. The EU Ambient Air Quality Directive does, however, set out air quality standards for $PM_{2.5}$ including an exposure reduction obligation, a target value and a limit value (216). Local authorities are expected to work towards reducing emissions and concentrations of $PM_{2.5}$ in their local area as practicable. In doing so they are not required to carry out any additional local review and assessment (including monitoring), but make use of national monitoring (217).

The government's Clean Air Strategy notes a variety of actions are needed to fill the gap between where we are now and what we want the quality of our air to be like in 10 years' time and beyond. Many technologies and solutions already exist to support the move towards a clean economy, and this is true of industrial interventions (6). However, in some cases readily available technologies and solutions to air quality challenges are not yet taken up at scale. In these cases, levers such as incentives, disincentives, behaviour change and regulation may help overcome barriers such as a lack of information or awareness, or access to finance. They should be considered as part of overall approaches that comprise both industrial and behavioural interventions.

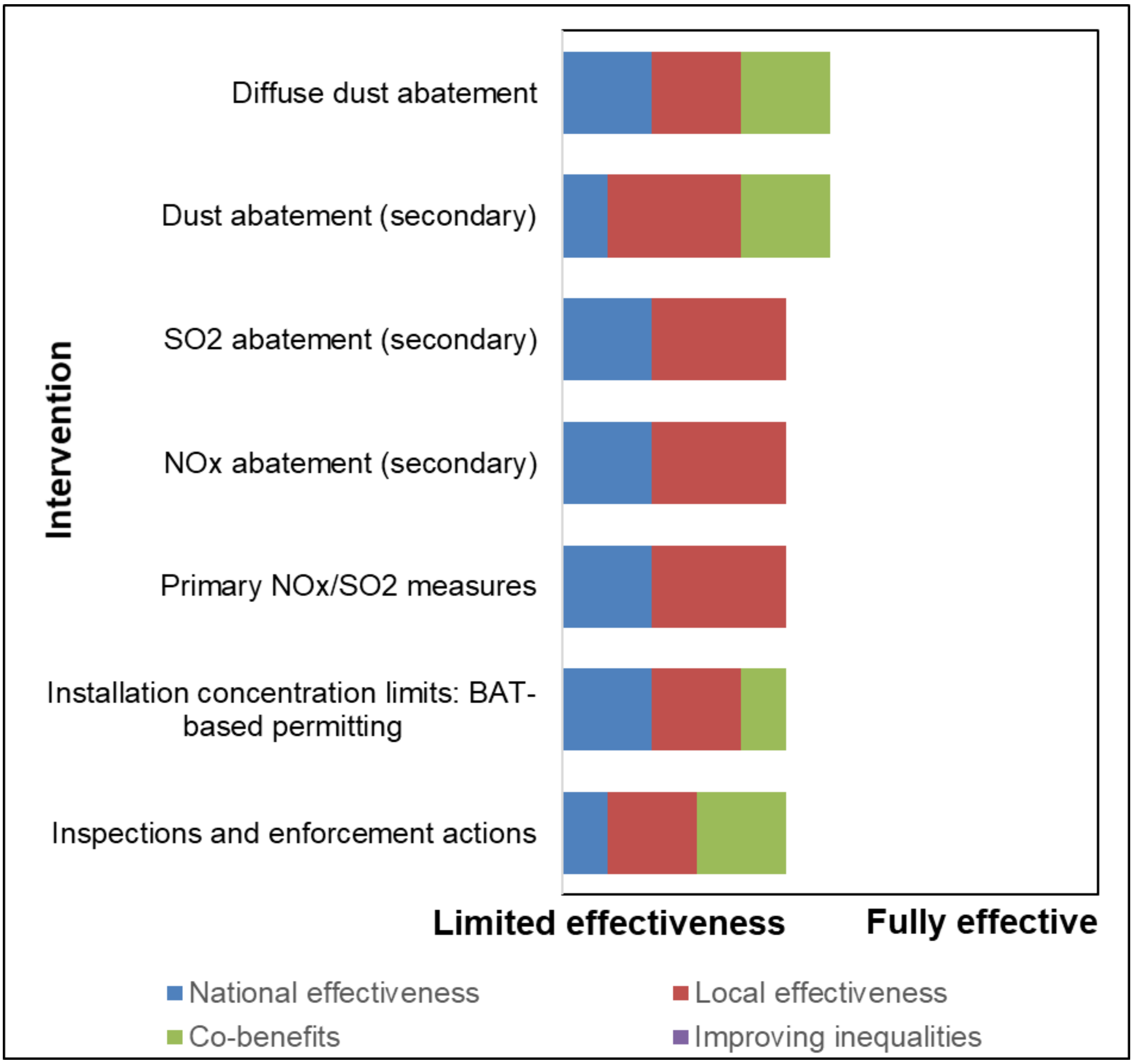
A shift in emphasis from a focus on meeting nationally set limit values is required. Standards have their place: compliance with standards provides a baseline for environmental quality and defines an 'acceptable' level of exposure. However, substantially improving health across regional/national scales requires that population health be placed at the heart of evaluation of projects, plans and policies. The paucity of evidence found in the rapid evidence assessment in relation to evaluations of interventions' effects on environmental exposures and health outcomes highlights a real gap, and apposite evaluation needs to be built into interventions from their design and inception to maximise their potential benefits. To do so requires consideration of evaluation methodologies.

The rapid evidence assessment of industrial interventions illustrated potential differences in approaches based on consideration of tonnage-based abatement (see economics section below) versus exposure-based abatement. Using approaches which account for changes in population-level exposure rather than changes in emissions is desirable. This would embed the principle that efforts to reduce exposure by smaller amounts may be justified if larger numbers of people are benefited. This is applicable to:

- environmental impact assessment (in the context of spatial planning) – where compliance with limit values and contributions to predicted environmental concentrations are the arbiters of acceptability of new developments
- environmental permitting (part of industrial regulation) – likewise, where compliance with limit values and contributions to predicted environmental concentrations are the arbiters of acceptability of new permits to operate
- regulatory impact assessments - likewise, where compliance with limit values and contributions to predicted environmental concentrations are the arbiters of acceptability of new regulations and policies

Interventions within the Industrial domain which were assessed by the public health evaluation to have higher potential to deliver overall health benefits are presented in Figure 25.

Figure 25: Selected industrial and regulatory interventions' evaluated public health impact



EU Best Available Techniques Reference Documents (BREFs) set out industry standards across each sector and have brought about significant past improvement, as they define techniques to consider when determining BAT for industrial installations. However, technologies within BREFs can take time to implement, and this requires consideration when assessing timescales to benefit.

It was clear from the rapid evidence assessment that for the majority of the interventions, there was limited evaluation of direct public health benefits associated with implementation alone or as part of a group of interventions. The evidence focussed on wider environmental benefits or cost-benefit-assessments of interventions to reduce emissions from industrial sources.

Interventions within the industry sector are well documented and, therefore, workable combinations of technological interventions are likely to be specified within BAT guidance for each sector.

The PHE evaluation allowed interventions to be categorised for local and national effectiveness. Technological industrial interventions assessed as being fully effective in terms of their potential to benefit air quality public health outcomes locally were: diffuse dust abatement (secondary), primary NO_x/SO_2 measures, NO_x abatement (secondary), SO_2 abatement (secondary), primary VOC measures and VOC abatement (secondary). All were assessed to be potentially feasible, with a timescale to benefit of long-term years +). Co-benefits, such as the reduction of odours and dust, were noted.

Eleven industrial interventions were assessed to be potentially effective in terms of their potential to improve air quality public health outcomes at wider spatial scales, such as nationally (Figure 26). They can generally be split into technological measures which abate air pollution at an installation level and policy measures which reduce or control emissions across a sector or sectors. No one industrial policy intervention alone would fully realise potential public health gains: what is clear is that the maximum benefit for the population as a whole would come from a mix of effective technology interventions within regulatory frameworks.

Figure 26: Industrial technological and policy interventions

Abatement / technology measures

- diffuse dust abatement
- primary NO_x/SO_2 measures
- NO_x abatement (secondary)
- SO_2 abatement (secondary)

Policy measures

- ambient air concentration limits
- installation emission concentration limits: BAT-based permitting
- trading schemes
- Installation absolute emission caps
- national emissions ceilings
- eco-design and product standards
- elimination of plants (or plant) (sector)

Economics

Across industrial sectors, the rapid evidence assessment identified that overall approaches to the implementation of identified interventions were not significantly different; however, assessments of economic viability remain important. The technologies (interventions) considered in the review are already considered to be BAT; thus, are already applied and considered cost-effective. However, this reflects a national perspective, and when local impacts are accounted for (or the value of potential health benefits associated with reduced emissions is considered) conclusions regarding cost-effectiveness may differ. In some cases, there may be significant benefits to health economic outcomes by implementing more effective interventions at a local level.

Damage costs are a simple way to value changes in air pollution. They estimate the cost to society of a change in emissions of different pollutants (tonnes abated). Damage costs are provided by pollutant, source and location (218). They can inform national prioritisation of action on health grounds, because they indicate where health impacts may be highest and where targeted action may be most cost-effective. The rapid evidence assessment concluded that due to limited estimates of 'tonnes abated' for industrial policy interventions, it was not possible to calculate comparable benefits using damage costs.

When cost-benefit assessments are undertaken of interventions to be implemented at the installation level (eg, capital investment in abatement technologies to meet regulatory requirements), they may focus on the *costs of meeting standards* rather than the potential monetised *health benefits in going beyond standards*. The use of damage costs in practice could move beyond impact assessment and mitigation to option appraisal and intervention design, with the aim of maximising health gains.

To maximise health benefits, it is also important to consider population exposure, as the larger the population, the greater the impact per unit of pollutant, and, conversely, the greater the benefit should effective interventions be implemented. Cost benefit analyses could consider aspects of reducing population exposure as £ per unit reduction in exposure *per person*, rather than cost per tonne of pollutant emission reduction in isolation.

Health inequalities

It is important to consider distributional effects, for example, health inequalities if industry relocated to rural areas, and whether approaches to embedding population-level exposure can be, or need to be, supplemented by additional consideration of externalities associated with the nature of the population exposed (such as likely impacts on vulnerable groups).

Industrial impacts cannot be considered in isolation from spatial planning. As with health outcomes, there are opportunities to consider and address industrial impacts on health inequality in more detail within current and future industrial and spatial planning consent frameworks.

Industrial and regulation priorities

The vision and aims of local and national planning and permitting strategies should include creating places where people's exposure to air pollution is minimised. This may require a risk assessment which includes an assessment of all polluting activities (including industrial) at local or regional levels and population exposure and vulnerability.

At local and national level, evaluation of exposure and health outcomes needs to be built into industrial interventions from their design and inception in order to maximise their potential benefits.

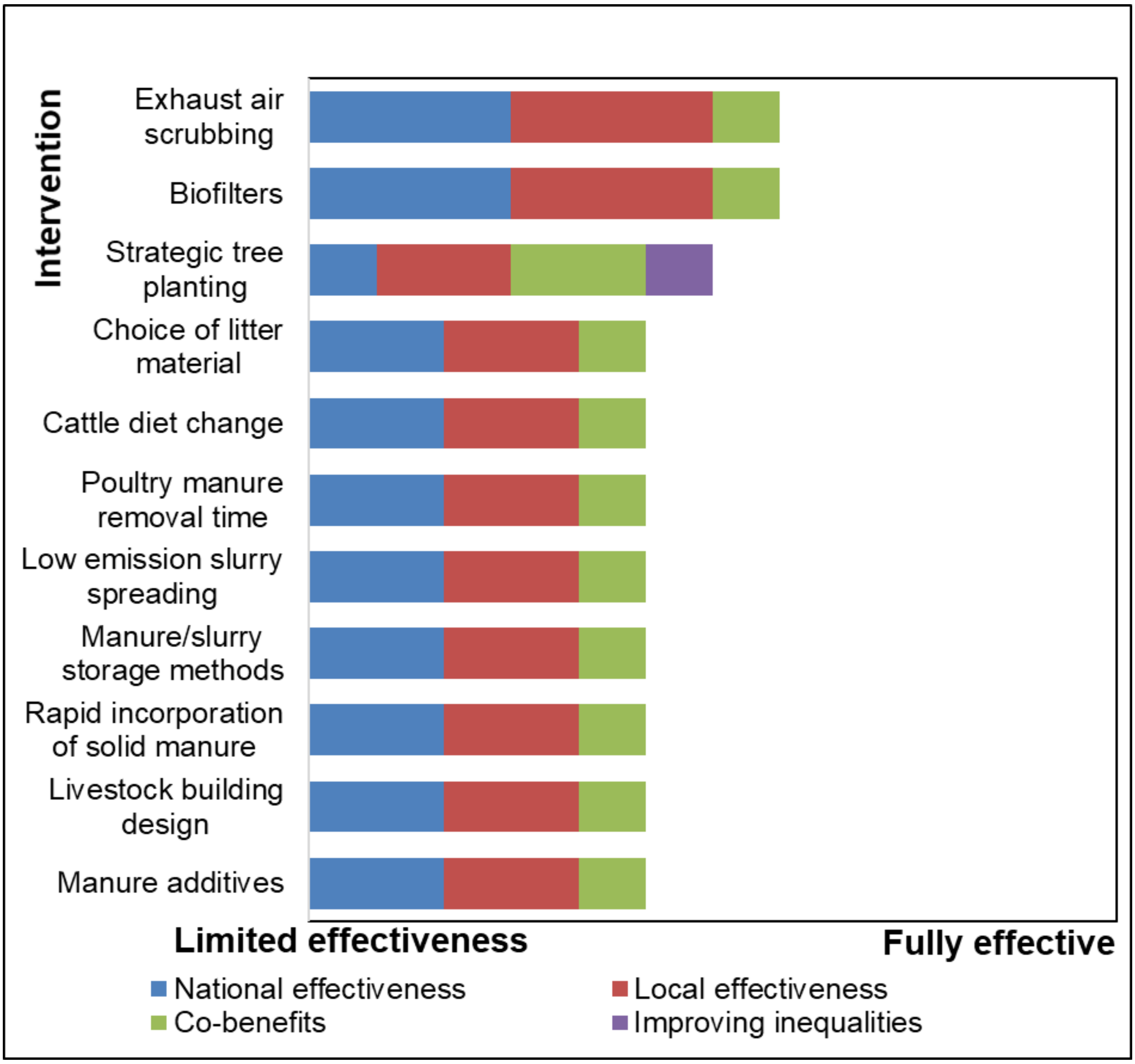
Agricultural interventions

Overall, the rapid evidence assessment demonstrated that the research so far has mostly focussed on interventions aimed at reducing NH_3 emissions, with little emphasis on other pollutants. Studies evaluating sources of emissions and emission quantification were the main types of evidence. Air pollutant concentration data were limited and tended to be local and site-specific.

Based on PHE’s evaluation of the effectiveness of interventions on public health, the interventions within the agriculture domain considered to have higher potential to deliver overall health benefits are presented in Figure 27. Bio-filters and exhaust air scrubbing scored the greatest in terms of effectiveness at both a local and national level, and were considered potentially feasible to implement. In common with industrial interventions, interventions which remove pollution at source scored higher for their potential benefits to health.

Vegetation to form shelter belts to reduce the transport of particulate matter from farms was considered to have the potential to help improve public health through mitigation. Planting more trees has a complementary effect in helping to achieve the government’s afforestation ambitions (219).

Figure 27: Selected agricultural interventions' evaluated public health impact



Reductions of NH_3 emissions are already a key governmental priority to achieve established emission limits. Whilst the rapid evidence assessment was not able to quantify the expected impact of mitigation options at local, regional and national levels, the mitigation measures designated by the rapid evidence assessment as high priority (based on potential effectiveness to reduce NH_3 emissions) were:

- choice of N fertiliser and/or urease inhibitor
- slurry acidification
- low-emission slurry spreading
- manure/slurry storage methods

These measures have already been shown to be successful in reducing NH_3 emissions in the Netherlands and Denmark (27). It should be noted that as these measures were solely prioritised based on their potential to lead to emission reductions, not all of them were evaluated as delivering the highest overall health benefits in the PHE evaluation. This was because they were not thought to deliver wider co-benefits (of these, only low-emission slurry spreading and manure/slurry storage methods were judged as having potential to deliver wider co-benefits, such as odour reduction). This is an important point when considering what criteria are to be used to determine overall benefits associated with intervention strategies – solely emission reduction, or more holistic evaluations which provide for wider co-benefits. However, the main impacts of NH_3 arise through its contribution to the formation of $PM_{2.5}$. Modelled data suggest that a 30% reduction in UK NH_3 emissions would reduce $PM_{2.5}$ concentrations by 0.3 to 0.5 $\mu g/m^3$ over most of England and Wales (28).

The Delphi process showed that stakeholders judged almost all of the agricultural problems to be ‘very important’. The results of the Delphi confirmed that when livestock are housed indoors, there were a large number of potential interventions that could address emissions, all of which had medium strength of evidence, and the 2 which were judged fully effective at improving local air quality and health were bio-filters and exhaust air scrubbing.

In terms of the implementation of a combination of interventions, bio-filters and exhaust air scrubbers scored the greatest in terms of effectiveness (locally and at wider spatial scales). If combined with livestock building design and strategic tree-planting, these interventions were thought to have high potential to benefit air quality and public health outcomes.

The rapid evidence assessment considered the impact of feed change on cattle, pig and poultry in terms of effectiveness, but the fact that this has already been widely implemented for pigs and poultry will potentially minimise its potential to reduce emissions further in future. This intervention is less relevant to grazing cattle and is only applicable to housed cattle. While it has been shown to work successfully, effectiveness will be dependent on uptake.

One Delphi problem related to pressure for high-intensity farming due to demand for food products: increasing productivity or changing consumption patterns were potential solutions. Sector-level pressures and demand and supply are potentially important determinants of emissions from the agricultural sector, and the uncertainty regarding the effectiveness of matched interventions in the results section of this report indicates that this is an area to consider in future when considering longer-term approaches and emission and exposure trends.

Agricultural emissions include a myriad of air pollutants that have potential negative effects on both human and animal health. These emissions also have wide-ranging environmental effects including acidification, eutrophication and climate change across different geographical scales (ie, local, national and global). Taking action can also result in a number of co-benefits for biodiversity, water and soil quality. While greenhouse gases were out of the direct scope of the rapid evidence assessments, in terms of co-benefits (and negative impacts), they require particular consideration as the majority of agricultural livestock and manure-related interventions are relevant to them (affecting emissions of methane, in particular).

Economics

The rapid evidence assessment did not generally find any appropriate studies that had evaluated the cost effectiveness of agricultural interventions. Implementation costs and cost-effectiveness are considered further in a recent review of interventions to reduce ammonia funded by the Royal Society (220).

Health inequalities

The rapid evidence assessment identified no papers which contained information on the impact of agricultural/rural interventions on inequality.

Agricultural priorities

At local and national level, evaluations of agricultural interventions should consider cost effectiveness, impact on health and health inequalities.

Promising interventions in the agricultural sector that could improve air quality and public health include a combination of bio-filters and exhaust air scrubbers, along with livestock building design and strategic tree-planting. With finances tight, farmers are more likely to take action if appropriate incentives are made available.

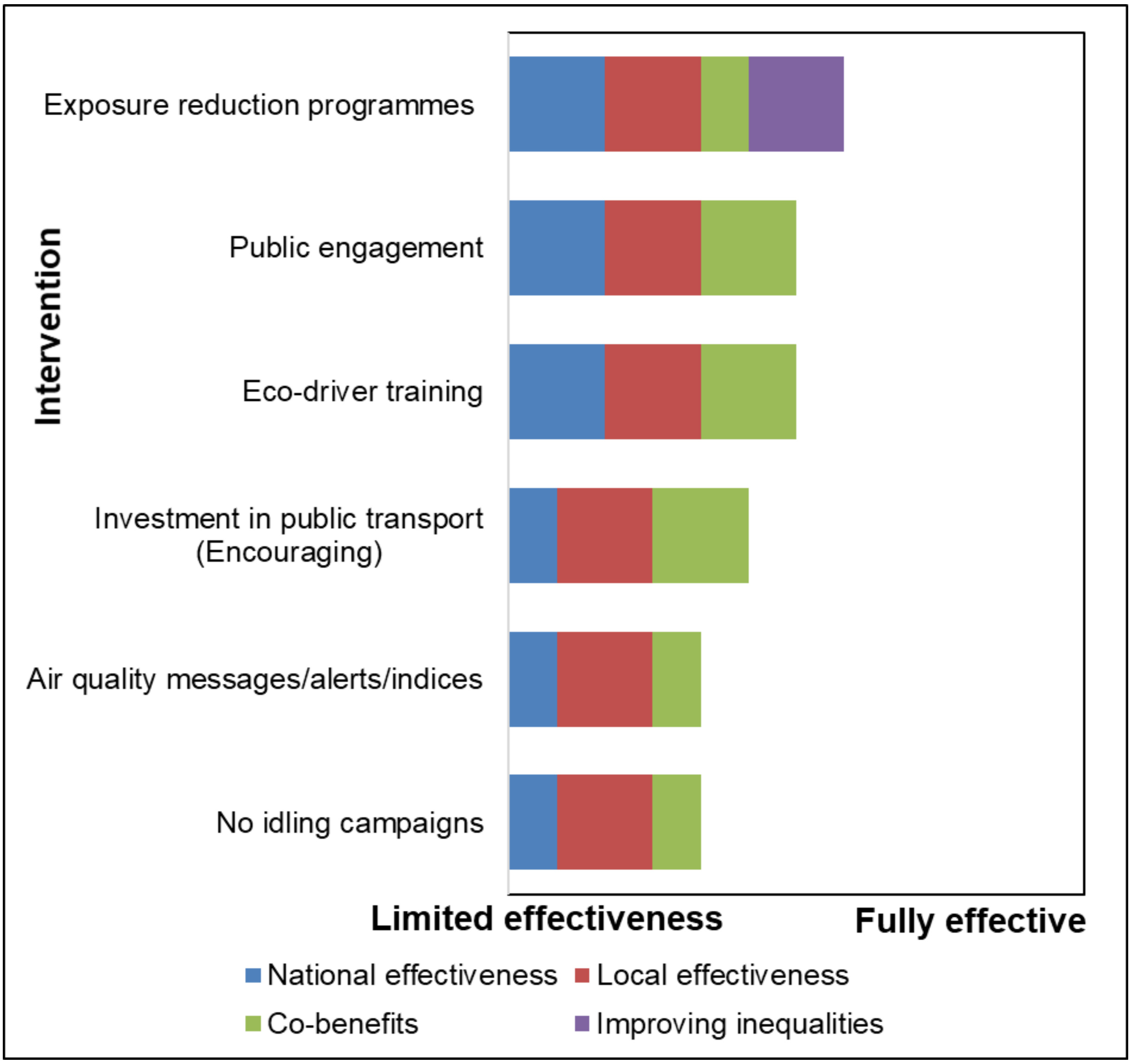
At national level, policy-makers must gather data on the current uptake of agricultural mitigation measures to enable tracking and monitoring of progress.

Further research is needed to consider the relationship between high-intensity farming, demand for food products and the potential impact on emissions and health.

Behavioural interventions

Interventions within the behavioural domain which were assessed by the PHE public health evaluation to have higher potential to deliver overall health benefits are presented in Figure 28. Exposure-reduction programmes scored highly in terms of strong potential benefits to vulnerable groups, especially in providing advice on how to reduce personal exposures to air pollutants. These interventions included educational programmes to inform the most vulnerable, with wider potential to help people make better choices about their lives. Such programmes can be targeted to specific groups, with local tailoring of national advice. For example, encouraging students to walk and cycle to school along less polluted routes was a recommendation in the London Mayor’s schools air quality audit programme (221). A lack of stakeholder engagement was identified as a key barrier to their feasibility – there is a need to improve public awareness of air quality and public health and strengthen the role and awareness of health care professionals for this to be successful.

Figure 28: Selected behavioural interventions' evaluated public health impact



Whilst public engagement interventions were thought potentially effective at improving health outcomes and the wider impact on public health, the rapid evidence assessment indicated there is limited evidence of improvements in air quality. There is however, potential for this intervention to affect attitudinal change, which is (variably) associated with behavioural intentions or behaviour.

For all the behavioural interventions identified, the effectiveness strength (potential emissions reduction) was low and the uncertainty range was high, with the exception of 2 interventions: eco-driving training and large-scale national events. However, the overall paucity of evidence of behavioural interventions' effectiveness should not be taken as evidence of ineffectiveness.

Little evidence was identified of behavioural interventions promoting alternative methods of transport having a direct impact on air pollution or health outcomes.

However, they should not be discounted, as there is a wealth of evidence showing that removing vehicles from the road can reduce emissions. There is also strong evidence of health benefits of physical activity associated with active travel, such as walking and cycling. MPs launched an inquiry in August 2018 to consider ways to increase active travel across England (222).

Interventions aimed at reducing emissions over the short-term (eg, during an episodic event of high pollution), help raise public awareness of air pollution, but the effectiveness of such approaches in improving air quality in the longer term remains unproven. Short-term episodes of high air pollution may be good opportunities to communicate about the importance of wider, sustained efforts to improve air quality.

Eco-driving (including improved driving behaviour and reduced engine idling time), smooth driving and speed reduction can reduce fuel consumption and there is some evidence that it can reduce pollutant emissions. Ensuring motorists drive steadily at the optimum speed helps reduce stop-go driving, reducing exhaust emissions, as well as particles emitted from brake wear. Furthermore, reducing traffic speed in residential areas can reduce road danger and injuries and make walking and cycling more appealing.

Stakeholders within the Delphi process recognised engine idling as a problem and a mix of interventions that include eco-driving, enforcement (vehicle/fuel), and no-idling campaigns may be a useful combined approach that could address hotspots of air pollution related to idling traffic, such as outside schools.

The Clean Air Strategy notes that an increase in burning solid fuels in our homes has led to it being the single largest contributor to national PM emissions at 38% (6). No evidence related to the effectiveness of specific measures to reduce the burning of solid fuels was identified. Defra published a consultation on wood and coal burning in 2018 (223), following on from a call for evidence/views on the use of fuels for domestic heating. The call for evidence received a wide range of comments from those suggesting a ban on domestic burning, due to personal experience of nuisance or health impacts, while others were concerned about the impact on those in fuel poverty. It was noted that more should be done to help inform consumers; Defra has produced a practical guide to provide simple steps to those that use wood burning stoves or open fires to reduce the impacts (165).

The highest potential to improve air quality and public health outcomes is associated with combining behavioural interventions with other policy or infrastructure-based interventions (eg, improving public transport or cycling infrastructure and then using behavioural interventions to maximise the use of specific walking and cycling pathways) – in this way, behavioural interventions can be used to supplement other interventions and maximise their potential effectiveness if they are implemented in conjunction with them.

Achieving significant changes in behaviour and reducing road transport demand and traffic emissions requires a combination of a wider range of soft and hard measures to boost the effectiveness of the overall approach (164). For example: the provision of public transport information and marketing (‘soft measures’), alongside ‘hard’ policies (such as congestion charging) aiming to decrease the attractiveness of car use by introducing economic disincentives, laws and regulations, as well as modifying physical environments.

The DfT’s British Social Attitudes Survey 2017 (207) showed there had been little change since 2011 in the frequencies per week with which people cycle and that there is a widespread perception that it is too dangerous to cycle on the roads. Land use and urban design are themselves determinants of people’s behaviour (they affect people’s available transport choices, for example), so a longer-term vision is required that incentivises the creation of urban and rural environments that enable beneficial personal choices and behaviour changes that reduce people’s contributions, and exposures, to air pollution. Guidance exists regarding the use of behavioural science to improve how governments make decisions (224), and on influencing behaviour through public policy, together with evaluation of impacts (225). PHE has published a strategy for applying behavioural and social sciences to improve population health and wellbeing in England (189).

Much depends on effectively combining long-term traffic and spatial planning interventions to maximise synergies between them: working to create local environments over time that reduce sources of pollution, mitigate exposures, provide means of reducing personal exposures and encourage modal shift at scale. Urban planning policies can reduce the need for private car usage in the longer-term, for example, by allowing higher densities of buildings close to travel hubs and mandating large offices be a set distance from public transport (226). In the shorter-term it is important to provide responsive, flexible capacity to meet variations in local demand, particularly for events and mass gatherings, in order to give businesses and the public a viable option to use public transport.

The cumulative effect of effective long-term local approaches and incremental gains can build a critical mass: shifting to active travel, improving and creating sustainable environments, and leading to improvement in air quality and health at scale.

For the behavioural interventions, exposure reduction programmes, public engagement and eco-driver training interventions scored highest with respect to perceived potential to deliver benefits at scale (Figure 28). These, along with the following interventions, were also thought to have the potential to benefit local air quality and public health outcomes: investment in public transport, no idling campaigns, air quality messages/ alerts/ indices, and encouraging cycling and walking pathways. Such measures can be considered in combination.

Economics

The rapid evidence assessment found no substantive evidence of economic costs and benefits associated with behavioural interventions in any of the papers assessed.

Compared to the implementation of new technologies or construction of new infrastructure, the cost of implementing behaviour change interventions is low, unless they are significant campaigns.

Short-term and local promotional or awareness campaigns to increase uptake of public transport may be low cost; however, they still require adequate and reliable transport infrastructure to be established first. National and long-term campaigns are likely to be costly, and it is important that the messaging is evidence-based and they provide clear actions for the public.

Where interventions associated with high capital or implementation costs are being considered, behavioural interventions may be a cost-effective means of maximising their impacts and benefits (and increasing the overall package’s cost-benefits).

Health inequalities

The rapid evidence assessment identified no papers that contained information on the impact of behavioural interventions on health inequalities. However, the public health evaluation of behavioural interventions concluded that exposure-reduction programmes are potentially effective at having an impact on health inequalities.

The use of air quality alerting systems can help to minimise the exposure of the most vulnerable in society. For example, the Daily Air Quality Index (186) provides current and forecast levels of air pollution with advice for vulnerable groups, such as those with pre-existing respiratory or cardiovascular conditions (and the general public). During episodes of high air pollution, they can take steps to reduce their exposure or moderate their activity levels.

Behavioural priorities

Raising awareness alone is not enough to effect change: it must be done in conjunction with other interventions.

Researchers need to consider longer-term follow up of behavioural interventions to establish whether behaviour change and benefits can be sustained.

Further work is needed to assess the impact of interventions on health inequalities, as only exposure-reduction programmes had associated evidence of potential to improve health inequalities.

Behaviour change programmes need to align with and be supported by social marketing.

Summary

This report highlights where evidence in our rapid evidence assessments seemed strongest and where gaps in evidence and intervention evaluations require further work. There is strong evidence to show that the uptake of active travel measures has a large proven benefit on health. However, predominantly due to being implemented at a small scale, it has had little overall impact on air pollution emissions to date. Unlike industry, which has an established record of emission reduction through national and European prescription of abatement technologies, the transport and planning domains lack the same level of evidence-based guidance for holistic sector-wide emission reduction.

For transport, planning and behavioural interventions, key interventions such as LEZs related to traffic restrictions and reducing polluting vehicles (exposure reduction), are effective in benefiting public health by driving down local emissions. If some such local measures are applied at scale, they have much greater potential to lead to reductions in population-level exposure to air pollutants.

Effective interventions which reduce air pollution within the industrial and agricultural sectors were associated with emission reduction, and predominantly fell within the category of 'prevention', with the key driver being to meet emission limits and air quality standards (thereby reducing the burden of air pollution on health). Industrial interventions are well established, and as they are broadly applied across industry sectors at a national level, they have contributed towards reducing population exposure.

The PHE evaluations showed that industrial interventions could deliver benefits for health at both local and national level, and as such, exploring ways of improving local air quality impacts is important when considering national policy approaches. In their Clean Air Strategy, Defra notes that they intend to strengthen powers given to local authorities by bringing in new legislation which will create a stronger and more coherent framework for action to tackle air pollution. This will be underpinned by new England-wide powers to control major sources of air pollution, in line with the risk they pose to public health and the environment, plus new local powers to act in areas with air pollution problems. These will support the creation of CAZs in cities to lower emissions from all sources of air pollution, backed up with clear enforcement mechanisms (6).

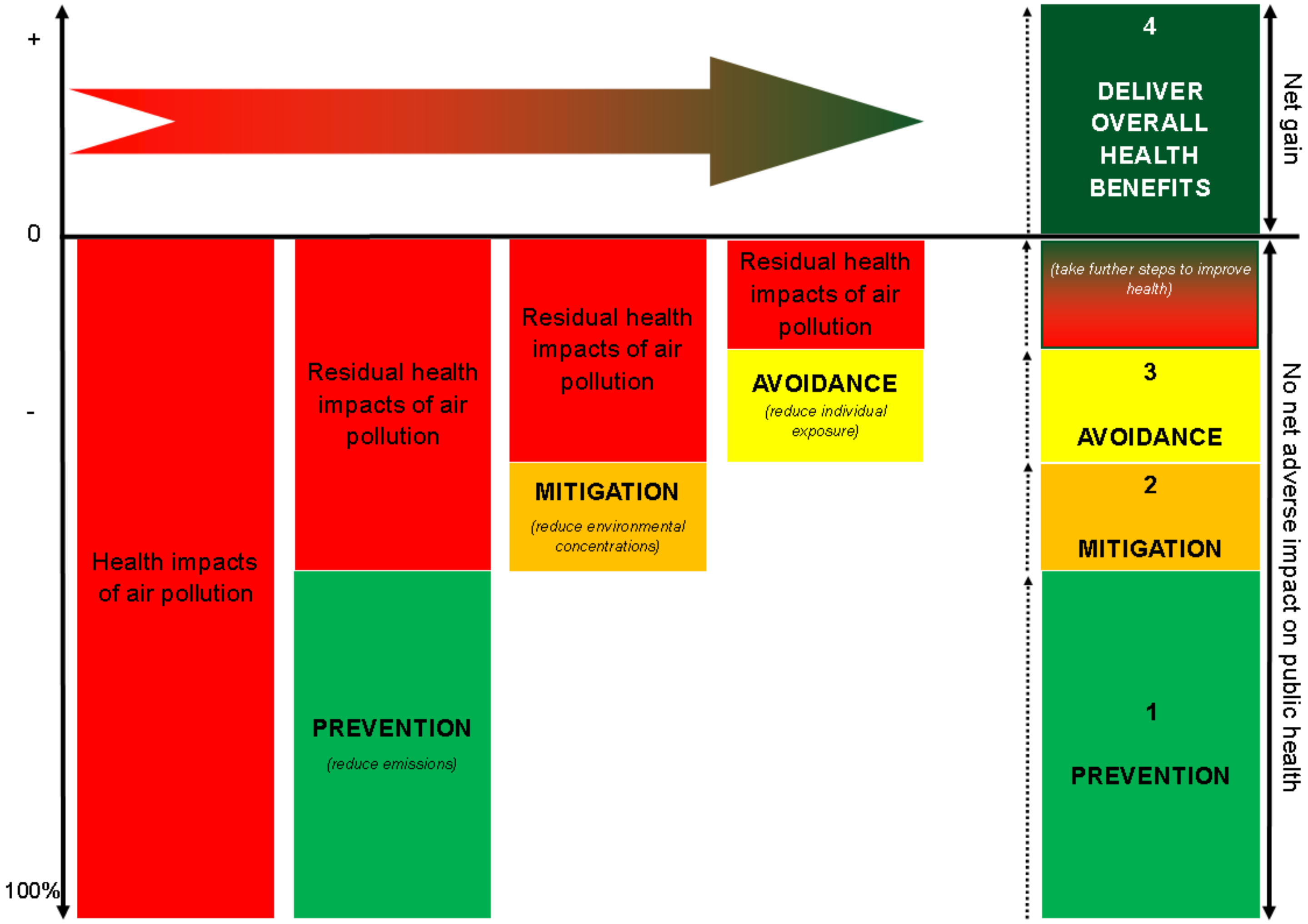
General principles and recommendations

PHE's rapid evidence assessments provided an overview of the range of existing interventions and their potential to improve air quality and health. This section sets out general principles that provide a wider context and framework for the consideration and implementation of intervention strategies within policies, programmes and plans and local and national approaches.

In their 25 Year Environment Plan *A Green Future: Our 25 Year Plan to Improve the Environment,* Defra seeks to embed a 'net environmental gain' principle for development to deliver environmental improvements locally and nationally.

PHE proposes that local and national government should aim for better integration of policies, programmes, plans and projects to achieve improvement of air quality and public health for maximum health gain. The establishment of a 'net health gain' principle (Figure 29) to be developed and implemented for all plans and policies that could improve air quality and health, could complement Defra's proposed 'net environmental gain' principle and realise health benefits by addressing all aspects of health and health determinants.

Figure 29: The intervention hierarchy and net health gain



Policies, programmes, plans and projects can prevent or reduce emissions of pollutants to air, take steps to reduce air pollution in the environment, and help people avoid *exposure* to air pollution. After prevention, mitigation and avoidance measures have been taken, residual health impacts associated with unavoidable air pollution could be addressed by taking steps to deliver health benefits by other means. In common with a key part of adhering to a core environmental planning principle called the mitigation hierarchy, this is a last resort and does not change the fact that health impacts should first be minimised. If considering wider measures to improve health, investment in disease prevention and promotion of health and well-being could be used to address residual health impacts of air pollution and go beyond these to realise a net health gain: Table 25 illustrates some determinants and behaviours that cost-effective public health interventions may focus on.

Table 25: Taking steps to improve health (examples adapted from (227))

Determinants	Behavioural interventions
Green space, Wider environment, Employment, Housing, Transport	Mental health, Violence prevention, Limit alcohol, Tobacco control, Healthy nutrition, Physical activity

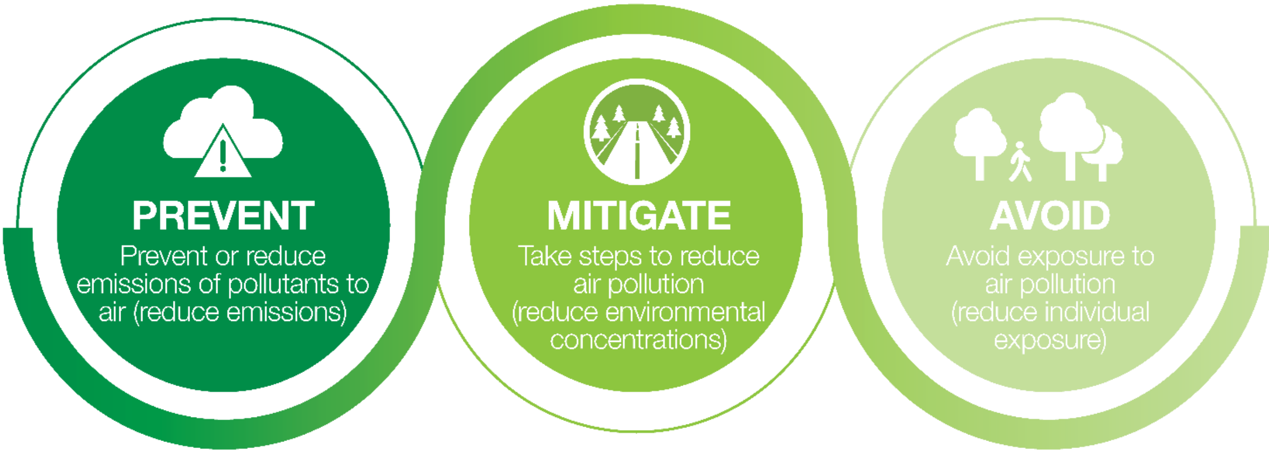
This also supports a recommendation made by the Environment Food and Rural Affairs, Environmental Audit Committee, Health, and Transport Committees to government to prioritise the protection of public health and the environment over the demonstration of compliance with legal limits in a limited number of places (228). To maximise health gains, it is also important to account for this principle in plans and policies that are not directly concerned with air pollution and health (but affect them), as well as those that are.

In common with Defra's 'net environmental gain' proposal, the practical implementation of a 'net health gain' principle will require more detailed consideration, particularly when differentiating between minimising impacts and realising health benefits, and in addressing and improving health inequalities by design.

Embedment of this 'net health gain' principle can help develop a 'culture of clean air' in policy, practice and public life that seeks to prevent pollution and improve health. This fits within a wider aspiration to support population health improvement by promoting a culture in which healthy behaviours are the norm, and in which the institutional, social, and physical environment supports this mindset (189).

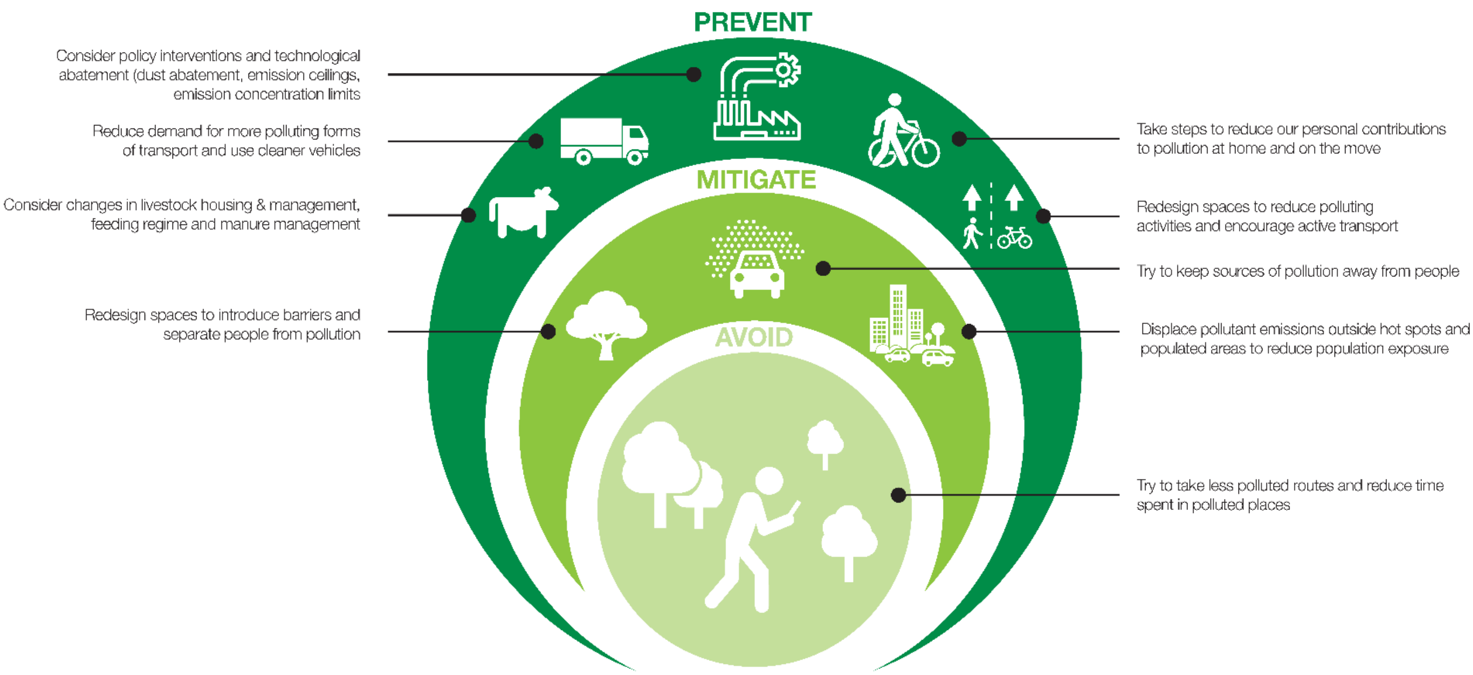
To help translate this into practice, PHE recommends the use of a hierarchy of interventions (Figure 19 and Figure 30, below) to prioritise prevention or reduction of polluting activities (emission reduction), in preference to only taking steps to reduce air pollution once it has occurred (concentration reduction) or relying on avoidance (exposure reduction).

Figure 30. Air pollution intervention hierarchy



There is not necessarily any need to stop or reduce *activities*, if they can be carried out in a way that is less polluting. Exposure reduction and concentration reduction measures still have a critical role to play to supplement emission reduction interventions, and interventions in all 3 categories have the potential to be cost-effective. Figure 31 illustrates this air pollution intervention hierarchy with some examples of interventions found by the 5 rapid evidence assessments.

Figure 31. Illustrated air pollution hierarchy



Interventions that target specific activities or pollutants can have wider benefits (for instance, reducing other pollutants or encouraging exercise). Overarching strategies to improve air pollutants should take a holistic approach to reduce the burden of air pollution as a whole wherever possible. The cumulative effects and benefits of local action and many small-scale interventions are significant.

Most of the burden of disease of air pollution is due to long-term exposure. Therefore, the primary focus should be on addressing this issue. However, short-term episodes of elevated levels of air pollution will also require the application of some interventions, for example, using the daily air quality index (186) and awareness-raising to reduce individuals' exposure.

This PHE report has focused on interventions for outdoor air pollution; however, we recognise that indoor air pollution will have significant impacts on public health. Research in this area is ongoing and future reports will consider total exposure (ie, indoor and outdoor exposure).

Our overarching recommendations are described in more detail below, along with a summary of the priorities for specific intervention categories.

Maximise health benefits

Recommendation: All local and national policy programmes, strategic, local and community plans should include consideration of effects on air quality, potential health impacts and mitigation strategies, and maximisation of potential health benefits

- plans should adequately consider the public health impact of current levels of exposure to air pollutants and health inequalities. This may require a risk assessment that includes an assessment of polluting activities at local or regional levels and population exposure and vulnerability
- both 'hotspots' and population-level exposure should be addressed (ie, action to reduce exposures in the most polluted areas and to reduce public exposure to air pollution more generally)
- focus should be on ways to maximise co-benefits and exposure reduction (rather than avoidance of impacts)
- depending on local air quality, there may be a need to consider whether there is space for regional/local adaptation of some policy interventions. For example, applying tighter emission controls in areas where vulnerable populations are affected
- embed pollution reduction beyond standards as far as possible, for non-threshold pollutants such as NO_2 and PM

We recommend that the vision and aims of local and national planning and permitting strategies include creating places where people's exposure to air pollution is minimised. This requires a fundamental shift in emphasis from the focus on meeting nationally set limit values. Standards have their place: compliance with standards provides a baseline for environmental quality and defines an ‘acceptable’ level of exposure. However, substantially improving health across regional/national scales requires that population health be placed at the heart of evaluation of projects, plans and policies.

The damage cost methodology (103) provides an established means of estimating monetised health benefits associated with reduced exposure to air pollution. Damage costs’ use in practice could move beyond impact assessment and mitigation (eg, *costs of meeting standards*) to option appraisal and intervention design (eg, *health benefits in going beyond standards*), with the aim of maximising health gains.

Stakeholders in PHE’s Delphi process noted that air quality impacts were not always adequately considered for housing developments, and this was identified as an unmatched problem (ie, no evaluated interventions were identified in the rapid evidence assessments to address it).

Strategic land use and transport planning are likely to continue to influence air quality and health. Given the government’s ambition to address the requirement for building millions of homes in the UK, the role of strategic planning is critical in determining air quality and health in the UK over the decades to come.

Take a holistic approach

Recommendation: Action to improve air quality should include a range of intervention measures across all domains and pollutants. This should include initiatives to engage the public and professionals to stimulate action. The impact on vulnerable parts of the population should be considered in any intervention measures

Policies and planning approaches aiming at reducing air pollution and improving public health outcomes will vary from region to region to accommodate differences in terrain, land use characteristics, pollution sources, populations and population density, movement and vulnerability. Therefore, the applicability of an intervention or suite of interventions needs to be assessed on a location-by-location basis.

PHE developed an aide memoire for Directors of Public Health to help them consider whether air quality plans adequately consider public health. See Table 26 below.

Table 26: Aide memoire for Directors of Public Health and others to ensure public health is adequately considered in air quality plans

<table>
<tr><th colspan="5">Does the plan adequately consider the public health impact of current levels of exposure to pollutant levels, in particular where these are above UK guidelines/ WHO guidelines? Recognition that statutory limits for pollutants are for the protection of human health.</th></tr>
<tr><th>Action Areas</th><th>Inequalities</th><th>Wider Determinants & Co-benefits</th><th>Stakeholder Engagement</th><th>Changing Attitudes & Behaviour</th></tr>
<tr><td>Source Reduction</td>
<td rowspan="3">(a) Does the plan address inequalities in adverse health outcomes from pollution and include actions specifically to address inequalities?

(b) Does the plan demonstrate the intention to deliver maximum benefit for those that are most vulnerable (individuals/ settings)

Examples of vulnerable individuals include children, the elderly and those with co-morbidities such as asthma. Settings to consider include schools, care homes and hospitals</td>
<td rowspan="3">(a) Does the plan consider and include options to address air quality that deliver health co-benefits. For example:
Physical activity
Community cohesion
Mental health

This provides an opportunity to align action on air quality including return on investment with other public health strategic priorities such as obesity and mental health

(b) Does the plan consider the impact on and synergies with other local priorities that link to the wider determinants of health?

This would include:
Sustainability
Growth and regeneration
Planning for large scale developments
Business
Transport
Localism and community engagement</td>
<td rowspan="3">(a) Does the plan demonstrate evidence of engagement with stakeholders internal to the organisation?
Within the LA, this could include planning, transport, schools teams etc. Stakeholders in local government will vary depending on local structures but will include district councils, upper-tier authorities, unitary authorities and combined authorities

(b) Is there evidence of the plan linking to the Health & Well Being Strategy?

(c) Is there evidence of engagement with stakeholders external to the organisation?
Examples of organisations that could be engaged include:
Universities
Schools
Local health partners: hospitals; CCGs; STPs; primary care
Community groups and Third Sector Organisations
Industry
Local businesses

(d) How does the plan engage communities and individuals in driving collective action?
Examples could include citizen science initiatives, involvement of elected members, community group advocacy.</td>
<td rowspan="3">(a) Is there evidence of initiatives to engage public and professionals to stimulate action?

For example:
Campaigns such as the National Clean Air Day; Walk to School
Inclusion in school curricula
Text & press alerts regarding pollution levels
Awareness-raising

(b) Are these informed by evidence including behaviour change science?</td></tr>
<tr><td>Exposure Reduction</td></tr>
<tr><td>Health Improvement</td></tr>
<tr><td>Evaluation</td><td colspan="4">Is there a process outlined for evaluation?</td></tr>
</table>

Of particular note:

- plans should address health inequalities in adverse health outcomes from pollution and include actions specifically to address health inequalities (ie, aim to deliver maximum benefit for those that are most vulnerable for example, children, elderly)
- inform the development of initiatives with behavioural science evidence and frameworks, where possible
- decision-makers should consult both internal and external stakeholders. Within local authorities, these include spatial and transport planners, community groups, environmental and public health professionals. Engagement with external organisations should also be considered (for example, local health partners, clinical commissioning groups, primary care, community groups, industry and local business)
- consider a range of interventions including working with children and their parents to implement no-idling zones outside schools and make it easy for children to walk or cycle to school. This will reduce air pollution in the vicinity of schools and reduce children's exposure accordingly
- options for active travel – cycle to work schemes, bike tax free schemes, travel plans (underpinned by improvements to transport infrastructure)

The approach developed by PHE to evaluate the potential impact on public health of interventions to improve air quality can be used to supplement the aide memoire above.

Together, Table 3 (fully detailed in Annexe A8) and Table 26 offer practitioners and policy-makers a framework for assessing the potential health benefits of policies, plans and specific interventions on a case-by-case basis.

Find and share good practice

Recommendation: Local authorities and government should collate, evaluate and share current practices and evaluations of interventions

Information about intervention case studies and their evaluation, including those published on council websites and other grey literature sources, need to be made more accessible and widely available. This should include data on innovations with a potential impact on air pollution and health, which are less likely to be found in the peer-reviewed literature.

The *Low Emission Hub* (229) is a free resource to guide best practice for reducing transport emissions. It provides guidance, templates and over a hundred case studies. Expanding this to include air quality interventions within a single, publicly available website would support local authorities' efforts to select the most effective interventions.

A problem identified in the Delphi process was a lack of planning guidance in local authorities. Further work is required to ensure planners have access to appropriate air quality related guidance. Examples exist of locally tailored guidance and nationally, PHE's *Spatial planning for health: evidence review* (137) might help to address this perceived issue.

PHE should develop guidelines for the systematic selection and implementation of interventions within a holistic framework at local-authority and/or city level.

Delphi respondents identified a potential need to raise awareness and influence the agricultural and industrial sectors to further address sources of air pollution. Policy-makers should provide awareness tools and training on the impacts of air pollution to take action for the agricultural and industrial sectors.

Evaluate interventions

Recommendation: Develop a framework for evaluating interventions to tackle air pollution and improve public health

Although many inventions to improve air quality are implemented across the country, the paucity of evaluation evidence found in the rapid evidence assessments highlighted a real gap, and apposite evaluation needs to be built into interventions from their inception. Such studies can be difficult and costly, but a framework that could assist in designing appropriate evaluation strategies would help to increase the number of studies that can provide useful information about interventions' effectiveness. The framework should include principles (scope, methods, resources needed) of evaluations for interventions of various types and scales.

Evaluate air quality interventions to assess effectiveness in terms of emissions reductions, exposure reductions and health improvement. Include health, economic and health inequalities outcomes in the evaluations:

- establish a baseline
- evaluate them from the outset (intervention appraisal and design)
- plan for and carry out post-hoc evaluations to address evidence gaps

Development/utilisation of source apportionment techniques in order to estimate the air quality impacts of interventions: there are a number of confounding factors that affect the evaluation of interventions, such as emissions from non-traffic sources, meteorology and vehicle fleet variability.

Consider other hazards and considerations such as noise, traffic congestion and potential co-benefits (such as increased physical activity).

Consider the development/utilisation of health impact assessment methodologies to assess the positive and negative impacts of sets of interventions and the indirect implications for the wider community.

There is evidence of short-term benefits to air quality from interventions such as driving restrictions during large sporting events. However, there is a need to consider the long-term effects of some air quality interventions. It is important to design evaluation strategies for multiple interventions throughout cities over the long-term. Due to meteorology and atmospheric variability, a long time-series (eg, 10 years) is recommended for detecting whether interventions have a significant effect on air quality.

Funding should be considered at the onset to enable evaluation of interventions. Any funding for innovations to reduce air pollution and its impact at local and regional levels should be contingent on a built-in relevant evaluation strategy.

The economic impacts from walking and cycling may be quantified when evaluating new interventions, using a newly developed model from Sustrans (102). This is based on Defra's damage costs (103) and includes the benefits of emissions avoided due to reduced car journeys and impacts of a cycle/walking route user's changed exposure to pollution.

Help people avoid exposure to air pollution

Recommendation: Local and national government should provide guidance for members of the public explaining how to reduce their exposures to air pollution, training for health professionals, school governors and staff, and social care professionals

The consideration of measures that foster awareness of the effects of air pollution in the local population can empower people to make informed decisions on how to reduce their exposure and, if required, to better manage their health conditions. For example:

- awareness of the sources of air pollution that the public can do something about (such as traffic pollution, wood burning, exposure to pollutants inside vehicles)
- awareness of personal exposure reduction strategies (use of less busy roads for walking/cycling, active travel) and how to manage symptoms during pollution episodes (eg, for asthmatics)
- any information needs to be proportionate and consider the risks and benefits. For example, the advice supporting the daily air quality index notes that nobody need fear going outdoors and children need not be kept from school or taking part in games (230). In healthy individuals, the benefits of physical exercise are likely to outweigh any exposure-reduction benefits from staying indoors

- the CMO report recommended that air pollution be included in the medical professional training curriculum, so practitioners can advise patients on how best to avoid exposure to air pollution

Further work to develop the evidence base

Overarching priorities

A framework needs to be developed to provide guidance for evaluating interventions to tackle air pollution and improve public health.

Investment to enable evaluation of air quality interventions to assess effectiveness in terms of emissions reductions, exposure reductions and health improvement. Include health, economic and health inequalities outcomes in the evaluations:

- establish a baseline
- evaluate them from the outset (intervention appraisal and design)
- plan for and carry out post-hoc evaluations to address evidence gaps (particularly over larger spatial scales and longer time-frames to examine scalability and persistence of benefits)

Development/utilisation of source apportionment techniques in order to estimate the air quality impacts of interventions: there are a number of confounding factors that affect the evaluation of interventions, such as emissions from non-traffic sources, meteorology and vehicle fleet variability.

Consider the development/utilisation of health impact assessment methodologies to assess the positive and negative impacts of sets of interventions and the indirect implications for the wider community.

Vehicle/fuel priorities

Monitoring of the observed impact and multiple outcome measures for traffic intervention studies is needed.

More evidence on interventions for the aviation, rail and maritime sectors.

Planning/structural priorities

Review the evidence of how urban form (the physical characteristics of the built environment, including shapes, size, density and configuration) may influence local air quality and public health.

Evaluate the impact of strategic land use and transport planning on modifying emissions, air quality and health, as strategic planning sets the framework for local interventions.

There is a need for longitudinal studies of green infrastructure interventions (not just green space studies), on a relatively large scale, together with controlled, long-term, measurements of changes in air concentration of pollutants.

There is a need for better inclusion of health and equity outcomes in studies on green space interventions, through improved monitoring of local green space management and related health and equity impacts.

For traffic-related interventions, such as road pricing/congestion charge and speed limitations, there is a need to evaluate other potential sources of air pollution or simultaneous interventions as well as a need for longer-term monitoring.

Specifically for LEZs**,** monitoring other PM metrics, such as black smoke or elemental carbon, may be more useful in determining their traffic-specific impacts.

Studies should be done of the impact of road infrastructure changes on a wider area, to account for traffic displacement. A longer period of evaluation is needed to tease out impacts of weather and other potentially confounding variables.

Given the difficulty in evaluating the co-implementation of various measures in the complex systems of the built and natural environment, there is need to develop further research methodologies, which could follow a complex, whole-systems approach to examine causality.

Industrial priorities

Review permitting approaches to ensure they maximise potential benefits to public health outcomes and account for local health profiles and health inequalities when evaluating applications for installations' environmental permits at installation level (including the possibility of local approaches which impose tighter controls in certain areas or circumstances).

Evaluate the contribution of smaller LAPPC-regulated processes and processes not subject to environmental permit requirements to population-level exposures to air pollution (ie, their cumulative impact).

Explore innovations with a potential impact of improving air pollution and health.

Applicability of interventions given the variability in existing industrial equipment, performance and installation location.

Specific consideration of the relationship between industry and spatial planning.

Improving consideration of public health outcomes in the regulation of industrial emissions and choice and implementation of associated interventions.

Agricultural priorities

Review the factors that motivate farmers and barriers to the adoption and implementation of mitigation measures (interventions) in the UK and monitor the current level of uptake. This will help to identify and secure 'quick wins', identify and avoid unwanted trade-offs, and help to understand where long-term improvements can be made.

Evaluate the agricultural sources, distribution and impact of other pollutants (besides ammonia), such as oxides of nitrogen and bio-aerosols.

Within the context of UK-wide emissions, NH_3 abatement by slurry acidification needs further study.

Characterise how agricultural mitigation measures can be aligned with other sector strategies and policies (eg, water and climate change) to maximise co-benefits and minimise negative trade-offs.

Conduct studies which also consider the impact of agricultural/rural interventions on inequality.

Behavioural priorities

Develop interventions using a recognised behavioural framework (such as the COM-B model and Behavioural Change Wheel (166)) to better identify facilitators, barriers and levers to behaviour change.

More work is required to identify how various behaviours might differ from each other and which tools might best be used for understanding causal processes or for effectively achieving change.

Researchers need to consider longer-term follow up of behavioural interventions, which are required to establish if behaviour change and benefits can be sustained.

Evaluation of the effectiveness of social marketing, particularly in transport planning and travel behaviour (194).

Looking ahead

Emerging health evidence has the potential to inform future estimates of the burden of disease due to air pollution, and the prioritisation of future interventions. The international PROSPERO database of prospectively registered systematic reviews in health and social care returns over 100 ongoing reviews from an “air pollution” search term. Reviews examining the short and long-term effects of exposure to outdoor air pollution include studies examining effects on respiratory conditions in infants, children and young adults; effects on cardio-pulmonary disease, diabetes, fertility, adverse birth outcomes and neurodevelopment, mental health outcomes, autism, cancer, and mortality. Fewer reviews focus on specific sources such as traffic-related pollution and biomass burning.

Papers on socioeconomic factors and air pollution have the potential to inform future health inequalities evaluations, though there are fewer registered examples. One ongoing review examines effect-measure modification of socioeconomic position on the association between air pollution and cardio-respiratory outcomes (231).

Papers on health economic factors and air pollution have the potential to inform future health economic evaluations and cost-benefit-analyses. Similarly, fewer registered reviews examine this area: one ongoing review addresses the financial implications of air pollution on health in Asia (232).

Government horizon scanning recognises future challenges related to air pollution. The Environment Agency’s 2018 ‘state of the environment’ report (233) considered air quality, acknowledging developing evidence of new and emerging pollutants from familiar sources, such as road transport, and others, such as microplastics. Future interventions will be needed to address sources of pollutants of concern brought to light by new evidence.

Whilst PHE’s rapid evidence assessments identified few publications describing innovative interventions under development, the future development of a framework for evaluating interventions and sharing practice has the potential to improve awareness and early uptake of new technologies and practices with the potential to improve air quality and health. For example, there is increasing interest in shore-to-ship charging to prevent idling of ships’ engines whilst berthed (195); such infrastructure-based interventions require early consideration and incorporation into long-term development plans once proven effective. The continued development of battery storage technologies and improvement in clean energy infrastructure offers notable opportunities to reduce emissions associated with fuel use and power generation, which forward-looking spatial plans can capitalise on. To continue the example above, the provision of cheap, clean electricity and planned improvement to dockside power infrastructure over time could create the conditions necessary to enable routine charging of ships at berth and improved air quality in and around ports; in this way, changes to practice can be enabled by planned improvements to infrastrucuture that phase-in promising new interventions.

The Clean Air Programme for Europe envisages a regular update of impact assessment analysis, to track progress towards the objectives of the related European Directive and to serve as input into stakeholder forums. The 2017 Clean Air Outlook (234) considered the impacts of current and future policy and specific source-control measures including eco-design of stoves and boilers, transport emission standards, and industrial standards and techniques. The next Clean Air Outlook is scheduled for 2020 and will reflect on the analysis of the National Air Pollution Control Programs due from member states, including the UK, by April 2019.

Glossary

Glossary terms attribution (115, 235-238). For a full list of terms, refer to the *WHO's Glossary on Air Pollution* (239).

Terms	Explanation
1,3-Butadiene (C_4H_6)	1,3-butadiene, like benzene, is an organic compound emitted into the atmosphere principally from fuel combustion (eg, petrol and diesel vehicles). Unlike benzene, however, it is not a constituent of the fuel but is produced by the combustion of olefins. 1,3-butadiene is also an important chemical in certain industrial processes, particularly the manufacture of synthetic rubber. It is handled in bulk at a small number of industrial locations. Other than in the vicinity of such locations, the dominant source of 1,3-butadiene in the atmosphere is the motor vehicle. 1,3-Butadiene is a known, potent, human carcinogen
Acid Deposition	The total atmospheric deposition of acidity is determined using both wet and dry deposition measurements. Wet deposition is the portion dissolved in cloud droplets and is deposited during precipitation events. Dry deposition is the portion deposited on dry surfaces during periods of no precipitation as particles or in a gaseous form. Although the term acid rain is widely recognized, the dry deposition portion ranges from 20 to 60% of total deposition
Acid Rain	When atmospheric pollutants such as sulphur dioxide and nitrogen oxides mix with water vapour in the air, they are converted to sulphuric and nitric acids respectively. These acids make the rain acidic, hence the term 'acid rain'. Acid rain is defined as any rainfall that has an acidity level beyond what is expected in non-polluted rainfall. Acidity is measured using a pH scale, with the number 7 being neutral. Consequently, a substance with a pH value of less than 7 is acidic, while one of a value greater than 7 is basic. Generally, the pH of 5.6 has been used as the baseline in identifying acid rain, with precipitation of pH less than 5.6 is considered to be acid precipitation
Acute Lower Respiratory	Acute illness affecting the lungs, such as acute

Terms	Explanation
Infections	bronchitis and bronchiolitis, influenza and pneumonia
Air Pollution Bandings	The Air Pollution Information Service uses 4 bands to describe levels of pollution. The bands are Low, Moderate, High and Very High. Healthy people do not normally notice any effects from air pollution, except occasionally when air pollution is "Very High"
Air Pollution Bulletins	Air Pollution Bulletins are issued daily for each zone of the UK. The bulletins show current and forecast air quality for the next 24 hours. The forecast air quality is categorised using 4 Air Pollution Bandings and also using a numerical Air Pollution Index
Air Pollution Index	The Air Pollution Index is a numerical index for air pollution ranging from 1 to 10 related to the Low, Moderate, High and Very High Air Pollution Bandings.
Air Pollution Information Service	The Air Pollution Information Service provides free of charge, detailed, easy-to-understand information on air pollution. This information is particularly important to people with medical conditions which may be aggravated by poor air quality. The latest information is available by freephone, on Ceefax and Teletext, and via the Internet. The Service gives regionally based summaries and detailed information on current pollution levels, as well as forecasts for the next 24 hours
Air Quality Management Area (AQMA)	If a Local Authority identifies any locations within its boundaries where the Air Quality Objectives are not likely to be achieved, it must declare the area as an Air Quality Management Area (AQMA). The area may encompass just one or two streets, or it could be much bigger. The Local Authority is subsequently required to put together a plan to improve air quality in that area - a Local Air Quality Action Plan
Air Quality Limits	There are a wide range of terms and concepts in national and international initiatives, for example, standards, objectives, target values and limit values. The 2 which feature within the UK's air quality strategy are standards and objectives. The EU Ambient Air Quality Directive and fourth Daughter Directive contain Limit Values and Target Values. The national Air Quality Objectives and EU limit and target values with which the UK must comply are summarised in the National air quality objectives of

Terms	Explanation
	the Air Quality Strategy.
Air Quality Objectives	The Air Quality Objectives are policy targets generally expressed as a maximum ambient concentration to be achieved, either without exception or with a permitted number of exceedances, within a specified timescale. The Objectives are set out in the UK government's Air Quality Strategy for the key air pollutants
Air Quality Standards	Air Quality Standards are the concentrations (of pollutants in the atmosphere) recorded over a given time period, which are considered to be acceptable in terms of what is scientifically known about the effects of each pollutant on health (including the effects on sensitive sub-groups) and on the environment. Air Quality Standards can also be used as a benchmark to indicate whether air pollution is getting better or worse.
Air Quality Strategy	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland describes the plans drawn up by the government and the devolved administrations to improve and protect ambient air quality in the UK in the medium-term. The strategy sets objectives for the main air pollutants to protect health. Performance against these Objectives is monitored where people regularly spend time and might be exposed to air pollution
Air Scrubber	Air filter to remove gaseous and/or particulate pollutants
Ambient Air	The air (or concentration of a pollutant) that occurs at a particular time and place outside of built structures. Often used interchangeably with "outdoor air"
Ambient Air Pollution	Air pollution in the ambient environment, that is, in outdoor air, but able to enter homes
Anaerobic Digestion	Microbial break down in the absence of oxygen
Annual Mean	The annual mean is the average concentration of a pollutant measured over 1 year. This is normally for a calendar year, but some species are reported for the period April to March, which is known as a pollution year. This period avoids splitting a winter season between 2 years, which is useful for pollutants that have higher concentrations during the winter months
APU	An Auxiliary Power Unit (APU) is a device on a

Terms	Explanation
	vehicle that provides energy for functions other than propulsion. They are commonly found on large aircraft and naval ships as well as some large land vehicles
Attributable Cases	Attributable cases estimated from a specified risk factor (eg, an air pollutant)
Automatic Monitoring	Monitoring is usually termed "automatic" or "continuous" if it produces real-time measurements of pollutant concentrations. Automatic fixed-point monitoring methods exist for a number of pollutants, providing high resolution data averaged over very short time periods. BAM, TEOM and FDMS instruments are all automatic monitors
Average Speed Technology	Cameras with automatic number plate reading (ANPR) digital technology, placed in multiple locations (at least 2, at a minimum of 200 m apart) along a stretch of road to monitor a vehicle's average speed
BAM (Beta Attenuation Mass Monitor)	The BAM (Beta Attenuation Mass Monitor) measures particulate concentrations automatically
Bandspreading	Use of trailing hose or trailing shoe application methods to apply slurry to soil
Baseline	This refers to the ‘steady state’ of a factor assuming no change from current levels
Belt (in poultry houses)	Conveyor belt used to remove manure
Benzene (C_6H_6)	Benzene is an aromatic organic compound which is a minor constituent of petrol (about 2% by volume). The main sources of benzene in the atmosphere in Europe are the distribution and combustion of petrol. Combustion by petrol vehicles is the largest component (70% of total emissions) whilst the refining, distribution and evaporation of petrol from vehicles accounts for approximately a further 10% of total emissions. Benzene is emitted in vehicle exhaust as unburnt fuel and also as a product of the decomposition of other aromatic compounds. Benzene is a known human carcinogen
Bi-mode train	An electro-diesel locomotive (also referred to as a dual-mode or bi-mode locomotive) is powered either from an electricity supply (like an electric locomotive) or by using the on-board diesel engine (like a diesel-electric locomotive)
Bioaerosol	Aerosols of microbial, plant or animal origin
Biofilter	A wet air filter where pollutants are degraded by

Terms	Explanation
	microorganisms
Bioscrubber	See biofilter
Biotrickling Filter	See biofilter
Black Smoke	Black Smoke consists of fine particulate matter. These particles can be hazardous to health especially in combination with other pollutants which can adhere to the particulate surfaces. Black Smoke is emitted mainly from fuel combustion. Following the large reductions in domestic coal use, the main source is diesel-engined vehicles. Black smoke is measured by its blackening effect on filters. It has been measured for many years in the UK. Now interest is moving to the mass of small particles regardless of this blackening effect
Carbon Monoxide (CO)	Carbon monoxide is a colourless, odourless gas resulting from the incomplete combustion of hydrocarbon fuels. CO interferes with the blood's ability to carry oxygen to the body's tissues and results in adverse health effects
Cardiovascular Disease	Disorders of the heart and blood vessels including disease of the coronary blood vessels supplying the heart (coronary heart disease) and the blood vessels supplying the brain (cerebrovascular disease)
Chronic Obstructive Pulmonary Disease	A collection of chronic lung conditions characterized primarily by a persistent blockage of airflow from the lungs
Clean Air Zone (CAZ)	A Clean Air Zone defines an area where targeted action is taken to improve air quality and resources are prioritised and co-ordinated in order to shape the urban environment in a way that delivers improved health benefits and supports economic growth (240)
CNG	Compressed natural gas (CNG) (methane stored at high pressure) is a fuel which can be used in place of gasoline(petrol), diesel fuel and propane/LPG
COMEAP	The Committee on the Medical Effects of Air Pollutants, COMEAP is an Advisory Committee of independent experts that provides advice to government departments and agencies on all matters concerning the potential toxicity and effects upon health of air pollutants
Crude Protein	A measure of how much protein is in feed, calculated from N content

Terms	Explanation
Crusting	Formation of a solid layer on the surface of stored slurry
Daily Air Quality Index	A number used by government agencies to tell the public how polluted the air is or will be. The number is provided with recommended actions and health advice. The index is numbered 1 to 10 and divided into 4 bands: low (1 to 3), moderate (4 to 6), high (7 to 9) and very high (10)
Days With Exceedances	The number of days with exceedances is the number of days on which at least 1 period has a concentration greater than, or equal to, the relevant air quality standard (the averaging period will be that defined by that Standard). Since the National Air Quality Standards cover different time periods (15 min average, 24 hour running mean etc.), this gives a useful way of comparing data for different pollutants
Deposition	See Acid Deposition
Digestate	Material remaining after the anaerobic digestion of manure or other biodegradable material such as food waste
Dispersion Model	A dispersion model is a means of calculating air pollution concentrations using information about the pollutant emissions and the nature of the atmosphere. In the action of operating a factory, driving a car, or heating a house, a number of pollutants are released into the atmosphere. The amount of pollutant emitted can be determined from knowledge of the process or actual measurements. Air Quality Objectives are set in terms of concentration values, not emission rates. In order to assess whether an emission is likely to result in an exceedance of a prescribed objective it is necessary to know the ground level concentrations which may arise at distances from the source. This is the purpose of a dispersion model
DOC	For compression-ignition (ie, diesel engines), the most commonly used catalytic converter is the diesel oxidation catalyst (DOC)
Dose–response	Or exposure response. Describes the change in health effect on an individual caused by differing levels of exposure to a stressor (in this case an air pollutant) after a certain exposure time
DPF	A diesel particulate filter (DPF) is a filter that captures

Terms	Explanation
	and stores exhaust soot (some refer to them as soot traps) in order to reduce emissions from diesel cars
E5, E10	Ethanol fuel mixtures have 'E' numbers which describe the percentage of ethanol fuel in the mixture by volume, for example, E85 is 85% anhydrous ethanol and 15% gasoline. Low-ethanol blends are from E5 to E25, although internationally the most common use of the term refers to the E10 blend
Emission Factor	An emission factor gives the relationship between the amount of a pollutant produced and the amount of raw material processed or burnt. For example, for mobile sources, the emission factor is given in terms of the relationship between the amount of a pollutant that is produced and the number of vehicle miles travelled. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory
Emission Inventories	Emissions inventories estimate the amount and the pollutants that are emitted to the air each year from all sources. There are many sources of air pollution, including traffic, household heating, agriculture and industrial processes. The UK National Atmospheric Emissions Inventory (NAEI) can be accessed from: www.naei.org.uk/
EPAQS	The Expert Panel on Air Quality Standards (EPAQS) was set up in 1991 to provide independent advice to the UK government on air quality issues, in particular regarding the levels of pollution at which no or minimal health effects are likely to occur. The Panel's recommendations were adopted as the benchmark standards in the National Air Quality Strategy. EPAQS has now been merged into the Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP)
EU Directives	The European Union has been legislating to control emissions of air pollutants and to establish air quality objectives since the early 1970s. European Directives on ambient air quality require the UK to undertake air quality assessment, and to report the findings to the European Commission on an annual basis.

Terms	Explanation
	Historically this has been under the Air Quality Framework Directive (1996/62/EC) and the Daughter Directives (DD) (1st DD -1999/30/EC, 2nd DD - 2000/69/EC, 3rd DD 2002/3/EC and 4th DD- 2004/107/EC). In June 2008, a new Directive came into force: the Council Directive on ambient air quality and cleaner air for Europe (2008/50/EC), known as the "Air Quality Directive". This Directive consolidates the first 3 Daughter Directives, and was transposed into the Regulations in England, Scotland, Wales and Northern Ireland in June 2010. The 4th Daughter Directive remains in force
Euro Standards	Standards produced by EU Directives specifying maximum permitted emissions of various air pollutants. Light duty vehicle standards are referred to using Arabic numerals (Euro 1 to 6); standards for heavy duty vehicles use Roman numerals (Euro I to VI).
Exceedance	An exceedance defines a period of time (defined for each Air Quality Standard) during which the concentration of a pollutant is greater than, or equal to, the appropriate air quality criteria. For Air Quality Standards, an exceedance is a concentration greater than the Standard value. In order to make useful comparisons between pollutants, (the Standards may be expressed in terms of different averaging times), the number of days on which an exceedance has been recorded is often reported. For Air Pollution Bandings, an exceedance is a concentration greater than, or equal to, the upper band threshold
Field Capacity	Maximum water holding capacity of soil
Fine Particulate Matter ($PM_{2.5}$)	See $PM_{2.5}$
Fogging	Fine spray or aerosol application within livestock buildings
Global Warming	Global warming describes an increase in the temperature of the Earth's troposphere. It has occurred in the past as a result of natural influences, but the term is now more commonly used to refer to the warming predicted by computer models to occur as a result of increased emissions of greenhouse gases as a result of human activity

Terms	Explanation
Greenhouse Gas (GHG)	Greenhouse gases are atmospheric gases such as carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, ozone, and water vapour that slow the passage of re-radiated heat through the Earth's atmosphere. Most can be naturally occurring and human generated
Ground Support Equipment (GSE)	Ground Support Equipment (GSE) is the support equipment found at an airport, usually on the ramp, the servicing area by the terminal. This equipment is used to service the aircraft between flights while the aircraft is on the ground
Household air pollution	Air pollution generated by household fuel combustion, leading to indoor air pollution, and contributing to ambient air pollution
Hydrocarbons	Hydrocarbons are compounds containing various combinations of hydrogen and carbon atoms. They are emitted into the air by natural sources (eg, trees) and as a result of fossil and vegetative fuel combustion, fuel volatilization, and solvent use. Hydrocarbons are a major contributor to smog
Hydrocarbons (HC)	Compounds that contain mostly carbon and hydrogen. Often used interchangeably with volatile organic compounds (VOCs).
Incidence	The occurrence of new cases of a disease – not to be confused with prevalence
Incorporation (of manure into soil)	Soil cultivation to bury material applied to the soil surface
Integrated Exposure-Response Function	Models that combine exposure and risk data for 4 sources of combustion-related pollution, namely outdoor air, second-hand smoke, household air pollution and active smoking
Interim Target-1	A pollutant level higher than that set by the AQG, established as an interim target to assist implementing agencies to make progress towards meeting the AQG levels
Ischaemic Heart Disease	Disease characterized by reduced blood supply to the heart
Lagoon	Storage pond for slurry or waste water, often with earth banks and lined to prevent escape of contents
Limit values	EU Limit values are legally binding EU parameters that must not be exceeded. Limit values are set for individual pollutants and are made up of a concentration value, an averaging time over which it

Terms	Explanation
	is to be measured, the number of exceedances allowed per year, if any, and a date by which it must be achieved. Some pollutants have more than 1 limit value covering different endpoints or averaging times
Litter	Bedding in poultry buildings, which becomes mixed with excreta, feathers and spilt feed
LNG	Liquefied natural gas (LNG) is natural gas (predominantly methane, CH4, with some mixture of ethane C_2H_6) that has been cooled down to liquid form for ease and safety of non-pressurized storage or transport
Local Air Quality Action Plan	When a Local Authority has set up an Air Quality Management Area, AQMA, it must produce an action plan setting out the measures it intends to take in pursuit of the Air Quality Objectives in the designated area. The plan should be in place, wherever possible, within 12-18 months of designation and should include a timetable for implementation. See http://laqm.defra.gov.uk/action-planning/action-planning.html
Local Air Quality Management (LAQM)	The Local Air Quality Management (LAQM) process requires Local Authorities to periodically review and assess the current and future quality of air in their areas. A Local Authority must designate an Air Quality Management Area (AQMA) if any of the Air Quality Objectives set out in the regulations are not likely to be met over a relevant time period. See https://laqm.defra.gov.uk/
Low Emission Zone (LEZ)	A Low Emission Zone is a geographically defined area where the most polluting vehicles in the fleet are restricted or discouraged from using. The aim is to improve air quality by setting an emissions-based standard for the vehicles within the area (241)
Manure	Any type of animal excreta, solid or liquid, often mixed with straw or other bedding; sometimes mixed with washing water
Maximum Hourly Average	The maximum hourly average is the highest hourly reading of air pollution obtained during the time period under study
Methane (CH_4)	A gas that occurs naturally and is also human generated. It is a relatively potent greenhouse gas, having 25 times more global warming potential than

Terms	Explanation
	carbon dioxide
National Atmospheric Emissions Inventory (NAEI)	The NAEI compiles annual estimates of UK emissions to the atmosphere from sources such as road transport, power stations and industrial plants. These emissions are estimated to inform policy, and to help to identify ways of reducing the impact of human activities on the environment and our health. The NAEI is funded by Defra, the Scottish Executive, the Welsh Assembly Government and the Department for the Environment in Northern Ireland
National Statistics	The emissions and concentration statistics shown in Defra's air quality database are National Statistics. National Statistics are produced to high professional standards set out in the National Statistics Code of Practice. They undergo regular quality assurance reviews to ensure that they meet customer needs. They are produced free from any political interference
Nitrification/denitrification Inhibitors	Inhibitors of microbial nitrification/ denitrification processes in soil or manure
Non-Methane Volatile Organic Compounds (NMVOCs)	Compounds that contain carbon, oxygen, hydrogen, chlorine and other atoms that can evaporate easily into the atmosphere. They are found in nature as well as in some glues, solvents and paints. They help form O_3 near the ground
Out-wintering Pad	Outdoor area with drainage and often with a woodchip surface
Oxides of Nitrogen (NO_X)	Combustion processes emit a mixture of nitrogen oxides (NO_X), primarily nitric oxide (NO) which is quickly oxidised in the atmosphere to nitrogen dioxide (NO_2). Nitrogen dioxide has a variety of environmental and health impacts. It is a respiratory irritant which may exacerbate asthma and possibly increase susceptibility to infections. In the presence of sunlight, it reacts with hydrocarbons to produce photochemical pollutants such as ozone. NO_2 can be further oxidised in air to acidic gases, which contribute towards the generation of acid rain
Ozonation	Ozone application to reduce internal air pollutant concentrations in livestock buildings
Ozone (O_3)	An invisible gas occurring naturally in the upper atmosphere but at ground levels is a major component of smog. Ozone (O_3) is not emitted

Terms	Explanation
	directly into the atmosphere, but is a secondary pollutant generated following the reaction between nitrogen dioxide (NO_2), hydrocarbons and sunlight. Whereas nitrogen dioxide acts as a source of ozone, nitric oxide (NO) destroys ozone and acts as a local sink (NO_X-titration). For this reason, O_3 concentrations are not as high in urban areas (where high levels of NO are emitted from vehicles) as in rural areas. Ambient concentrations are usually highest in rural areas, particularly in hot, still and sunny weather conditions which give rise to summer "smogs"
PAHs	Polycyclic Aromatic Hydrocarbons (PAHs) belong to a large group of organic compounds, several of which have been shown to be carcinogenic
Particulate matter (PM)	Airborne PM includes a wide range of particle sizes and different chemical constituents. It consists of both primary components, which are emitted directly into the atmosphere, and secondary components, which are formed within the atmosphere as a result of chemical reactions. Of greatest concern to public health are the particles small enough to be inhaled into the deepest parts of the lung. Air Quality Objectives are in place for the protection of human health for PM_{10} and $PM_{2.5}$
PM_{10}	Solid or liquid particles with an aerodynamic particle size less than or equal to 10 micrometres, such as dust and aerosols, which may settle to the ground or stay suspended in air
$PM_{2.5}$	Small particles or liquid droplets measuring less than or equal to 2.5 micrometres in diameter. Due to their smaller size, these particles can be more harmful to public health than PM coarse particles
Parts per billion, ppb	Parts per billion, ppb, describes the concentration of a pollutant in air in terms of volume ratio. A concentration of 1 ppb means that for every billion (10^9) units of air, there is 1 unit of pollutant present
Parts per million, ppm	Parts per million, ppm, describes the concentration of a pollutant in air in terms of volume ratio. A concentration of 1 ppm means that for every million (10^6) units of air, there is 1 unit of pollutant present
Percentile	A percentile is a value below which that percentage of data will either fall or equal. For instance, the 98th

Terms	Explanation
	percentile of values for a year is the value below which 98% of all of the data in the year will fall, or equal
POPs	Persistent Organic Pollutants (POPs) are chemical substances that persist in the environment as they are resistant to environmental degradation via chemical, biological or photolytic processes. The compounds are known to bioaccumulate through the food web and pose a risk of causing adverse effects to human health and the environment. These include dioxins and furans (see TOMPS)
Prevalence	This is the total number of cases of a disease in a particular population. This indicates how widespread the disease is
Products Of Incomplete Combustion	Mixtures of pollutant particles and gases formed by incomplete burning of fuels or other material
Respirable Particulate Matter	Particles (complex mixtures of pollutants) with aerodynamic diameters of 10 µm or less
Running Mean	This is a mean - or series of means - calculated for overlapping time periods, and is used in the calculation of several of the National Air Quality Standards. For example, an 8-hour running mean is calculated every hour, and averages the values for 8 hours. The period of averaging is stepped forward by 1 hour for each value, so running mean values are given for the periods 00:00 - 07:59, 01:00 - 08:59 etc. This can also be considered as a "moving average". By contrast, a non-overlapping mean is calculated for consecutive time periods. Using the same 8-hour mean example, this would give values for the periods 00:00 - 07:59, 08:00 - 15:59 and so on. There are, therefore, 24 possible 8-hour running means in a day (calculated from hourly data) and 3 non-overlapping means
Selective catalytic reduction (SCR)	Selective catalytic reduction (SCR) is a means of converting nitrogen oxides, also referred to as NOx with the aid of a catalyst into diatomic nitrogen (N_2), and water (H_2O)
Simulation	The imitation of a real-world process or system over time, such as the simulation of a virtual country population
Slurry	Liquid livestock manure

Terms	Explanation
Slurry Bag	Large storage bag with inlet and outlet valves
Solid Fuel	Solid materials burned as fuels, includes coal as well as biomass fuels
Synthetic Paraffinic Kerosene (SPK)	Synthetic Paraffinic Kerosene (SPK) is a biofuel that has been hailed by the aviation industry as a means of curbing carbon emissions from aircraft
Street Ventilation	Air in a street flows in a pattern determined by many factors, including the shape and design of buildings. It mixes with air from outside the street. If there are sources of pollution in the street (primarily motor vehicles) the air flow is restricted
Sulphur Dioxide (SO_2)	Sulphur dioxide is a corrosive, acidic gas which combines with water vapour in the atmosphere to produce acid rain. Both wet and dry deposition have been implicated in the damage and destruction of vegetation and in the degradation of soils, building materials and watercourses. SO_2 in ambient air is also associated with asthma and chronic bronchitis
Surficial	Relating to the surface
Target values	Target values are used in some EU Directives and are set out in the same way as limit values. They are to be attained where possible by taking all necessary measures not entailing disproportionate costs
Telematics	Technologies that store and send information on the speed, position, acceleration and deceleration of road vehicles. This, together with global positioning system (GPS) data, can be used to compare driving styles and estimate the impact on fuel consumption, emissions or wear and tear
TEOM	The tapered element oscillating microbalance (TEOM) is used to continuously measure particulate concentrations
TOMPS	Toxic organic micropollutants (TOMPs) are produced by the incomplete combustion of fuels. They comprise a complex range of chemicals some of which, although they are emitted in very small quantities, are highly toxic or carcinogenic. Compounds in this category include PAHs (Polycyclic Aromatic Hydrocarbons), PCBs (PolyChlorinated Biphenyls), Dioxins and Furans
Total Ammoniacal Nitrogen	Total amount of nitrogen in the forms of NH_3 and NH_4+

Terms	Explanation
Trailing Hose	Equipment for applying slurry to soil at or just above ground level through a series of hanging or trailing pipes
Trailing Shoe	Equipment for applying slurry to soil, through pipes which terminate in metal "shoes" designed to ride along the soil surface, parting the crop (if present) so that slurry is applied directly to the soil surface
Travel plans	Travel plans are a way of assessing and then mitigating the potential negative effects that new developments could have on air pollution by generating significant amounts of motor traffic
Tuberculosis	Infectious disease caused by *Mycobacterium tuberculosis*, which most commonly affects the lungs
Urease Inhibitor	A fertiliser additive with urea fertiliser to inhibit the enzyme urease and thereby reduce the hydrolysis of urea to ammonia and carbon dioxide
Vegetative buffer	Trees, bushes or other vegetation planted in a strip
WHO Air Quality Guideline	Value at or under which a pollutant is considered to have no, or minimal impact on health
$\mu g/m^3$	Microgramme per metres cubed. Microgramme is a unit of mass equal to 1 millionth ($1\times10^{-}6$) of a gram

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