Air Quality and Road Transport

Impacts and solutions

Guy Hitchcock, Beth Conlan, Duncan Kay, Charlotte Brannigan & Dan Newman

June 2014

RAC Foundation

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About the Authors

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Guy Hitchcock is a principal consultant at Ricardo-AEA with over 20 years' experience of transport and environmental issues. He has worked in both consultancy and academia and his expertise includes vehicle emissions modelling, low-emission vehicle technology, local air quality management and carbon reduction policy. Guy has worked on a range of national and international studies on transport technology and emissions, in relation to air quality and climate change policies. He is currently working with a number of local authorities on Low Emission Zones and Strategies. Previously he carried out air quality and carbon assessments of local transport plans, supported Defra in the review of local Air Quality Action Plans, helped develop the concept of Low Emission Zones in the UK, and played a key role in the development of a 'Heavy Duty Vehicle Emission Strategy for Abu Dhabi'.

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Beth is a business manager at Ricardo-AEA responsible for Air Quality Modelling, Mapping and Assessment. She has over 20 years of experience of air quality management at the local, national and international level. She has been involved in over 200 air quality review and assessments for local authorities and is working for Defra in the review of local air quality management. Recently, Beth advised the European Commission on air quality management implementation and the review of the Air Quality Directive. Since 1998 Beth has been a trainer of air quality management to local authorities as part of the Chartered Institute of Environmental Health EMAQ training programme which is endorsed by the Institute of Air Quality Management. Most recently Beth has been working with Defra and the Health Protection Agency on communicating air quality issues to health protection professionals within local Health and Wellbeing Boards and she has been appointed to COMEAP (the Committee on the Medical Effects of Air Pollutants).

Charlotte Branningan
Charlotte Brannigan is a senior consultant for Ricardo-AEA with over seven years' experience in the transport and environment policy sector. Charlotte has recently been involved in projects for the European Commission on assessing options for greenhouse gas emission reductions from transport until 2050, and for the Committee on Climate Change on development of marginal abatement cost curves for the transport sector, and research on the abatement technologies for the shipping sector. Charlotte also has a wide range of experience in undertaking Strategic Environmental Assessment (SEA) and Sustainability Appraisal (SA) for both local and national plans and programmes. Alongside this she has experience of Health Impact Assessment, having carried out this role for a major transport scheme in London for Transport for London.

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Duncan Kay is a senior technical consultant for Ricardo-AEA and has a background of 16 years' experience in the automotive sector, working as a research and development engineer developing new technologies to improve fuel economy and reduce emissions from passenger cars. Since leaving the industry he has spent the last five years advising and consulting on a wide range of transport issues, particularly analysis of the automotive industry and transport greenhouse gas emissions reductions. Duncan has led studies for the Low Carbon Vehicle Partnership, the European Environment Agency and the European Commission amongst others. In 2012, he completed a study for the Joint Research Centre of the European Commission examining the role of research and development in maintaining the competitiveness of the European automotive industry.

Dan Newman
Dan Newman is a consultant for Ricardo-AEA with over three years of experience on sustainable transport projects for both governments and the private sector. Dan recently co-authored the 2013 RAC Foundation's Powering Ahead: The Future of low-carbon cars and fuels report. He has particular expertise in battery/hybrid electric vehicles and natural gas fuelled vehicles. He has been involved in a range of work for the European Commission and has recently been instrumental in investigating the effect of environmental regulations and standards on vehicle prices. Dan has led tasks assessing the impact of ICT on the large-scale deployment of battery electric vehicles for the European Commission, and has modelled how natural gas can contribute to achieving cost-effective greenhouse gas emissions reductions across the European transportation sector.

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Disclaimer

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List of Abbreviations

AEI	average exposure indicator
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
AURN	Automatic Urban and Rural Network
CO	carbon monoxide
COMEAP	Committee on the Medical Effects of Air Pollutants
COPD	chronic obstructive lung disease
CPC	Certificate of Professional Competence
DfT	Department for Transport
DI	direct injection
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
DPH	Director of Public Health
EGR	exhaust gas recirculation
GHG	greenhouse gas
HC	hydrocarbons
HGV	heavy goods vehicle
HWB	Health and Wellbeing Board
IDI	indirect injection
LAQM	local air quality management
LCV	light commercial vehicle
LEZ	Low Emission Zone
LTP	local transport plan
NAEI	National Atmospheric Emissions Inventory
NO	nitrogen monoxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxide
O_3	ozone
PAH	polycyclic aromatic hydrocarbon
PCM	Pollution Climate Mapping [model]
PEMS	portable emissions measurement system
PHOF	Public Health Outcomes Framework
PM	particulate matter

$PM_{2.5}$	particulate matter of median diameter 2.5 microns or less: fine particulate matter
PM_{10}	particulate matter of median diameter 10 microns or less: coarse particulate matter
PTP	personalised travel planning
RAD	reactive airway disease
REVIHAAP	Review of EVIdence on Health Aspects of Air Pollution
SCR	selective catalytic reduction
SO_2	sulphur dioxide
TfL	Transport for London
TSP	total suspended particles
ULEV	ultra-low-emission vehicle
VED	Vehicle Excise Duty
VOC	volatile organic compound
WHO	World Health Organization

Foreword

Over the years there have been news stories about severe air pollution levels in the Far East – images depicting heavy pollution in Beijing come to mind – making it seem like a distant problem. But recent domestic episodes have served as a reminder that air pollution is also a real concern on our own doorstep: no sooner did the European Commission start legal proceedings against the UK in February 2014 for failing to meet the EU's air quality targets than news came from Paris that air pollution levels in the city had reached levels well above those recommended by the World Health Organization (WHO). Then in April there was a spate of headlines focusing on air pollution in London.

Poor air quality undoubtedly has negative effects – but of precisely what kind and to what extent? What leads to harmful air quality? And what can we do to reduce or mitigate the impact of bad air?

We commissioned Ricardo-AEA to review the latest evidence and address these questions. If there is one thing that this report shows, it is that whilst the issue of air pollution is complex, the evidence clearly shows that it is a major public health issue which needs careful consideration.

Although concentrations of some air pollutants – carbon monoxide and sulphur dioxide for example – have come down significantly over the past decade or so, current regulatory breaches relate to nitrogen dioxide (NO_2), generated from emissions of nitrogen oxides (NO_x), and particulate matter (PM), the latter both in its coarser PM_{10} form (particles with an average diameter of 10 micrometres or less) and the very fine $PM_{2.5}$ form (2.5 micrometres or less).

Where Local Air Quality Management Areas have been declared, road transport is the principal source of pollution, though domestic and background emissions also contribute to the problem. NO_x is mainly a by-product of fuel combustion, whilst PM results from fuel combustion as well as road, brake and tyre wear.

So what is the main culprit? In short: diesel engines. Whilst heavy-duty vehicles – buses and lorries – are still the main source of NO_x emissions, the contribution from diesel cars has increased rapidly over the last decade because of the 'dieselisation' of the car fleet.

This is a consequence of the focus on climate change. The automobile industry's response to the European average new car CO_2 emissions targets of

130 g/km by 2015 and 95 g/km by 2021 has been to make more diesel cars, as these are more fuel-efficient than their petrol counterparts. And greater fuel efficiency equals lower CO_2 emissions. Unsurprisingly, individual and fleet buyers have responded by choosing diesel, enticed not only by the prospect of reduced fuel costs, but also by lower rates of Vehicle Excise Duty and company car tax incentives, which both reward low-CO_2 options.

But as the report shows, this is not the whole story. The root of the problem lies in the fact that the official tests by which new vehicles are certified do not reflect real-world driving. This mismatch applies to both the emission of air pollutants and to fuel efficiency (and therefore CO_2), as both are measured on the same cycle. Technologies such as diesel particulate filters function well under test conditions, but when operating on the road, especially in towns and cities where speeds tend to be lower, there is a risk that they will not 'regenerate', that is the high temperature needed to burn off the collected particles will not be present. This is the case not only with the older Euro standards (Euro 3 and 4) but even the current Euro 5 standard; together, these make up the bulk of diesel cars on the road. The new Euro 6 standard appears to be more promising.

Whilst the majority of regulatory breaches are in relation to NO_2, from a health perspective the more concerning pollutant appears to be PM; it is the very finest particles ($PM_{2.5}$) which are the most worrying. Unfortunately there is much more to be learnt about these particles. To complicate matters, current EU standards – the ones we are already failing to meet – do not reflect the latest evidence put forward by WHO. The science is outpacing legislation.

Quantifying the impacts of air pollution is extremely difficult, but as this report notes it has been estimated that elimination of all human-generated $PM_{2.5}$ would increase UK life expectancy from birth by six months: this is a bigger impact than eliminating passive smoking or all road traffic accidents. Clearly this is an issue that needs tackling.

What, then, can be done about air pollution? The authors cite the three-pillar solution known as 'Avoid-Shift-Improve': *avoid* means cutting out motorised travel altogether; *shift* means getting people to switch from high-polluting modes to low-polluting ones; and *improve* is about reducing the harmful environmental impacts of vehicle technology.

The good news is that many behavioural policies – reducing excess speed, managing traffic volume and smoothing traffic flow – will not only improve air quality, but also cut CO_2 emissions, accidents and congestion. Access restrictions such as Low Emission Zones, if designed in the right way, can be effective, but care must be taken not to disadvantage lower-income groups disproportionately as it is these who are more likely to own older – and therefore more polluting – vehicles.

Modal shift can help too. However, we must not assume this is always the best option: moving people out of a fully loaded petrol hybrid car into a lightly loaded, old diesel bus operating in heavy traffic is unlikely to be the answer. Rather than adopting blanket measures, government should carry out proper analysis to ensure that the best solution is found for the specific context.

Technological solutions have the potential to deliver great benefits. In the short term, switching to petrol – a technology in which there is still great potential, mainly through turbocharging and engine downsizing, for improving fuel efficiency – will help. Better vehicle maintenance and eco-driving can also make a real difference. In the medium term, moving to natural gas and hybrid petrol electric vehicles – once there are a greater variety of more keenly priced options available, so that mass-market penetration can be achieved – will reduce air pollution further. Moreover, natural turnover of the fleet will lead to a growing number of vehicles on our roads that comply with the latest Euro standard (Euro 6). And in the longer term, ultra-low-carbon (for example, pure electric) vehicles will help in the fight.

Whatever happens, intelligent demand management, especially in urban areas, is going to be crucial because of the increased pressure on the road network caused by a recovering economy and a growing population. A well-designed scheme is both necessary and sufficient to secure improvements in air quality. One solution might be time- and place-variable pay-as-you-go charging, which both reduces harms and generates cash – yielding a net benefit to society. Obviously there are equitability considerations, but some of the revenue generated could compensate lower-income groups or in some way be used for the greater social good.

Many policies *are* going to cost somebody – whether road users or taxpayers – money. The calculations need to be done to ensure that the benefits they deliver stack up against the costs, not just in financial terms but also regarding loss of mobility.

Conclusions and recommendations

The following is a list of recommendations based on what we know so far. It is by no means exhaustive, nor should it be taken as the final word – it is intended to stimulate discussion amongst the public and decision-makers.

(1) There is a need for **more real-time measurement** of what is going on in the field. Prediction by modelling, whilst useful, has turned out to have limitations. In this field what happens at a fine grain is important; and the physics, chemistry and social behaviour at this scale is complex.

(2) A **scrappage scheme** for the dirtiest vehicles should be considered. Whilst expensive, it could prove worthwhile for government, the industry and consumers.

(3) History has shown that price incentives can really change behaviour. However, **fiscal instruments** such as fuel duty and Vehicle Excise Duty **should reflect the true cost to society** – air pollution, accidents, congestion, noise and so on – and not unnecessarily distort the market towards any particular technology or behaviour. We would like to see a proper calculation of these costs, and policies set accordingly.

(4) **Mitigation measures should apply when and where needed**. Blanket measures risk causing unnecessary compliance costs, and therefore rigorous evaluation of specific options must be undertaken. Air pollution is a systemic issue that requires a long-term approach – any short-term, drastic measure may have severe adverse effects.

(5) The current **drive cycle** (New European Driving Cycle, NEDC) and test procedure must be replaced by the Worldwide harmonized Light vehicles Test Procedure (WLTP) by 2017, as proposed by the European Commission. We recognise that it will be important to adapt the latest Euro and CO_2 standards accordingly, as the industry has high sunk investments in the current regime.

There is a great deal more to learn. The stakes are high and therefore it will be crucial to devote more resources to researching the evidence and improving the measurement of pollutants. Meanwhile, because of the nature of air pollution, the normal commercial domain cannot be expected to deal with the problems on its own. This must fall to government.

Stephen Glaister

S. Glaister.

Director, RAC Foundation

Executive Summary

"There are still major challenges to human health from poor air quality. We are still far from our objective to achieve levels of air quality that do not give rise to significant negative impacts on human health and the environment."

Janez Potočnik,
European Commissioner for the Environment (Potočnik, 2013)

Air pollution is a major issue of concern to the public and politicians, with the focus of attention being on poor air quality and way it affects the quality of life in urban areas. It is well recognised that road transport plays a significant part in air pollution in urban environments, and thus contributes to this public health issue.

This report reviews the latest evidence in relation to transport and air pollution, and aims to address three key questions:

1. What role does road transport play in relation to air pollution in towns and cities?
2. What is the health impact of this pollution, and what are the associated economic costs?
3. What are the main solutions for reducing air pollution from transport?

The contribution of transport to air pollution

The UK is failing to comply with European air quality limits in respect to nitrogen dioxide (NO_2) levels across most urban areas, and in particular at roadside locations. Levels of particulate matter (PM_{10} and $PM_{2.5}$; the subscript indicates the particle size in micrometres) are largely within the European limit values; however, the EU limit value is higher than the more stringent World Health Organization (WHO) guidelines. Therefore particulate matter (PM) is potentially a much more significant issue for public health than the compliance data alone might suggest. Overall, transport contributes some 30% of total nitrogen oxide (NO_x) emissions and 20% of total PM emissions, but these are concentrated on the road network in towns and cities, where the majority of air quality limit breaches occur, and where the population density is often high.

At the local level, breaches of the air quality limits have resulted in the declaration of some 600 Air Quality Management Areas (AQMAs) across the country. The vast majority of these have been declared for breaches of the NO_2 limit value, and in relation to road transport sources. The AQMAs cover the major cities, as might be expected, but also a wide number of much smaller areas such as local hotspots in market towns which have narrow congested streets. Thus the type and nature of the problems varies depending on the exact location and context.

In terms of NO_2 pollution concentrations, diffuse background pollution in urban areas ranges from 10 μg/m^3 to 30 μg/m^3, with road transport contributing around another 30 μg/m^3 to 50 μg/m^3 at roadside locations. This can give rise to pollution levels at twice that of the European limit values (40 μg/m^3). Although reductions in background concentrations achieved by tackling residential and commercial emissions will be important, major improvements will still have to be made in relation to emission from transport activity. In many roadside locations this will mean reducing transport emissions by at least 50%, and even by as much as 75–80% in some cases. Clearly this will be a significant challenge.

Heavy-duty trucks and buses are the main source of NO_x emissions, which contribute to NO_2 concentrations, but in absolute terms this has been reducing. Diesel cars are now the second-largest source of NO_x emissions, and this source has grown rapidly over the last 15 years. This indicates a potential conflict with climate change policy, which has to some degree supported the growth in diesel cars owing to their lower fuel consumption and CO_2 emissions.

Diesel vehicles are also the main source of PM emissions when it comes to road transport, but the difference in relation to petrol vehicle is much less than for NO_x, as PM emissions are also generated from brake and tyre wear and from road abrasion. Therefore PM emissions are not solely a diesel vehicle problem, and will require solutions that tackle non-combustion sources of pollution as well.

Moreover, levels of measured air pollution have improved little in recent years, despite progressively stricter vehicle tailpipe emission limits driven by European legislation. Estimated vehicle emissions have declined, but this has not resulted in significant improvements in local air quality. A mismatch between regulation and real-world NO_x emissions from diesel vehicles seems to be one of the key reasons why the expected reductions in NO_2 concentrations at the roadside have not materialised. This is further compounded by a growth in the share of diesel vehicles in the UK, and by the increase in direct NO_2 from newer diesel cars meeting Euro 4 and Euro 5 emissions legislation.

Understanding and putting a value on the impact of air pollution

There is clear evidence that there is a causal relationship between exposure to traffic-related air pollution and health impacts such as exacerbation of asthma, non-asthma respiratory symptoms, impaired lung function and cardiovascular mortality and morbidity (the frequency and severity of the condition in the exposed population). Overall, the strongest evidence for the most problematic pollutants in terms of human health is for particulate matter, especially fine particulate matter ($PM_{2.5}$) and ozone (O_3). NO_2 is also a key concern because of its direct health effects and also because it is a precursor to ozone formation.

Across Europe an estimated 20–30% of the urban population are exposed to $PM_{2.5}$ levels above EU reference values, and 91–96% are exposed to levels above the more stringent WHO guidelines. In the UK, the burden of particulate air pollution in 2008 has been estimated to be equivalent to nearly 29,000 premature deaths (at typical ages of death), and to an associated loss of population life of 340,000 life-years.

It has been calculated that if all anthropogenic $PM_{2.5}$ air pollution was removed, approximately 36.52 million life-years over the next hundred years could be saved in the UK. In addition, this elimination would be associated with an increase in UK life expectancy from birth (i.e. on average across new births) of six months. To put it into context, a study by the Institute of Occupational Medicine (Miller & Hurley, 2006) estimated that removing all fine particulate air pollution would have a bigger impact on life expectancy in England and Wales than eliminating passive smoking or all road traffic accidents.

Air pollution is therefore a major public health concern, and can be valued in terms of an economic cost. Across the EU, the economic cost of air pollution has been estimated to range between €330 billion and €940 billion per year in 2010, taking into account labour productivity losses and other direct economic damages. Similarly, in the UK the health impact of poor air quality has been calculated to cost between £9 billion and £19 billion per year (Defra, 2010). The transport contribution to this figure has been estimated at between £4.5 billion and £10.6 billion (at 2009 prices), in other words approximately half of the total.

In relation to other impacts of transport, air pollution ranks alongside excess delays, physical inactivity and accidents in terms of scale. Nevertheless, public concern in relation to transport air pollution seems to be waning, although this could be a consequence of heightened concern for the economic factors and cost of living following the recession that began in 2008.

Owing to its significant health impacts, air pollution – specifically $PM_{2.5}$ pollution – has been included as an indicator in the Public Health Outcomes Framework (PHOF) to be delivered by local authorities (DoH, 2013). This focus on PM in the PHOF contrasts with the focus on NO_2 compliance within the local air quality management (LAQM) framework.

Solutions to help reduce transport-related pollutant emissions

Transport activity is driven by a wide range of needs and behaviours, and has a range of impacts including congestion, air pollution, carbon emissions and accidents. Consequently there are a wide range of measures and actions that can be taken to influence travel patterns, mode choices and technologies with a view to reducing these impacts. Many of these measures are not designed primarily to reduce emissions or improve air quality, but are focused on reducing congestion; nevertheless, they will often help in the reduction of emissions, and can be enhanced so as to generate greater air quality benefits.

Much of the evidence on the air quality impacts and costs of these measures are indicative for several reasons:

- they have not been designed primarily to improve air quality, so this has not been directly assessed;
- they are often very locally specific, so it is difficult to draw clear results that are more widely applicable;
- there are still significant uncertainties as regards the effect of such measures on real-world vehicle emissions; and
- evidence on behavioural response to specific measures is still being gathered.

Demand management and behavioural change measures can be very cost-effective, as identified in the Sustainable Travel Towns demonstration, and can yield a wide range of benefits in the form of reduced congestion, improved air quality, reduced carbon emissions and increased levels of physical activity. However, our attitudes and habits when it comes to travel are very deep-rooted and can be hard to change, which means that significant and comprehensive packages of measures are needed to make a difference in the first place, and that thereafter maintaining this level of engagement has proved difficult. What is more, although significant impacts in terms of travel behaviour changes have been seen, these have not necessarily translated directly to improvements in air quality.

Traffic management and access control initiatives constitute a much more direct set of measures aimed at physically removing the source of the air pollution problem. As such they can be very effective, and when combined with redevelopment of an area – as has been done in Nottingham – can yield a wider ‘quality of place’ and economic benefits. On the other hand, they can be expensive to implement. Also, because of their restrictive nature they can be politically unpopular if not handled sensitively, which implies the need for considerable consultation and engagement.

The promotion of low-emission vehicles is the technology ‘fix’ that many favour as an alternative to changing behaviours. They can generate significant emission and air quality benefits if taken up substantially. However, they are not always as effective as expected, as has been shown to be the case with diesel emissions control, and many of the alternative technologies are still proving costly. Moreover, they do not provide the additional local benefits such as reduced congestion or increased levels of physical activity. However, at the national level they can provide economic benefits in terms of the development, production and servicing of new vehicle technologies.

These measures are not mutually exclusive – for example, a behaviour change programme can also be used to promote low-emission vehicles, and a bus quality partnership will generate improvements in overall bus services, assisting mode shift, as well as potentially improving the emission standards of the buses. Moreover, none of these measures in isolation is likely to prove sufficient to solve air pollution problems: most measures will generate no more than something like a 5–10% reduction in emissions, whereas reductions of over 50% may be needed (as noted above). Therefore an integrated, comprehensive and potentially radical package of measures will be required if real improvements in air quality are to be seen.

The idea of a focused and integrated package of emission reduction measures is being taken up by some local authorities in the form of Low Emission Strategies. This integrated approach is also the thinking behind Sustainable Urban Mobility Plans at the European level (European Commission, 2011b), and to some degree local transport plans (LTPs) in the UK. To support such an integrated approach, the wider benefits of a more sustainable transport system need to be promoted, which will include effects in the spheres of air quality, climate change, health, noise, congestion and economic development. Indeed, Department for Transport guidance on LTPs states (DfT, 2009c):

> "It is important that LTPs are effectively coordinated with air quality, climate change and public health priorities – measures to achieve these goals are often complementary. Reducing the need to travel and encouraging sustainable transport can reduce local emissions, whilst improving public health and activity levels."

Summary recommendations

Transport is the greatest contributor to urban air pollution, specifically at roadside locations, which is where the highest levels of pollution exist and where significant exposure occurs. This in turn gives rise to a direct health impact associated with the traffic-related pollution. Substantial reductions in transport emissions, of 50% of more, are required to improve air quality and reduce pollution exposure at roadside locations sufficiently to comply with existing legislative standards. Evidence is also emerging to suggest that these legislative standards need to be tightened to adequately protect human health. The scale of this reduction in permitted limit values is very challenging, and to support further progress the following key policy recommendations are proposed:

At the European level

1. Consider tightening the regulated particulate matter limits, especially $PM_{2.5}$, in line with WHO guidelines, to reflect the greater health impact of particulate matter.
2. Assess the real-world effectiveness of Euro 6/VI legislation and include the proposed NO_2 limit.

At the national level

3. Adopt a more action-focused approach in the LAQM regime, and increase the focus on PM concentrations.
4. Strengthen the obligations of transport authorities in managing air quality, by making improving air quality a key priority for transport policy, alongside carbon reduction and economic growth.
5. Continue support for low-emission vehicles through the ultra-low-emission vehicle strategy and other mechanisms, but use a wider low-emission vehicle definition which considers both air pollutants and carbon emissions.
6. Provide national guidance and financial support for local measures to reduce transport emissions, including improved emissions data and tools, and wider evidence on the impact of measures.

At the local level

7. Integrate air quality considerations across all areas of local authority activity to provide a comprehensive and action-based approach to tackling air quality locally.
8. Consider the full spectrum of benefits from health and quality of life, from congestion and transport benefits to wider economic development, to assess the business case for transport measures.

1. Introduction

1.1 Air pollution as a public health issue

Air pollution remains one of the principal environmental factors linked to preventable illness and premature mortality across the UK and the EU, and still has significant negative effects on much of Europe's natural environment. In 2010 it was estimated that across the EU, air pollution caused over 400,000 premature deaths as well as substantial avoidable sickness and suffering, including respiratory conditions (such as asthma) and exacerbated cardiovascular problems (European Commission, 2013).

The greatest impact on human health is in urban areas, where air pollution levels are at their highest. Of particular concern is the health impact of exposure to fine particulate matter ($PM_{2.5}$; the subscript indicates the particle size in micrometres) and ozone (O_3), but also of concern is nitrogen dioxide (NO_2), both in its own right and as a precursor to ozone. Across Europe it is estimated that 20–30% of the urban population are exposed to $PM_{2.5}$ levels above EU reference values, and 91–96% are exposed to levels above the more stringent World Health Organization (WHO) guidelines (Guerreiro et al., 2013). Internationally, the Organisation for Economic Co-operation and Development (OECD) states that "urban air pollution is set to become the top environmental cause of mortality worldwide by 2050, ahead of dirty water and lack of sanitation" (OECD, 2012).

Air pollution is therefore a major public health concern, which translates into an economic impact. Across the EU, the economic cost of air pollution has been estimated to range between €330 billion and €940 billion per year in 2010, taking into account labour productivity losses and other direct economic damages. Similarly, in the UK the health impact of poor air quality has been calculated to cost between £9 billion and £19 billion (Defra, 2010).

1.2 The contribution of transport to urban air pollution

Transport is a major source of air pollution in the urban areas of the UK and much of Europe. As such, it has a significant role to play in solving these problems, and in improving air quality and public health. In the UK it is estimated that road transport contributes 20–30% of national emissions of air pollutants (NAEI, 2013). However, it plays a much greater role in air pollution problems, because it is concentrated on the road network in the country's towns and cities. Of the 600 local Air Quality Management Areas (AQMAs) declared in the UK – areas which breach UK national air quality objectives – some 95% are a result of transport activity (Defra, 2013a). The cost of this urban transport-related air pollution to human health is estimated at between £4.5 billion and £10 billion annually to the UK economy (DfT, 2009b).

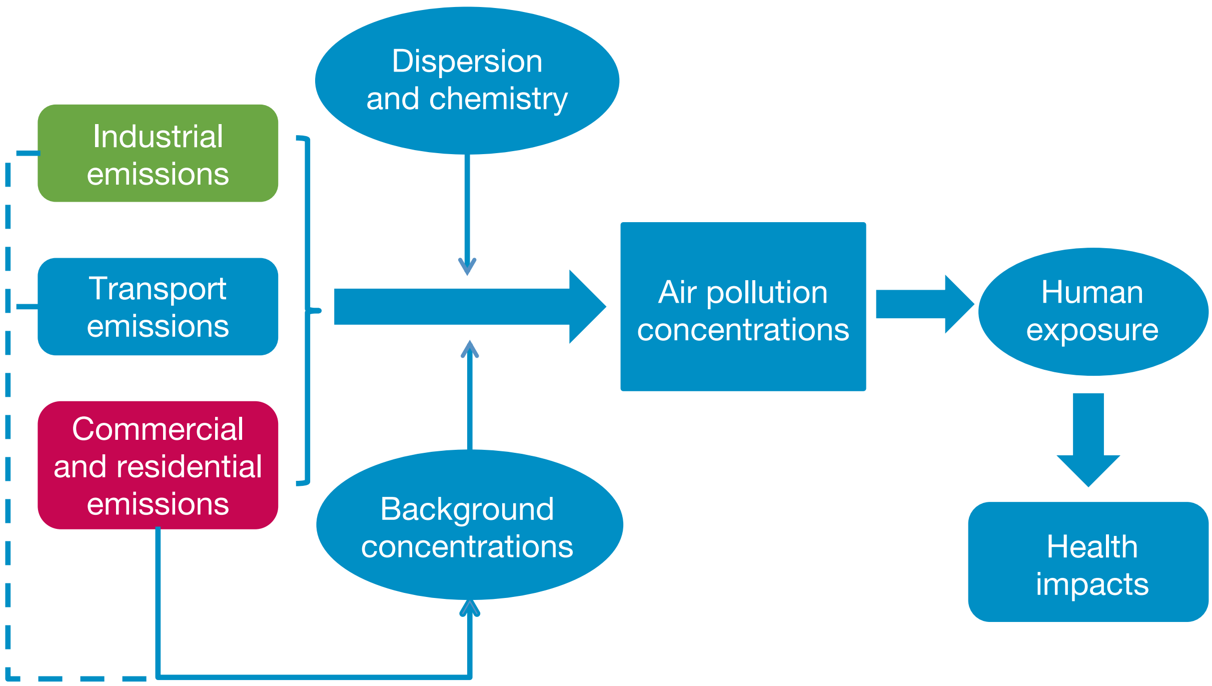
In order to tackle this problem, European air quality objectives and vehicle emission regulations have been in place for a number of years. Whilst compliance with many of the air quality objectives has now been achieved across the UK, compliance challenges remain with regard to the limit values for NO_2. In addition, although breaches of the coarse particulate matter (PM_{10}) regulatory limits are much less extensive, exposure to fine particulate matter ($PM_{2.5}$) remains the main public health concern owing to its greater health impact. In addition, where air quality objectives are being breached, air pollution levels remain stubbornly high – particularly for NO_2 – despite increasingly stringent European vehicle emission legislation and the wider the efforts of both national and local government.

1.3 The link between emissions, contributions and health impacts

In order to explore these air pollution issues, the relationships between emissions-generating activities, air pollution concentrations and health impacts need to be understood. This is illustrated briefly in Figure 1.1. Mass emissions are generated by transport, industrial, residential and commercial activities. Transport emissions are generated mainly along roads; industrial, residential and commercial emissions, on the other hand, are more diffuse. These emissions are subject to dispersion and chemical interactions which generate pollutant concentrations in the atmosphere. It is also useful to distinguish between:

- primary pollutants that are generated at source and then dispersed, for example direct emissions in the form of particulate matter (PM) and nitrogen oxide emissions (NO_x, a combination of NO (nitrogen monoxide) and NO_2);
- secondary pollutants that are formed by chemical interaction, for example the oxidation of NO into NO_2, and ozone formation; and
- transboundary pollutants, which are not generated locally but are blown in from other areas or countries.

Figure 1.1: The relationship between emissions, concentrations and health impacts



Source: Authors' own

All of these sources will contribute to the wider background pollution level seen in towns and cities, and at lower levels in rural areas. Road transport will provide a more direct source of emissions at roadsides, and when combined with background concentration will give rise to the typically higher air pollution concentrations monitored at kerbsides. Human exposure to this air pollution whilst commuting, cycling or simply staying at home gives rise to adverse health impacts.

It is important to distinguish between *emissions*, which are a mass measurement and representative of the source, and *concentrations*, which are a volumetric measurement of actual air pollution. Emissions are generally estimated or modelled, for example using activity data such as vehicle kilometres or fuel use and emission factors, to understand the sources. Air pollution concentrations, on the other hand, can be directly measured as well as modelled.

1.4 The objective of this report

This report sets out a review of the evidence in relation to transport and its impact on air pollution and public health. The review was carried out to answer three key questions:

1. What role does road transport play as a source of air pollution in towns and cities?
2. What is the latest evidence on the health impact of this pollution and what are the associated economic costs?
3. What are the main solutions for reducing air pollution from transport?

The following sections of this report explore the evidence related to each of these three key questions, to provide a wider understanding of the issues surrounding air pollution and transport. In the final section, the evidence is used to draw some conclusions and recommendations, and to point to potential policy implications.

2. Understanding the Problem

Although improvements in air pollution levels have been made in recent decades, there remains a failure to comply with European air quality limits in respect to NO_2 levels in many areas of the UK. There are also limited breaches of the national UK particulate matter standards at local hotspots. However, the legislative concentration limits for compliance are higher than the more stringent WHO guidelines, and this is generally considered a much more significant issue for public health than the compliance data alone suggests.

Although transport accounts for an estimated 20–30% of national pollutant emissions, because it is concentrated on road networks in towns and cities, it accounts for 95% of all declared breaches of the national air quality standards. Diesel vehicles, particularly diesel cars, are estimated to be the principal source of transport emissions which contribute to the breaches.

Levels of measured air pollution, particularly of NO_2, have improved little in recent years, despite progressively stricter vehicle emission limits driven by European legislation. A mismatch between regulation and real-world emissions from diesel vehicles seems to be one of the key reasons why the expected reductions in concentrations at the roadside have not materialised. This is further compounded by a growth in the share of diesel vehicles in the UK, largely due to climate change policy and associated tax incentives. In many key pollution hotspots, reductions in emissions from transport of 50–75% may well be required to comply with European limits and protect public health.

2.1 Air quality legislation and policy

In 2010 air pollution was estimated to have caused over 400,000 premature deaths in Europe, as well as substantial avoidable sickness and suffering, including respiratory conditions (such as asthma) and exacerbated cardiovascular problems (European Commission, 2013). This makes it one of the principal environmental causes of premature death in the EU, responsible for a death toll ten times that of road traffic accidents. The key pollutants of concern from a health point of view are particulate matter (especially the finer fraction particles below 2.5 micrometres, known as $PM_{2.5}$), ozone (O_3) and nitrogen dioxide (NO_2)

To tackle this problem of air pollution, and its related health impacts, the EU and the UK have had air quality legislation in place for many years. This legislation sets air quality objectives for protection of public health as set out below.

2.1.1 EU policy and legislation

The primary aim of EU air quality policy is to reduce the burden of ambient air pollution on human health, natural and managed ecosystems, and the built environment. The Air Quality Directive (AQD, 2008/50/EC) and 4th Daughter Directive (4DD 2004/107/EC) set limit, target and other threshold concentrations for ambient air quality, and prescribe the methods that can be used to assess and report compliance with these environmental objectives.

The Directive covers a wide range of pollutions, setting limit values for the key pollutants of concern as shown in Table 2.1. These are expressed in terms of a limit which should not be exceeded over a given averaging period. Alongside the EU limit values, the WHO guidelines for each pollutant are also shown. The WHO guidelines are designed to support the formulation of air quality policies to reduce the health impact of air pollution; the limit values are lower than the current values for a number of pollutants, specifically PM_{10} and $PM_{2.5}$ which are associated with the greatest health impacts.

Table 2.1: Pollutant limit values from the EU Air Quality Directive (2008/50/EC) and WHO guidelines

Pollutant	Averaging period	Concentration	
		EU limit	WHO guidelines*
PM_{10}	24-hour mean	50 µg/m³	50 µg/m³
	Annual mean	40 µg/m³	20 µg/m³
$PM_{2.5}$	Annual mean	25 µg/m³ **	10 µg/m³
Ozone	Daily 8-hour mean	120 µg/m³	100 µg/m³
NO_2	Hourly mean	200 µg/m³	200 µg/m³
	Annual mean	40 µg/m³	40 µg/m³

Source: European Commission (2008), 'DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe.

Notes:

* World Health Organization (2005), 'Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Global update 2005. Summary of risk assessment.'

** The $PM_{2.5}$ value is introduced in the new directive and is based on the average exposure indicator (AEI).

These Directives are complemented by source-based legislation including the National Emissions Ceilings Directive (2001/80/EC) and the Industrial Emissions Directive (2010/75/EU). These Directives provide a cap on total national emissions, with the intention of gradually driving down source emissions to improve overall air pollution levels.

Whilst compliance with many of the wider objectives has already been achieved across the UK, widespread compliance challenges remain with regard to the limit values for NO_2, and to a lesser extent PM_{10}, as is explored later in this section. However, the extent of the non-compliance PM objectives would increase significantly if the more stringent WHO guidelines were adopted. Moreover, at the national level there is potentially a risk of significant financial penalties from the EU for non-compliance.

The scale of the non-compliance with limit values for NO_2 in the UK is common across the rest of EU, and largely reflects the failure of recent Euro standards for diesel vehicles to deliver the expected reductions in emissions, as will be explored in detail later in this report. Compliance with limit values for PM_{10} is likely to be more challenging for several other member states than for the UK. Full compliance with long-term objectives for ozone – and to a lesser extent some of the heavy metals – is also likely to be challenging.

The ambient air quality Directives and source-based legislation form part of the EU Thematic Strategy on Air Pollution, which was reviewed towards the end of 2012. The European Commission launched the outcome of this review in December 2013. It includes a number of components:

1. A new **Clean Air Programme for Europe** with measures to ensure that existing air quality standards are met, with particular attention paid to reducing emissions from diesel cars in cities. WHO recently undertook a review of the medical evidence of the health impacts from air pollutants. Generally, this recommended tighter air quality standards than those currently in place.
2. A revised **National Emissions Ceiling Directive** with tighter emission levels governing how much of the main pollutants each member state can emit.
3. A new **Directive to reduce emissions from medium-sized combustion installations**, such as energy combustion plant for large buildings.

2.1.2 UK policy and the local air quality management regime

The UK's Air Quality Strategy sets the framework for local air quality management (LAQM) by local authorities. This framework predates the European Air Quality Directive, and although the limits values are the same, there are differences in focus and detail between the two systems, centring around monitoring methods and locations which are representative of human exposure. Under LAQM, personal exposure is the central focus, whereby an air pollution incident arises where people are exposed to high pollutant levels over the averaging period. By contrast, under the European Commission regulatory regime, areas should be representative of a wider area which has public access. For example, a house on a road junction would be a relevant location under LAQM, but not under the European Commission regime.

Essentially, LAQM requires all local authorities to regularly review and assess air quality in their areas. Where areas are found to be in probable breach of the national air quality standards and there is population exposure, then an AQMA should be formally declared. When an AQMA is declared, an Air Quality Action Plan (AQAP) to address the problem must be developed and implemented. Progress of implementation has to be reported by each local authority to Defra each year.

Since the Environment Act 1995 introduced LAQM, some 600 AQMAs have been declared in the UK. Over 90% of these are due to emissions from road traffic, principally in urban centres, but also in motorway / trunk road locations where residential dwellings are close to the roadside. Furthermore, the majority of these AQMAs are in relation to exceedance of the annual average NO_2 objective. Far fewer AQMAs have been declared consequent on a breach of the national air quality objective set for PM_{10}. However, from a health perspective it is known that fine particulate matter has no known safe threshold and is responsible for greater health impacts than the other main pollutants considered here.

To address the need to continue to focus on improving PM levels, the 2008 Air Quality Directive introduced an exposure reduction target for $PM_{2.5}$ (see Table 2.2). The objectives are set at the national level and are based on the average exposure indicator (AEI). The AEI is determined as a three-year running annual mean $PM_{2.5}$ concentration averaged over the selected monitoring stations in agglomerations and larger urban areas, set in urban background locations to best assess the $PM_{2.5}$ exposure to the general population.

Table 2.2: $PM_{2.5}$ exposure limits

Title	Metric	Averaging period	Legal nature
$PM_{2.5}$ exposure concentration obligation	20 µg/m³ (AEI)	Based on three-year average	Legally binding in 2015
$PM_{2.5}$ exposure reduction target	Percentage reduction* + all measures to reach 18 µg/m³ (AEI)	Based on three-year average	Reduction to be attained where possible in 2020, determined on the basis of the value of exposure indicator in 2010

Source: European Commission (2008), ‘DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe.

Note: $PM_{2.5}$ = particulate matter of median diameter 2.5 micrometres or less: fine particulate matter

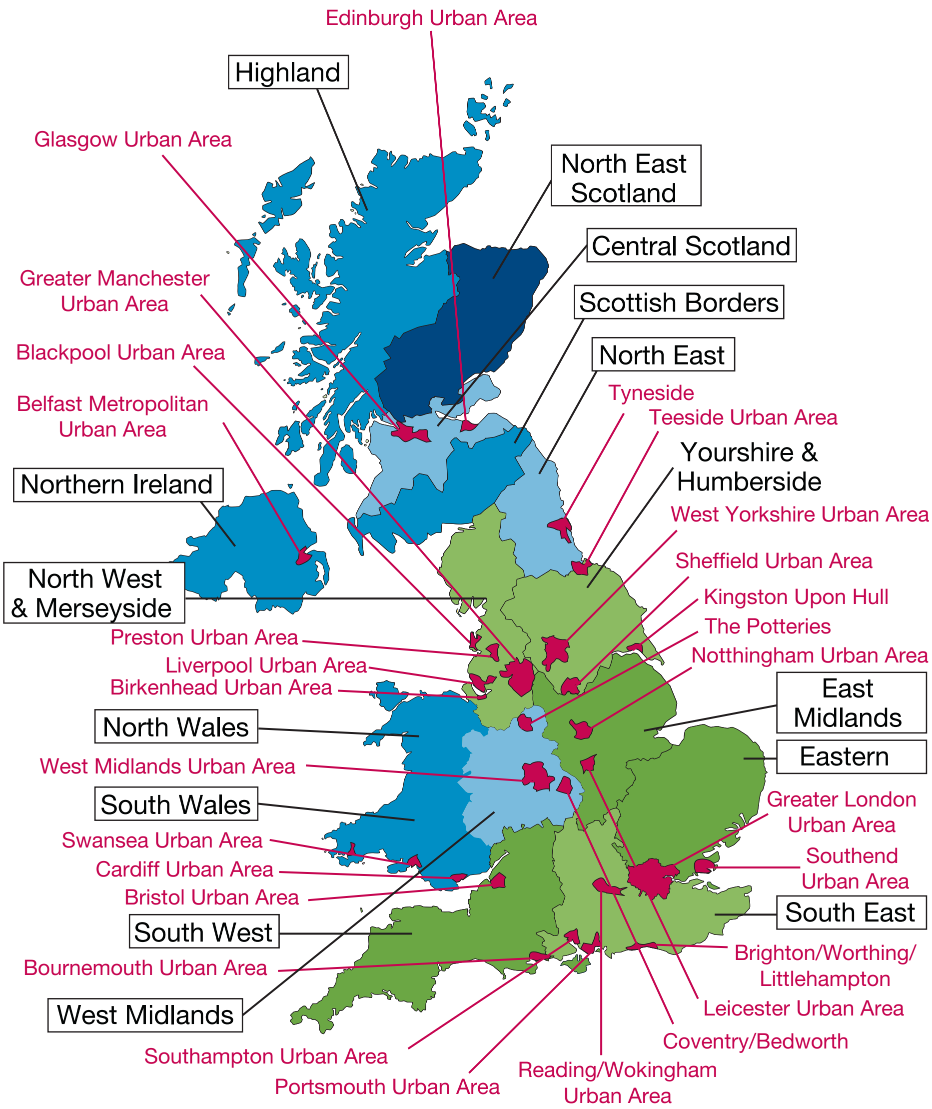
* Depending on the value of the AEI in 2010, a percentage reduction requirement (0%, 10%, 15% or 20%) is set in the Directive. If the AEI in 2010 is assessed to be over 22 µg/m³, all appropriate measures need to be taken to achieve 18 µg/m³ by 2020.

In the UK, Defra has recently launched a consultation on options for changes to LAQM. Options include an increased focus on *action to implement* measures to improve air quality in AQMAs, rather than *monitoring*, as this has largely been the focus to date. This could assist in the UK's requirement to achieve the European air quality standards.

2.2 National air quality and compliance

Assessment of compliance with the European Air Quality Directive is carried out for the whole of the UK and reported for each of 43 agglomeration zone ('agglomerations') and non-agglomeration zones ('zones') which are shown geographically in Figure 2.1.

Figure 2.1: UK zones for reporting air quality against the EU directive



Source: Defra (2013b)

Note: Red areas are agglomerated zones, blue and green areas are non-agglomerated zones

The assessment is based on a combination of information from the UK national monitoring networks and the results of modelling assessments. The inclusion of air quality modelling into the UK compliance reporting process reduces the dependence on monitoring alone, and ensures that a comprehensive assessment across the whole of the member state is achieved rather than focusing the assessment on specific spot locations. Considerably more monitoring sites would be required across the whole of the UK if monitoring data were to be used as the sole source of information for compliance assessment. The use of models has the added benefits of enabling air quality to be assessed at locations without monitoring sites, and providing additional information on source apportionment and projections required for the development and implementation of air quality plans.

Compliance results for 2008 to 2012 are shown in Table 2.3. This shows very clearly that the problem area in terms of compliance with limit values is NO_2, for which most zones have areas that breach the limit values, and also reveals that the situation has changed very little over the last few years. There have been a small and decreasing number of zones where PM_{10} levels have exceeded the limit, but all areas had fallen below the limit values in 2012.

Table 2.3: Number of zones with exceedances of EU air quality limits 2008 to 2012

Year	PM_{10}		$PM_{2.5}$	Ozone	NO_2
Averaging period	*Daily*	*Annual*	*Annual*	*Daily 8-hr*	*Annual*
2008	2	None	None	None	40
2009	3	None	None	None	40
2010	1	None	None	None	40
2011	1	None	None	None	40
2012	None	None	None	None	38

Source: Defra (2013b)

Note: assessment of annual or 24-hour limits; PM_{10} = particulate matter of median diameter 10 micrometres or less: coarse particulate matter; $PM_{2.5}$ = particulate matter of median diameter 2.5 micrometres or less: fine particulate matter; NO_2 = nitrogen dioxide

The national monitoring network, known as the Automatic Urban and Rural Network (AURN), currently comprises 140 monitoring locations and forms the core of the assessment. It is supplemented with monitoring data from Defra's other networks, including the metals monitoring network, hydrocarbons monitoring network, and PAH (polycyclic aromatic hydrocarbon) monitoring network. The supplementary assessment provided via modelling is undertaken using a national model known as the Pollution Climate Mapping (PCM) model (Ricardo-AEA, 2013b). The PCM models have been designed to assess compliance with the limit values and target values at locations defined within the Directives. Modelled compliance assessments are undertaken for 12 air pollutants each year.

The modelling is based on source emissions data taken from the National Atmospheric Emissions Inventory (NAEI), which is fed into models to provide air pollutant concentration results. The modelling consists of two components:

- background concentrations – on a 1 × 1 km resolution, representing ambient air quality concentrations at background locations;
- roadside concentrations – concentrations at the roadside of urban major road links throughout the UK (i.e. motorways and major A-roads); there are approximately 9,000 of these road links.

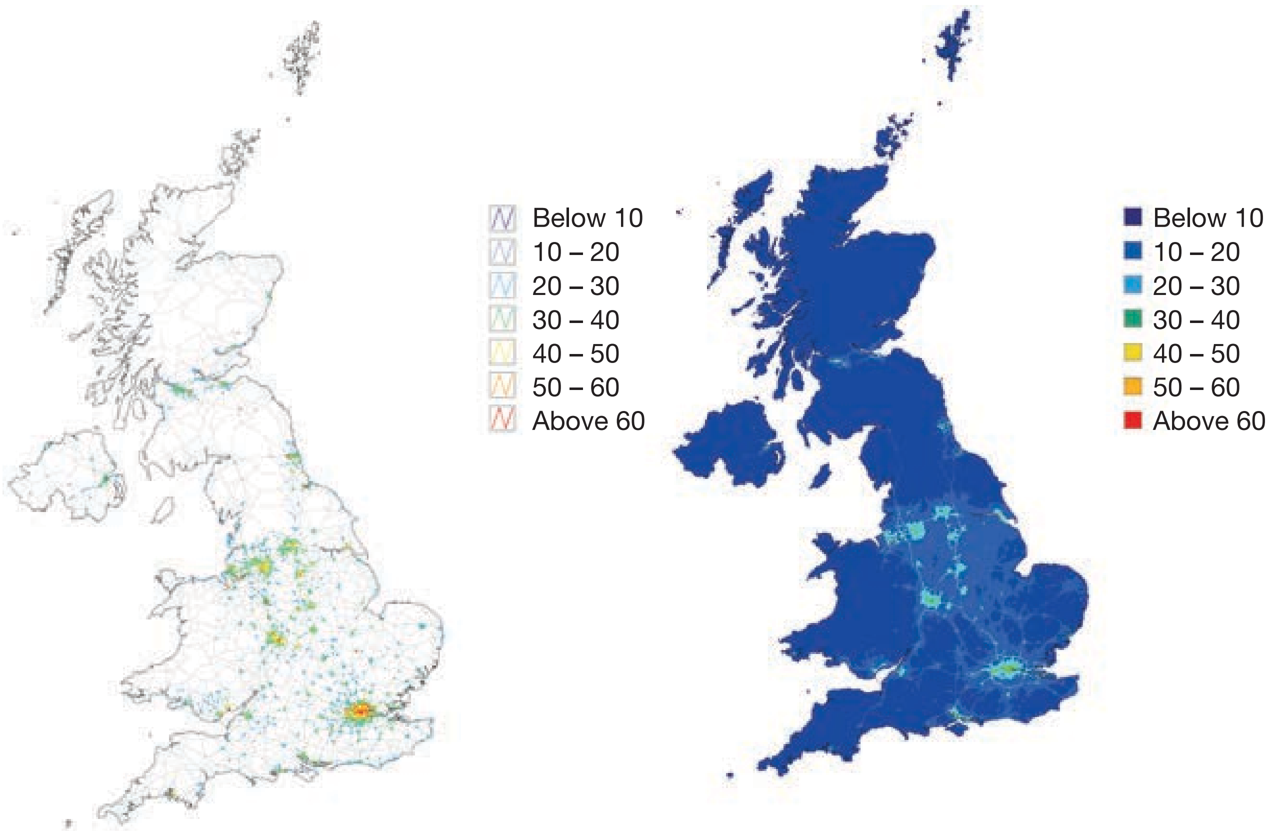
The 1 × 1 km background maps are made up of several components, which are modelled separately and then added together to make the final grid:

- large point sources (e.g. power stations, steelworks, oil refineries);
- small point sources (e.g. boilers in town halls, schools or hospitals, crematoria);
- distant sources (characterised by the rural background concentration); and
- local area sources (e.g. road traffic, domestic and commercial combustion, agriculture).

Roadside concentrations are determined by using a roadside increment model, which estimates the direct contribution from road traffic sources at the roadside and adds this on top of the modelled background concentrations discussed above. However, it should also be noted that the background concentrations also include a transport element as noted in the fourth category above; this is typically 10% for PM and 30% for NO_x.

In order to ensure that these ambient concentrations are representative of the real-world situation, they are compared with measurements taken from the national networks (including the AURN) in order to calibrate the models. An independent assessment of model performance is undertaken by comparing the model output with monitoring data that has not been used in the calibration process. There were 295 monitoring stations used in this verification process for 2012 from the London Air Quality Network, Welsh Air Quality Forum, Scottish Air Quality Archive, local authorities and airports. These modelled data sources are graphically illustrated in Figure 2.2 for NO_2.

Figure 2.2: Annual mean roadside and background concentrations of NO_2 on 2012

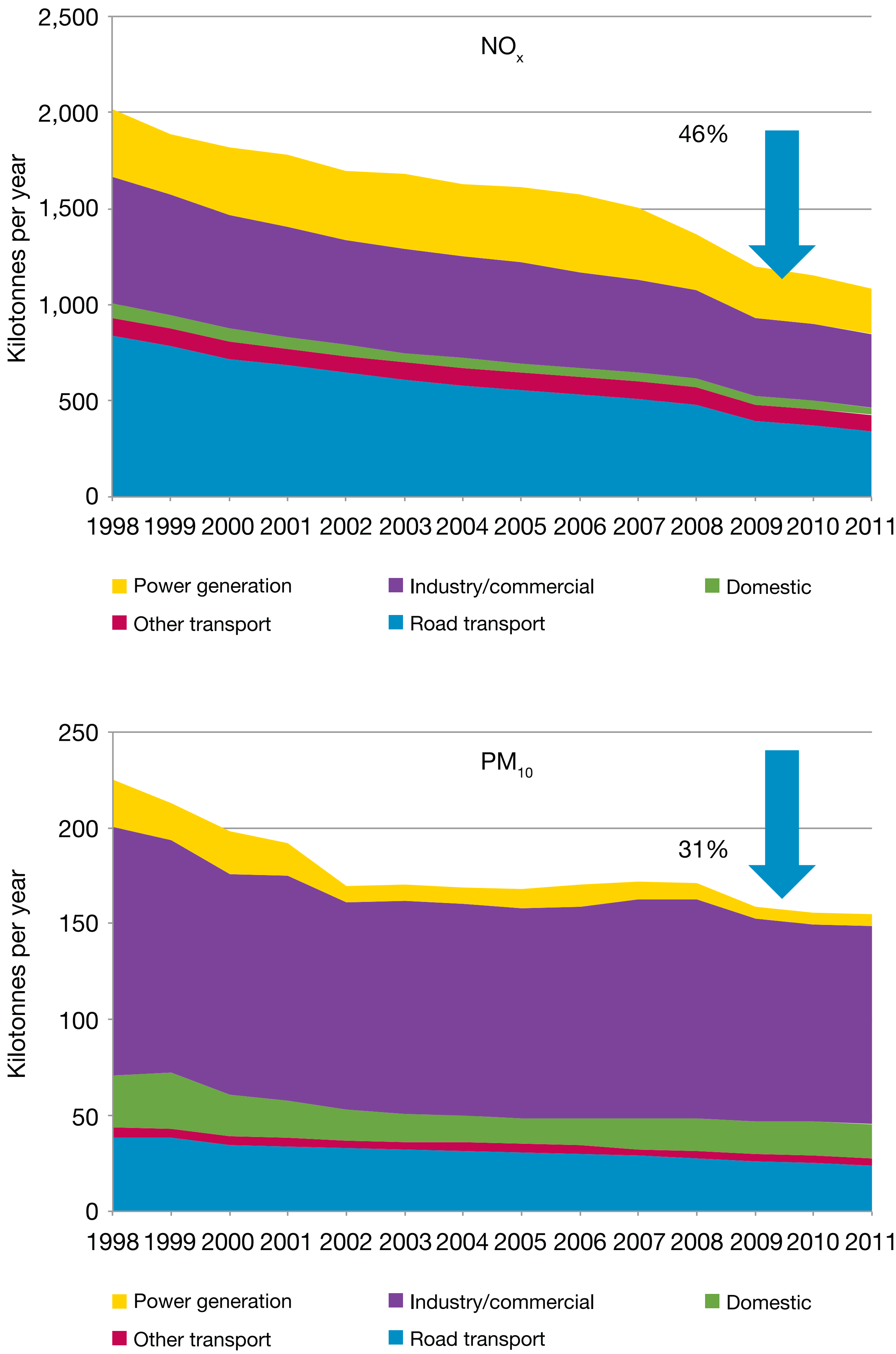


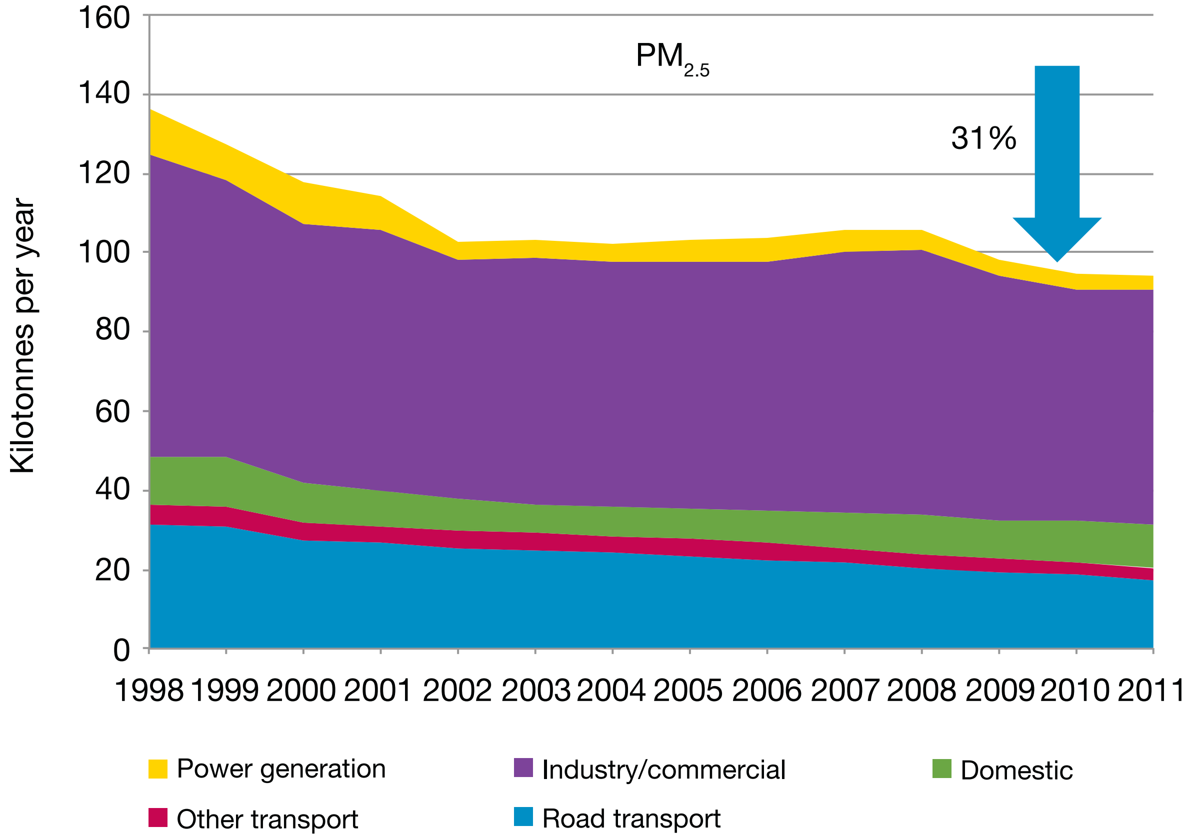
Source: Air pollution in the UK 2012 (Defra, 2013b)

This modelled data shows quite clearly that the diffuse background concentrations are not above the limit values, but roadside concentrations in towns, cities and on major roads are. At these roadside locations, transport is the principal source of emissions and therefore plays a major role in the exceedance of the NO_2 limits.

The NAEI provides an estimate of the emissions generated from all sources of activity across the UK. This is based on activity such as vehicle traffic or energy, and appropriate emission factors. This data suggests that for pollutants where compliance has been difficult, primarily NO_x (NO and NO_2 combined) emissions related to NO_2 concentrations and PM emissions, there have been significant reductions – between 46% and 31% nationally (Figure 2.3). However, this has not necessarily been reflected in urban areas, where the key pollution problems occur.

Figure 2.3: NO_x and PM emissions from all sources across UK, 1998 to 2011

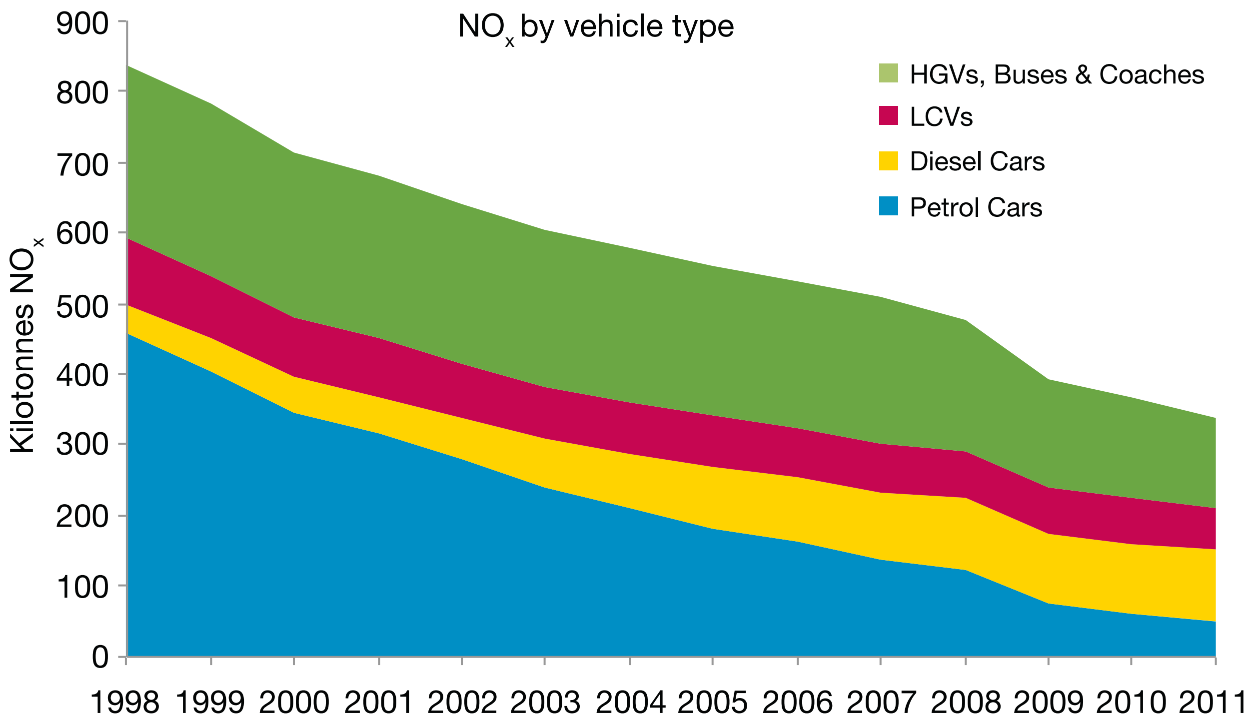


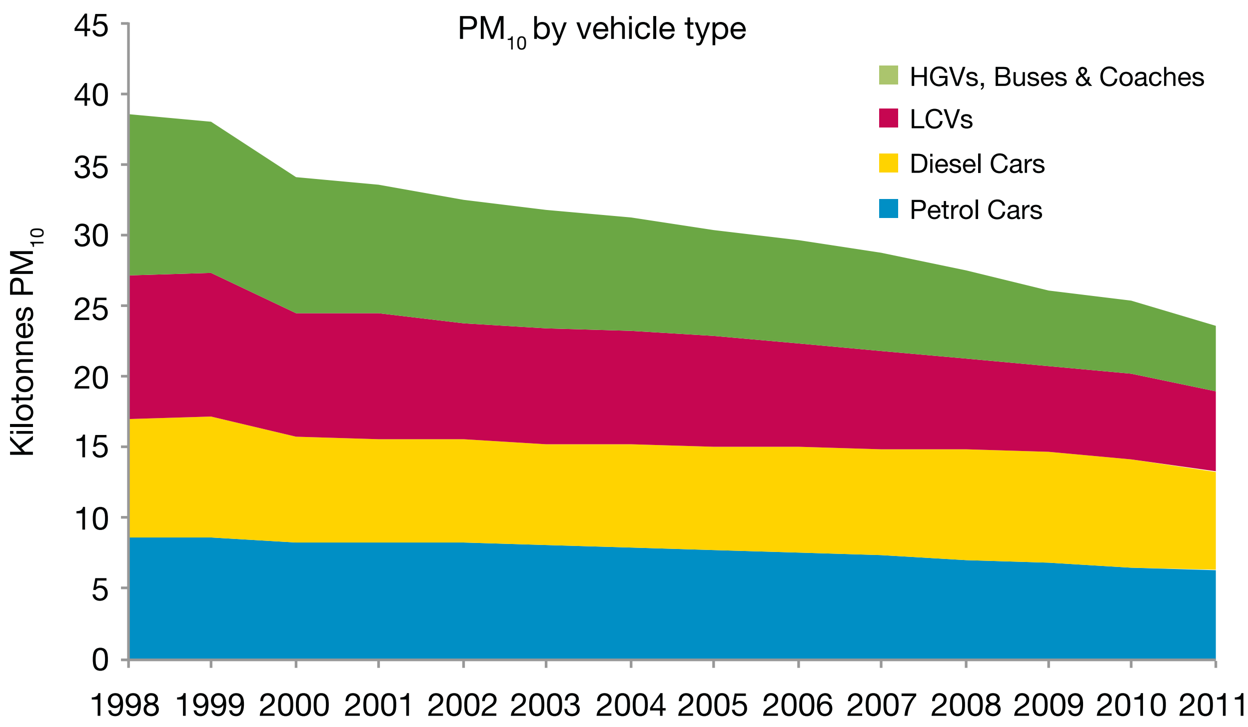


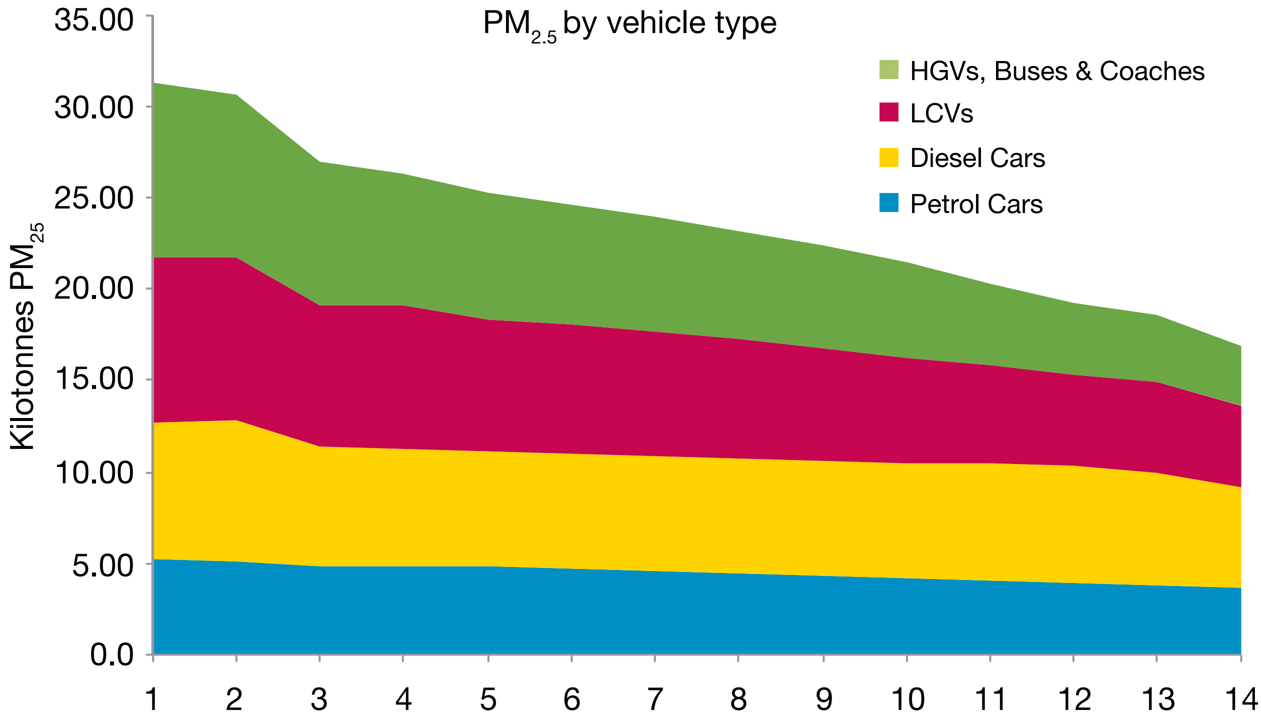
Source: NAEI (2013)

Looking at road transport's contribution to these emissions nationally, and focusing on NO_x, PM10 and PM2.5, it is seen that road vehicles are responsible for 33%, 15% and 18% of the totals, respectively (NAEI, 2013). The figure for NO_x is significant, and as seen above these emissions are concentrated on the road networks in the UK's towns and cities, where pollution levels peak, and are therefore a major contributor to breaches of the NO_2 limit values. The overall contribution to PM is less, but again can be significant when concentrated along roads in towns and cities. In line with total emissions, the road transport component has reduced by significant amounts. Between 1998 and 2011, overall NO_x emissions from road transport reduced by 60%, PM10 by 39% and PM2.5 by 46%, as shown in Figure 2.4.

Figure 2.4: Total NO_x, PM_{10} and $PM_{2.5}$ emissions by vehicle type (1998 to 2011)



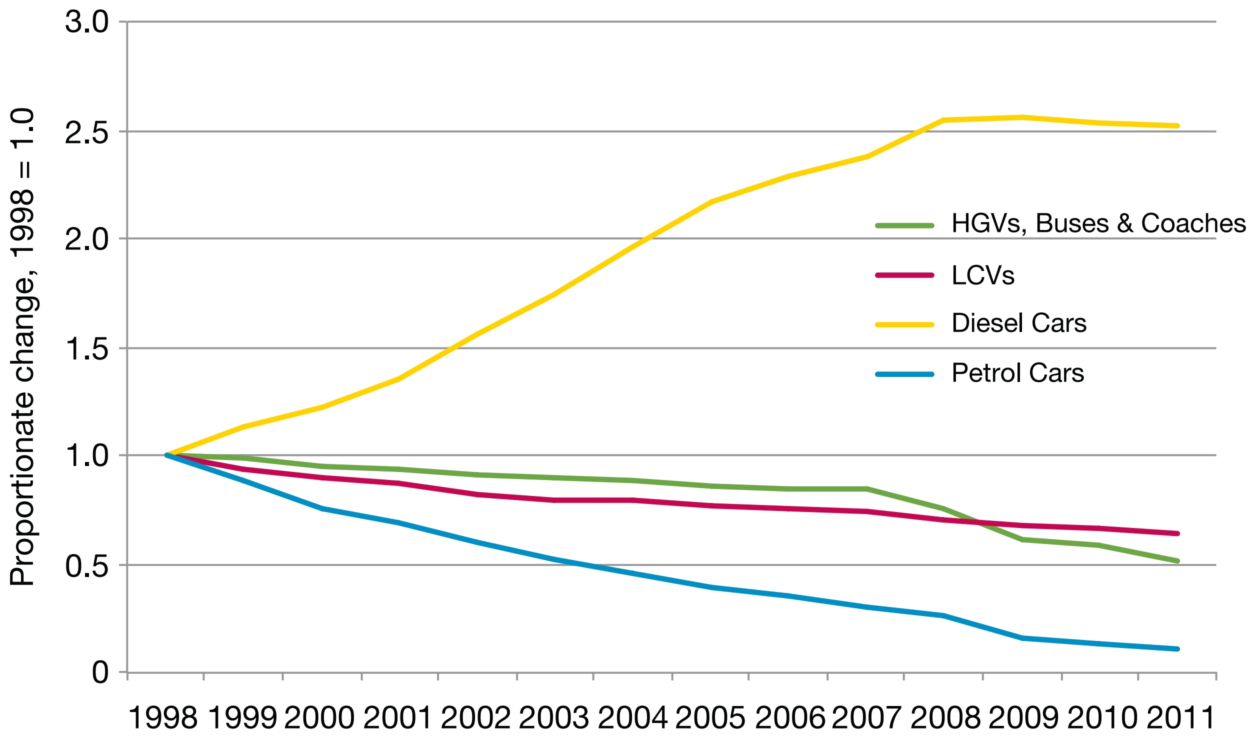




Source: NAEI (2013)

However, the change in emissions does vary between the vehicle types. NO_x emissions from petrol cars have reduced by some 90% over this period, whereas emissions from diesel cars have actually risen by 250%, as shown in Figure 2.5. This dramatic difference is a result of a rapid growth in the number of diesel cars in the parc, and relatively higher NO_x emissions of diesel vehicles compared to petrol vehicles. Estimated NO_x emissions for light commercial vehicles (LCVs) and heavy goods vehicles (HGVs), buses and coaches have gone down by 36% and 49% respectively. By 2011, the main source of NO_x emissions from road transport was the heavy-duty vehicles, contributing 38%, followed by diesel cars, which contributed 29%.

Figure 2.5: Change in total NO_x emissions by vehicle type 1998 to 2011

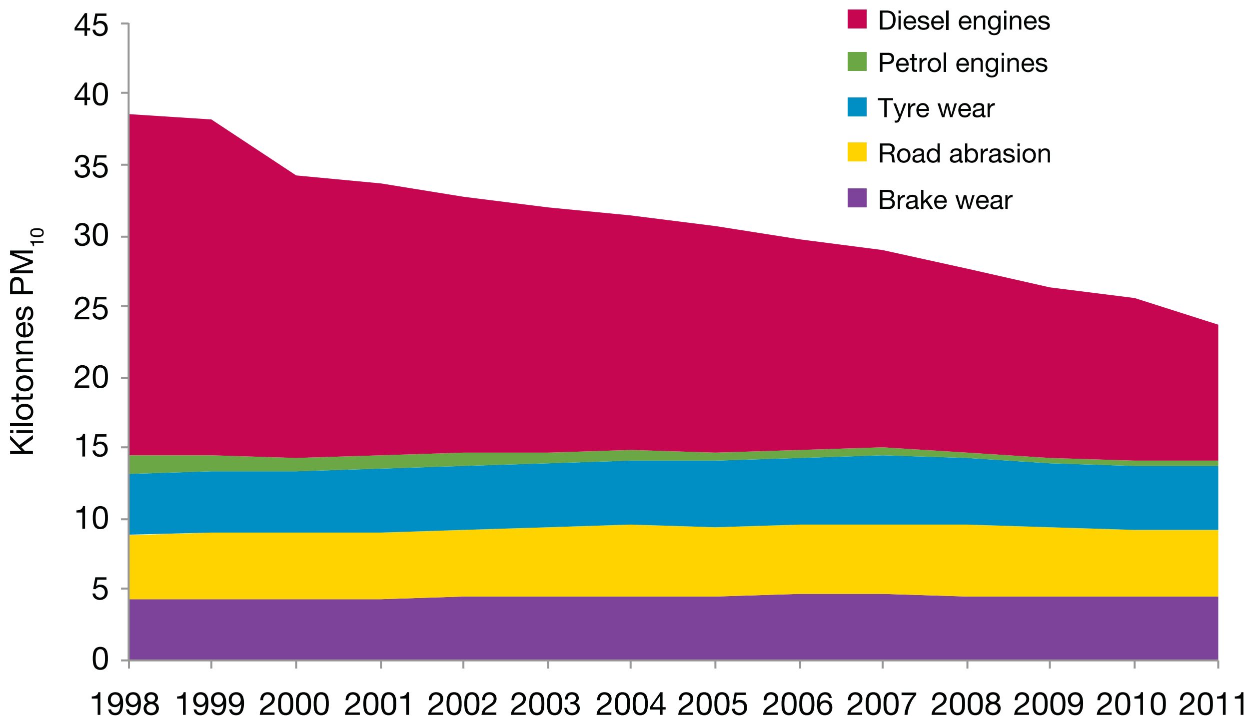


Source: NAEI (2013)

Estimated particulate emissions have reduced for all classes of vehicles. The greatest reductions have been in the case of heavy-duty vehicles, at some 60%, with cars reducing by about 20%. By 2011 the PM emissions from heavy-duty vehicles were lower than for cars or LCVs, with the greatest proportion being emitted by diesel cars. However, unlike NO_x the reduction in PM emissions is similar for both diesel and petrol cars. This is because the source of vehicle particulate emissions is more complex: as well as arising from fuel combustion, they can also originate from other non-combustion sources such as brake wear, tyre wear and road abrasion.

Total transport PM_{10} emissions in relation to the different sources are illustrated in Figure 2.6, and the picture is similar for $PM_{2.5}$ (not illustrated). Diesel engines have historically been the largest source of PM; however, since 1998 diesel engines have reduced PM_{10} emissions by some 60%. This accounts for almost all of the reduction in road PM emissions over this period. By 2011, PM emissions from diesel engines, at 42%, accounted for less than half of total PM, whilst emissions from tyre wear, road abrasion and brake wear accounted for 58%. So although petrol vehicles contribute very little engine PM, they still produce significant overall PM from other sources. Therefore to reduce PM emissions further will require technological improvements to reduce tyre wear, road abrasion and brake wear, as well as further emissions reduction from diesel engines.

Figure 2.6: Total PM10 emissions from combustion and non-combustion sources



Source: Analysis by Ricardo-AEA based on NAEI data

2.3 Local air quality

Local air quality management is the core of the UK's national air quality strategy and is designed to identify and tackle local hotspots. It is working to essentially the same limit values as the European directive, but is based on local monitoring and modelling work. Consequently, it picks up detail that cannot be seen at the national scale. Under the LAQM regime there have been over 600 AQMAs declared in the UK, as summarised in Tables 2.4 and 2.5.

Table 2.4: AQMAs declared by pollutant

Pollutant	Objective Declared	England	Wales	Scotland	N. Ireland	London	**Total**
Nitrogen dioxide NO_2	1-Hour and Annual Mean	13	6	3	1	7	**30**
Nitrogen dioxide NO_2	1-Hour Mean	1					**1**
Nitrogen dioxide NO_2	Annual Mean	453	27	19	21	26	**546**
Nitrogen dioxide NO_2	Interval Not Defined	1					**1**
Particulate Matter PM_{10}	24-Hour Mean	37	1	1	1	24	**64**
Particulate Matter PM_{10}	Annual and 24-Hour Mean	4		1	5	5	**15**
Particulate Matter PM_{10}	Annual Mean	1		8	1		**10**
Particulate Matter PM_{10}	Scotland Annual and 24-Hour Mean			4			**4**
Particulate Matter PM_{10}	Scotland Annual Mean			7			**7**
Sulphur dioxide SO_2	15-Minute and 1-Hour and 24-Hour Mean	2					**2**
Sulphur dioxide SO_2	15-Minute Mean	5		1			**6**
Total		**517**	**34**	**44**	**29**	**62**	**686**

Source: DEFRA (2013a)

The vast majority, some 85%, of AQMAs have been declared for breaches of the NO_2 limit value, which is consistent with the national assessment. However, there are about 15% of AQMAs declared as a result of a PM_{10} breach, showing that a small but significant PM problem remains in localised areas. However, this may mask a greater PM health risk, given that the EU limit value is higher than the WHO guidelines. Therefore this picture may underplay the importance of PM from a health perspective.

The reasons for the breaches are shown in Table 2.5, which reveals that over 95% have been attributed to transport emissions. In most cases the attribution of emissions is carried out through a modelling process known as ‘source apportionment’, which estimates the proportion of emissions from various sources contributing to air pollution in the given area. This again indicates that most of the air pollution problems are related to transport activity.

Table 2.5: AQMAs declared by source

Source	England	Wales	Scotland	N. Ireland	London	**Total**
Road transport unspecified	175	12	21	22	26	**256**
County or Unitary Authority Road	158	16	5		1	**180**
Mixture of road types	79	4	3		2	**88**
Highways Agency Road	43	1				**44**
Transport and Industrial Source	10		1		4	**15**
Transport, Industrial and domestic sources	8					**8**
Industrial Source	10	1	1			**12**
Domestic Heating	2		1	5		**8**
Not Defined	4			2		**6**
Total	489	34	32	29	33	**617**
Total with a transport element						**591**
% of total						**95.8%**

Source: Defra (2013a)

The AQMAs cover the major cities, as might be expected, but also a wide number of much smaller areas such as local hotspots in market towns which have narrow congested streets. To illustrate these air quality issues at the local level, two specific case studies are now considered: one for Leicester, representing a city AQMA; and one for Farnham, representing a small market town.

Leicester case study

Leicester is a city with a population of about 300,000, and, like most other cities of a similar size in the UK, has declared an AQMA. The AQMA has been in place since 2000 and covers the central area of the city and the main traffic routes into the city, as shown in Figure 2.7. The area covers about 3% of Leicester's population, many of whom are amongst the most deprived of the city's residents. The AQMA was declared on the basis of NO_2, and there remain widespread and substantial breaches of the annual mean objectives for NO_2. Coarse particulate matter (PM_{10}) is also of concern: although the daily and annual mean PM_{10} objectives were achieved at all sites in 2011, at two of the sites only a small margin remained for achieving the daily objective.

Monitoring data is collected across the city at a number of key sites, both roadside and background, and complemented by modelled emissions and air quality data. The monitored data for NO_2 and PM_{10} is shown in Figures 2.8 and 2.9 respectively. The NO_2 data shows levels well above the 40 μg/m^3 mean annual limit, reaching 70 μg/m^3 or more with little clear sign of a downward trend. This lack of improvement in NO_2 concentrations appears to be largely due to a poor real-world NO_x emission performance of diesel vehicles as explored later. As for the PM_{10} data, this is generally within the limit values.

Figure 2.7: The Leicester AQMA

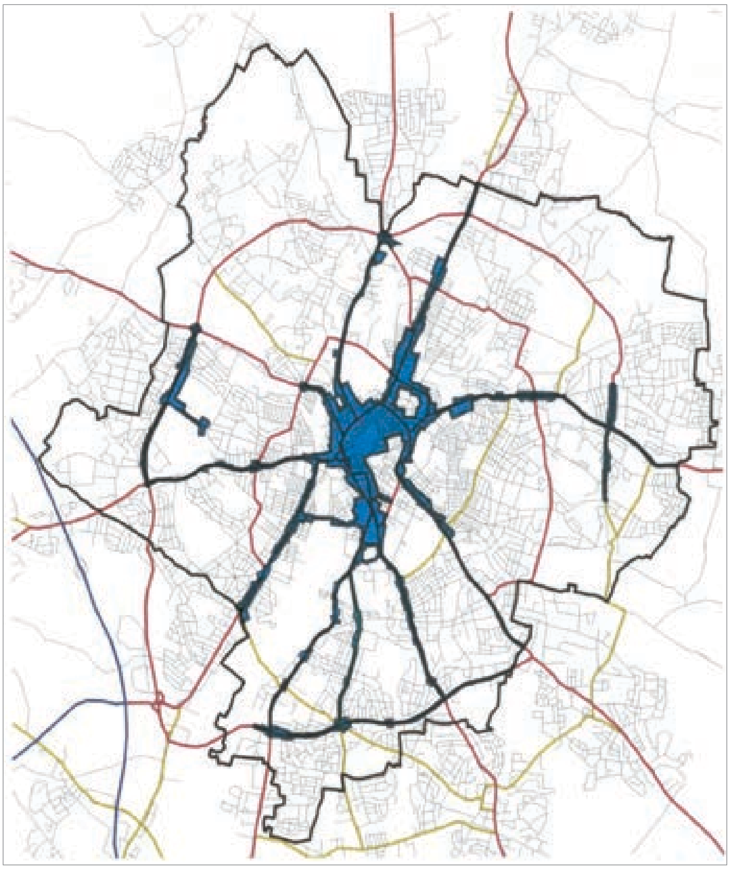
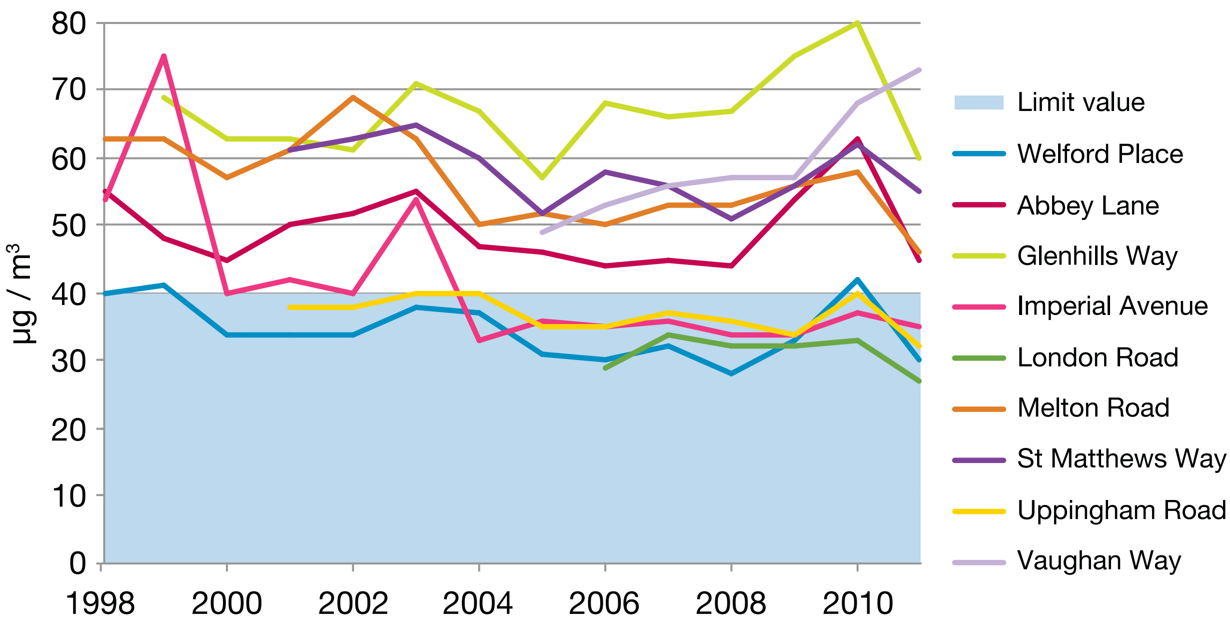
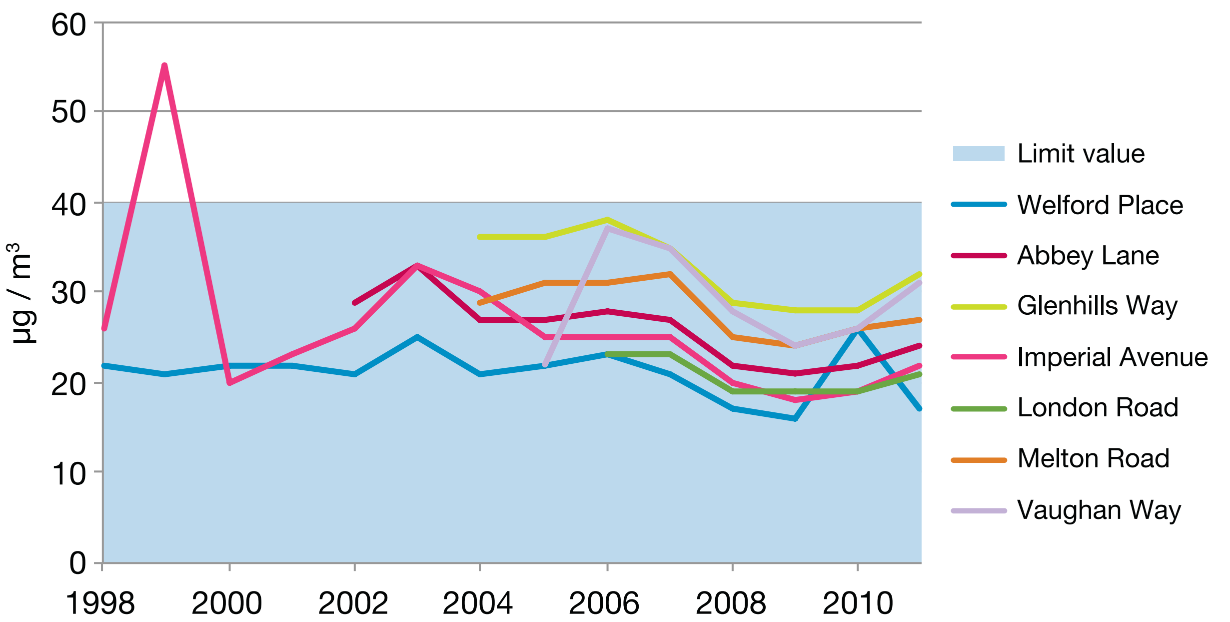


Figure 2.8: Mean annual NO_2 concentrations across a number of Leicester sites



Source: Davies & Pollard (2012)

Figure 2.9: Mean annual PM10 concentrations across a number of Leicester sites



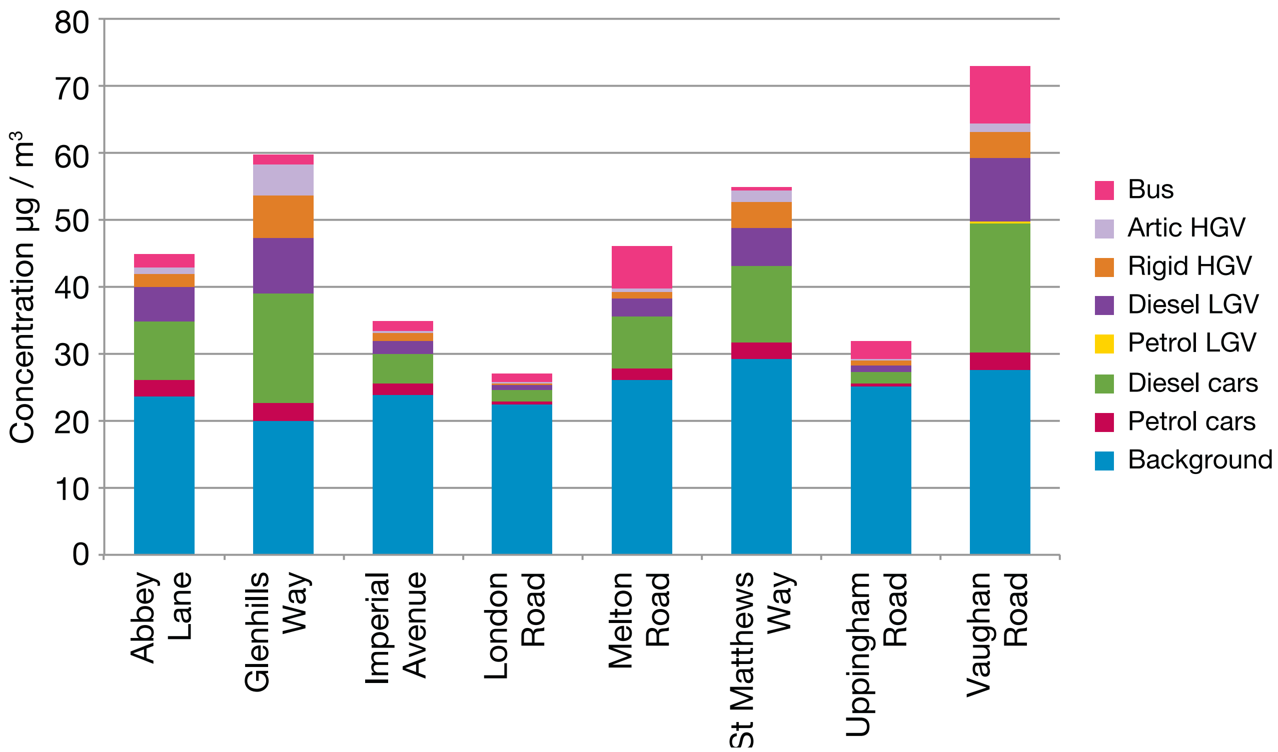
Source: Davies & Pollard (2012)

Recent modelling work has been carried out to assess the contribution of various different vehicle types to measured NO_2 concentrations as part of a wider study to consider measures to help reduce emissions. The results of this source apportionment work are shown in Figure 2.10.

This data suggests that diffuse background concentrations are in the range 20–30 µg/m³. These background concentrations are derived from domestic, commercial and industrial emissions, as well as the more diffuse transport component from minor roads, and will be similar across the city. At the roadside there is also a direct transport component, which varies more widely, with levels ranging from 10 µg/m³ to 50 µg/m³ depending on the volume and proximity of traffic activity.

In terms of the transport component, diesel cars and diesel vans contribute a significant part of the NO_2 concentrations in all locations. In some areas, such as Vaughan Way and Melton Road –key bus routes in the city – buses are a significant contributor. In other areas, such as Glenhills Way, goods vehicles make up a significant part of the problem. Overall, the modelling work for Leicester indicated that cars, especially diesel cars, were responsible for about 50% of the road transport emissions in most areas. On the radial roads and inner ring road with high bus flows, the buses were next most important element. However, on the outer roads and outer ring road, goods vehicles were the next most important source after cars.

Figure 2.10: Source apportionment of monitored NO_2 data



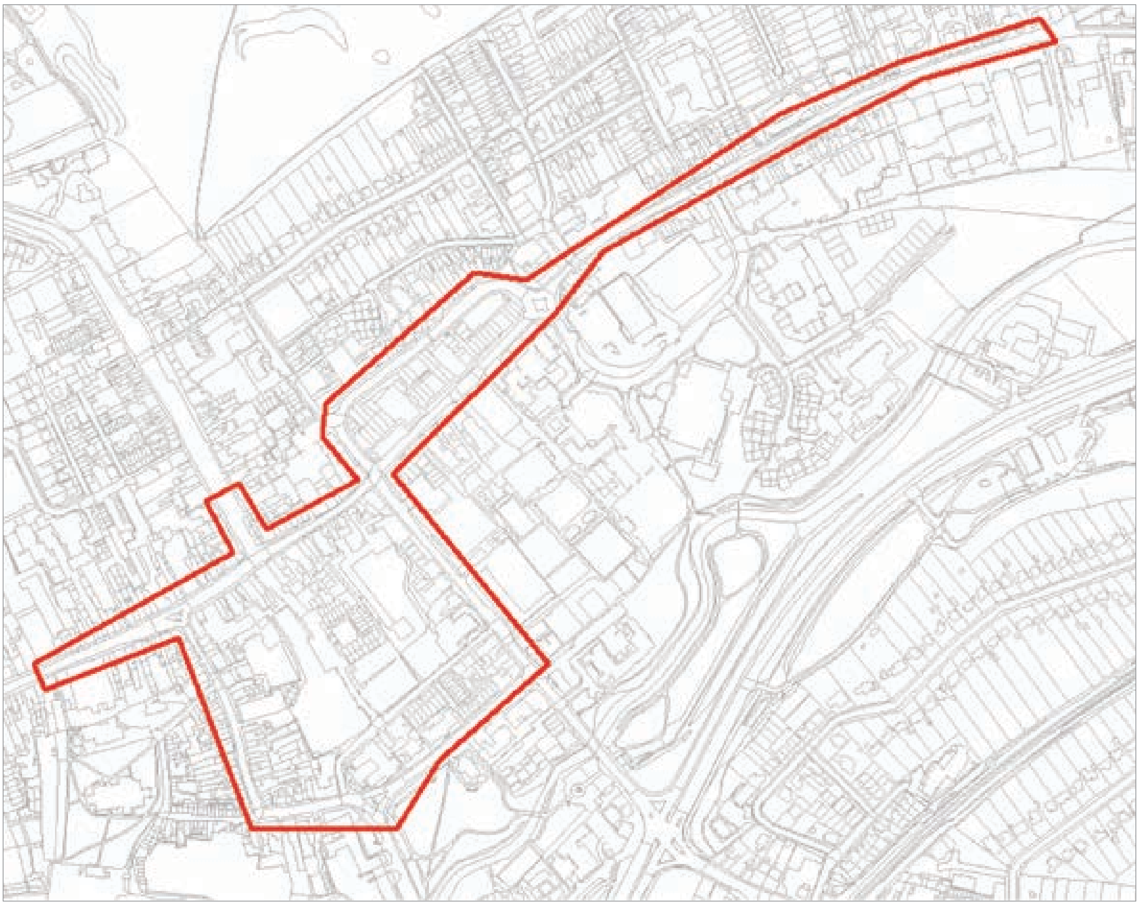
Source: Abbott (2013)

This pattern is typical for a city like Leicester with high traffic flows, a network of buses on key routes and freight activity in and around the city. The background pollution levels are in the range 20–30 µg/m³, with transport emissions contributing another 10–50 µg/m³, giving overall NO_2 levels of 70 µg m³ or higher.

Farnham case study

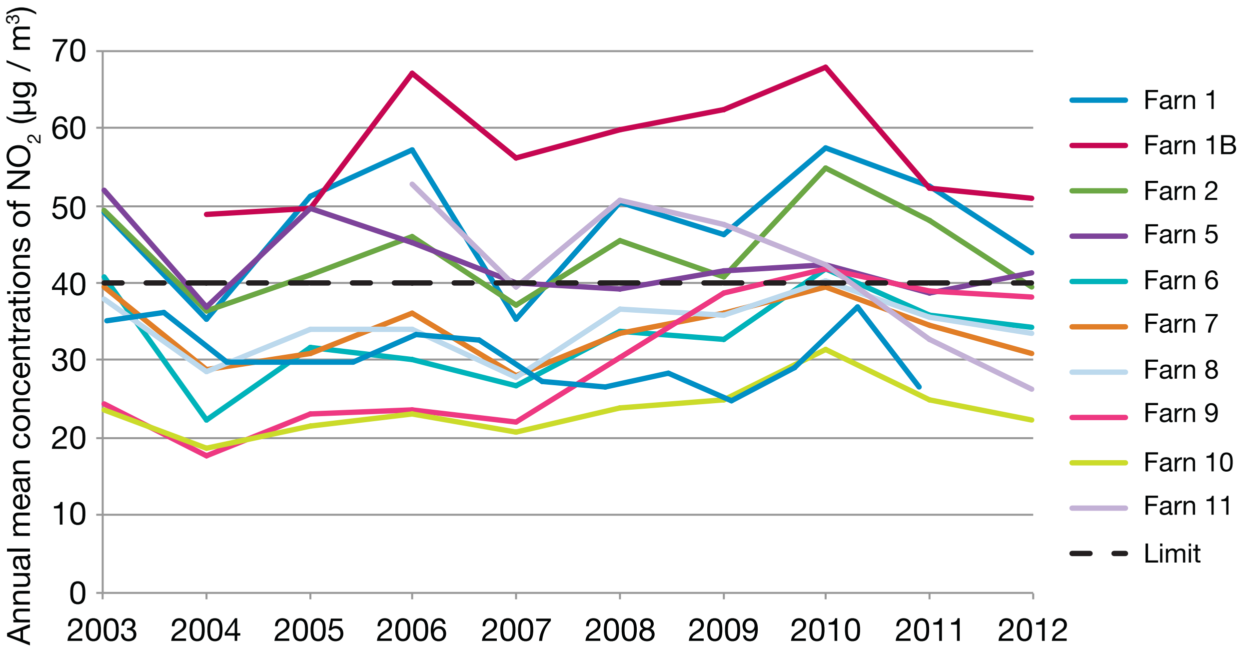
Farnham is a historic market town with a population of about 40,000, located in West Surrey, close to the border with Hampshire. Although the main A31 (Guildford to Winchester) road bypasses the town, there is significant traffic on the other A-roads that pass through the town centre. The town has a one-way system around the central area, part of which comprises narrow roads and pavements in places, leading to conflict between vehicles and pedestrians. As a result of this congested and slow-moving traffic, an AQMA was declared in 2007 for the breaching of NO_2 limits in the central area of the town as shown in Figure 2.11.

Figure 2.11: The Farnham AQMA



Monitoring data is collected in a number of key sites within Farnham, and again is complemented by modelled emissions and air quality data. The monitored data for NO_2 is shown in Figure 2.12, where it can be seen that concentrations have not decreased since 2003, with many monitoring sites consistently having NO_2 concentrations above the annual limit value of 40 μg/m^3.

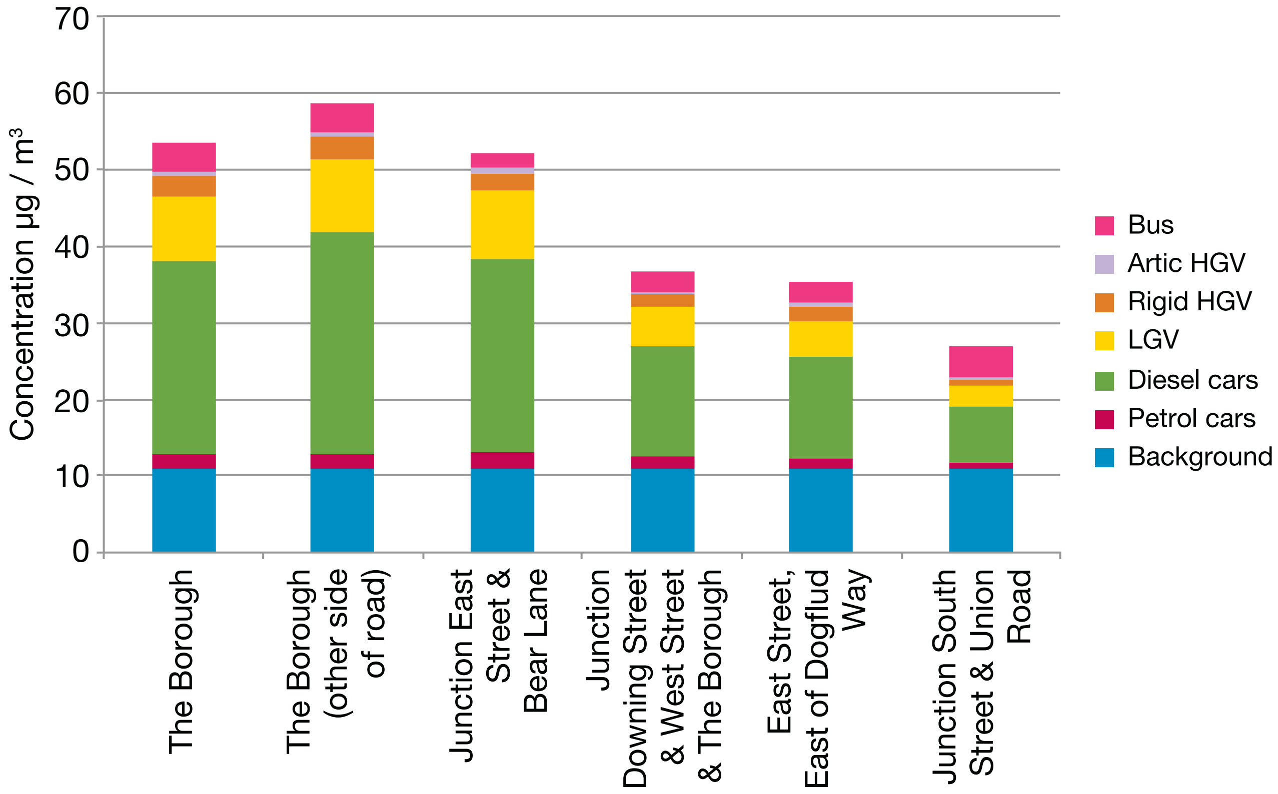
Figure 2.12: Annual mean concentrations of NO_2 (µg/m³) across a number of Farnham sites



Source: Collated from numerous Air Quality Progress reports from Waverley Borough Council

Analysis by Ricardo-AEA for Farnham for 2015 (Figure 2.13) shows that the majority of NO_2 emissions will be from diesel engine vehicles, of which diesel cars will account for the largest share. The modelling work shows that the diesel cars in the urban Farnham environment account for around 50% of the NO_2 concentrations and at some roadside locations could amount to 25 µg/m³.

Figure 2.13: Modelled source apportionment of NO_2 in Farnham at selected sites for 2015



Source: Ricardo-AEA analysis

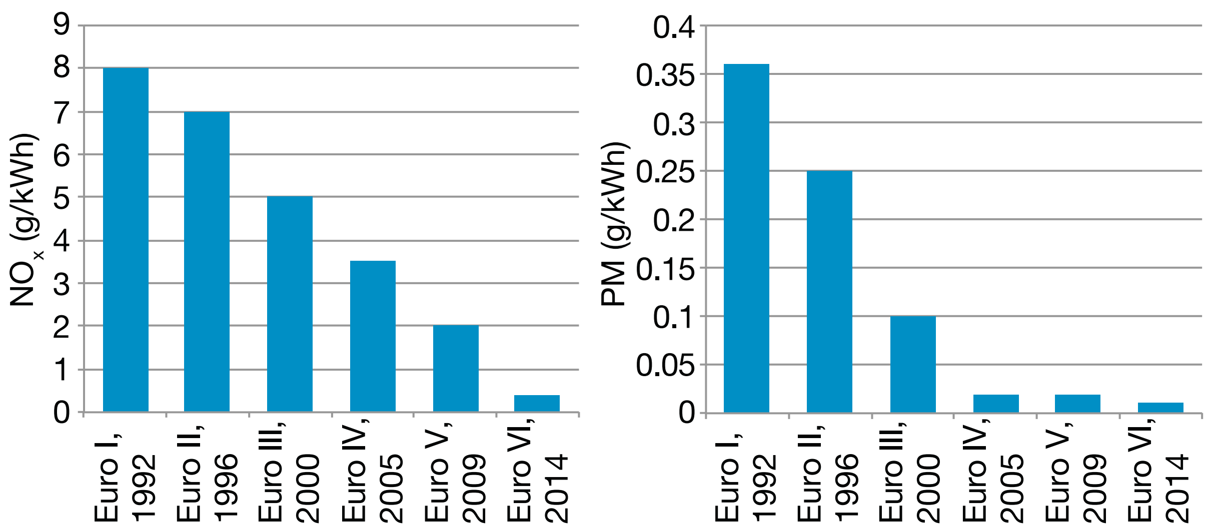
This is typical of air quality problems experienced in market towns where old historic streets struggle to couple with modern vehicles. The vehicle flows are congested and the emissions are trapped in narrow streets, giving rise to high pollution concentrations. Moreover, the majority of emissions arise from cars, especially diesel cars, rather than heavy-duty vehicles. In addition, the background level of pollution is less than that found in larger urban areas, at some 10–20 µg/m^3.

2.4 Vehicle emission standards, performance and prediction

One of the key mechanisms for reducing emissions from transport and improving national and local air quality is the introduction of vehicle emission standards. This has been implemented at the European level, and the standards are known as ‘Euro standards’. Standards have been set for carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM). However, it is the latter two – NO_x and PM – that are of the most relevance, as these continue to be important contributors to air quality problems.

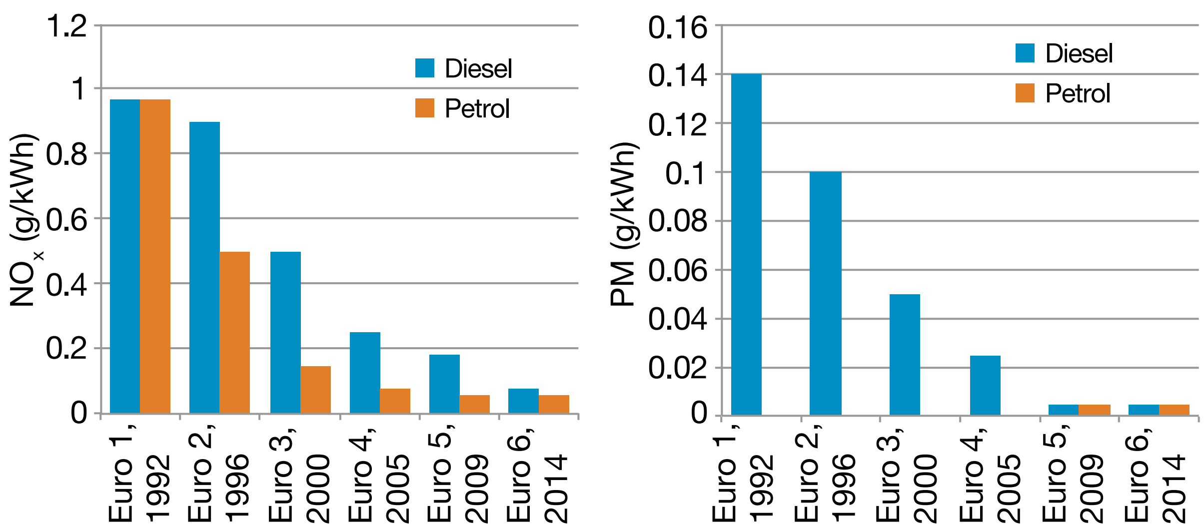
These standards were introduced in 1992 and have become progressively tighter over time, as shown in Figures 2.14 and 2.15, with the tightest standards to date coming into force for vehicles manufactured in 2014. The latest emission standards are over 90% lower than the first standards introduced in 1992.

Figure 2.14: NO_x and PM emission standards for heavy-duty vehicles



Source: European Commission

Figure 2.15: NO_x and PM emission standards for passenger cars



Source: European Commission

Manufacturers have had to introduce a range of engine and fuel system design options, along with exhaust emission controls, in order to meet these standards. The main technologies deployed on diesel vehicles to meet these standards are summarised in Table 2.6 – key amongst them are diesel particulate filters (DPFs) to reduce PM, and selective catalytic reduction (SCR) to reduce NO_x emissions.

As well as the emission limits getting tighter, the test procedures have become stricter. For heavy-duty vehicles, steady state tests were supplemented with transient tests in 2000 (with Euro III), and for the latest Euro standards there are requirements for in-service compliance testing in order to improve real-world performance. These in-service testing requirements are still being developed for light-duty vehicles. There are also tests for emissions durability, to ensure that emissions performance is maintained over a vehicle's lifetime, and particle number limits have been put in place in addition to the particle mass measurements.

All of this adds up to a stringent regulatory framework designed to drive down vehicle emissions and improve air quality. However, there is significant evidence that in real-world operation, outside of the regulatory test cycles, vehicle emissions are not improving as might be expected, considering these regulations. This seems to be the case particularly for diesel vehicles in urban areas, which is where the main air quality problems occur.

Table 2.6: Diesel technology and Euro standards

Standard*	Light-duty diesel car and van	Heavy-duty bus and truck
Euro 1/I (1992)	Engine and fuel system design (IDI engines only) – some EGR	Engine and fuel system design
Euro 2/II (1996)	Engine and fuel system design (now fully electronic), mechanical 'on/off' EGR + DOC (mix of IDI and DI engines)	Engine and fuel system design
Euro 3/III(2000)	Engine and fuel system design, electronic (fine) control EGR + DOC (DI engines only from now on generally on sale)	Engine and fuel system design (now fully electronic)
Euro 4/IV (2005)	Engine and fuel system design, electronic (fine) control EGR + DOC + DPF (on heavier vehicles)	Engine and fuel system design + SCR (no DPF), or EGR with partial DPF
Euro 5/V (2009)	Engine and fuel system design, electronic (fine) control EGR + DOC + DPF	Engine and fuel system design + SCR (no DPF), or EGR with partial DPF
Euro 6/VI (2014)	Engine and fuel system design, electronic (fine) control EGR and/or SCR + DOC + DPF	Engine and fuel system design + SCR and/or EGR, both with DPF
Technology definitions		
IDI, DI	Indirect injection and direct injection; IDI is less efficient but cheaper	
DOC	Diesel oxidation catalyst – reduces CO and HC, but increases direct NO_2	
EGR	Exhaust gas recirculation – decreases NO_x by 30–50%, but can increase fuel use	
DPF	Diesel particulate filter – reduces PM by 80–90%, passive systems use NO_2 from related DOC to regenerate	
SCR	Selective catalytic reduction – reduces NO_x by 80–90%	

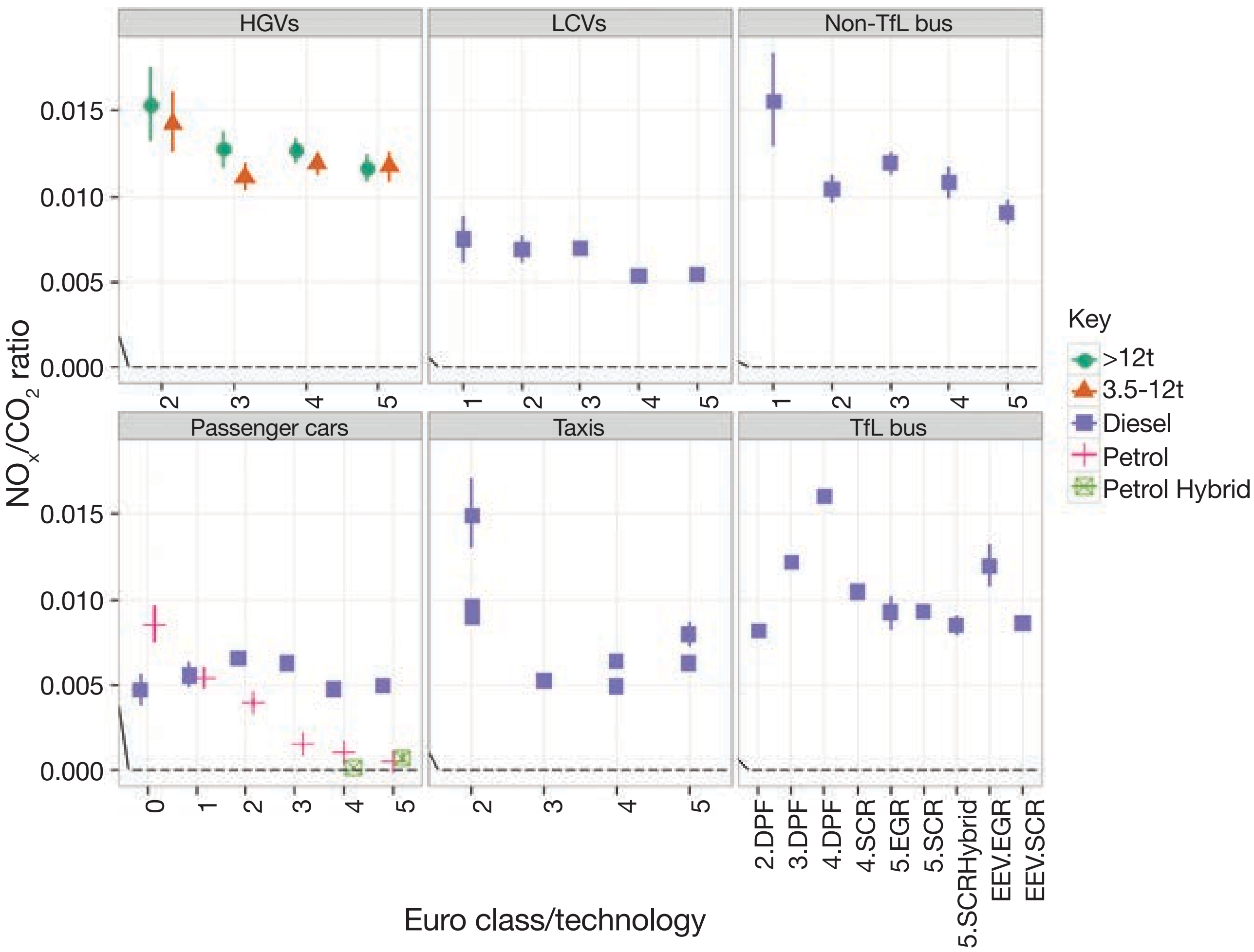
Source: Hitchcock et al. (2011)

* Arabic numerals refer to Euro standards for light-duty vehicles (cars) while roman numerals refer to heavy-duty vehicle standards.

Real-world emissions testing has been carried out in a number of ways. The largest number of measurements has been taken using a technique called remote sensing detection. This technique uses beams of infrared and ultraviolet light that are projected across the road to take a snapshot of instantaneous emission levels from passing vehicle exhausts. In a recent study by Carslaw and Rhys-Tyler (2013) which focused on NO_x emissions in London, the emissions data was matched with vehicle data using an automatic number plate recognition system to match the emissions with vehicle type and Euro standards. A summary of the results is shown in Figure 2.16 which relates NO_x emission to Euro standards for key vehicle types. The NO_x emissions are shown as a ratio to CO_2 emissions which normalises the results in relation to engine power (CO_2 being a proxy for engine power). The Euro standards on the x-axis are shown as simple Arabic numerals, with the exception of Transport for London buses which include a reference to the exhaust after treatment employed. The key outcomes of the study in relation to real-world urban vehicle emissions were:

- petrol cars have shown a steady reduction in NO_x emissions over time;
- diesel cars have shown little or no reduction in NO_x emissions;
- HGVs showed a reduction in NO_x emissions between Euro II and Euro III, but little since;
- bus emissions have shown little significant improvement; and
- the fraction of NO_x released as direct NO_2 rather than NO has increased from about 10–15% for pre-Euro 3 cars to 30–50% for Euro 4 and 5 cars, whereas heavy-duty vehicles seem to show a reduction in this proportion.

Figure 2.16: Results of the remote sensing study by Carslaw and Rhys-Tyler (2013)

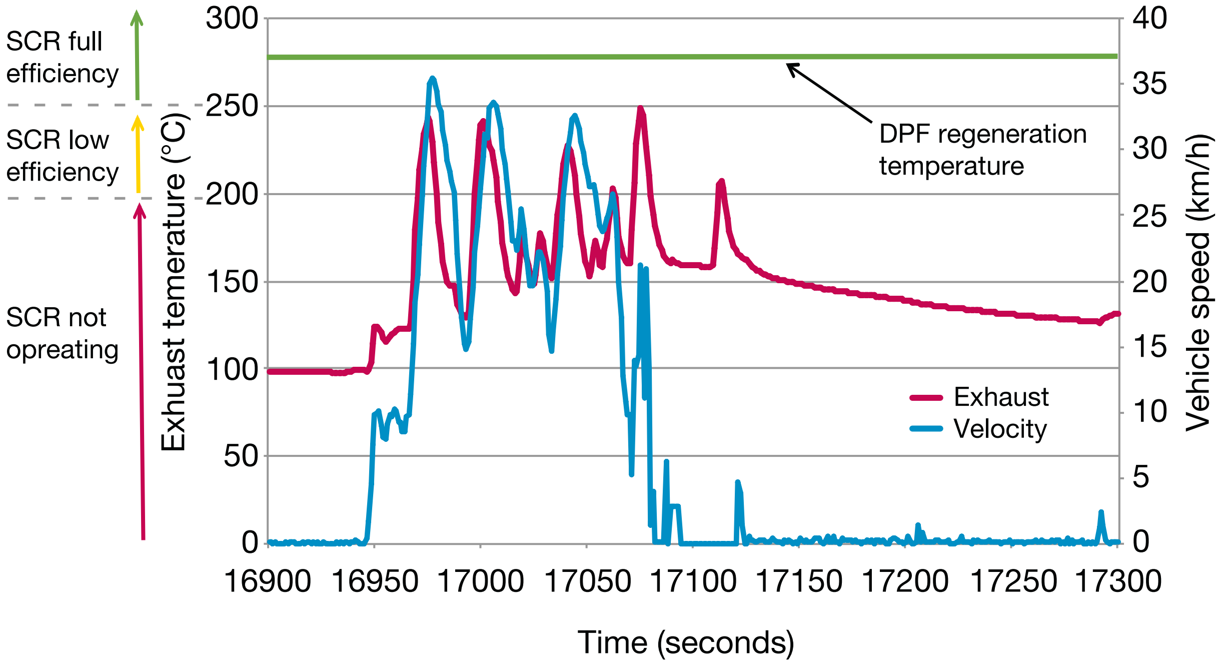


Source: Carslaw & Rhys-Tyler (2013)

Other real-world emissions data has been collected using non-regulatory real-world test cycles and portable emissions measurement systems (PEMS) during normal operation. A study by the European Joint Research Centre (JRC) using the PEMS method supports the data from the remote sensing study in London. This study suggested that petrol cars were remaining largely within the expected regulatory emission limits during real-world driving, but diesel cars were not. The diesel vehicles had NO_x emissions 4 to 7 times higher than the limit, and showed little improvement between vehicles which were subject to Euro 3 emission limits and those subject to Euro 5 emission limits (Weiss et al., 2011).

The main reason for the difference between real-world and regulation emissions seems to be the effectiveness of emissions control technology across a range of operating conditions. The main technology used in petrol vehicles, the three-way catalyst, seems to operate well across all duty cycles. However, the two main technologies used to control emissions from diesel – DPF and SCR – are influenced by operating conditions. This is illustrated well by some analysis undertaken for ground vehicles at Heathrow Airport (Hitchcock et al., 2011). This work looked at a typical airport vehicle drive cycle, with associated vehicle exhaust temperature, and mapped on the typical operating temperatures for both SCR and DPF, as shown in Figure 2.17. This clearly showed that in this slow speed, stop–start operation the control technology did not reach a sufficiently high temperature to operate at maximum efficiency for much of the time. This situation could well be analogous to much urban operation of vehicles.

Figure 2.17: SCR and DPF operating temperature related to Heathrow drive cycle



Source: Hitchcock et al. (2011)

This type of evidence prompted the 'off-cycle' (non-regulation cycle) and in-use tests to be implemented as part of the Euro 6/VI emission regulations. The intention is to ensure that real-world performance matches regulation. Some early test work comparing Euro V and VI vehicles is suggesting that this wider approach to regulation could be working. Tests in Norway showed that Euro 6 cars had significantly better real-world NO_x emissions than Euro 5 cars, although still higher than the regulation limits. However, the results for HGVs showed very low NO_x emissions for Euro VI vehicles, comparable with those of a car (Hagman & Amundsen, 2013). Similar work from the Netherlands with heavy-duty vehicles showed variable and often poor NO_x emissions from Euro V vehicles, but much better performance for Euro VI vehicles (Vermeulen et al., 2012).

The focus of much of the real-world emissions analysis has been on NO_x emissions, with particulate emissions showing much more robust reductions. Overall, therefore, the evidence suggests that emission regulations have driven down vehicle pollutant emissions, with the exception of NO_x emissions from diesel vehicles. However, this looks set to change with the introduction of Euro 6/VI limits and the new testing regime.

There has also been a knock-on effect in terms of air quality policy formulation and assessment. Air pollution concentrations are directly measured; however, contributing emissions from transport can only be estimated. When estimating vehicle emissions, vehicle emission factors are used relating emissions to the type of vehicle and its Euro standard. These emission factors are derived from both regulatory and non-regulatory vehicle test data, in order to give a best estimate of how the Euro emission standards will perform across a range of driving conditions. However, if vehicles are not performing in real life as expected, then the emission factors used will not represent their performance correctly – and in the case of NO_x are likely to underestimate emissions. These factors are updated regularly, and improved in line with the best available evidence on real-world performance. The main data set used in the UK comes from the NAEI, with the data being used for both national and local assessments.

This mismatch between regulation and real-world NO_x emissions from diesel vehicles seems to be one of the key reasons why the expected reductions in NO_2 concentrations at the roadside have not materialised. This is further compounded by a growth in the share of diesel vehicles in the UK, and by the increase in direct NO_2 from diesel cars in the case of new Euro 4 and Euro 5 vehicles.

2.5 Summary

Health-based air pollution standards have been set at the European level and have been adopted nationally, forming the basis of LAQM. At the national level, the key area where the UK is failing to comply with European limits is in respect to NO_2 levels, where most areas in the country have some breaches. Road transport contributes 30% of NO_x emissions nationally, but plays a major role in exceeding limit values because it is concentrated on the road network in towns and cities.

In terms of NO_2 pollution concentrations, diffuse background pollution in urban areas ranges from 10 μg/m^3 to 30 μg/m^3, with road transport contributing on average around another 30 μg/m^3 to 50 μg/m^3 at pollution hotspots. This can give rise to pollution levels at twice that of the European limit values. Although reductions in background concentrations achieved by tackling residential and commercial emissions will be important, major improvements will still have to be made in relation to emission from transport activity. In many hotspots this will mean reducing transport emissions by at least 50%, and even by as much as 75–80% in some cases. Clearly this will be a significant challenge.

Heavy-duty trucks and buses are the main source of NO_x emissions, which contribute to NO_2 concentrations, but in absolute terms this has been reducing. Diesel cars are now the second-largest source of NO_x emissions, and this source has grown rapidly over the last 15 years. This indicates a potential conflict with climate change policy, which has to some degree supported the growth in diesel cars owing to their lower fuel consumption and CO_2 emissions.

Levels of PM_{10} and $PM_{2.5}$ are largely within the European limit values, but are very close to those limits in some areas. However, the EU limit value used for compliance is higher than the more stringent WHO guidelines. Therefore, as discussed further in the following section, PM is a much more significant issue for public health than the compliance data alone suggests.

Again, diesel vehicles are the main source of these emissions when it comes to road transport, but the difference between diesel and petrol is less than for NO_x, because PM emissions are also generated from break and tyre wear and from road abrasion. Therefore PM emissions are not solely a diesel vehicle problem, and will require solutions that tackle non-combustion sources of pollution as well.

At the local level, breaches of the air quality limits are found across the country, with some 600 AQMAs being declared. The vast majority of these have been declared for breaches of the NO_2 limit ,value and in relation to transport sources. The AQMAs cover the major cities, as might be expected, but also a wide number of much smaller areas such as local hotspots in market towns which have narrow congested streets. Thus the type and nature of the problems varies depending on the exact location and context. However, in general diesel cars will be a significant contributor to NO_2 and PM pollution, along with buses and HGVs, especially in larger towns and cities.

Moreover, levels of measured air pollution have improved little in recent years, despite progressively stricter vehicle emission limits driven by European legislation. Estimated vehicle emissions have declined, but this has not resulted in significant improvements in local air quality. A mismatch between regulation and real-world NO_x emissions from diesel vehicles seems to be one of the key reasons why the expected reductions in NO_2 concentrations at the roadside have not materialised. This is further compounded by a growth in the share of diesel vehicles in the UK, and by the increase in direct NO_2 from diesel cars as a result of diesel oxidation catalysts in newer vehicles meeting the Euro 4 and Euro 5 emissions legislation.

3. Assessing the Impacts

There is clear evidence of the impact of traffic-related air pollution on human health. The greatest evidence is in relation to particulate emissions, most importantly the fine particulate matter $PM_{2.5}$. The burden of particulate air pollution in 2008 has been estimated to be equivalent to nearly 29,000 premature deaths at typical ages of death in 2008, and an associated loss of population life of 340,000 years lost in the UK. It has been calculated that if all anthropogenic (human-generated) $PM_{2.5}$ air pollution was removed, approximately 36.52 million life-years over the next hundred years could be saved in the UK. In addition, this would be associated with an increase in UK life expectancy from birth (i.e. on average across new births) of six months.

The Committee on the Medical Effects of Air Pollutants (COMEAP, 2010a) also identified that policies which aim to reduce the annual average concentration of $PM_{2.5}$ by 1 µg/m_3 would result in a saving of approximately 4 million life-years, or an increase in life expectancy of 20 days in people born in 2008. A study by the Institute of Occupational Medicine (Miller & Hurley, 2006) estimated that removing all fine particulate air pollution would have a bigger impact on life expectancy in England and Wales than eliminating passive smoking or road traffic accidents. The health impacts of poor air quality caused by transport in urban areas in England are estimated to cost between £4.5 billion and £10.6 billion (at 2009 prices).

3.1 The link between traffic pollution and health impacts

A detailed report by the Health Effects Institute considered the health effects of traffic-related air pollution by summarising and synthesising information linking emissions from, exposure to, and health effects of traffic sources (HEI, 2010). The panel found that the evidence is sufficient to support a causal relationship between exposure to traffic-related air pollution and exacerbation of asthma. Suggestive evidence was also identified indicating that there was a causal relationship with the onset of childhood asthma, non-asthma respiratory symptoms, impaired lung function, and cardiovascular mortality and morbidity (the relative frequency of occurrence of the condition), although it should be noted that the data in the studies is not sufficient to fully support causality. Overall, sufficient and suggestive evidence for these health outcomes indicates that exposure to traffic-related pollution is likely to be a matter of concern regarding public health, and deserves public attention in light of the fact of the large numbers of people residing within 300m to 500m of major roads.

Similarly, a recent WHO review of evidence on the health impacts of air pollution looked specifically at the proximity to roads and health impacts (WHO, 2013). This study concluded that “adverse effects on health due to proximity to roads were observed after adjusting for socioeconomic status and after adjusting for noise." The health impacts are related to a mixture of pollutants at the roadside, including PM, NO_2, CO and polycyclic aromatic hydrocarbons. However, the evidence does not allow discernment of the direct impact of specific pollutants, although the association with direct tailpipe PM is increasingly identified.

Exhaust emissions constitute the principal source of traffic-related pollution, and several epidemiological and toxicological studies have linked such emissions to adverse effects on health. However, road abrasion, tyre wear and brake wear are non-exhaust traffic emissions that become relatively more important with progressive reductions in exhaust emissions. Toxicological research increasingly indicates that such non-exhaust pollutants could be responsible for some of the observed adverse effects on health.

More generally, particulate matter – especially $PM_{2.5}$ and ozone – is considered the most problematic in terms of human health (Guerreiro et al., 2013). NO_2 is also a key concern owing to both its direct health effects and its indirect role in nitrate particle formation and as a precursor to ozone formation. According to the European Environment Agency (Guerreiro et al., 2013), an estimated 20–30% of the urban population are exposed to $PM_{2.5}$ levels above EU reference values, and 91–96% are exposed to levels above the more stringent WHO guidelines.

A summary of the quantified and unquantified health effects of air pollution is presented in Table 3.1. The evidence on the health impacts of these three key pollutants is discussed in more detail below.

Table 3.1: Human health effects of common air pollutants

Pollutants	Quantified health effects	Unquantified health effects	Other possible effects
Particulate matter / TSP / sulphates	Mortality Chronic and acute bronchitis Minor RAD Chest illness Days of work loss Moderate or worse asthma status	Changes in pulmonary function	Chronic respiratory diseases other than chronic bronchitis Inflammation of the lung
Ozone	Mortality Respiratory RAD Minor RAD Hospital admissions Asthma attacks Changes in pulmonary function Chronic sinusitis and hay fever	Increased airway responsiveness to stimuli Centroacinar fibrosis Inflammation in the lung	Immunologic changes Chronic respiratory diseases Extrapulmonary effects (changes in the structure or function of the organs)
Nitrogen oxides	Respiratory illness	Increased airway responsiveness	Decreased pulmonary function Inflammation of the lung Immunological changes
Carbon monoxide	Mortality Hospital admissions – congestive heart failure Decreased time to onset of angina	Behavioural effects Other hospital admissions	Other cardiovascular effects Developmental effects
Sulphur dioxide	Morbidity in exercising asthmatics: Changes in pulmonary function Respiratory symptoms		Respiratory symptoms in non-asthmatics Hospital admissions
Lead	Mortality Hypertension Nonfatal coronary heart disease Nonfatal strokes IQ loss	Neurobehavioural function Other cardiovascular diseases Reproductive effects Foetal effects from maternal exposure Delinquent and antisocial behaviour in children	

Source: VTPI (2013)

Note: RAD = Reactive airway disease, a general term for various illnesses that cause breathing difficulties; TSP = Total suspended particles

3.2 The health impact of key pollutants

A vast range of studies have been published presenting evidence on the health impacts of air pollution. As part of the European 'Year of Air in 2013', WHO reviewed the most recent evidence on the long-term impacts of air pollution, and found overwhelming evidence of the impact on mortality and morbidity, including cardiovascular and respiratory disease, birth outcomes and neurological effects (WHO, 2013). The Committee on the Medical Effects of Air Pollutants (COMEAP) has also published a series of studies reviewing current evidence on a range of related air pollution and health topics. This section aims to summarise the health effects of various air pollutants, particularly the effects of those originating from transport, and then considers the most recent evidence in support of these effects.

3.2.1 Fine particulates – $PM_{2.5}$/PM_{10}

Fine particulates ($PM_{2.5}$) are able to penetrate deeply into the human respiratory system. Acute effects of short-term exposure to particulates have been found to include increases in hospital admissions and premature death of the old and sick due to disease of the respiratory and cardiovascular systems. Incidences of high concentrations of both $PM_{2.5}$ and PM_{10} have been found to cause additional hospital admissions and deaths (COMEAP, 2009; AQEG, 2012). During pollution episodes, other less severe effects of short-term particle exposure can be witnessed, including worsening of asthma symptoms, and general feelings of being unwell leading to a lower level of activity (COMEAP, 2009; AQEG, 2012).

Lung and heart conditions can be exacerbated during short-term episodes of high levels of PM, significantly affecting quality of life and increasing both deaths and hospital admissions (Defra, 2012). It has been identified that children, the elderly and those with pre-existing respiratory and cardiovascular disease are most likely to be susceptible to the health impacts of air pollution. Intervention studies have shown a marked improvement in health as a result of pollution abatement (as in the case of the ban on coal sales in Dublin).

It has been recognised that long-term exposure to PM has the biggest impact on health. Long-term PM exposure has led to increased levels of fatal cardiovascular and respiratory diseases, including lung cancer. Both impacts have been revealed through increased death in cities with higher concentrations of airborne particles (AQEG, 2012). Long-term exposure to PM has also been shown to increase age-specific mortality risk, particularly from cardiovascular causes (Defra, 2012). COMEAP (2009) has quantified the chronic health impact of PM exposure as a 6% increase in death rates per 10 $\mu g/m^3$ $PM_{2.5}$ concentration.

Many of the results for the health effects of PM are related to particle mass, rather than the various sources or components of PM – there is currently no clear understanding of which properties of particles (e.g. size, presence of specific chemical substances) are most responsible for toxic effects. Therefore improved understanding of the ‘behaviour’ and composition of PM will help to improve our understanding of its impacts (AQEG, 2012). No wholly safe level has been identified, for either acute or long-term effects.

The recent REVIHAAP (Review of evidence on health aspects of air pollution) study reviewed the effects of short-term exposure to $PM_{2.5}$ on mortality and morbidity with reference to a number of multi-city epidemiological studies, and of long-term exposure, again on both mortality and morbidity. The review was based on several studies of long-term exposure conducted on large cohorts in Europe and North America, and concluded that short-term exposure is a cause of both cardiovascular mortality and morbidity (WHO, 2013).

Epidemiological, clinical and toxicological studies reviewed have provided significantly more insight into the physiological effects and plausible biological mechanisms that link short- and long-term $PM_{2.5}$ exposure with mortality and morbidity (ibid.). Long-term exposure to $PM_{2.5}$ has been linked, through additional studies, to several new health outcomes, including atherosclerosis, adverse birth outcomes and childhood respiratory disease (ibid.). The emerging evidence from the review also suggests that there are possible links between long-term $PM_{2.5}$ exposure and neurodevelopment and cognitive function, as well as other chronic disease conditions, such as diabetes (ibid.).

In a 1995 COMEAP report, it was concluded that exposure to ambient concentrations of air pollutants (including PM) is associated with an increase in exacerbations of **asthma** in those who already have the condition. It is recognised that air pollutants cause irritation and inflammatory responses of the airways, therefore it is not too surprising that air pollutants can produce this kind of effect, since those suffering from asthma are predisposed to respond to such effects through bronchoconstriction[1]. More recent studies have also produced evidence to suggest that air pollution might play a part in the induction of asthma in some individuals who live near busy roads, particularly those carrying high numbers of HGVs, which produce more emissions than passenger cars (COMEAP, 2010b).

A report considering the possible effects of outdoor pollution (including PM) on **cardiovascular disease** concluded that the review of the evidence demonstrated clear associations between both daily and long-term average concentrations of air pollutants and effects on the cardiovascular system, reflected by a variety of outcome measures including risk of death and of hospital admissions. COMEAP concluded that many of these associations were likely to be causal in nature, and therefore a precautionary approach should be taken in future planning because of the public health implications.

1 Bronchoconstriction the constriction of the airways in the lungs due to the tightening of surrounding smooth muscle, with consequent coughing, wheezing, and shortness of breath.

It is not certain from the evidence which components of the ambient pollution mixture are responsible for these effects, although it is likely that fine particles play a part (DoH, 2006). However, other factors such as family history, active smoking and hypertension are thought to play a larger role. The suggested health impact mechanism is that particles set up an inflammatory response in the interstitial tissue of the lung, and that this (in time) provokes an increase in the likelihood of the blood clotting and/or atheromatous[2] plaques rupturing. A reflex effect on the heart is a second hypothesis, which is provoked by the interaction between pollutants, or secondary factors produced by inflammation, and receptors in the airways and lung. It is anticipated that more than one mechanistic process may result in these effects, and that the effects may act in concert. Additionally, these hypotheses should not be viewed as mutually exclusive (DoH, 2006).

3.2.2 Ozone (O_3)

Although not a primary emission of transport, ozone (O_3) is formed in the lower atmosphere by complex reactions involving volatile organic compounds (VOCs), CO and nitrogen oxides (all primary emissions from transport) in the presence of sunlight. It is considered to be a region-wide air pollution problem, as it can travel long distances, rather than a specifically urban pollutant. Ozone is a respiratory irritant. There has been increasing epidemiological evidence that short-term exposure to O_3 has significant adverse effects on asthmatics and places increased demands on the NHS. Exposure to O_3 is likely to enhance cardiovascular disease through its pro-inflammatory effects on the lung. O_3 episodes are associated with increased respiratory morbidity in older people, especially those with co-existent chronic obstructive lung disease (COPD). Ozone exposure is also associated with higher mortality rates in studies that are reporting coefficients which are larger than previously estimated from the primarily time-series studies for England. There is also mounting evidence that O_3 is associated with myocardial infarction and cardiac arrhythmias in older people.

The WHO (2013) study identified a number of cohort analyses on the long-term ozone exposure and mortality published since 2005. Some evidence has been identified on the effect of long-term exposure to ozone on respiratory and cardiorespiratory mortality. Evidence is also identified, from other cohorts, of the effect on mortality among people with potentially predisposing conditions, including COPD, diabetes, congestive heart failure and myocardial infarction. Long-term ozone exposure studies were identified which reported adverse effects on asthma incidence, asthma severity, hospital care for asthma and lung function growth.

Large, multi-centre time-series studies in Europe, the United States and Asia published since 2005 produced new evidence on the adverse effects of short-

2 Atheroma is the degeneration of the walls of the arteries caused by accumulated fatty deposits and scar tissue, leading to restriction of the circulation and a risk of thrombosis.

term exposure to ozone. The adverse effects of short-term exposure to daily concentrations of ozone (measured as maximum 1-hour exposure, or an 8-hour mean) on all-cause, cardiovascular and respiratory mortality, and of exposure to daily ozone concentrations on both respiratory and cardiovascular hospital admissions, after adjustment for the effects of particles (PM_{10}), have been reported in Europe (WHO, 2013).

Evidence previously existed in the 2005 WHO review in support of the short-term effects of ozone on a range of pulmonary and vascular health-relevant endpoints in the form of toxicological data from animal and human exposure studies. Since then the evidence has strengthened, with studies showing chronic injury and long-term structural changes on the airway in animals exposed for long periods to ozone and to ozone allergens combined (these studies representing a range of experimental animal including primates). Evidence based on new epidemiological and experimental data also suggests that there is an effect of ozone exposure on cognitive development and reproductive health, including pre-term birth (WHO, 2013).

3.2.3 Nitrogen dioxide (NO_2)

Exposure to elevated concentrations of NO_2 has been linked to a range of respiratory symptoms including bronchoconstriction, increased bronchial reactivity, airway inflammation, and decreases in immune defence leading to increased susceptibility to respiratory infection (COMEAP, 2011). However, it is not clear to what extent the health effects observed in epidemiological studies are attributable to NO_2 itself, as opposed to other correlated pollutants. In controlled exposure studies where there has been exposure to lower levels of NO_2, health effects have been identified more consistently in asthmatics than in non-asthmatics. Chamber studies / epidemiological studies have suggested that NO_2 exposure enhances the response to allergens in those who are sensitised (COMEAP, 2011). In population studies concerning exposure to NO_2, adverse health effects have been identified even when the annual average NO_2 concentration complied with the WHO annual guideline value of 40 µg/m^3. NO_2 is an important constituent of combustion-generated air pollution, and is highly correlated with other primary and secondary combustion products. (COMEAP, 2011).

Evidence is available that shows the associations between short-term exposure to NO_2 concentration and mortality, hospital admissions and respiratory symptoms. Similarly, evidence is available to show the associations between long-term exposure and both mortality and morbidity. Studies in both cases found adverse effects at concentrations that were at, or even below, current EU limit values (WHO, 2013).

Mechanistic support for causal interpretation of the respiratory effects has been found from chamber and toxicological evidence. These studies support an update of the WHO air quality guidelines last published in 2005. It is possible that this would result in lower guideline values (WHO, 2013).

3.3 Putting a value on the health effects of air pollution

Human exposure to air pollution is central to the determination of its health impact, with the severity of this impact depending on the period of exposure, the level of exposure (in terms of concentration) and the number of people exposed. Therefore the health impact of air pollution will vary by location, and the impact on any given individual will vary by that individual's particular level of exposure. For example, some primary work by Kings College using personal air pollution exposure monitors showed that simply choosing cycling or walking routes that run along less-trafficked roads can significantly reduce one's exposure to air pollution.

A standard methodology to quantify the health impacts associated with changes in the emissions of air pollutants in the UK has been developed by Defra. This methodology captures the impact of air pollution on chronic mortality effects (quantifying the numbers of life-years lost over a hundred years per tonne of pollutant reduced); acute mortality effects (quantifying the numbers of deaths brought forward); and the morbidity effects (quantifying the number of hospital admissions saved per year, for both respiratory and cardiovascular illnesses, per tonne of pollutant reduced) – see Table 3.2. For particulate matter, these factors vary according to the source of emission, with for transport also varying by geographical location. For example, removing a tonne of PM_{10} from road transport in inner London would have a greater positive impact on respiratory admissions than removing a tonne of emissions from transport in a rural area, which reflects the overall level of human exposure to the pollution in these location types.

Table 3.2: Health impacts per tonne reduced

	Years of life lost over 100 years		Respiratory hospital admissions (annually)	Cardiovascular hospital admissions (annually)
	No lag[1]	40-year lag		
PM_{10} (transport)[2]	2.059	2.238	0.017	0.017
Central London	10.226	9.409	0.079	0.080
Inner London	10.517	9.677	0.082	0.082
Outer London	6.870	6.321	0.053	0.053
Inner conurbation	5.438	5.003	0.042	0.042
Outer conurbation	3.379	3.109	0.026	0.026
Urban big	4.028	3.706	0.031	0.031
Urban large	3.245	2.985	0.025	0.025
Urban medium	2.551	2.347	0.020	0.020
Urban small	1.611	1.482	0.013	0.013
Rural	0.694	0.638	0.005	0.005
PM_{10} (Power generation)	0.112	0.103	0.001	0.001
PM_{10} (Domestic)	1.298	1.194	0.010	0.010
PM_{10} (Agriculture)	0.448	0.412	0.003	0.003
PM_{10} (Waste)	0.962	0.885	0.007	0.007
PM_{10} (Industrial)	1.164	1.071	0.009	0.009
NO_x (nitrogen oxide)	0.082	0.089	0.001	0.001
SO_2 (sulphur dioxide)	0.121	0.132	0.001	0.001

Source: Defra (2011a)

Notes:

[1] A range of values is often given because assumptions are based on the lag time between exposure to air pollutants and health effects being realised – 'no lag' refers to the high end of the range, whereas '40–year lag' is at the low end of the range.

[2] Health impacts for PM are estimated at UK-wide level, with disaggregated damage costs split by National Transport Model area.

[3] PM_{10} = particulate matter of median diameter 10 micrometres or less: coarse particulate matter

Impacts can also be quantified in relation to the change (positive or negative) in concentration of the pollutant emissions. COMEAP (2013) has developed coefficients for short-term exposure to PM_{10}, NO_2 and ozone, and long-term exposure to $PM_{2.5}$, which are shown in Table 3.3. For example, when considering short-term exposure to PM_{10}, with each 10 μg/m^3 increase in PM_{10} concentration (24-hour mean) there is a 0.75% increase in deaths, whereas there is a 2.5% increase in respiratory hospital admissions per 50 μg/m^3 increase in NO_2 (24-hour mean).

Table 3.3: Quantifying the health effects of selected air pollutants – short and long-term exposure

Metric	Health endpoint	Coefficient	
Estimates of coefficients to quantify short-term exposure to particulate matter PM_{10}	Deaths, all causes	+0.75% per 10 µg/m^3 increase in pollutant concentration (24-hour mean)	
	Respiratory hospital admissions	+0.8% per 10 µg/m^3 increase in pollutant concentration (24-hour mean)	
	Cardiovascular hospital admissions	+0.8% per 10 µg/m^3 increase in pollutant concentration (24-hour mean)	
Estimates of coefficient to quantify the health effects of short-term exposure to NO_2	Respiratory hospital admissions	+2.5% per 50 µg/m^3 increase NO_2 24-hour mean	
Estimates of coefficients to quantify the health effects of short-term exposure to ozone	Deaths (all causes)	+ 3.0% per 50 µg/m^3 increase in ozone, 8-hour mean	
	Respiratory hospital admissions	+ 3.5% per 50 µg/m^3 increase in ozone, 8-hour mean	
Estimates of coefficients to quantify the health effects of short-term exposure to sulphur dioxide (SO_2)	Deaths (all causes)	+ 0.6% per 50 µg/m^3 increase in SO_2 24-hour mean	
	Respiratory hospital admissions	+0.5% per 10 µg/m^3 increase in SO_2 24-hour	
Estimates of coefficients to quantify long-term exposure to particulate matter $PM_{2.5}$	All-cause mortality	1.06 95% confidence interval 1.02–1.11 (per 10 µg/m^3 increase $PM_{2.5}$, annual average concentration)	For impact assessment of all-cause mortality and assessing policy interventions designed to reduce levels of air pollutants
		1.01 and 1.12 as the 12.5th and 87.5th percentiles of the probability distribution (per 10 µg/m^3 increase $PM_{2.5}$, annual average concentration)	For sensitivity analysis
		1.00 and 1.15 (per 10 µg/m^3 increase $PM_{2.5}$, annual average concentration)	For reports on quantification of risks from long-term exposure to particulate air pollution represented by $PM_{2.5}$
	Cardiorespiratory mortality	1.09 95% confidence interval 1.03–1.16 (per 10 µg/m^3 increase $PM_{2.5}$, annual average concentration)	
	Lung cancer mortality	1.08 95% confidence interval 1.01–1.16 (per 10 µg/m^3 increase $PM_{2.5}$, annual average concentration)	

Source: COMEAP (2013)

Note: PM_{10} = particulate matter of median diameter 10 micrometres or less: coarse particulate matter; $PM_{2.5}$ = particulate matter of median diameter 2.5 micrometres or less: fine particulate matter; NO_2 = nitrogen dioxide

The health impacts associated with air pollution are not included in the price of goods or services which create this pollution and are known in economics as external costs or 'externalities'. There are economic and social costs associated with these health impacts. Therefore, where improvements in air quality are achieved, health and environmental improvements are likely also to be realised, and these provide an economic and social benefit to society. For example, improved air quality can lead to a range of health benefits, including a reduction in the numbers of cases of respiratory hospital admissions from high-pollution episodes. This reduces health-care costs, lost time at work, and the pain and suffering of individuals.

The health benefits of reducing air pollution can be valued using economic evidence on resource savings, health valuations, productivity losses and similar metrics (Defra, 2009a). In impact assessments, this assigns a value to health impacts to represent the economic benefit not reflected in practice.

Advisory guidance has been developed by Defra (2009a, 2013c) on establishing general economic principles and economic appraisal methods in the valuation of the impacts of changes in air pollution (this was developed primarily for English local authorities carrying out their LAQM duties under Part IV of the Environment Act 1995).

As part of its guidance, summary values (known as 'damage costs') have been developed by Defra for use in appraisal processes where the impacts on air pollution are relatively small (defined as impact valued at less than £50 million). Damage costs provide the benefits of marginal air quality improvements in benefits (reckoned in £ per tonne of pollutant reduced). The damage costs value the health impact of a unit of air pollutant emission on mortality (both chronic and acute) and morbidity (hospital admissions). These unit values also value non-health impacts, such as damage to buildings and effects on crop yields.

Damage costs have been developed for PM_{10}, SO_2 (sulphur dioxide), NO_x and ammonia, with those for PM_{10} shown in Table 3.4. There are multiple damage cost values for PM, reflecting the sector and location of emissions, with the key difference between values relating to the level of human exposure. A number of assumptions have been made during the development of these damage costs; they are potentially better suited for national policies rather than local analysis, as values are based on national-level analysis/averages.

Table 3.4: Interdepartmental Group on Costs and Benefits air quality damage costs per tonne, 2010 prices

		Sensitivities	
	Central estimate[1]	Low central range[2]	High central range[2]
Nitrogen oxides	£955	£744	£1,085
Sulphur oxides	£1,633	£1,320	£1,856
Ammonia	£1,972	£1,538	£2,241
PM domestic	£28,140	£22,033	£31,978
PM agriculture	£9,703	£7,598	£11,027
PM waste	£20,862	£16,335	£23,708
PM industry	£25,229	£19,753	£28,669
PM power generation	£2,426	£1,900	£2,757
PM transport average	£48,517	£37,987	£55,133
PM transport urban large	£70,351	£55,081	£79,944
PM rural	£15,041	£11,776	£17,091

Source: Defra (2011a)

Notes:

[1] This estimate is intended for use only where a single-point estimate is necessary, and should always be accompanied by the central range.

[2] Variation between the central values reflects uncertainty about the lag between exposure and the associated health impact.

[3] PM = particulate matter

When using the damage cost values, it is important to note that some impacts of air pollution are not captured. Using the damage costs will therefore underestimate the total value of reducing air pollution. Where impacts are excluded, this is primarily due to quantification not being possible at this stage, or there being a high degree of uncertainty; nevertheless, these impacts could be significant. These unit values also err on the side of caution, as they take account of only the strongest health impact evidence; they could thus further underestimate the value of air pollutant impacts.

The impacts excluded from the current values of damage cost include:

- effects on ecosystems;
- impacts on productivity;
- impacts on buildings of cultural or historical importance;
- impacts of transboundary pollution;
- potential additional morbidity from acute exposure to PM;
- potential morbidity effects from chronic (long-term) exposure to PM or other pollutants;
- effects of exposure to ozone, including both health impacts and effects on materials;
- macroeconomic effects of reduced crop yield and damage to building materials; and
- non-ozone effects on agriculture.

When determining the air-quality-related health benefits of a policy (for which no valuation necessary), the following formula is used:

Total health impact = *sum of number of tonnes of pollutant reduced (across appraisal period)* × *health benefits per tonne*

Using this approach, it has been estimated that the annual economic costs associated with the impacts of air pollution in the UK lie between **£9 billion and £19 billion** (at 2008 prices) (Defra, 2010). This has been estimated using existing evidence to produce an indication of the overall health impact of air pollution. The dominant component contributing to the value is the effect of current levels of fine particles ($PM_{2.5}$) on life expectancy, as is reflected in the significantly higher damage cost shown in Table 3.4.

Table 3.5 shows the estimated value of the overall health impact from total or current projected levels of $PM_{2.5}$. A range in values has been given owing to different assumptions about the lag time between exposure and the health effects, ranging from no lag (leading to the figure for the high end of the range) to a 40-year lag (corresponding to the low end of the range). However, the economic impact of air pollution on health is likely to be at the higher end of the range, in other words assuming a shorter lag between the exposure to pollutants and health effects being realised. This estimate can also be considered conservative as it reflects only the long-term chronic impact on life expectancy from fine particles, and does not include a range of other health impacts such as acute mortality, morbidity and indirect health impacts (Defra, 2010).

Table 3.5: Estimated value of overall health impact from total current or projected levels of anthropogenic $PM_{2.5}$ (£ million per year)

	Monetised health impact	
Base year for prices	Main result (0.6%)	Central estimate*
Value in line with the Air Quality Strategy (2005 prices)	£7,710–£16,904	£14,876
Updated values (2008 prices)	£8,584–£18,913	£16,379

*The most appropriate way of describing these results is to give the full range and to explain that a noteworthy proportion of the effect is likely to occur towards the higher end of the range, based on a shorter lag. While it is possible to derive a single estimate by using a distribution of different lags skewed towards shorter lags, this requires further assumptions so cannot be taken to be more certain than the description given in the previous sentence. The underlying evidence is not clear and this uncertainty needs to be reflected in presenting the answer as a range.

Source: Defra (2010)

Although the values presented in Table 3.5 for the economic impacts of air pollution are related to anthropogenic sources of $PM_{2.5}$, they do not distinguish between the various sectors, so they cannot separate out transport's contribution to the health effects of air pollution. A study for the Cabinet Office (DfT, 2009b) calculated the costs of poor air quality associated with transport in English urban areas. Poor air quality costs were based on figures included in the 2007 Air Quality Strategy. They are therefore related to the health impacts of particulates only (as in the Defra 2010 study), and do not include any non-health impacts such as the degradation of the physical environment, losses of crops and the impact on ecosystems (e.g. acidification and eutrophication[3]). Costs associated with poor air quality due to transport in urban areas were estimated to stand at between **£4.5 billion and £10.6 billion per year** (at 2008 prices). Again, it is thought that the costs are likely to be at the higher end of the range presented.

3 Eutrophication is a process by which pollution from such sources as sewage effluent or leachate from fertilized fields causes a lake, pond, or fen to become overrich in organic and mineral nutrients, so that algae and cyanobacteria grow rapidly and deplete the oxygen supply.

Similar assessments have been carried out at the European level, and it has been estimated that across the EU the economic cost of air pollution ranges between **€330 billion and €940 billion per year** (valued in 2010 prices). This estimate includes impacts on health and other direct economic damages, but also includes a valuation of impacts not captured in the Defra approach (and hence in their valuation of the damages of particulates described above), such as labour productivity losses (European Commission, 2013).

This data on damage costs can be used to assess the air quality impacts and benefits of transport schemes both locally and nationally. However, it must be noted that these valuation methodologies lag behind the latest health evidence, as they are not continually updated. Therefore the values currently used by the Defra valuation framework could be an underestimate.

3.4 Relation to other impacts

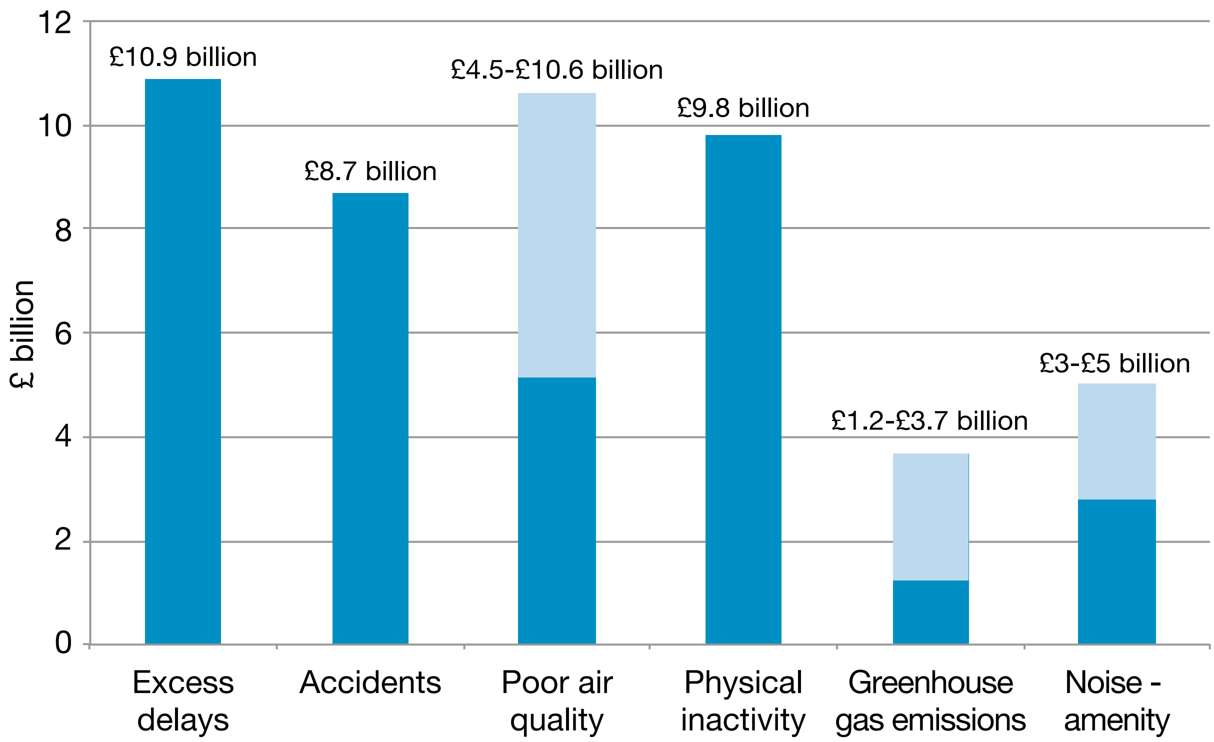
There is clear evidence of a relationship between traffic-related air pollution and health impacts, arising from both the levels of emissions related to traffic and the human exposure at roadside locations (HEI, 2010). These health impacts can also lead to significant economic costs, as described above. However, it is interesting to compare these costs with other wider impacts of transport, particularly when considering prioritising policy actions.

Widely quoted figures for the costs associated with these other transport impacts come from a study by the Cabinet Office (DfT, 2009b). The study focused on the wider costs of transport in English urban areas of population 10,000 or greater (restricted to surface modes, including walking, cycling, car (whether as driver or passenger), bus, goods vehicles, train, light rail and underground), including those costs associated with congestion, poor air quality, accidents, CO_2 emissions from transport activity in urban areas, and transport-related noise (the nuisance cost). The study did not consider or include the direct costs of transport in urban areas, which typically include infrastructure costs (e.g. the cost of building and maintenance of road and rail links) and operating costs (e.g. the cost of fuel).

The results showed that the greatest costs were associated with excess delays (caused by congestion) at £10.9 billion. This was closely followed by poor air quality (ranging from £4.5 billion to £10.6 billion) and physical inactivity (at £9.8 billion) – see Figure 3.1. Greenhouse gas (GHG) emissions have been estimated at between £1.2 billion and £3.7 billion, whereas noise is valued at £3 billion to £5 billion.

It is important to note that the authors are of the opinion that if the same analysis were to have been undertaken a year later, GHG would be relatively more important and poor air quality relatively less important, as a result of tighter vehicle emission standards brought in to reduce air pollution. It is also worth noting that costs such as congestion are internalised to the user, whereas costs such as poor air quality are external and affect the wider public. These externalities are, it should be noted, not directly taken into account when making travel choices.

Figure 3.1: Comparison of the wider cost of transport in English urban areas (£ billion per year, 2009 prices and values)



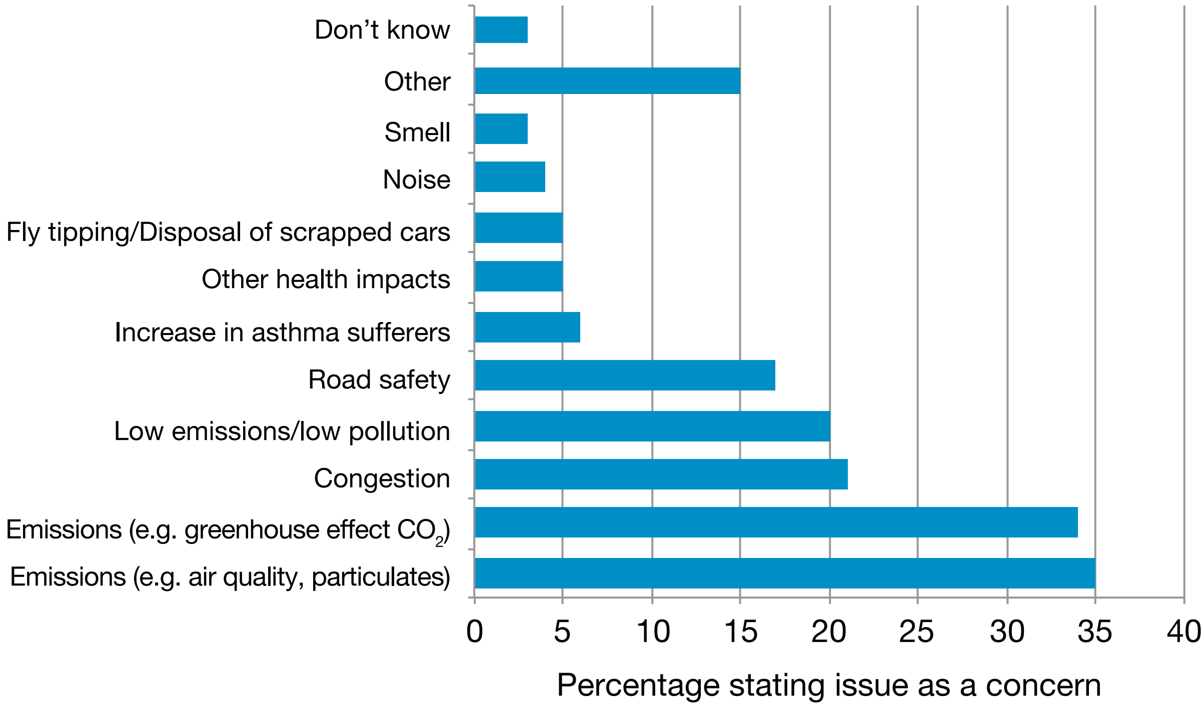
Source: DfT (2009b)

3.5 Perceptions of transport and urban air pollution

Various studies, including those undertaken by the Department for Transport (DfT), Defra and the European Commission, have attempted to explore the public's perceptions of the impacts of transport, or transport-related impacts compared with other issues of concern to the general public. The results of these studies help us to understand how much of a priority air pollution and health is, in the view of the public, compared with other concerns that local, national and international bodies can influence.

A survey asking drivers which impacts of driving a car concerned them the most reported that the issue of greatest concern to drivers was air pollution emissions (35%). This was followed by GHG emissions (34%) and congestion (20%) (see Figure 3.2) (DfT, 2004).

Figure 3.2: Which, if any, of the impacts of driving a car concern you the most?

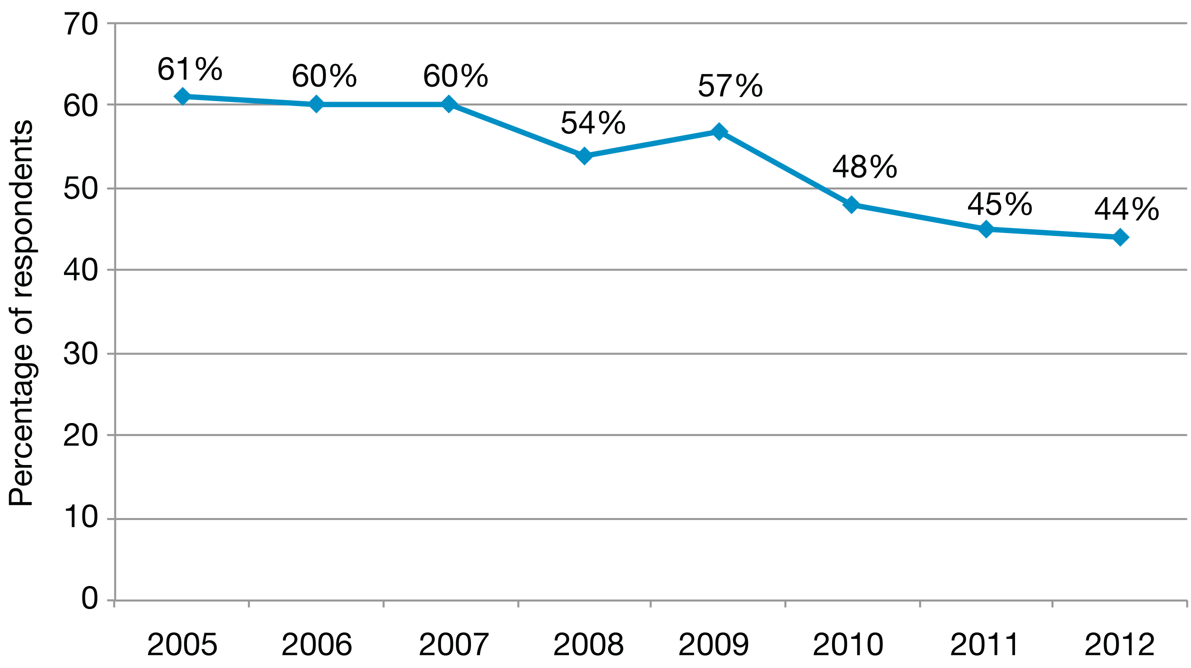


*Base – all those who bought a car registered post-March 2001 and/or planning to buy a car in the following 12 months

Source: DfT (2004)

A more recent piece of research undertaken by NatCen Social Research for DfT (DfT, 2013) looked at attitudes towards vehicle exhaust fumes in towns and cities (Figure 3.3). In 2012, 44% of respondents stated that exhaust fumes in towns and cities were a problem (“serious” or “very serious”). This had decreased from 45% in 2011, but was also the lowest level of concern since the question was introduced in 1997, where the figure was 77% of respondents (DfT, 2013).

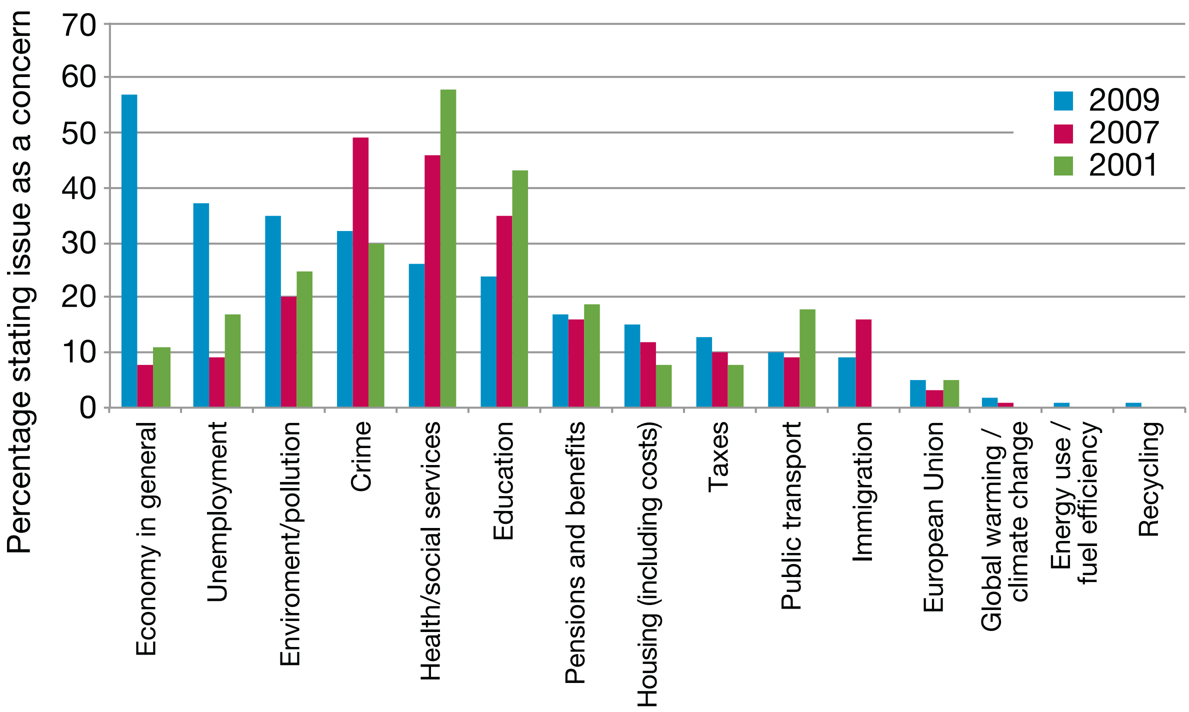
Figure 3.3: Attitudes towards exhaust fumes in towns and cities as a serious or very serious problem – 2005–2012



Source: DfT (2013)

In Defra’s survey of public attitudes and behaviours towards the environment (2009), respondents were asked which issues the government should be dealing with. In the most recent version of the survey (2009b), as shown in Figure 3.4, the areas of most concern were the economy in general (57%), unemployment (37%) and environment/pollution (35%). Environment/ pollution has been in the top four answers in at least the last three surveys, with 25% in 2001, 19% in 2007, and its highest level of concern in 2009, at 35%. Crime, health and social services, and education were all issues that were rated of higher concern than environment/pollution in the previous two surveys. However, these issues have moved into lower positions, with concern for the economy and employment rising significantly following the economic crisis of 2008 onwards.

Figure 3.4: Issues that the government should be dealing with

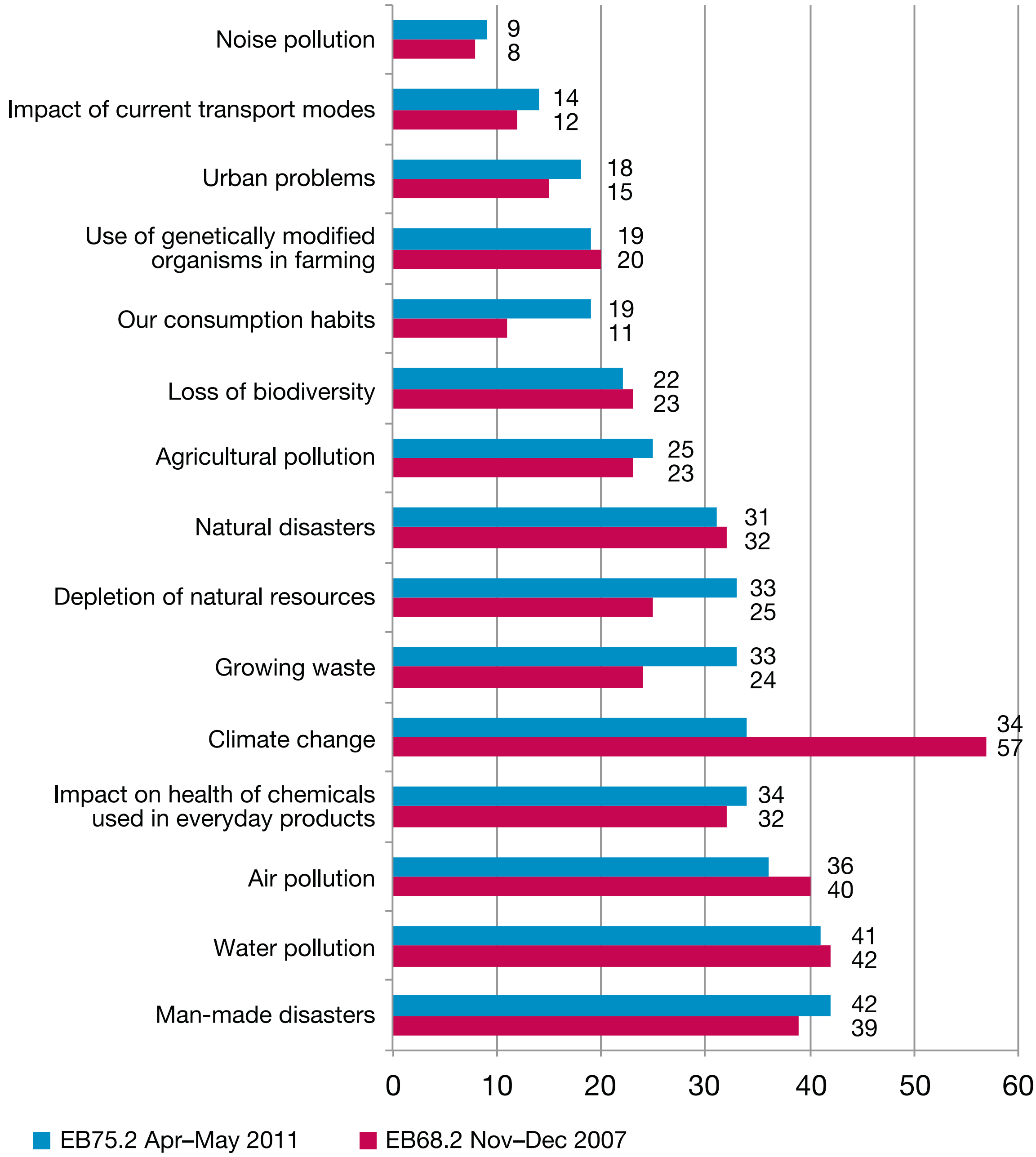


Source: Defra (2009b)

Note: Figures do not match sum of total mentions as respondents were able to give more than one response.

A Eurobarometer study (European Commission, 2011a) asked what were the five environmental issues respondents were most worried about (the survey was conducted among the EU-27 member states). In 2011, the top answers (see Figure 3.5) included man-made disasters (42%), water pollution (41%), air pollution (36%), the impact on health of chemicals used in everyday products (34%) and climate change (34%). Air pollution was previously third in 2007, but was mentioned by 40% of respondents, indicating a decline in concern since then. 'Urban problems' (traffic jams, pollution, lack of green space), 'impact of current transport modes' (more cars, more motorways, more air traffic, etc.) and 'noise' were all at the bottom of the list of concerns (at 18%, 14% and 9% respectively in 2011).

Figure 3.5: Main environmental issues that respondents are worried about, 2007/2011 (maximum of five answers allowed)



Source: European Commission (2011a)

In the surveys available, air pollution/environment has been identified by respondents as an issue of concern, often within the top three responses. A recent Eurobarometer study (European Commission, 2013) looked specifically at attitudes to air quality. Some of the key findings of this survey included:

- 87% felt that respiratory diseases and asthma are a serious problem;
- 56% think that air quality has got worse in the last ten years;

- the principal sources of pollution were identified as transport (96%) and industry (92%);
- using public transport, cycling and walking was considered by 63% to be actions that will help reduce emissions;
- electric cars where considered to be the most environmental friendly vehicle type (71%), followed by hybrid cars (39%); and
- 72% think that public authorities are not doing enough to promote good air quality.

3.6 Health policy and the new air quality health indicator

As outlined above, there is compelling evidence of the negative impact of poor air quality on human health. To bring this issue into government policy, a new air quality indicator was included in the Public Health Outcomes Framework (PHOF). This framework has been introduced with the vision to "improve and protect the nation's health and wellbeing, and improve the health of the poorest fastest." It focuses on two high-level outcomes:

- increased healthy life expectancy (taking account of the health quality as well as the length of life); and
- reduced differences in life expectancy and health life expectancy between communities (through greater improvements in more disadvantaged communities).

A supporting set of 66 public health indicators have been developed. The indicators are grouped into four domains:

- improving the wider determinants of health;
- health improvement;
- health protection; and
- health care, public health and preventing premature mortality.

Councils and government will be able to see the improvements that are being made, and therefore take any action if needed. The selected indicators will help to focus understanding of progress year by year, both nationally and locally, on what matters for public health.

Because of the significant public health impact of particulate air pollution, the framework includes an indicator on air pollution:

"Fraction of mortality attributable to particulate air pollution (proportion, %)" (DoH 2013).

The baseline data for 2010 for each of the upper-tier local authorities in England was calculated on the basis of modelled concentrations of $PM_{2.5}$. The results ranged from 4% in rural areas to over 8% in cities. In England in 2010, 5.60% of mortality was attributable to particulate air pollution. This percentage decreased to 5.36% in 2011.

In conjunction with the introduction of an air quality health indicator, public health became the responsibility of local authorities under the Health and Social Care Act 2012 (Great Britain, 2012). The health impacts of poor air quality and of exposure to airborne particulate matter can be significant, as discussed above; as a consequence, local authority environmental health departments have a statutory duty to provide publicly accessible information on air quality and its health impacts, and – if necessary – to react to mitigate public risk.

Each local authority with new public health responsibilities is required to employ a Director of Public Health (DPH). DPHs are responsible for exercising the local authorities' new public health functions, and they lead on driving health locally. Health and Wellbeing Boards (HWBs) are statutory bodies that have been set up to increase the influence of local people. DPHs are required to be active members of these boards. The aim of the HWBs is to promote and improve integrated working between local health care, social care, public health and other public service practitioners. They are also locally responsible for reducing health inequalities.

It is anticipated that the air pollution indicator is likely to be of real value in promoting air quality at the local level, and will support local authority action to improve air quality and public health. The DPHs will be able to prioritise action on air quality in their local areas to help reduce the health burden from air pollution.

3.7 Summary

There is clear evidence that there is a causal relationship between exposure to traffic-related air pollution and health impacts such as exacerbation of asthma, non-asthma respiratory symptoms, impaired lung function and cardiovascular mortality and morbidity. Overall, the strongest evidence for the most problematic pollutants in terms of human health is for particulate matter, especially $PM_{2.5}$ and O_3. NO_2 is also a key concern because of both its direct health effects and also because it is a precursor to ozone formation.

Across Europe an estimated 20–30% of the urban population are exposed to $PM_{2.5}$ levels above EU reference values, and 91–96% are exposed to levels above the more stringent WHO guidelines. In the UK, the burden of particulate air pollution in 2008 has been estimated to be equivalent to nearly 29,000 premature deaths (at typical ages of death) in 2008, and to an associated loss of population life of 340,000 life-years.

It has been calculated that if all anthropogenic $PM_{2.5}$ air pollution was removed, approximately 36.52 million life-years over the next hundred years could be saved in the UK. In addition, this elimination would be associated with an increase in UK life expectancy from birth (i.e. on average across new births) of six months. To put it into context, a study by Miller and Hurley (2006) estimated that removing all fine particulate air pollution would have a bigger impact on life expectancy in England and Wales than eliminating passive smoking or all road traffic accidents.

Air pollution is therefore a major public health concern and can be valued in terms of an economic cost. Across the EU, the economic cost of air pollution has been estimated to range between €330 billion and €940 billion per year in 2010, taking into account labour productivity losses and other direct economic damages. Similarly, in the UK the health impact of poor air quality has been calculated to cost between £9 billion and £19 billion per year (Defra, 2010). The transport contribution to this figure has been estimated at between £4.5 billion and £10.6 billion (at 2009 prices), in other words approximately half of the total.

In relation to other impacts of transport, air pollution ranks alongside excess delays, physical inactivity and accidents in terms of scale. Nevertheless, public concern in relation to transport air pollution seems to be waning, although this could be a consequence of heightened concern for the economic factors and cost of living following the recession that began in 2008.

Owing to its significant health impacts, air pollution – specifically $PM_{2.5}$ pollution – has been included as an indicator in the PHOF to be delivered by local authorities. This focus on PM in the PHOF contrasts with the focus on NO_2 compliance within the LAQM framework, though it should be noted that many transport measures to reduce emissions will improve both PM and NO_2.

4. Exploring the Solutions

Significant reduction in transport emission will be needed if air quality in the UK's towns and cities is to be improved. Transport activity and its associated emissions are driven by a wide range of needs and behaviours. The challenge is that many of these attitudes and habits are very deep-rooted and can be hard to change, which means that significant and comprehensive packages of measures will be needed to make a difference in order to reduce emissions and improve air quality. To support such an integrated approach, the wider benefits of a more sustainable approach to transport need to be promoted, which will include effects in the spheres of air quality, climate change, health, noise, congestion and economic development.

4.1 A framework to manage emissions and air quality

If transport is to remain effective and sustainable, there are a number of transport impacts – including air pollution, carbon emissions, congestion and accidents – that need to be managed. It is now generally accepted that a demand-side-focused approach is needed to reduce these impacts of transport and develop a more sustainable transport system. A commonly used framework is the three-pillar system known as Avoid-Shift-Improve (Dalkmann & Brannigan, 2007; UNEP, 2013):

- **Avoid** the need to travel to access goods and services, through efficient urban planning, communication technology, consolidation activities and demand management.
- **Shift** people and goods that need to be moved towards more inherently sustainable modes such as walking, cycling, public transport, rail and (where appropriate) water transport.
- **Improve** the environmental performance of vehicles by the adoption of low-emission vehicle technologies and more efficient operation of vehicles.

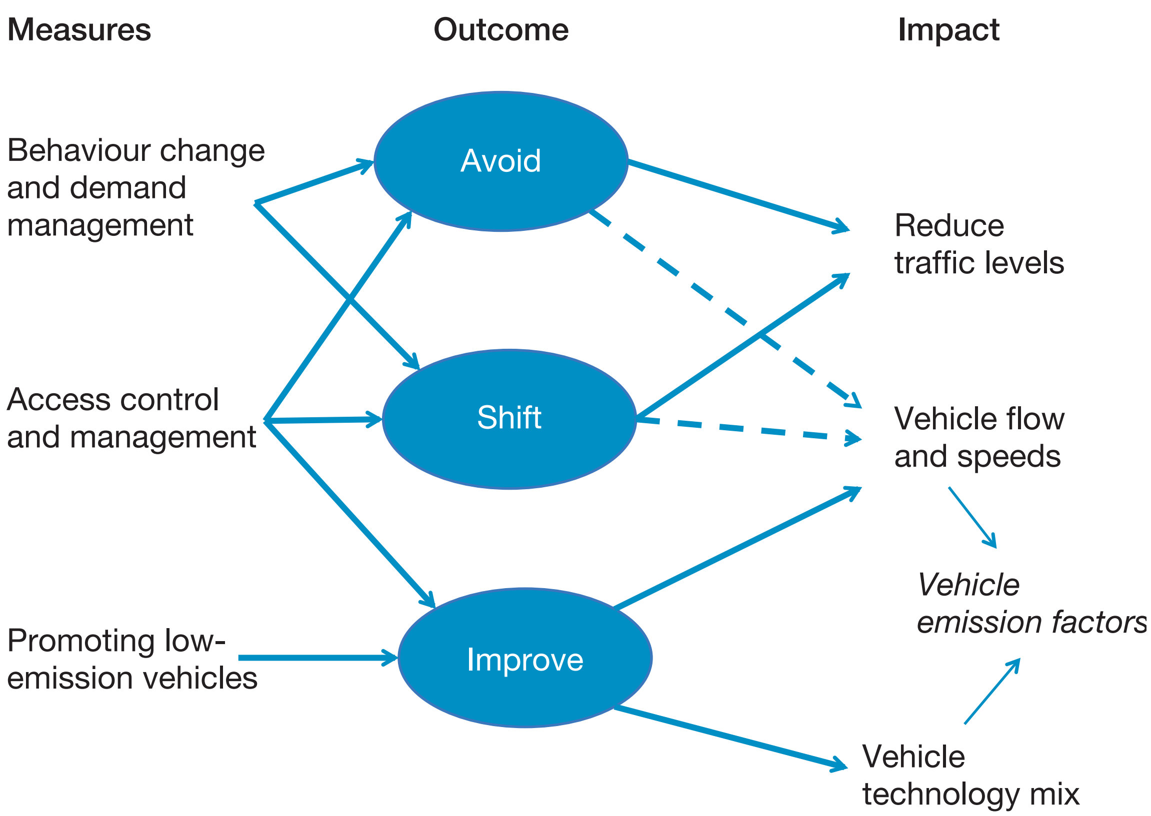
Many of the measures that can be considered under this framework are not specifically focused on reducing air pollution, but will nevertheless have an impact on air pollution, and so provide a useful framework for looking at solutions. This is illustrated in Figure 4.1, where Avoid-Shift-Improve will be the *outcomes* of a range of transport *measures*, and this will *impact* on transport emissions and air quality in the following three ways:

- *Reducing traffic levels* – for all, or at least certain, vehicle types will be the main impact of 'avoid' and 'shift' outcomes, whether it is from reducing overall travel or restricting certain types of vehicles. Fewer vehicles will then produce proportionally fewer emissions, and hence lower air pollution concentrations.
- *Improve vehicle flow* – through affecting vehicle speed, congestion levels and so on, to reduce the direct emissions from a vehicle. 'Avoid' and 'shift'

outcomes will help reduce congestion by reducing traffic volumes. Direct measures, such as traffic management and improving driver behaviour, can further reduce total vehicle emissions.

- *Improve vehicle technology* – by promoting low-emission vehicles, or restricting more polluting vehicles, will improve the overall emission performance of the vehicle fleet.

Figure 4.1: A framework to manage transport emissions and air quality



Source: Authors' own

Any particular transport measure may have one or more outcomes, for example a behaviour change campaign may both avoid trips and shift trips. This in turn will have an impact by reducing traffic levels and congestion, and so reducing vehicle emissions. In considering measures there are perhaps three broad categories into which they fall:

- *Behaviour change and demand management* – make up a wide range of measures aimed at reducing trips and mode shift. It covers land-use planning, behaviour change campaigns, infrastructure investment and pricing measures.
- *Access control and management* – covers the more traditional measures such as vehicle restricted areas, traffic management and fleet management.

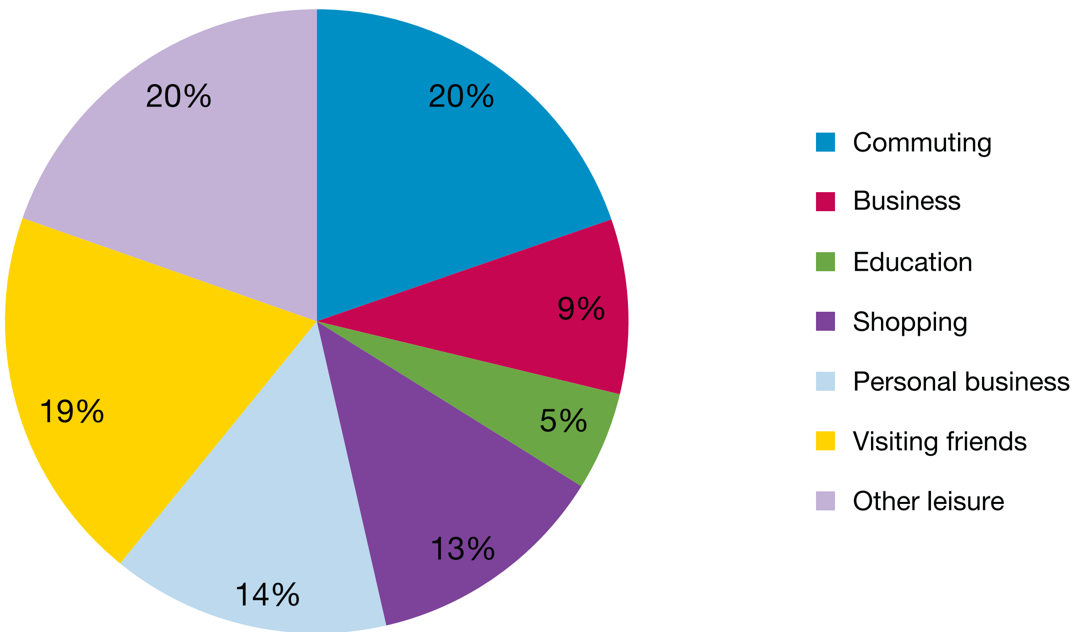
- *Promoting low-emission vehicles* – can be done through a number of mechanisms such as planning, procurement and partnership work, as well as direct access control.

Each of these groups of measures is explored below, alongside a consideration of what outcomes and impacts they may have, and also what policy instruments are available to implement them, and the potential costs of doing so. However, it has to be noted that many are not focused specifically on reducing air pollution, but rather have a range of impacts. In many cases their specific impact on air pollution has not been directly considered. Moreover, as discussed above in Section 2, the nature of an air pollution problem can be very local and specific. Therefore, any given package of measures will need to reflect this local situation if it is to provide an effective solution. Similarly, the impact and potential cost of measures will relate to the local context. There will be common themes that can be drawn out, and these will drive wider policy measures at both national and European level.

4.2 Demand management and behaviour change

When considering solutions aimed at reducing the environmental impacts of transport, it is important first to appreciate what drives transport demand. Very few journeys are made for the sake of the journey alone – even most leisure trips are made in order to visit a specific destination. To illustrate this, Figure 4.2 shows the split of average personal travel by trip purpose.

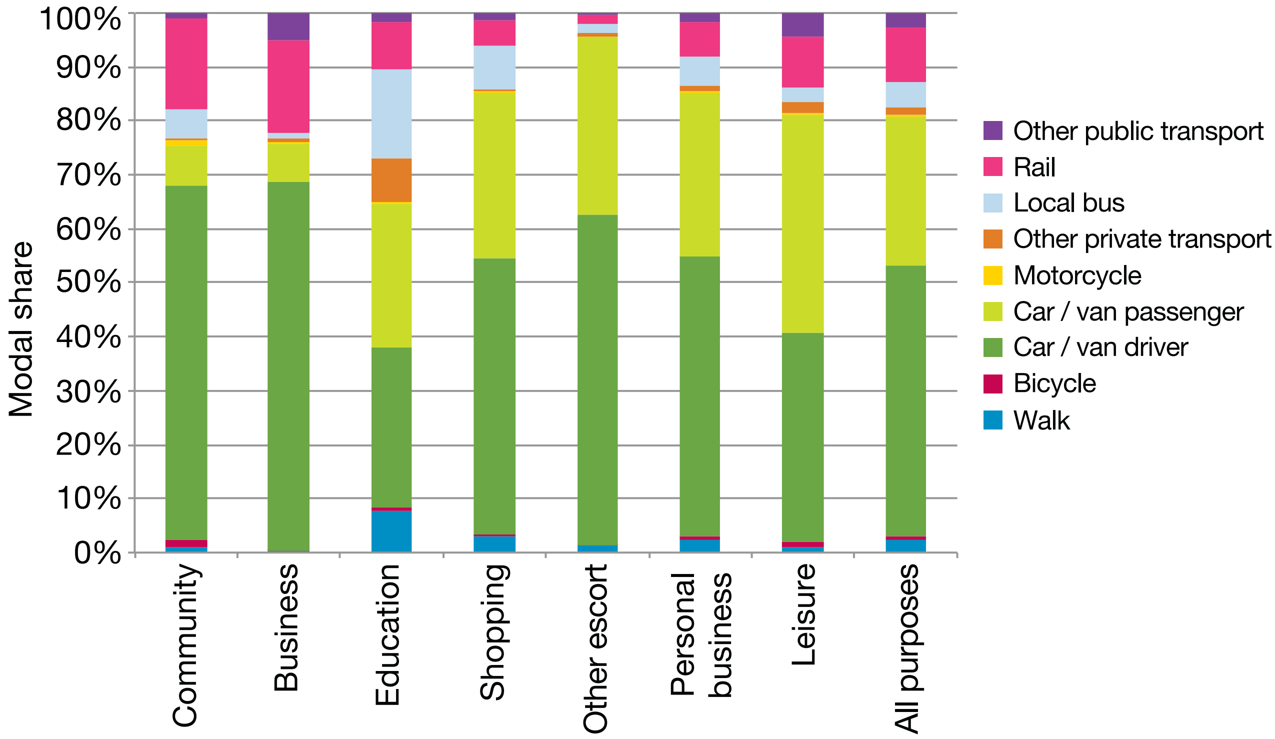
Figure 4.2: Share of personal travel by trip purpose



Source: National Travel Survey (2012)

The length of these journeys, and the type of transport that is used to undertake them, are strongly influenced by land-use and spatial planning policies. For passenger transport in most UK urban locations, and even more so in rural ones, private car use is the most common choice, as illustrated in Figure 4.3. Factors such as the proximity of public transport facilities, and the relative convenience and perceived safety or otherwise of cycling and walking, will determine whether these modes are chosen in preference to the car (for those who have access to one).

Figure 4.3: Mode share by trip purpose



Source: National Travel Survey (2012)

4.2.1 Land-use planning and development control

Land-use and spatial planning policy can be used to control patterns of land use, which in turn determine demand for transport. If land-use planning is to be employed to minimise the environmental impacts of transport, including air pollution, then it must be done in such a way that patterns of land use are created which reduce trip lengths and encourage journeys to be made by the most sustainable modes. Reducing the need for motorised traffic in turn reduces air pollution and noise, benefiting health (Frank et al., 2006).

One overarching principle that has been identified as helping to achieve this aim is *increased density* or the *'proximity principle'* (CPRE, 2008). This is based on the idea that "compact cities, towns and villages produce the best social, economic and environmental outcomes." The main aim is to increase density, usually measured in dwellings per hectare. There has been much work on density and its relationship to sustainability (Newman & Kenworthy, 1989a, 1989b). For transport, this suggests the following three key outcomes of increasing density (CfIT, 2009):

- Transport energy consumption and CO_2 emissions are generally lower at higher densities. By implication, this should also result in reduced air pollution.
- Convenient, efficient and affordable public transport provision becomes more viable.
- Car use is generally reduced, in terms of both the car's modal share and distance travelled.

In addition to this there are a number of other considerations which should be taken into account if planning policy is to minimise transport impacts:

1. **Settlement size:** In general, larger settlements can offer their residents a greater range of opportunities within the built-up area, reducing the need for inter-urban travel. They can offer a wider mix of shops, services and employment than would be the case in a smaller settlement, and can support the development of better public transport with which to access them.
2. **Strategic development location:** When a major new residential/non-residential (employment, leisure and retail) development is being planned, it should be located in such a way as to minimise travel distances. Ideally it should be located within an existing urban area. The choice of location should also consider existing AQMAs, and reducing exposure to air pollution.
3. **Strategic transport network:** This refers to the need for transport infrastructure which supports medium- and long-distance travel along major corridors in urban areas. The network needs to consider all modes of travel and integrate them. A particular aim should be to create development patterns which support public transport usage by locating close to public transport nodes which have sufficient capacity.
4. **Mixed land use:** By ensuring that there is an appropriate mix of jobs and housing as well as a good range of local facilities in close proximity to households, journey lengths can be minimised. Mixed-use areas typically have 5–15% less vehicle travel going on within them; however, location of retail facilities close to residential areas can result in problems such as noise from delivery vehicles.
5. **Urban realm design and street layout:** Creating a high-quality urban realm with safe, convenient and direct routes for walking and cycling can also help to reduce car use for short journeys (up to one or two miles in length).

Consideration of the requirements for both passenger and freight transport is crucial to successful urban planning and the avoidance of potential conflicts.

Moving towards more city-centre shopping and living may help to reduce passenger transport demand, but can cause inefficiencies in freight transport (Dablanc, 2011). Centres with a greater range of small independent shops and businesses may be harder to service than those with fewer larger businesses. Planners and transport departments must work with businesses to ensure that deliveries are managed efficiently. Separation of planning and transport functions within local authorities can be a key barrier here.

4.2.2 Information and behaviour change

Achieving travel behaviour change can be an effective strategy to manage transport demand, and so reduce negative environmental impacts. Behaviour change measures such as providing information on alternative ways of travelling, or encouraging lift sharing, can be implemented relatively quickly compared to provision of transport infrastructure or the development and introduction of cleaner vehicles, and in many cases can be a more cost-effective approach.

A key demonstration and evaluation of these techniques was carried out in three Sustainable Travel Towns: Darlington, Peterborough and Worcester. The evaluation of the Sustainable Travel Towns suggested that travel behaviours were shifting towards more sustainable modes by the end of the project period (Sloman et al., 2010). Across the three towns, the following outcomes were observed from the household survey or traffic counts:

- there was a reduction in the number of car driver trips (down by 8%) and car driver distance (down by 5–7%) per resident;
- the overall reduction in traffic was around 2%, and 8% in inner areas;
- bus and other public transport trips per resident increased in two out of the three towns, and by 14% overall;
- cycle trips per resident increased by 26% overall; and
- walking trips per resident increased by 13% across the towns.

The estimated cost of the ‘smarter choices’ work in these three towns was 4p per car-kilometre removed. When considering only the congestion benefits of this mode shift, the benefit:cost ratio of these measures is in the order of 4.5.

However, there can be significant barriers to influencing travel choices and behaviours. Many of the journeys that are made are habitual, and the way in which they are made is firmly integrated into people’s daily routines. These choices can also be influenced by values and aspirations (Goodwin & Lyons, 2010). Over 80% of journeys are under ten miles long – daily commuting, shopping trips, taking children to school and the like. People typically do not consider what alternatives exist each time they make such journeys.

For this reason, behaviour change measures are often most effective when targeted at certain ‘life change’ events, for example when changing job, moving house or starting a family (Defra, 2011b). Often these events can lead to reduced levels of physical activity (Allender et al., 2008), but by providing information and in some cases incentives, people can be encouraged to take up alternatives to private car use such as walking, cycling and public transport.

Simple approaches can be employed, such as providing maps showing safe and pleasant routes for cyclists and pedestrians, or disseminating information on the times and routes of local bus services; however, simply making information available is often not enough to prompt a change in behaviour. Personalised travel planning (PTP) involves households and workplaces being visited in person by 'travel advisors'. Specific journeys are then reviewed and, where possible, more sustainable alternative options identified. The PTP approach has been shown to typically reduce car trips by 11% (DfT, 2008). It can also result in walking, cycling and public transport use increasing by 15–33% (Sustrans, 2013).

However, while many people in the UK are positive about wanting to walk and cycle more, detailed research suggests that there are three main barriers preventing this (Pooley et al., 2011):

1. concerns about the physical environment, especially with respect to safety;
2. the difficulty of fitting walking and cycling into complex household routines (especially with young children); and
3. the perception that walking and cycling are in some ways abnormal things to do.

As a result, policy recommendations extend beyond focusing merely on improving infrastructure, to also include tackle broader social, economic, cultural and legal issues. The recommended aim is to make walking and cycling seem the normal choice, and choosing to drive for short journeys seem abnormal.

The specific health and air quality benefits of such travel behaviour programmes can be promoted alongside the transport and congestion benefits. A particular example is the 'active travel' concept, which encourages people to incorporate physical activity into their daily lives, and is emphasised in the Department of Health's Public Health White Paper. The public health benefits of increasing cycling are considerable – evaluation of DfT's Cycling Demonstration Towns initiative shows these to outweigh the costs of the programme by three times (Sloman et al., 2010).

A number of authorities are also linking travel behaviour change and air quality directly. For example, the 'Go Easy' for Kendal project is a marketing and media campaign which has been developed to influence travel behaviour in order to reduce NO_2 levels within the town. Its aim is to promote alternatives to car travel by encouraging residents to consider dropping 'one in ten' of their car journeys through and into town, both now and into the future.

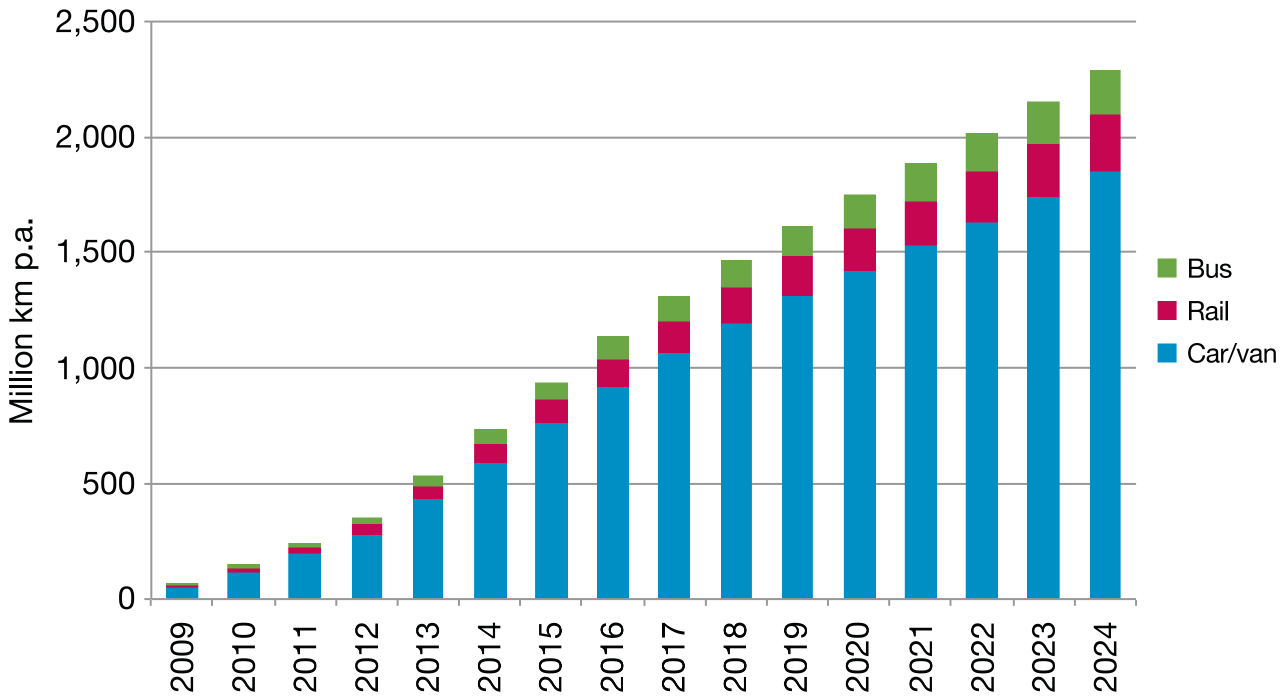
4.2.3 Communication technology and travel behaviour

The rapid growth and improvement of information networks is making audio and video conferencing, home and flexible working, and e-commerce solutions accessible to a much wider range of people. Superfast broadband is now accessible from 65% of premises, and the government's stated aim is to increase this proportion to 90%, while also ensuring universal access to standard broadband (DCMS, 2013).

The number of people working from home in the UK is estimated to have risen by 13% between 2008 and 2013, with just over 4.5 million employees usually working from home in 2012, and many more occasionally doing so (Work Wise UK, 2013). However, government figures are reported to show 4.5 million people would still like to work from home more often. Avoiding commuter travel can often be financially beneficial, as well as enabling people to combine work with caring commitments. Although there is evidence that homeworkers may make additional trips during the day, and that working at home results in increased energy use and emissions for example through additional home heating, most studies suggest that the number of trips and overall distances travelled are less for home-based teleworkers (Corpuz, 2011).

The *UK Broadband Impact Study* commissioned by the Department for Culture Media & Sport estimates that faster broadband will result in a reduction in annual commuting distances by car, van, rail and bus of about 2.3 billion kilometres by 2024 (about 2% of the current annual total) – see Figure 4.4 (SQW, 2013).

Figure 4.4: Net annual commuting distance saved, attributable to faster broadband speeds since 2008



Businesses utilising audio and video conferencing are reported to reduce their business travel by 10–30%, as well as saving significant travel costs and staff time (Cairns, 2009). The *UK Broadband Impact Study* estimates savings in business travel of 5.3 billion kilometres (around 9% of the current annual total) by 2024 as a result of faster broadband.

Growth in online shopping has coincided with a 12% reduction in the number of shopping trips per person per year between 2002 and 2012 (SQW, 2013). However, conversely there has also been a growth in van traffic over this period.

There remain arguments about whether growing use of such ICT can be linked directly to reductions in travel, with some analysts pointing out that societies with growing use of ICT often exhibit growth in travel as well. However, it is clear that in a situation in which there is a desire to reduce the environmental impacts of travel, ICT can provide other solutions to enable people to continue to meet their needs while reducing the amount of travel required.

Provision of information through ICT can also encourage greater public transport use. Multimodal journey planning websites and apps can make it easier to find alternatives to private car use. In addition, real-time travel updates can help give travellers a greater sense of control and confidence. Smart ticketing systems can also assist in making multimodal journeys more seamless and integrated, as well as reducing lost revenue for public transport operators. The introduction of the Oyster card in London is reported to have reduced fare evasion on the underground from 17% to less than 3%.

4.2.4 Driver behaviour and fleet management

Driver behaviour can be the single largest determinant of the emissions and fuel consumption of a vehicle. Most drivers can improve their fuel consumption by up to 15% when taught 'eco-driving' techniques (EST, 2013). However, research indicates that fuel savings may decline in the longer term, with one study reporting that initial average fuel savings of 10% had fallen to 3% only one year after training (TNO, 2006). Nevertheless, the same study reported that in combination with gear shift indicators (which show a driver when it is most economical to change up a gear), eco-driver training can result in over 4% fuel savings even in the long term. Overall it is likely the eco-driving will generate fuel and associated CO_2 savings of between 5% and 10% (Wengraf, 2012)

Eco-driving techniques have been included as part of the UK driving test since 2008, although not as a pass/fail criteria. They are also available as part of the Certificate of Professional Competence (CPC) training for professional drivers (covering HGVs, commercial passenger vehicles and taxis). However, DfT decided not to make eco-driver training a compulsory requirement for the CPC following strong industry opposition.

Eco-driver training encourages gentle acceleration and leaving a larger gap behind the vehicle ahead, reducing the need for braking. NO_x and particulate emissions are associated with higher engine speeds and loads, so avoiding harsh acceleration can reduce both of these air pollutants. Reducing brake use can also reduce particulate emissions from brake friction materials.

As well as saving fuel costs by ensuring that all drivers receive eco-driver training, fleet managers can also fit equipment to vehicles to improve fuel consumption and reduce emissions. Speed limiters can be used to restrict maximum speeds to the legal limit of 70 mph. Engine rev limiters can be more effective, as they promote more efficient driving styles. The limiter can be set at the point of maximum torque to ensure that vehicle performance is not compromised. As well as reduced fuel consumption and emissions, the benefits to fleet operators can include reduced engine, gearbox and clutch wear and damage.

4.2.5 Managing freight demand and supply

Improved freight logistics to reduce the overall numbers of freight journeys can give further air quality benefits, with heavy-duty diesel vehicles being a significant source of emissions in many cities. A study of UK urban freight data (Allen & Browne, 2010) provided information on loading factors, showing that they ranged from 40% for local deliveries to 70% for primary inbound deliveries. This suggests there is scope for greater consolidation of urban freight activity, particularly for deliveries to small retail or catering businesses, which often have inefficient delivery patterns (MDS Transmodal Limited & Centro di Ricerca per il Trasporto e la Logistica, 2012).

One route to reducing freight movements is to manage demand through the use of a planned approach to organising deliveries to a single business or area. Transport for London (TfL) has developed this approach with delivery and servicing plans, which have reduced the number of deliveries by about 20% (TfL, 2009).

Managing the supply of freight into urban areas is a possibility, thanks to the concept of 'urban consolidation centres'. These consolidation centres allow goods for various different businesses to be combined on the urban periphery for onward delivery into the urban centre. These consolidated deliveries can achieve much higher loading factors, reducing the number of trips required. Examples in Bristol and Heathrow have shown trip reductions of 60–75% (Scott Wilson Ltd, 2010).

The air quality benefits of such consolidation can be improved if consolidation centre operators use the latest low-emission delivery vehicles. The introduction of consolidation centres can be supported by providing additional benefits for consolidation centre vehicles, such as use of bus lanes or exemptions from access restrictions. An example of this is Cargohopper in Utrecht, which is an electrically powered goods vehicle delivering light-weight ambient retail goods and parcels into the historic centre of Utrecht from a transfer site close to the city centre.

4.2.6 Shared modes and new mobility services

There are a growing number of transport modes which sit somewhere between public transport and private vehicle ownership. In many cases they can combine the best of both worlds, and can be integrated to improve efficiency and complement existing traditional public transport (Schipple & Puhe, 2012).

Public bicycle or bike-share schemes

The concept of public bicycles has seen strong growth in recent years, and there are now almost 670 cities worldwide with a bike-share scheme (Gauthier et al., 2013). The schemes allow a person to remove a bicycle from a range of purpose-built docking stations, use it for a journey, and then return it to the same or another docking station. Such schemes provide a very visible signal of support for cycling from transport authorities and can help encourage a cycling culture. They also address three potential barriers to cycling: theft; home storage; maintenance.

In a survey of the Vélib' bike-share scheme in Paris, 46% of users reported lower private car use; 27% of long-term subscribers used the bicycles for commuter trips, 13% for business trips, and 28% used Vélib' to start or finish a public transport journey (Beroud et al., 2010). However, bike-share trips often replace public transport use far more than any other mode, with one report finding that only 7–13% of trips replaced car, motorbike or taxi trips (CSD, 2011). Results from the first year of operation of the Barclays Cycle Hire scheme in London (2010) showed that two thirds of trips replaced travel by car, taxi or public transport (TfL, 2010).

Car clubs

In a car-club scheme (also referred to as car sharing, particularly in the USA), members typically pay an annual fee and then pay per hour of use to access a car. In most schemes, vehicles are located at designating parking spaces and are booked and paid for in advance via the internet, but some so-called 'free-floating' schemes (such as Daimler's Car2Go and BMW's DriveNow) allow the user to pick up a car without pre-booking and drop it off wherever they wish. Members of car-share schemes have lower average annual mileages and use a much greater range of other modes than traditional car owners (Carplus, 2013). Car-share vehicles also have 20% lower CO_2 emissions than average private cars (Carplus, 2013). The more intensive usage of car-share vehicles means low-emission technologies are more cost-effective for companies running the scheme, and they often promote electric and other low-emission city car technologies (Schipple & Puhe, 2012).

Ride sharing

One of the simplest ways of reducing the environmental and air quality impacts of car use is to reduce the number of journeys by sharing lifts. A 1% increase in the current average occupancy of 1.6 persons per car would result in an annual reduction of over one billion vehicle miles. For many people, choosing to lift-share may be an easier or more acceptable alternative to single-occupancy car use than walking, cycling or public transport.

Here again ICT is helping to enable people to make more sustainable choices. Internet lift-sharing sites such as liftshare.com enable people to quickly and easily find others making similar journeys. The growth in ownership of smart phones with GPS location awareness has facilitated the development of real-time ride-sharing services. Internet-based social media allows lift-sharers to establish trust and provide feedback.

4.2.7 Pricing measures

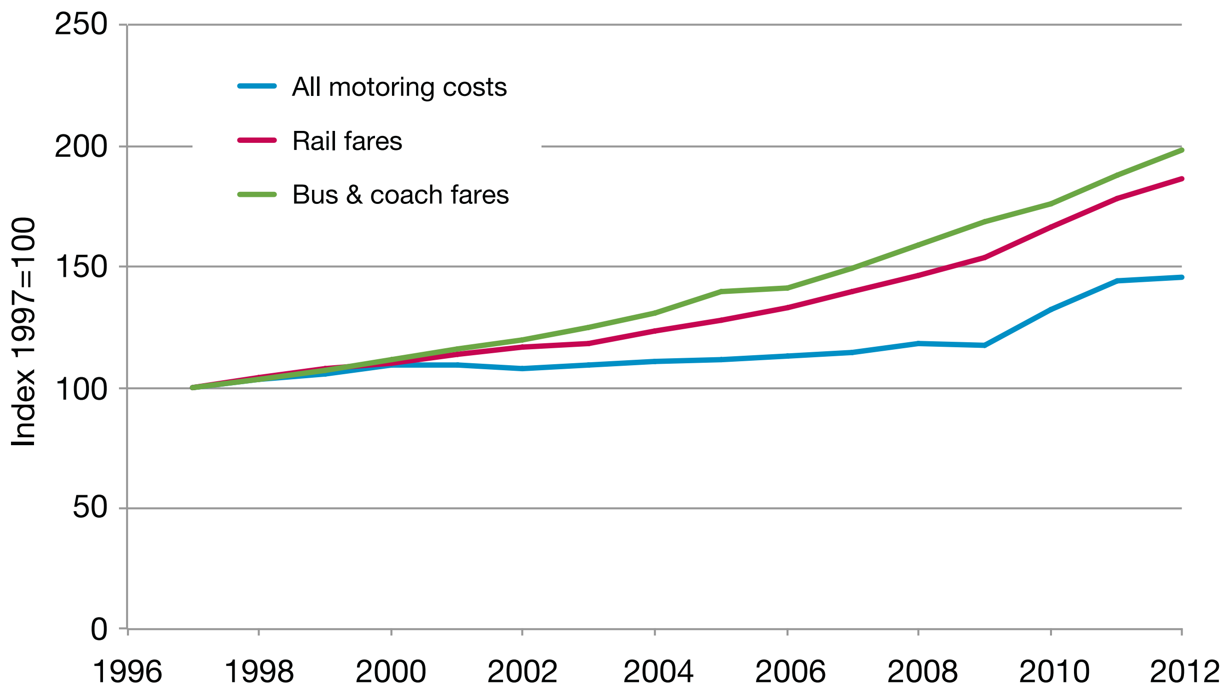
The approach of classical economics to influencing travel demand and behaviours is through pricing. According to economic theory, transport price signals should be set to achieve an optimal level of mobility for society. They should also encourage people to choose modes of transport which minimise the negative social and environmental impacts of travel, such as air pollution. In order for transport prices to lead to optimal choices, the costs of these externalities must be internalised into the prices people pay, a process sometimes known as the ‘polluter pays’ principle.

While taxes on road transport are often justified by these externalities, they may be poorly targeted. Private motor vehicle use is a good example of where price signals for users fail to capture the overall costs to society. Alongside air pollution, the largest estimated costs of our current urban transport patterns are congestion and lack of physical exercise. However, these costs are not directly reflected in the costs that motorists must pay.

A further problem is that a significant proportion of the costs that motorists pay are ‘fixed’ annual costs – principally depreciation, insurance, servicing, MOT and Vehicle Excise Duty (VED). This can act as an incentive to greater car use, since there is little point in paying these costs and then hardly using the vehicle.

This can also lead to distortions in comparing transport choices. For example, people will often compare the cost of a train or bus fare, to that part of the total cost of running a car that is merely the fuel cost of the trip in question. All the fixed costs of vehicle ownership including depreciation and servicing tend to be ignored. However, even when comparing the total costs of motoring to public transport, it is clear that trends in relative prices have acted to discourage public transport use (Figure 4.5).

Figure 4.5: Changes in relative costs of public transport and motoring (1997–2012)



Source: DfT (2013)

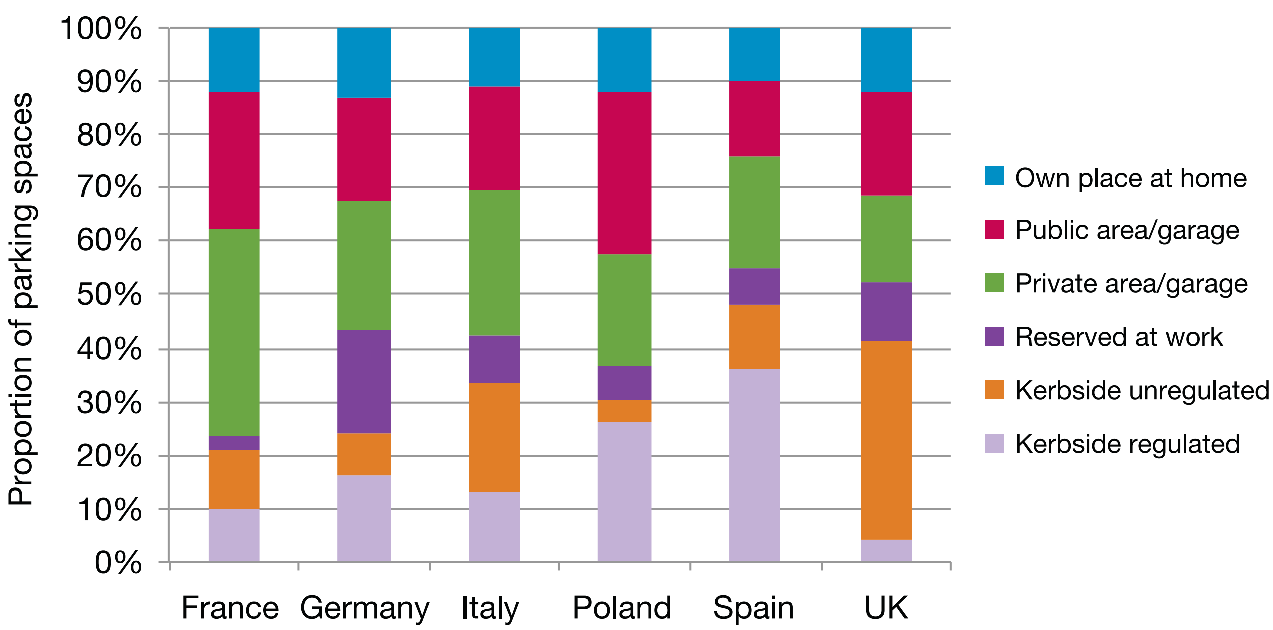
Previous research for the RAC Foundation has highlighted how the introduction of road pricing could help to address the problem of internalising congestion costs (Johnson et al., 2012). By making a clearer link to the cost of car use per journey, road pricing may also help address this distortion when comparing transport options. This would be particularly true if road pricing were to replace or reduce other charges on motorists such as VED and fuel tax.

Road pricing could also provide a more direct way of linking air pollution costs to the prices of transport choices. Roads in areas with poor air quality as a result of road transport could be priced more highly, and use of vehicles with technologies to reduce their air quality impacts could be encouraged through differentiated pricing policies. Incentives for low-emission vehicles have already been implemented as part of the London Congestion Charge scheme, but with a focus on lowering carbon emissions rather than reducing air pollutant emissions in general.

Public transport fares policy is another area in which transport pricing policies could encourage cleaner transport choices. Recognising the air quality and other benefits of encouraging public transport use, many countries invest heavily in public transport infrastructure and do not expect revenues from fares to cover operating costs. A comparison of buses in a selection of European countries revealed that the highest percentage of operating costs being met by fares was found in the UK, at 90%. Data from a variety of European metropolitan areas reveals a wide range in the percentage coverage of operating costs by public transport fares, from 26% in Prague through to 72% in Cadiz Bay, but the average value is 46% (EMTA, 2011).

The price and availability of parking can also strongly influence travel choice, being one of the most important determinants of car use (SPUR Transportation Committee et al., 2004). Land which is currently used for car parking could be made available for other uses. A minimum estimate of the total area devoted to car parking in the UK is 590 square kilometres, an area of land twice the size of Birmingham (Gathorne-Hardy, 1995). The UK stands out from many European countries when it comes to the proportion of unregulated kerbside parking as a percentage of total parking, as shown in Figure 4.6 (Pasaoglu et al., 2012) Free parking is effectively a hidden subsidy promoting increased private car use (Shoup, 2005). Regulating these parking spaces and introducing charges could allow more economically efficient use of this land, and help to create more balanced choices between alternative modes of transport.

Figure 4.6: Distribution of types of parking places (Monday to Friday)



Source: Pasaoglu et al. (2012)

4.3 Access control and management

There are a range of traffic management and control powers that have been traditionally used to manage vehicle flows in and around our towns and cities. These traffic regulation powers have the flexibility to enable them to be used to reduce vehicle emissions and improve air quality. The key mechanisms discussed below are:

- vehicle restricted areas;
- Low Emission Zones;
- parking management; and
- traffic management.

4.3.1 Vehicle restricted areas

Access control is widely used in cities across Europe to restrict vehicle activity, particularly in historically or architecturally sensitive areas. Such control covers a wide range of measures including time restrictions, size and weight restrictions, and controls related to vehicle emissions. It is used to avoid inappropriate traffic and unnecessary trips, and is generally implemented for environmental or congestion-related reasons. Most schemes are targeted at freight and freight/private cars, rather than solely at private cars (Directorate-General for Mobility and Transport, 2010). The targeting of heavier vehicles reflects their proportionally higher environmental impact.

In the UK, such restrictions are implemented through road traffic regulations and they can be used in pursuit of air quality objectives. They are typically used to set up pedestrian areas or put in place vehicle size and weight restrictions. However, they can be targeted at restricting specific vehicles that are contributing to an air quality issue. For example they can be used to prevent through traffic or large goods vehicles. They can be combined with safety and public realm improvements to greatly enhance areas such as shopping streets and public spaces. This in turn will contribute to the attractiveness and economic vitality of an area.

Examples in the UK include York's Footstreets scheme, Nottingham's Clear Zone and Bath's Bus Priority Gate. All these schemes have been designed to reduce traffic levels and the associated safety and environmental impacts, and form part of wider economic development and regeneration work. The York scheme is largely about city-centre pedestrianisation; Bath has used the measure to cut down through traffic in the city centre; and Nottingham has linked its scheme with the introduction of a tram to increase public transport access to the city. Such access control and restriction schemes are also widely used across Europe to reduce the impact of urban traffic and enhance the public realm.

When implemented well, access restrictions can be very effective at improving air quality and the wider environment in an area, as they directly remove the source of the emissions. However, to ensure their success it is important to consider the needs of all users of an area so that the scheme is equitable, and the area remains economically attractive. Key areas of consideration are access for elderly and disabled people, delivery and collection of goods from premises in the restricted area, and unhindered access for emergency vehicles.

The costs of any scheme will vary depending on its scale and how it is managed and enforced. The main costs comprise signage, enforcement (either manual with traffic wardens, or by means of automatic systems such as rising bollards), and related road and public realm improvements. The most costly element is likely to be the investment in public realm changes, and these will be important to the wider success and impact of the scheme.

4.3.2 Low Emission Zones

A specific type of vehicle restricted area is the Low Emission Zone (LEZ), where vehicles not meeting specific emission criteria are restricted. The restrictions can be linked to specific vehicle types and related to Euro emission standards, vehicle age or technology. They can take the form of an outright ban or variable charging, and in many cases are aimed at heavy-duty vehicles, as these have the highest emission rates per vehicle. The most well-known example in the UK is the London LEZ, but there are a number of other major schemes across Europe including ones in Berlin, Amsterdam and Stockholm.

The London scheme was introduced in 2008 and was targeted at HGVs and buses, with an access criterion of Euro 3 vehicle emission standard or alternatively an accredited diesel retrofit particulate filter. In 2012 the scheme was widened to include vans and minibuses, and the standard for HGVs and buses was tightened to Euro 4. The LEZ in Berlin was introduced in the same year and was targeted at all diesel vehicles; it currently has a access criterion of Euro 4 or Euro 3 plus a particulate filter. The scheme in Stockholm restricts access to all HGVs and buses older than six years, with exceptions for approved retrofit technology.

The effectiveness of a LEZ will depend on how it is designed in terms of vehicle types covered, emission criteria set and enforcement approach taken (manual or automatic). In general a LEZ will have the most effect when applied to all vehicle types in an area. However, direct assessment of the impact of a LEZ can be complicated by wider factors effecting the change in vehicle activity and fleet composition.

A recent study of the impact of the London LEZ showed that the scheme had a significant impact on the fleet composition operating in the city, with a shift to ensure compliance (Ellison et al., 2013). However, the fleet pattern returned to normal after this initial shift. In terms of impact on air quality, the study found a small impact on PM concentrations at around a 1% improvement per year relative to changes in concentrations areas outside the LEZ. However, no discernible improvement was seen in NO_2 concentrations.

An analysis of the impact of stage I of the Berlin LEZ also showed a major improvement in the vehicle fleet and estimated that this had led to a decrease in direct vehicle emissions of PM and NO_x of 24% and 14% respectively. As for air pollution concentrations, however, results of a source apportionment study for a measurement site in the city centre indicated a 3% decrease in the PM_{10} concentration, and little change in levels of NO_x (Lutz, 2009).

A study of five schemes in the Netherlands, directed at heavy-duty vehicles, found limited impacts on overall pollution concentrations of schemes of that scale (Boogaard et al., 2012). Another review of LEZ schemes also suggested that they did not necessarily perform as had been expected in terms of reducing pollutant concentrations (Barratt, 2013). The greatest impact of many LEZs appears to have been a reduction in fine particulate matter ($PM_{2.5}$) and black carbon, related largely to the introduction of particulate filters as a result of the scheme. Similarly, areas of high HGV traffic have shown greater impacts than other areas, as HGVs are generally a key target of such schemes. The impact on overall PM_{10} and NO_2 levels has been considerably less.

The difficulty in tackling overall PM_{10} concentrations is because they are also affected by other combustion sources, and non-exhaust emissions such as brake and tyre dust, which are not directly reduced by LEZs. The limited impact on NO_2 is mainly due to the fact that to date most schemes have been targeted at reducing particulate emissions from diesel vehicles through Euro standards or retrofit particulate filter, and so will not necessarily reduce NO_2 emissions. More recently, schemes are starting to focus on reducing NO_x emissions more directly with minimum standards at Euro 4 or retrofitting with NO_x-reduction equipment. However, another factor behind the difficulties in reducing these emissions is likely to be the underperformance of Euro emission standards in real-world urban driving, as previously noted.

Another approach to LEZs is the use of variable charging, rather than direct restrictions and fines. An example of this type of scheme is Milan's Ecopass scheme, which levies a charge to allow entry to the city that is directly related to the vehicle's emissions performance, with the cleanest being allowed in free. The scheme has had a significant impact on vehicle fleet composition, with the number of passenger vehicles in the charged categories dropping by 70% over a three-year period (Danielis et al., 2011). It also seems to have had a significant impact on PM concentrations in the city, but a more variable impact on NO_2 concentrations. The scheme has also provided a very positive cost:benefit ratio in relation to revenue, congestion benefits and air quality benefits. Such pricing mechanisms may provide a more flexible approach than simple regulations, and can have additional benefits in wider demand management.

Detailed cost data on LEZs is not readily available, and what has been collected or estimated varies significantly depending on the size and type of LEZ being implemented. The main cost categories to consider are:

- set-up costs – covering feasibility/consultancy, legal costs, and consultation;
- capital costs – including enforcement systems, signage and public realm works, and back-office administration systems;
- operating costs – for the enforcement and back-office systems;
- revenues – from fines; and
- compliance costs – for the users in terms of purchasing new vehicles or modifying existing vehicles.

The London LEZ was estimated to cost £50 million to set up and £9.5 million per year to operate, and to take in £6.5 million per year revenue from fines, with some £270 million of user compliance costs (Directorate-General for Mobility and Transport, 2010). However, this is a very large scheme with automatic enforcement. The much smaller bus-only scheme in Oxford is estimated to have cost £0.3 million to set up and to cost £0.2 million per year to operate, with user compliance costs being between £2 million and £20 million depending on whether operators replace or retrofit vehicles (Jones & Parker, 2007).

4.3.3 Parking management

The control of the supply and price of parking can be used to manage transport demand and make a direct impact on traffic levels. Instead of allowing unregulated, free parking, many argue that prices should be set to limit demand to about 85% of maximum occupancy (Shoup, 2005). Inefficient and poor parking controls generate additional traffic and congestion, with as much as 50% of traffic congestion potentially caused by drivers cruising around in search of a cheaper parking space (Gauthier et al., 2013). A 2012 RAC Foundation report on UK parking policy also recognised the impact of inefficient parking on congestion and vehicle emissions. The report called for better provision of information to ensure efficient vehicle parking, and a more consistent approach to pricing, both to cover the direct costs of parking and as a tool to manage congestion (Bates & Leibling, 2012).

Parking management can also be used to encourage less-polluting vehicles by means of establishing priority/dedicated parking, or reduced-price parking, for low-emission vehicles. Examples of such policies are designated parking for electric vehicles, car-club vehicles and car-share vehicles, or lower parking charges for vehicles that meet a specific emission standard. Measures can be targeted at cars, or at HGV parking and loading areas. This kind of scheme represents an alternative to a formal LEZ, and can potentially be enforced more easily through existing decriminalised parking enforcement powers.

Milton Keynes has introduced a 'green' parking permit for drivers of vehicles which are in tax band A (i.e. have CO_2 emissions of 100g/km or less). This provides a discount when using standard-rate parking spaces. In Edinburgh, residents' parking permits are graded according to engine size or CO_2 emission levels, with those in the highest bands paying over six times more than those in the lowest. Richmond offers free residents' parking permits to owners of tax band A vehicles, and York has also introduced low-emission vehicle parking permits which give discounts of up to 50% on residents' parking. In Europe, Bremen has a system of environmental loading points for low-emission delivery vehicles, and Madrid is currently studying the possibility of a parking charge differential of 20% in from one area to another, depending on parking demand and the level of NO_x emissions.

In most cases the main assessment has been of the impact on parking revenues assuming a continuation of the current fleet, rather than taking account of the potential change to that fleet and the consequent emissions benefits. In general the impact will depend on the scale of the charges or the nature of restrictions applied. Moreover, any such policies can be undermined by the availability of uncontrolled private off-street parking.

4.3.4 Traffic management

There are a range of traffic management techniques that can be used to smooth the flow of vehicles, or particular groups of vehicles. The associated reduction in braking, acceleration and stop–start driving will improve the emissions performance of vehicles. Particulate emissions from brake and tyre wear may also be reduced as a result. Traditional traffic control systems use traffic light systems that help control the flow of vehicles around a road network. These are widely used in cities and at key road junctions to reduce congestion and improve traffic flow. The main objective is to reduce journey times, but this in itself will help reduce vehicle emissions.

However, they are increasingly being looked at as a means of helping to reduce and manage vehicle emissions more directly. Traffic control systems that are linked to air quality monitoring and forecasting have been used to give priority to low-emission vehicles and to direct traffic away from congested and polluted areas. For example, in Utrecht they trialled a system to route goods vehicle traffic away from areas with high pollution in real-time (CIVITAS, 2013), and in Leicester they have been developing an integrated traffic management and air quality system that will generate traffic control scenarios which are optimised to improve air quality (European Space Agency, 2012).

Another example is the concept of ‘gating’, where traffic can be held away from areas of sensitive exposure such as schools or busy pedestrian areas, or held back from congested junctions. A particular example of this is known as ‘ramp metering’, where vehicles are released in small groups to join a trunk road or motorway to prevent congestion at the junction. This has been shown to increase traffic speed past these junctions by some 7.5% (Highways Agency, no date). Variable speed limits are also being used on many parts of the motorway junctions to manage vehicle flows for congestion purposes, and are part of a wider traffic management and information approach know as Smart Motorways (Highways Agency, 2014a). Most recently, the Highways Agency is (as of early 2014) consulting on a scheme on the M1 to set a maximum speed limit of 60 mph to complement all-lane running capacity improvements, specifically to address air quality impacts in adjacent AQMAs (Highways Agency, 2014b).

Physical changes to road layout and use can also help smooth the flow of vehicles and reduce emissions. These include measures such as:

- priority lanes for buses, freight vehicles or high-occupancy vehicles;
- junction improvements to ease the flow of vehicles; and
- parking management to prevent obstructions to traffic flow.

4.4 Promoting low-emission and alternative-fuel vehicles

Promoting a switch to low-emission vehicles has as its primary objective the reduction of carbon and air pollutant emissions from transport. However, it does not yield the additional benefits, such as congestion reduction and increased levels of physical activity, that are generated by 'avoid'- and 'shift'-type measures. New low-emission technologies such as battery electric cars and hybrids are becoming increasing available, and alternative fuels are also rising in prominence; this relates particularly to the use of natural gas engines for heavy-duty vehicles and in the longer term, hydrogen fuel cell vehicles. It is also worth noting that vehicles that incorporate regenerative braking, such as electric and hybrid vehicles, can reduce non-exhaust particulate emissions relating to tyre and brake wear, thus further reducing air pollution levels (Brannigan et al., 2012).

4.4.1 Cleaner buses and taxis

Public transport vehicles typically have a more compelling financial case for investing in clean and fuel-efficient technologies because they travel much higher annual mileages than privately owned vehicles, with the lower running costs being more likely to offset the higher capital costs. Since buses are one of the principal contributors to NO_x and particulate emissions in urban areas, it makes sense for local authorities and central government to encourage operators to switch to newer, cleaner technologies. Rounds 1 to 3 of the UK government's Green Bus Fund paid over £75 million in grants to fund purchase of almost 1,000 cleaner buses, with a further £13 million and almost 250 buses expected to be funded in Round 4. The vast majority of these have been hybrids, but the list also includes electric and biomethane (a purified form of biogas) options.

Analysis of the real-world performance of four hybrid buses compared to four conventional buses indicates a reduction in fuel consumption of over 40% on a typical operating vehicle test cycle (Low Carbon Vehicle Partnership, 2013). It is to be hoped that this would lead to a significant reduction in air pollutant emissions. However, while on average NO_x and PM measurements were found to be lower for the hybrids, the reductions were not enough to inspire confidence that there would be any clear benefit. The analysis suggested that engine designs need to be optimised to suit hybrid applications, whereas existing hybrid variants tend to use the same engine as conventional alternatives. It would be expected that newer vehicles meeting the Euro VI emissions standards which came into force at the end of 2013 are likely to show much clearer benefits, as the legislation has been designed to ensure that real-world emissions results match legislated testing more closely.

Nottingham, Coventry, Milton Keynes, Durham and Poundbury (in Dorset) have all bought battery electric buses through the Green Bus Fund, with London, Manchester, York and Cheshire also making orders in the latest round of funding. With no tailpipe emissions, these should make a substantial contribution to improving local air quality; and as power station emissions reduce, overall life-cycle air pollution will be further reduced.

Hydrogen fuel cell buses also eliminate tailpipe air pollution, emitting only water vapour. However, as with battery electric technologies, consideration needs to be given to upstream emissions associated with hydrogen production and the current high costs of the technology. Buses fitted with natural gas engines virtually eliminate particulate emissions, and can have significantly lower NO_x emissions than conventional diesel engines, as well as halving noise levels. If running on biomethane gas, they have the added benefit of achieving substantial reductions in carbon emissions.

Taxis can also contribute disproportionately to air quality problems in cities, as they tend to be driven in a stop–start style, and operate high numbers of urban miles. In the City of London, they are the largest source of PM_{10} emissions, and the second-largest source of NO_x (City of London, 2011). The Mayor's Air Quality Strategy (2010) includes an aim to have zero-tailpipe-emissions taxis in operation by 2020 (GLA, 2010).

4.4.2 Cleaner lorries

Natural gas engines are the most promising technology solution for HGVs, in terms of both air quality improvements and, particularly when run on biomethane, carbon reduction (Ricardo-AEA, 2013a).

For long-haul and regional delivery journeys, 'dual fuel' engines, which can switch between diesel operation and natural gas, can offer a cost-effective option and provide the reassurance of being able to switch back to diesel operation if gas refuelling facilities are not available. However, the air quality benefits of dual fuel engines can be significantly lower than those which run on gas alone, particularly in low speed, urban traffic where a dual fuel engine will almost always be running on diesel.

Operators can be encouraged to switch to gas if they can be confident that lower fuel costs will pay back the costs of the new technology and result in an overall saving within an acceptable timeframe (Ricardo-AEA, 2013a), but fuel cost savings would be dependent on the stability or otherwise of fuel taxation policy. As a result, the report recommended a guarantee of a fuel duty differential between gas and diesel for a rolling ten years.

For lorries making urban deliveries (as well as refuse collection vehicles and road sweepers), hybrid and battery electric solutions appear to be the most promising options. This is particularly true where the body of the vehicle requires an auxiliary power source. Conventionally this requires that the engine is kept running; however, with a large on-board battery, the diesel engine can be stopped and power provided electrically, reducing both air pollution and noise.

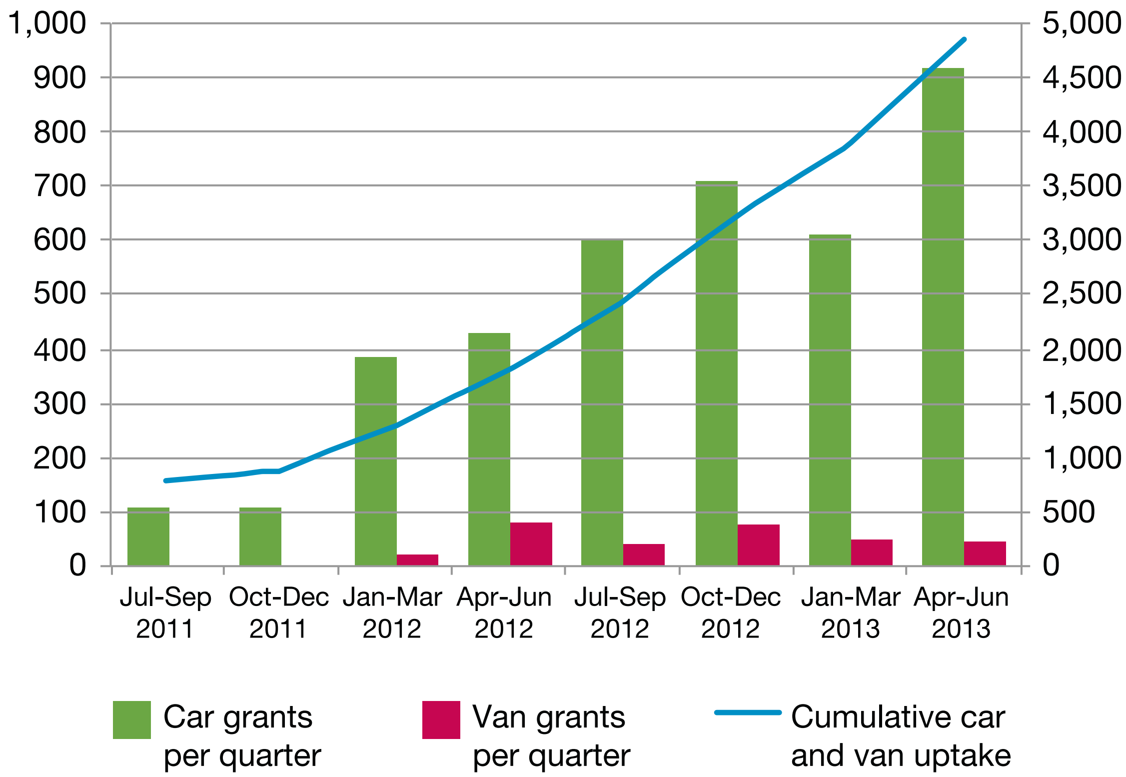
Uptake of hybrid and electric urban heavy-duty vehicles can be encouraged through direct grants, exemptions from congestion charging schemes, and permits to operate in noise-sensitive areas if the vehicle can run in electric-only mode. An additional incentive would be to compensate the weight impact of the battery and hybrid systems on payload capacity by allowing higher gross vehicle weight limits for these vehicles where it is safe to do so.

4.4.3 Cleaner cars and vans

Technologies which eliminate conventional tailpipe emissions, such as battery electric and hydrogen fuel cell vehicles, will provide the largest air quality benefits. However, the costs and limitations of these technologies at their current development level are limiting their sales. In 2012 the UK market share for battery electric cars was 0.06%, and even hybrid cars accounted for a mere 1.2%. Most commentators expect strong growth in sales of plug-in vehicles when breakthroughs in the cost and performance of battery technology are achieved, probably in the 2020–2030 timeframe (Kay et al., 2013).

In the meantime, UK government policies such as the Plug-in Car and Van Grants play an important part in encouraging sales of these new technologies, by making the total cost of ownership more comparable to conventional petrol and diesel alternatives. These grants (which have taken off in the last two or three years – see Figure 4.7) have been reported to form a significant element of the purchase decision for 85% of purchasers (Hutchins et al., 2013). Other measures, such as exemption from VED and congestion charges, and provision of free parking and recharging facilities, can also increase uptake.

Figure 4.7: Growth in Plug-in Car and Van Grants



Source: Office for Low Emission Vehicles (2013)

Nevertheless it is the higher upfront purchase cost which, combined with the limited range, appears to present the biggest barrier to battery electric vehicle take-up. In Norway, electric vehicles have the highest market share in the world at 3% in 2012; indeed, in January 2014 it was reported that this had risen to 10%. It is notable that their exemption from the high purchase taxes applied to conventional vehicles results in the Nissan Leaf having approximately the same purchase price as a Volkswagen Golf with a 1.4-litre petrol engine. Electric vehicles are also exempt from road tolls, public parking charges, vehicle tax, and company car tax, and are able to use bus lanes to avoid congestion. The Leaf was the overall best-selling car in Norway in October 2013.

4.4.4 Fiscal incentives

Creating a situation in which there are clear financial benefits to investing in cleaner vehicle technologies will stimulate market uptake. The government determines the taxes and charges which are applied to both motorists and vehicle sales, and can therefore significantly influence this. Key policies which are currently used to promote uptake of low-emission vehicles include:

- fuel duty and the resulting differentials;
- VED;
- company car tax; and
- capital allowances.

However, vehicle purchasers, particularly commercial operators, need to be sure that these policies will not change during their ownership of the vehicle, thus adversely affecting their expected payback period for investing in cleaner technology. For example, compressed natural gas and liquefied natural gas for road use currently benefit from lower fuel duty than diesel, which may make switching to gas engines attractive for road hauliers. However, a clear message from recent research into barriers to uptake of low-emission technologies for heavy-duty vehicles was that this differential needs to be guaranteed for at least ten years, particularly given that operators may have to invest in their own refuelling infrastructure in order to switch to gas (Ricardo-AEA, 2013a).

At the local level, fiscal incentives can be applied by through parking fees, as discussed in section 4.3.3 above. Similarly, local road pricing schemes can be used to differentiate between different types of vehicles, for example the clean vehicle exemptions in the London Congestion Charge. In the case of the London Congestion Charge scheme, the direct impact of the exemption on air quality is hard to separate from other impacts, but it is clear that it has had an impact on the vehicle fleet, which has displayed a much faster growth in hybrid vehicles in the capital than in other areas in the UK and Europe.

4.4.5 Low-emission vehicle infrastructure

Provision of suitable infrastructure to support low-emission vehicles is critical to their introduction. For commercial vehicle operators, the financial case for investing in battery electric vehicles is strongly dependent on ensuring high usage rates. With the limited range of existing battery technologies, achieving this requires investment in rapid charging facilities which can recharge to 80% of capacity in around 20 minutes. Equally, switching to natural gas engines and hydrogen fuel cell vehicles will require the development of complete refuelling networks.

The UK government published its strategy *Driving the Future Today* in September 2013 (Office for Low Emission Vehicles, 2013). This includes plans to increase the number of rapid charge points to around 500 in the near future, and commits £37 million to building a national charge point infrastructure. It is widely accepted that most privately owned electric vehicles will be predominantly charged at home. However, the availability of public rapid charging facilities is seen as a key requirement for sales of electric vehicles to grow, as it allows longer journeys to be made more conveniently and reduces ‘range anxiety’.

Inductive charging makes recharging electric vehicles easier by eliminating the need to physically plug the vehicle in using a heavy cable. Instead, the vehicle can be parked over an inductive charging facility which can recharge the battery without a physical connection. While inductive charging is not as efficient as using a cable, and is more costly, it may result in lower real-world emissions overall as there is some evidence that drivers of plug-in hybrid cars appear to plug in their car only rarely or not at all (E&HVTI, 2013). Inductive charging technology will be used in Milton Keynes to recharge eight electric buses (Office for Low Emission Vehicles, 2013).

The strategy document also gives support for about 65 hydrogen refuelling stations in the 2015 timeframe, with the possibility of this rising to 330 before 2025 and 1,150 by 2030 if plans put forward by UK H_2Mobility come to fruition. UK H_2Mobility’s own analysis estimates that £418 million of financing would be needed to create this network of hydrogen refuelling stations, of which £62 million would be needed before 2020 (UK H_2Mobility, 2013). After this it predicts that provision of further stations would be self-sustaining. This course of action is estimated to be sufficient to allow fuel cell vehicles to reach 10% market share by 2030. These estimates are based on an assumption that policies on fuel excise duty will continue as at present, and that hydrogen will be taxed as a road fuel.

The joint government and industry Low Carbon HGV Technology Task Force is working to develop a strategy for switching larger freight vehicles to gas engines. Initial infrastructure for natural gas refuelling of HGVs is being funded through the £11.3 million Low Carbon Truck and Infrastructure Trial, which will see several publicly available gas refuelling points being built between 2013 and 2015 (Office for Low Emission Vehicles, 2013).

Local planning policy can also be used to support the development of alternative vehicle fuel infrastructure. For example the West Midlands have developed Good Practice Planning Guidance that promotes the adoption of electric vehicle charging points for all new developments over a certain size (Walsall Metropolitan Borough Council, 2013).

4.4.6 Procurement policies

The public sector has significant spending power, and the EU along with UK national and local government has identified that public sector procurement can play a major role in supporting the uptake of low-emission vehicle technology. Indeed, many local authorities are leading the way in the use of low-emission vehicles in their fleets. To support this, the EU has put in place the Clean Vehicles Directive (2009/33/EC) to promote the uptake of clean and energy-efficient vehicles. This states that when the public sector either buys or leases a vehicle, they must take into account the energy consumption, CO_2 emissions and pollutant emissions over the whole lifetime of vehicles.

The regulations require that the environmental performance of vehicles and transport services must be considered through the technical specification for the vehicle or service, the contract award criteria, or a whole-life cost assessment which includes the monetised damage cost of vehicle emissions.

4.4.7 Partnership working

Quality partnerships provide a framework for collaborative working between local authorities and bus and freight operators, and can be used to drive the uptake of low-emission vehicles through agreed standards. A formal framework for bus quality partnership has been established through the Transport Act 2000 and amended by the Local Transport Act 2008, providing for voluntary agreements, statutory agreements and comprehensive quality contract schemes. The Birmingham Statutory Quality Partnership Scheme is an example of this, and includes emissions standards for buses that improve over time.

There is no formal framework for freight quality partnerships, but they are encouraged by central and local government as a forum to develop an understanding of freight transport issues and problems, and to promote constructive solutions, which reconcile the need for access to goods and services with local environmental and social concerns. Many authorities have such partnerships in place, and they provide an excellent platform from which to explore air quality issues related to freight and help identify solutions.

Through such partnership working, a number of more ‘formal’ schemes have been developed such as the ECO Stars scheme developed in South Yorkshire, and the London Freight Operators Recognition Scheme. The ECO Stars scheme is a voluntary freight recognition scheme that aims to drive improvements in local freight operations. The South Yorkshire scheme is badged under their Care4Air clean air campaign and has been rolled out to a number of other authorities in the UK such as Thurrock and Nottingham. The London scheme is run by TfL as part of the wider engagement scheme with the capital's freight industry, called 'Freight Matters'.

Promotion of low-emission vehicles can be done by working directly with businesses to provide information, incentives and infrastructure to support the use of low-emission vehicles. A number of authorities have provided guides or information on low-emission vehicles through the transport information sites, travel plans and freight partnerships. Incentives are also being provided, for example through low-emission parking schemes. There are also a range of infrastructure projects taking place looking at electric recharging, mainly through the government's Plugged-in Places initiative, and gas refuelling infrastructure. Examples include the Plugged-in Midlands and Source East initiatives.

4.5 Summary conclusions

Transport activity is driven by a wide range of needs and behaviours, and has a range of impacts including congestion, air pollution, carbon emissions and accidents. Consequently there are a wide range of measures and actions that can be taken to influence travel patterns, mode choices and technologies with a view to reducing these impacts. Many of these measures are not designed primarily to reduce emissions or improve air quality, but are focused on reducing congestion; nevertheless, they will often help in the reduction of emissions, and can be enhanced so as to generate still greater air quality benefits. The key measures that can have an impact on transport-related air pollution have been discussed in the sections above and are summarised in Table 4.1.

Much of the evidence on the air quality impacts and costs of these measures are indicative for several reasons:

- they have not been designed primarily to improve air quality, so this has not been directly assessed;
- they are often very locally specific, so it is difficult to draw clear results that are more widely applicable;
- there are still significant uncertainties as regards the effect of such measures on real-world vehicle emissions; and
- evidence on behavioural response to specific measures is still being gathered.

Demand management and behavioural change measures can be very cost-effective, as identified in the Sustainable Travel Towns demonstration, and can yield a wide range of benefits in the form of reduced congestion, improved air quality, reduced carbon emissions and increased levels of physical activity. However, our attitudes and habits when it comes to travel are very deep-rooted and can be hard to change, which means that significant and comprehensive packages of measures are needed to make a difference in the first place, and that thereafter maintaining this level of engagement has proved difficult. What is more, although significant impacts in terms of travel behaviour changes have been seen, these have not necessarily translated directly to improvements in air quality.

Traffic management and access control initiatives constitute a much more direct set of measures aimed at physically removing the source of the air pollution problem. As such they can be very effective, and when combined with redevelopment of an area – as has been done in Nottingham – can yield wider quality of place and economic benefits. On the other hand, they can be expensive to implement. Also, because of their restrictive nature they can be politically unpopular if not handled sensitively, which implies the need for considerable consultation and engagement.

The promotion of low-emission vehicles is the technology ‘fix’ that many favour as an alternative to changing behaviours. They can generate significant emission and air quality benefits if taken up substantially. However, they are not always as effective as expected, as has been shown to be the case with diesel emissions control, and many of the alternative technologies are still proving costly. Moreover, they do not provide the additional local benefits such as reduced congestion or increased levels of physical activity. However, at the national level they can provide economic benefits in terms of the development, production and servicing of new vehicle technologies.

These measures are not mutually exclusive – for example, a behaviour change programme can also be used to promote low-emission vehicles, and a bus quality partnership will generate improvements in overall bus services, assisting mode shift, as well as potentially improving the emission standards of the buses. Moreover, none of these measures in isolation is likely to prove sufficient to solve air pollution problems: most measures will generate no more than something like a 5–10% reduction in emissions, whereas reductions of over 50% may be needed in some cases. Therefore an integrated, comprehensive and potentially radical package of measures will be required if real improvements in air quality are to be seen.

The idea of a focused and integrated package of emission reduction measures is being taken up by some local authorities in the form of Low Emission Strategies. This integrated approach is also the thinking behind Sustainable Urban Mobility Plans at the European level (European Commission, 2011b), and to some degree local transport plans (LTPs) in the UK. However, there are significant barriers to the successful development of an integrated approach, amongst which are:

- the existing dominance of the car and associated car-orientated infrastructure;
- a lack of joint working between sectors, particularly transport and land use;
- gaps in relevant knowledge among officials;
- insufficient funds for the preparation of strategies, and increasingly for infrastructure itself; and
- resistance to change, within both municipalities and key stakeholder organisations.

To support such an integrated approach, the wider benefits of a more sustainable approach to transport need to be promoted, which will include effects in the spheres of air quality, climate change, health, noise, congestion and economic development. Indeed, DfT guidance on LTPs states (DfT, 2009c):

> “It is important that LTPs are effectively coordinated with air quality, climate change and public health priorities – measures to achieve these goals are often complementary. Reducing the need to travel and encouraging sustainable transport can reduce local emissions, whilst improving public health and activity levels.”

Table 4.1: Summary of key measures to reduce transport emissions

Measure	Outcome			Impact					Cost/investment
	A	S	I	Traffic	Speed	**Technology**	**AQ**	**CO_2**	
Demand management and behaviour change									
Planning measures	✓	✓		++			++	++	Low
Alternatives to travel	✓			++			++	++	Low
Behaviour change programmes	✓	✓		++			++	++	Low/Medium
Driver training / fleets			✓		+		+	+	Low
Shared modes		✓	✓	+		+	+	+	Medium
Pricing measures	✓	✓		++			++	++	Medium/High
Access control and traffic management									
Vehicle restricted areas		✓		+++			+++	+	Medium
Low Emission Zones		✓	✓	++		+++	++		High/Medium
Parking management		✓	✓	+		+	+	+	Low
Traffic management		✓	✓	+	++		+	+	Medium/Low
Promoting low-emission vehicles									
Fiscal measures			✓			++	++	++	Medium
Infrastructure			✓			+	++	++	Medium/High
Procurement			✓			+	++	++	Low
Partnerships			✓			+	++	++	Low

Source: Authors' own

Note**:** This table provides an indicative summary of the likely outcomes, impacts and costs of measures:

Outcome of measure: A = avoid, S = Shift, I = improve

Impact on measures: in relation to traffic levels, speed or technology, and overall on air quality (AQ) and carbon emissions (CO_2)

Scale of impact: + small, ++ medium, +++ large

5. Conclusions and Policy Recommendations

Air pollution is the principal environmental factor linked to preventable illness and premature mortality in the UK and Europe. It is a significant contributing factor to increases in both respiratory and cardiovascular disease. Its impact on health is estimated to cost the UK economy between £9 billion and £19 billion per year.

Road transport emissions are a significant contributor to air pollution, especially in urban areas, with high numbers of slow-moving vehicles. The proximity of these emissions to human population also increases their potential health impact. Of the 600 Air Quality Management Areas (AQMAs) declared in the UK, over 90% are related to traffic emissions. Some 50% of the total national health impact of air pollution is estimated to be related to urban traffic emissions, amounting to between £4.5 billion and £10.6 billion per year.

In many air pollution hotspots, a 50% or more reduction in transport emissions is likely to be required to bring pollution levels below existing health-based limit values. This is a significant challenge, one which requires a major improvement in vehicle emissions performance along with an integrated, comprehensive and potentially radical package of wider transport measures to generate real improvements in air quality.

5.1 Air quality legislation and limit values

There is clear evidence on the adverse impact of air pollutants on human health from both short (hourly) and long (annual) exposure. Acute effects have been found to include increases in hospital admissions and premature death of the old and sick owing to disease of the respiratory and cardiovascular systems. Those already suffering from respiratory conditions such as asthma find their condition exacerbated by high pollution levels.

Particulate matter (PM) generates the greatest health impacts in terms of respiratory and cardiovascular health. Long-term exposure to $PM_{2.5}$ (the subscript indicates the particle size in micrometres) has been linked to several new health outcomes, including atherosclerosis, adverse birth outcomes and childhood respiratory disease. The emerging evidence from the World Health Organization (WHO) also suggests that there are possible links between long-term exposure to $PM_{2.5}$ (fine particulate matter) and neurodevelopment and cognitive function, as well as other chronic disease conditions, such as diabetes.

Legislation setting health-based air pollutant standards includes the European Air Quality Directive and UK national Local Air Quality Management Regulations. There is widespread non-compliance for the annual average nitrogen dioxide (NO_2) standards, and in some cases the hourly NO_2 standard. The scale of the non-compliance with limit values for NO_2 in the UK and across the EU reflects the inability to tackle high levels of congested urban traffic, and a failure of recent Euro standards for diesel vehicles to deliver the expected reductions in emissions.

Levels of PM10 (coarse particulate matter) and PM2.5 are largely within the European limit values, but are very close to those limits in some areas. However, the EU limit value used for compliance is higher than the more stringent WHO guidelines. Moreover, there is no known safe threshold for PM2.5 in terms of protecting human health. Therefore with a focus in the UK on the compliance of the NO_2 standards there is a potential mismatch with public health protection, where the main concern is the impact of PM concentrations. Although a relatively new statutory requirement is in place to reduce the overall background levels of PM2.5 across Europe, which should help to reduce the impact on the population across the UK, there is potential further scope for tightening the legislation relating to PM in line with the WHO guidelines, to focus greater effort in this area.

The European Commission has also recently announced a new package of policy measures to address air pollutant levels. There is much concern that WHO's recent review of the medical evidence indicates that tighter air quality standards are required to protect human health, but current limits are exceeded over much of Europe. To help drive down current concentrations, a new Clean Air Programme for Europe has been launched with measures to ensure that existing air quality standards are met, with particular attention to reducing emissions from diesel cars in cities.

5.2 Vehicle technology and European emissions regulation

One of the key policy measures aimed at reducing the impact of transport on air quality was the introduction of vehicle emission standards. These have become progressively tighter, with the most recent standards setting levels that are some 80–90% lower than those introduced in the early 1990s. This has largely been effective at driving down vehicle emissions, with the exception of nitrogen oxide (NO_x) emissions, and to a lesser degree PM emissions from diesel vehicles. The evidence reviewed suggested that real-world emissions performance of diesel vehicles, particularly in the urban environment, has failed to meet expectations.

However, the latest Euro 6/VI standards aim to address this with real-world (off-cycle and in-use) compliance tests to ensure that the expected reductions are in fact achieved. This should result in improvements over Euro 5/V standards, and if effective will generate significant improvements in air quality over time as the vehicle fleet is renewed. A further enhancement to Euro 6/VI that is being considered is a specific limit for direct NO_2. This would help combat the increase in direct NO_2 that has been seen in some diesel vehicle emissions, which is considered another factor in the lack of progress in reducing NO_2 concentrations at the roadside. A limit of 15% of NO_x as direct NO_2 would help to manage these emissions.

One consequence of the mismatch that exists between the real-life and legislated emissions of the existing vehicle fleet is that restrictions which only allow higher Euro standard vehicles, for example Low Emission Zones, may not reduce NO_x emissions and NO_2 concentrations as much as expected. This is particularly the case when diesel vehicles are the most significant source of the emissions. This suggests that other metrics, rather than Euro standards, might need to be considered when designing policies and measures to reduce emissions.

Similarly, if the main failure of the emissions legislation is in relation to diesel vehicles in urban areas, especially diesel cars, there is an argument for discriminating against diesel vehicles in favour of other vehicle technologies. In particular this would suggest a policy of promoting petrol over diesel cars in urban areas, for example through differential charging in the London Congestion Charge. This has the potential to conflict with climate change objectives, as diesel vehicles have traditionally been more fuel-efficient than petrol vehicles. However, the latest generation of efficient downsized petrol engines are approaching the efficiency of diesel units. In addition, the fuel efficiency benefits of petrol hybrids are at their greatest in busier urban areas, and electric vehicles are now becoming increasingly viable for urban operation.

With regard to heavy-duty vehicles, one of the key alternatives to diesel engines is gas technology. If the expected reductions in emissions from Euro VI diesel technology do not materialise in real-world conditions, gas could well prove to be a viable option to reduce emissions from urban buses and goods vehicles. If gas engines are run on biomethane (a purified form of biogas), they provide substantial reductions in greenhouse gas emissions, as well as air quality benefits. Hybridisation of buses, in particular, is becoming an increasingly popular choice because of the potential fuel savings; however, to date these vehicles have not been optimised to generate similar benefits in air pollutant emissions. Pure-electric buses provide another increasingly available option, while in the longer term, technologies such as hydrogen fuel cell heavy-duty vehicles are expected to become more affordable.

To prevent conflicts with climate change policy, technology options should be promoted on the basis of both air pollution and carbon emission benefits, whereas in many cases they are currently promoted in relation to either one or the other. Technology policies or measures should include a definition of low-emission vehicles that is related to both air quality and carbon emissions, and not simply to the Euro emission standards. Suggested low-emission vehicle definitions are given in Table 5.1 and could be used as the basis of financial incentives or restrictions.

Table 5.1: Suggested low-emission vehicle criteria

Low-emission vehicle category	Cars	Vans	Trucks and buses
Low emission	Euro 5 vehicles, excluding diesels CO_2 < 100 g/km	Euro 5 vehicles, excluding diesels CO_2 < 175 g/km	Euro V vehicles, excluding diesels CO_2 30%* < Euro IV
Ultra-low emission	Euro 6 vehicles, including diesel if shown to perform CO_2 < 75 g/km	Euro 6 vehicles, including diesel if shown to perform CO_2 < 120 g/km	Euro VI vehicles, including diesel if shown to perform CO_2 50%* < Euro IV
Zero emission at the tailpipe	Zero tailpipe emissions Effectively battery electric or fuel cell hydrogen vehicles	Zero tailpipe emissions Effectively battery electric or fuel cell hydrogen vehicles	Zero tailpipe emissions Effectively battery electric or fuel cell hydrogen vehicles

* Note: percent reduce relative to Euro standard; CO_2 = carbon dioxide
Source: Authors' own

5.3 National policy

The core of national air quality policy is the Local Air Quality Management (LAQM) regime, which is currently under review by Defra. The key benefit of this approach has been a significant amount of information and data collected on air pollution across the country, together with its causes. This has resulted in around 600 AQMAs being declared, and the development of associated action plans. Significant progress has been made in implementing these actions, but there has been little assessment of their actual impact on air quality. Although improvements to air quality are being achieved, to date this has resulted in the revocation of only a few AQMAs.

Because of the lack of real progress in reducing breaches of the air quality limits, a key element in the consultation on the LAQM process was the need to focus more on action planning and a better understanding of the impact of different measures. This greater focus on action is clearly necessary to make progress, and as transport is one of the major causes of air pollution this means a greater focus on local transport measures.

This highlights one of the key disconnects in the current LAQM process: environmental health professionals at district level have the duty to improve air quality, but transport measures are controlled by their transport colleagues at the county level. In unitary authorities where both functions sit in one authority this can work well, but in two-tier authorities there can be conflicting priorities and a lack communication. Increasing the level of responsibility that transport authorities have as regards managing local air quality would help to address this problem. This strengthening of responsibilities has already taken place with regard to public health and air quality, with public health boards becoming a local authority responsibility, and air quality being one of the outcome indicators on the public health framework.

Strengthening the link between transport and air quality can be achieved through the LAQM process itself, but is also possible by means of national transport policy. Currently the key priorities of the national – and consequently local – transport policy are economic development and carbon reduction. Clearly there is a strong link between reducing carbon emissions and air-quality-related emissions, but although it is recognised in much policy work, it does not seem to emerge clearly in transport priorities or guidance. Given that the economic impact of poor air quality related to transport is estimated to be higher than either road casualties and collisions or carbon impacts, it would make sense to give it a higher priority. We suggest that it should be made very clear in both national and local transport objectives that improving air quality should rank alongside economic development and carbon reduction as a key priority.

Support can also be provided at the national level through:

- political support for strong local action to reduce traffic volumes and emissions;
- continued financial support, via initiatives such as the Local Sustainable Transport Fund, provided there are clear criteria concerning improving local air quality; and
- guidance on local transport powers and measures that can be used to reduce transport emissions.

The other key national policy is with regard to technology development and the promotion of low-emission vehicles. This is a policy element that has traditionally been focused at the national level and has been linked to the wider economic benefits of technology development. It is also an area where the UK government has been quite active with initiatives such as:

- the Plug-in Car and Van Grants to support electric vehicles;
- the Plugged-in Places scheme, supporting the development of electric vehicle recharging infrastructure;
- the Green Bus Fund, supporting low-carbon buses; and
- the Clean Bus Technology Fund, supporting emission reduction retrofits.

This work has continued with the Department for Transport's strategy for ultra-low-emission vehicles (ULEVs) *Driving the Future Today* strategy and its communications campaign *Go Ultra Low*, which promotes the use of ULEVs. The strategy is aiming for all vehicles to be ultra-low-emission by 2050, with ultra-low-emission defined as cars and vans with CO_2 of less than 75 g/km. However, although air quality is mentioned, the focus of the strategy is on carbon emissions. Continued support for low-emission vehicles and technology improvement is important, but it should focus on both carbon emissions *and* air-quality-related emissions.

5.4 Local action

The potential emissions improvements generated by the Euro 6/VI emissions legislation, and the introduction of ULEVs could have a significant impact on air quality. However, to complement this European and national-level activity, local measures to reduce traffic flows, promote low-emission vehicles and tackle specific hotspots will be necessary to make major improvements in local air quality.

Action needs to be taken across all areas of an authority's activities to improve air quality – from environmental health, through transport planning and regulation, to planning and development control. All of these powers can be brought to bear to reduce traffic flows and promote low-emission vehicles. However, such a comprehensive and integrated approach that reaches across an entire authority is rarely taken. For this reason, authorities are being urged to take this route by means of Low Emission Strategies.

To support such an integrated approach, the full spectrum of benefits that can be accrued from reducing vehicle traffic and emissions needs to be promoted. This covers:

- the health benefits of improved air quality;
- the even greater health benefits of increased physical activity from walking and cycling;

- reductions in carbon emissions;
- reductions in congestion;
- improved public spaces giving a greater sense of place; and attracting greater economic activity.

These benefits need to be linked to the objectives of other policy areas in order to generate commitment for authority-wide action.

In the current economic situation, the resources available to enable action to be taken are limited. Quantifying the key economic benefits of any measures will therefore be essential in supporting the case for action, and this should include all the potential benefits listed above. However, it needs to be recognised that the relationship between a particular measure and its air quality and economic benefit is complex, and so this quantification will not be easy. It will require bold vision, commitment and leadership from local politicians to make the level of change needed to see real improvements in air quality.

5.5 Summary policy conclusions

Transport is the greatest contributor to urban air pollution, and substantial reductions in transport emissions are required to improve air quality. The scale of the reduction needed is very challenging, and to support further progress the following key policy recommendations are proposed:

At the European level

1. Consider tightening the regulated particulate matter limits, especially $PM_{2.5}$, in line with WHO guidelines, to reflect the greater health impact of particulate matter.
2. Assess the real-world effectiveness of Euro 6/VI legislation and include the proposed NO_2 limit.

At the national level

4. Adopt a more action-focused approach in the LAQM regime and increase the focus on PM concentrations.
5. Strengthen the obligations of transport authorities in managing air quality, by making improving air quality a key priority for transport policy, alongside carbon reduction and economic growth.
6. Continue support for low-emission vehicles through the ULEV strategy and other mechanisms, but use a wider low-emission vehicle definition which considers both air pollutants and carbon emissions.
7. Provide national guidance and financial support for local measures to reduce transport emissions, including improved emissions data and tools, and wider evidence on the impact of measures.

At the local level

8. Integrate air quality considerations across all areas of local authority activity to provide a comprehensive and action-based approach to tackling air quality locally.
9. Consider the full spectrum of benefits from health and quality of life, from congestion and transport benefits to wider economic development, to assess the business case for transport measures.

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The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

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