Transport for London

London
Low Emission Zone

Impacts Monitoring
Baseline Report, July 2008

MAYOR OF LONDON

Transport for London

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Overview

This report sets out the work that Transport for London (TfL) is doing to monitor and assess the impacts of the London Low Emission Zone.

This scheme, the first two phases of which were introduced successfully on 4 February and 7 July 2008 respectively, aims to contribute to improved air quality in Greater London by reducing emissions of particulate matter (PM_{10}) from the more heavily-polluting road vehicles. The scheme will also have beneficial effects on emissions of other pollutants such as oxides of nitrogen (NO_X).

Local authorities and the Mayor of London have an obligation to work towards the achievement of both national and European air quality objectives. These objectives are health-based, in recognition of the relationship between outdoor air quality and poor public health. Meeting these objectives has so far proved to be challenging in Greater London, requiring action on a number of fronts. The London Low Emission Zone is one of the more effective ways through which progress can be made.

This report is one of a series of reports and updates being produced by TfL looking at specific schemes and policies arising from the transport and air quality strategies of the Mayor of London. It is the first such report dealing with the London Low Emission Zone, and its primary purpose is to describe the monitoring and assessment work being conducted by TfL in relation to the scheme. It sets out conditions and trends applying prior to the start of the scheme, providing a 'baseline' against which scheme impacts can be set. It also provides some initial feedback on the operational performance and impacts of the scheme following the launch of the first phase in February 2008.

What is the London Low Emission Zone scheme and what will it help to achieve?

- The London Low Emission Zone scheme is a key part of the Mayor of London's Air Quality Strategy. It is designed to reduce the emissions of harmful pollutants from road traffic in London and, in conjunction with a wider range of related air quality improvement initiatives, to help London move towards achievement of UK and European air quality objectives.
- Studies have shown that diesel-fuelled goods and service vehicles (vans, lorries, buses and coaches) are responsible for disproportionate amounts of the total road traffic emission of fine particulate matter (PM_{10}). By progressively reducing emissions from this source, the scheme aims to deliver air quality and public health benefits.
- The scheme works by requiring operators of these vehicles in London to meet minimum emissions standards, defined with reference to the 'Euro' emissions standards, from certain specified dates. The scheme has four 'phases', the first of which applied to heavy goods vehicles of over 12 tonnes maximum gross vehicle weight and was effective from 4 February 2008.
- A second phase of the scheme, affecting buses, coaches and medium or heavy goods vehicles of between 3.5 and 12 tonnes maximum gross vehicle weight, came into effect on 7 July 2008.

- A third phase, effective from October 2010, will affect light goods vehicles and vans of up to 3.5 tonnes gross vehicle weight and also minibuses.
- A fourth phase, from 2012, will involve the further tightening of the established emissions standards for heavy goods vehicles, buses and coaches.
- From the date of each individual phase of the scheme, operators of affected vehicles in London will be required to ensure that their vehicle meets the Euro III emission standard for particulate matter (and the Euro IV standard for heavy goods vehicles, buses and coaches from 2012). If this is not the case, then operators of non-exempt vehicles that do not comply with the requirements of the scheme will be subject to a daily charge of £200 (£100 for vans and minibuses).
- This amount is set so as to encourage operators to take steps to make their vehicles compliant and hence deliver air quality benefits, rather than to continue to operate non-compliant vehicles in London on anything other than a very occasional basis.
- The London Low Emission Zone scheme will not entirely solve London's air quality problems on its own. Indeed, it is estimated that some locations in London would still occasionally exceed the daily limit values for PM_{10} even if all road traffic were removed from the metropolitan area. This reflects the complexity of the physical and chemical interactions that determine local pollutant concentrations in the atmosphere – 'air quality' as conventionally recognised – and the contribution to London's air quality of pollution from outside London and the UK.
- Nevertheless, it is expected that the London Low Emission Zone will ultimately address, and reduce in magnitude, the approximately 30 percent of the total road traffic emissions of PM_{10} in Greater London that arise from vehicles that are subject to the scheme. There are also expected to be net beneficial effects on other pollutants such as oxides of nitrogen (NO_X).
- In doing this, the scheme is projected to reduce total road traffic related emissions of PM_{10} in Greater London by 2.6 percent in 2008, and by up to 6.6 percent in 2012. Although these expected reductions are small in absolute terms, the consequent air quality and health benefits should be proportionately greater, owing to the complex nature of the relationship between emissions change and air quality and health change. Furthermore, the beneficial impact of the scheme will be concentrated in central London and close to busy roads – locations where levels of pollution tend to be the greatest, and where many people are exposed to its effects.
- In this way, TfL expects the scheme to reduce the area of Greater London that exceeds the (nominal for 2010) annual mean air quality objective for PM_{10} of 23 μg m^{-3} by about 5.8 percent in 2008, assuming full implementation of the first two phases of the scheme. The equivalent reduction to the area of Greater London that exceeds the annual mean NO_2 objective, reflecting reductions to emissions of NO_X, is 5.0 percent.
- By reducing emissions and improving air quality the scheme is expected to deliver substantial benefits to the health of Londoners. It is estimated that poor outdoor air quality was directly responsible for up to 1,000 premature deaths in London in

2005. Many more people suffer exacerbated symptoms that reduce their quality of life.

- Projections of the impact of the scheme on public health over an illustrative ten-year period suggest that approximately 5,000 years of life that would otherwise be lost would be regained. In simple terms, people who would otherwise die prematurely as a result of poor air quality would gain additional life expectancy. In addition, lower levels of illness would deliver widespread benefits in terms of fewer 'restricted activity days' – a reduction of about 250,000 such days over the ten-year period. There would also be in excess of 300,000 cases where respiratory symptoms that would otherwise be more acute are reduced in severity.
- These health benefits can also be valued in monetary terms. Using two alternative methodologies for quantifying the value of health benefits (Defra's recommended Inter Governmental Cost Benefit method and the European Union CAFÉ method), TfL estimates, respectively, that they lie in the range £70m to £110m (Defra's recommended method), and £160m to £420m (CAFÉ method). These values relate to the area of Greater London only.
- The scheme will also have implications for air quality more widely in Great Britain outside London. While there could be some localised negative effects as some vehicle operators re-deploy the older vehicles in their fleet to work outside the zone, these are expected to be more than offset by the beneficial effect from vehicles that have been upgraded to meet the requirements of the London scheme. Such vehicles, typically operating large distances on the national motorway network, will contribute to reducing emissions outside Greater London.
- Using the same health impact valuation methodologies set out above, TfL estimates that the scheme will deliver net benefits of between £70m and £100m (IGCB method), or between £90m and £250m (CAFÉ method) in the rest of the UK outside Greater London.

Why is TfL monitoring the impacts of the scheme and what are the key benefits and limitations of this work?

- The London Low Emission Zone is a new scheme and is intended to have significant beneficial effects. It is important that these effects are measured and thoroughly understood, both to verify that the scheme is working as intended, and also to contribute insights to the development of future transport and air quality policies.
- Accurately quantifying the expected key impacts of the scheme will nevertheless be challenging. Outdoor air quality is affected by a wide range of factors, and the scheme only addresses a small proportion of these, albeit a proportion that is both significant and that can be tackled by local action.
- These 'external' factors include 'background change' to the vehicle fleet. This is the natural process of renewal as older vehicles become life expired and are replaced by newer ones which conform to the latest Euro emission standards. The scheme aims to **accelerate** this process in respect of the most heavily

polluting vehicles, but there will be parallel and ongoing changes to other vehicles, such as cars, that are not affected by the scheme.

- In assessing these scheme-related effects and isolating them from wider background changes, TfL has developed innovative assessment methods that break new ground in traffic and air quality science.
- For example, the cameras that TfL has put in place across Greater London to monitor the scheme provide – for the first time – an 'observed profile' of the emissions performance of vehicles actually operating in the zone, as opposed to projections based on national (licensed) vehicles.
- In addition, innovative use of air quality monitoring equipment should allow much better characterisation of the relationships between measured pollutant concentrations and local road traffic than has hitherto been possible.
- In pursuing these initiatives, TfL aims to contribute to the wider scientific effort of the air quality community. However, much of this work is necessarily exploratory in nature and TfL has not yet completely assimilated the full picture shown by these new data. The findings from the work so far should therefore be regarded with a degree of caution at this early stage in the monitoring of the scheme.

How is TfL monitoring the impacts of the scheme?

- Conceptually, the key impacts from the scheme are visualised in terms of a hierarchy.
- The scheme is expected to cause a **primary change** to the emissions performance of potentially affected vehicles operating in Greater London.
- This will lead to **secondary impacts** on emissions and air quality, and to **compliance costs** for affected road transport operators.
- These, in turn and in proportion, should lead to **tertiary impacts** such as improved public health and implications for the economy.
- Primary impacts are the most immediately measurable. Secondary impacts can generally be estimated with a high degree of confidence based on the observations of the primary change. Tertiary and other impacts are generally less easily measured and may take some time to become fully apparent, although are nevertheless important. These ideas underlie the design of the monitoring work.
- The following paragraphs outline the scope of each of the key elements of the monitoring work.

Establishing the population of vehicles affected by the scheme

- The **total volumes of the vehicles** affected by the scheme, in terms of measurements such as unique vehicles affected and vehicle kilometres operated per year inside Greater London, define the 'population of interest' for this work and underlie the quantitative estimates of scheme impacts.
- TfL has therefore utilised available traffic trend data from across Greater London to establish the 'base populations' of vehicles that will be affected by the scheme, and will ensure that changes to traffic volumes or composition by

vehicle type, either in relation to the scheme or for external reasons, such as fuel prices, are taken into account.

Measuring the emission characteristics of vehicles in Greater London

- Having established the 'vehicle population of interest', the key monitoring task is to establish the emissions characteristics of these vehicles, in terms of Euro emissions standard, and measure how this profile changes over time in relation to the various phases of the scheme.
- TfL is adopting an innovative approach using semi-permanent number plate reading cameras, located across Greater London to be representative. These cameras detect a sample of the vehicles of interest and TfL can then assign a Euro emissions standard to each vehicle using a process similar to that used to enforce compliance with the scheme. These cameras operate continuously, taking full account of data protection principles, and provide around 40 million individual observations per year.
- In this way, TfL can obtain 'measured' indicators of the emissions profile of vehicles operating in Greater London – data that has not until now been available. Because previous assessments as used in air quality models have been based primarily upon national fleet profiles, the new measured data will not correspond exactly to that previously used.
- An important methodological step, therefore, is to align the resulting modified 'base case' monitoring measurements (conditions in the absence of a scheme) with previous projections of the scheme impacts made by TfL, and to account for any differences.
- During this first year of the monitoring work, TfL has focused on those vehicles of most direct interest for estimating scheme impacts. In due course, however, these cameras are expected to offer wider and valuable new insights into traffic characteristics in Greater London.

Estimating the impact of the scheme on emissions from road traffic

- Having established the emissions profile of vehicles of interest operating in Greater London, the next step is to translate these profiles into quantified estimates of emissions of key pollutants. TfL is adopting standard methodologies based on the London Atmospheric Emissions Inventory for this element of the work.
- An emissions inventory is a database detailing emissions to the atmosphere from all identifiable sources across Greater London. This includes road traffic as well as a wide variety of other polluting activities, such as industrial and domestic energy consumption.
- By manipulating the components of the emissions inventory it is possible to represent changes to the emissions profile of the vehicle fleet, both those reflecting the immediate impact of the scheme but also wider 'background' changes. It is also possible to represent and separately account for changes to emissions that are unrelated to the scheme. For example changes to cars and taxis, which are not affected by the scheme but will nevertheless change as a

proportion of the fleet is renewed from year to year, and changes to emissions from other non-traffic activities.

- In this way the emerging impacts of the scheme can be quantified through successive 'emissions scenarios', and set against separate quantifications of the impact of all other 'non-scheme' changes.

Assessing the impacts of the scheme on air quality

- Having obtained quantified estimates of the emissions change, both attributable to the scheme and unrelated to it, TfL will use a standard air quality model to estimate the impact of the observed emissions change on ambient air quality across London. In this way, the impact of the scheme on the quality of outdoor air breathed by Londoners can be estimated.
- In using both the emissions inventory and air quality model for this work, TfL is again breaking new ground. Despite having been widely and successfully used for air quality assessment in London over a long period, the tools available are not entirely optimal for assessing some of the more subtle impacts of the scheme. An example is the secondary effects on emissions of other pollutants that can be introduced from measures to tackle emissions of PM_{10} – for example, retrofitting of pollution abatement equipment to vehicles.
- In parallel with this work, TfL is also taking forward research to further explore some of these issues. Insights gained will be used to selectively modify the emissions and air quality assessment tools for the scheme, where this can be done robustly. These insights will also be made available to the wider air quality community in due course.
- A key advantage of this approach is that it is possible to isolate effects that can be attributed to the scheme from the diversity of other factors all affecting air quality at the same time – year-to-year variability in the weather being an important example.
- A key disadvantage is that it produces synthetic estimates of air quality impacts that, although based on observed vehicle data, will not correspond directly to trends in measured air quality. A parallel approach looking at measured air quality trends is therefore required.

Trends in measured air quality

- These measurements, as produced by the 100 or so air quality monitoring sites across Greater London comprising the London Air Quality Network, will be the first point of reference for stakeholders assessing the air quality impacts of the scheme and are the legal basis for assessing compliance with UK and European air quality objectives.
- TfL is therefore assembling data from these sites and using statistical tools to detect trends – both in general terms and to ultimately identify those that may be attributable to the scheme.
- Data from these sites going back to year 2000 will provide a robust baseline for assessing future developments. However, it is already evident that recent trends, such as increased primary nitrogen dioxide (NO_2) from diesel-engined road

vehicles, and perturbations caused by the weather, will complicate the assessment of future trends.

- To arrive at a robust appreciation of the air quality impacts of the scheme, it is therefore necessary to use both modelled and observed air quality change data in combination. It is quite possible, for example, that measured air quality in the first year of the scheme could actually deteriorate, despite models indicating improvements. This might reflect a particularly hot summer, as happened for instance in 2003 and 2006.
- More likely, however, is that trends attributable to the scheme will be obscured by variation in all of the other factors affecting measured air quality, and that it will take a year or more before a 'scheme impact' becomes statistically detectable in the measured air quality data.

Enhanced air quality monitoring sites

- Aggregate analysis of air quality trends across London will not reveal the more detailed nature of scheme impacts. Furthermore, because the impacts of the scheme will be most effective in locations that experience high levels of pollution – in central London and alongside major roads – area wide averages will not reveal the true extent of 'exceedences' of air quality objectives, or the changes from the scheme that are expected to be most pronounced in these locations.
- TfL has therefore enhanced six existing air quality monitoring sites specifically for the monitoring work. These are established sites close to major roads in locations where the design work for the scheme suggested the biggest change would be experienced. A completely new site has also been established at the northern approach to the Blackwall tunnel.
- These enhanced monitoring sites have a full array of pollution monitoring equipment, TfL having supplemented where necessary the existing equipment at each site. Comprehensive traffic monitoring is also provided, with continuous automatic traffic counters and number plate reading cameras, together with a local meteorological station.
- Although these enhanced air quality monitoring sites are specifically placed in locations where the impacts of the scheme are likely to be most visible, their primary purpose is not to 'detect' an impact from the scheme. Rather, they will allow TfL to examine the detailed nature of the relationships between different pollutants, in conjunction with the changing characteristics of road traffic directly adjacent to the monitoring site.
- These sites are operated as part of the London Air Quality Network and data from them will be published on the London Air Quality Network website.

Impacts outside Greater London

- An important dimension to this work is the potential emissions and air quality impacts of the scheme outside Greater London. This reflects the fact that vehicles are not confined to Greater London, and improvements to their emissions performance will also deliver benefits when they operate elsewhere.
- Partly offsetting these benefits is the possibility that a proportion of operators of older vehicles that are not compliant with the requirements of the scheme may

divert these vehicles to operate outside London, thus avoiding the scheme. To tackle these issues TfL has extended certain elements of the monitoring work outside Greater London.

- The net effect of these changes is nevertheless expected to be significantly positive, the health benefits of the scheme outside London being potentially comparable in aggregate to those achieved inside London, although at a correspondingly lower level of intensity.
- Periodic camera-based measurements of the emissions profile of vehicles potentially affected by the scheme operating outside London will be made. Sample locations include the immediate surrounding area of London and the M25 motorway, but measurements are also being taken in several other locations remote from Greater London that should not be directly affected by the scheme.
- In a similar way, TfL will analyse measured air quality trend data from other urban locations such as Greater Manchester and Paris, so that observed scheme-related trends in Greater London can ultimately be distinguished from unrelated national and regional trends in air quality.
- Once sufficient observed data from outside London is available, TfL will use the framework provided by the National Atmospheric Emissions Inventory to produce quantified assessments of the emissions and air quality impacts of the scheme outside London – which are expected to be positive overall.

Impacts on public health

- The ultimate objective of the scheme is to contribute to improved public health by reducing the significant amount of mortality and morbidity in London arising from poor air quality. However, these outcomes are the least amenable to direct measurement.
- This reflects the wide range of non-scheme factors affecting trends in public health – for example the recent public places smoking ban; and the typically lengthy timescales required for the expression of health effects.
- Therefore, in the medium term, TfL is taking an estimation approach based on re-calibration of established health impacts forecasting models, using observed data on air quality change arising from the wider monitoring work.
- Exploratory studies will consider trends in primary and acute health incidents, and will also include a case study looking at respiratory health in a cohort of schoolchildren from across Greater London.

Impacts of the scheme on vehicle operator costs, business and the economy

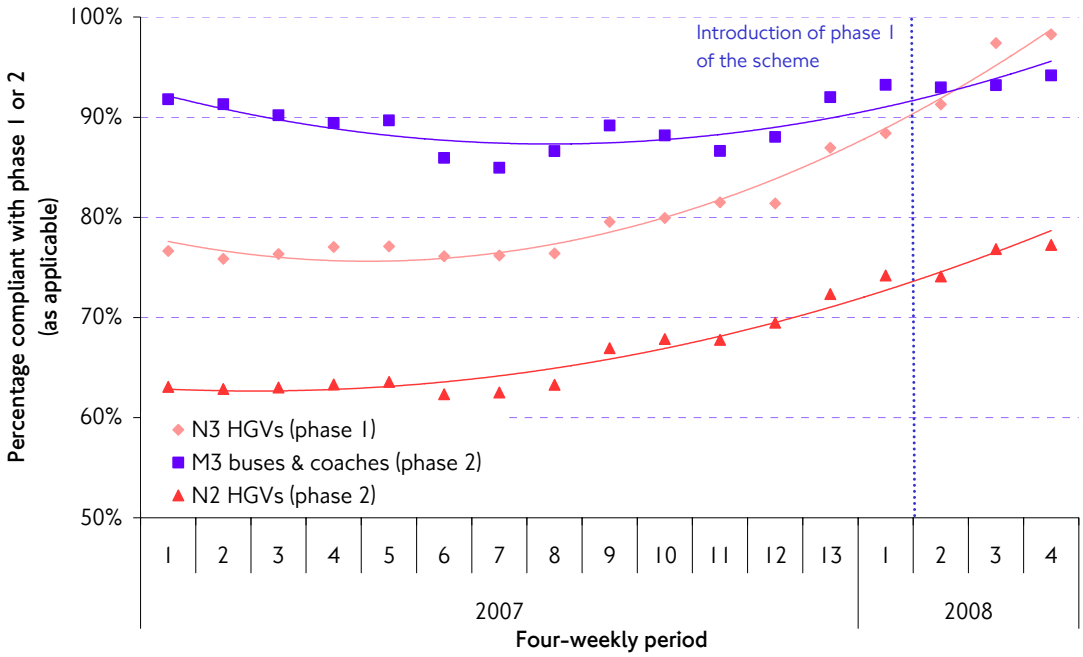
- The scheme will impose additional costs on business, as a proportion of vehicle operators will need to take steps to comply with the requirements of the scheme. Typically, this could involve purchasing newer vehicles or fitting pollution abatement equipment to existing vehicles.
- Some of these actions would be expected to occur in the normal course of events, as vehicles reach life expiry. The scheme will nevertheless have the effect of 'bringing forward' these costs for some operators.

- TfL has quantified these 'compliance costs' and their consequent impact on the UK economy in its Business and Economy Impacts Assessment, as part of the scheme design process. These pre-scheme forecasts were partly based on data describing the structure of the UK haulage fleet and on various vehicle operator surveys. The overall compliance costs of the scheme are significant.
- In future monitoring work, TfL will use observed data on how the profile of the vehicle fleet changes in response to the scheme to re-estimate compliance costs based on observed data. TfL will also undertake additional surveys of operators to gain feedback as to how they have responded to the requirements of the scheme.
- Official national statistics relating to the road haulage industry will provide a view of background trends affecting the industry. These will be important in separating any scheme effects from wider trends, such as the recent increase in fuel prices.
- A focus of this work will be those operators who may be disproportionately affected by the scheme, so that the nature of any adverse impacts can be properly understood by TfL.
- The monitoring work will therefore, in future assessments, be able to assess the outturn impacts of the Low Emission Zone on vehicle operators and on the economy more widely.

How have the first phases of the scheme settled down, and what are the initial findings from the monitoring work?

- The first phase of the scheme affected heavy goods vehicles of 12 tonnes or more maximum gross vehicle weight. From 4 February 2008, all vehicles of this type operating within the area covered by the scheme and not subject to an exemption were required either to meet the Euro III emissions standard or higher for particulate matter – or to pay a daily charge of £200.
- Prior to the introduction of the scheme, TfL put in place an extensive public and vehicle operator information campaign. This was designed to make vehicle operators aware of the coming requirements from the scheme. It also provided information to those operators who needed to take action in respect of the scheme and the options available to them.
- During 2007 TfL also established the key operational infrastructure of the scheme. This included appropriate signage and enforcement cameras, to establish the emissions performance of vehicles operating in the zone. Internet and call centre arrangements were set up, and certification processes established whereby vehicle operators who had chosen to fit pollution abatement equipment to existing older vehicles could be recognised by TfL as complying with the requirements of the scheme.
- The thorough preparation work undertaken by TfL was reflected in a trouble-free implementation period, and the scheme continues to function well.
- TfL's camera-based monitoring of the emissions profile of vehicles in London has provided robust evidence of the success of the first phases of the scheme. As is shown in the figure below, April 2008 saw a 98 percent compliance rate with the requirements of the first phase of the scheme-based on vehicle kilometres operated. In terms of unique vehicles seen within the zone (ie at least once), the compliance rate was 96 percent.

Trend in scheme compliance during 2007 and into 2008. Vehicle kilometre based estimate, phases 1 and 2 of the scheme, automatic number plate recognition camera data.



- When allowance is made for the small proportion of operators whose vehicles are exempt, who attempt evasion or who pay the daily charge, virtually 100 percent compliance with the first phase of the scheme has been achieved.
- This compares to an equivalent rate of only 70 percent during 2007. This means that about one-third of the heavier goods vehicles operating in Greater London are significantly cleaner than they were one year ago, and that London is already benefiting from reduced emissions.
- The graphic clearly shows an accelerated trend of compliance during 2007, as vehicle operators took action ahead of the actual implementation date for the first phase of the scheme. A similar trend is also seen for vehicles in-scope for phase 2 of the scheme from July 2008.
- This meant that the majority of the impacts from the first phase of the scheme had in fact been realised ahead of the actual implementation date.
- The graphic also shows very encouraging trends ahead of the implementation of phase 2 of the scheme, from 7 July 2008. The per-kilometre compliance rate for buses and coaches was typically 95 percent in spring 2008, while that for medium goods vehicles of between 3.5 and 12 tonnes was around 80 percent, although trending upwards steeply.
- Based on these trends, TfL estimates that, as at the end of 2007, this 'operator pre-compliance' with the requirements of the scheme had already delivered – during 2007 – about one-half of the changes to vehicles and emissions that TfL ultimately expects from phases 1 and 2 of the scheme during 2008.
- Initial findings in relation to the London Low Emission Zone scheme are therefore encouraging. TfL will continue to monitor developments closely and report progress at appropriate intervals.

1. Introduction

1.1 Background

This report describes the monitoring work that is being undertaken by Transport for London (TfL) to assess and understand the impacts of the London Low Emission Zone scheme.

The scheme is intended to improve air quality and ultimately public health by encouraging improvements to the emissions performance of heavier vehicles (goods vehicles, buses and coaches) travelling in London. As a key part of wider policies being pursued by the Mayor of London as set out in his Air Quality Strategy[1], the London Low Emission Zone is expected to help London work towards achieving European limit values for air quality and the UK national air quality objectives. The first phase of the London Low Emission Zone was introduced successfully on 4 February 2008. Monday 7 July 2008 saw the successful introduction of the second phase of the scheme.

1.2 Purpose of this report

This report is one of a series of monitoring reports and updates being produced by TfL looking at specific schemes and policies arising from the work programme associated with the Transport and other Strategies of the Mayor of London.

The focus of this particular report is twofold.

- Firstly, it describes the monitoring work being put in place by TfL to ensure that the impacts of the London Low Emission Zone scheme are comprehensively measured, assessed and understood.
- Second, it identifies and summarises key trends in traffic characteristics, air quality and other factors such as business trends in the road haulage sector that are likely to be affected by the scheme. It establishes a 'baseline' of data characterising conditions before the introduction of the scheme, against which observed changes following introduction can be assessed.

It also provides feedback on some early results from the first phase of the scheme, affecting heavy goods vehicles over 12 tonnes maximum gross vehicle weight, reflecting developments over the spring of 2008.

1.3 Why monitor?

Large-scale road traffic schemes such as the London Low Emission Zone are intended to have significant beneficial impacts. Nevertheless, they do attract a certain amount of controversy. Although TfL takes great care to ensure that all of the significant consequences of the schemes are understood and quantified beforehand as part of the scheme design process, there is still the possibility that actual impacts could differ from those projected, or that specific adverse or disproportionate impacts could arise. Furthermore such novel schemes provide wider learning

opportunities to assist with the development of future transport and environmental policy.

The monitoring work associated with these schemes will therefore help the Mayor, TfL and other interested parties to more fully understand their effects by providing an evidence base. It will also provide much of the information that will enable the Mayor and stakeholders to assess the performance of the schemes, and whether adjustments to them should be considered in the future.

Monitoring the London Low Emission Zone is guided by a series of **key principles**:

- The monitoring work should detect and robustly characterise the key impacts of the scheme. These results will be compared against expected impacts.
- The monitoring should allow unexpected or unanticipated effects to be detected and further examined if necessary.
- The monitoring should seek to understand as well as measure.
- The scope of the monitoring should reflect legitimate stakeholder needs and concerns and contribute to wider scientific understanding of the air quality science associated with the scheme.
- The monitoring effort should be proportionate and provide good value for money.

1.4 Organisation and orientation of the monitoring work

The monitoring programme for the London Low Emission Zone has been designed and will be managed by a team of permanent TfL staff, with independent contractors undertaking most of the main data collection elements. Where possible, advantage has been taken of key existing third party data sources or monitoring programmes, as these provide both ready-made historical datasets and also give a degree of transparency and objectivity to the work.

Thus, the work fits into the wider context of air quality assessment and research in London. It reflects techniques commonly used in Air Quality Reviews undertaken by the London boroughs, co-ordinated and long-standing air quality monitoring programmes such as that of the London Air Quality Network, and tools such as the London Atmospheric Emissions Inventory (LAEI) and related Air Quality Toolkit, sponsored by the Greater London Authority. Insights gained from this work will be made available to the wider air quality community in due course.

The general scientific basis for understanding the air quality impacts of the scheme is not entirely complete in some respects, and in recognition of this, the monitoring work includes a significant component of original research work, directed to illuminate particular topics that are essential to fully understand scheme impacts. This work is intended to complement the efforts of the wider scientific community to further understand aspects of air quality science, although some areas of imperfect knowledge in relation to scheme impacts will nevertheless ultimately remain.

1.5 Contents of this report

The remainder of this report summarises the key elements of the monitoring programme for the London Low Emission Zone scheme.

- **Section 2** provides an overview of the scheme itself; the emissions standards being applied and a summary of the expected impacts. More detailed information can be found on the TfL website[2].
- **Section 3** provides essential orientation to the monitoring work, with the range of impacts of the scheme organised in terms of an 'impact hierarchy', each subsequent chapter dealing with one key element of this hierarchy. It also considers the scientific basis for the assessment of scheme impacts, and highlights some of the key scientific limitations associated with this work.
- **Section 4** identifies the key vehicle populations affected by the scheme, and looks at recent trends in aggregate vehicle numbers and traffic composition in London. It also identifies the contribution of the 'vehicle populations of interest' to air pollution.
- **Section 5** considers the impacts of the scheme on the emissions performance of vehicles in Greater London, focusing on changes to those vehicles that will be directly affected by the scheme, and providing the primary 'observed change' data for the subsequent stages of the monitoring work. It introduces new data which measures the emissions performance of vehicles operating in London using cameras.
- **Section 6** looks at how this new information on the emissions performance of the vehicle fleet in London is being used to quantify the changes to the emissions of key atmospheric pollutants resulting from the scheme. It presents baseline estimates of emissions for the year before the scheme, including an assessment of the beneficial impacts of 'pre-compliance' by vehicle operators with the requirements of the scheme ahead of the actual implementation date.
- **Section 7** takes this assessment one stage further, in describing how estimates of the emissions changes resulting from the scheme are being used to derive detailed, quantified model-based assessments of the impacts of the scheme on air quality, ie the concentration of key pollutants in outdoor air breathed by Londoners.
- **Section 8** looks at the air quality impacts of the scheme from the point of view of observed measurements of pollutant concentrations, drawing on the widespread and long-standing monitoring work undertaken by the London Air Quality Network and London boroughs. This section provides a complementary view of scheme air quality impacts to that provided by Sections 5 through 7.
- **Section 9** considers measured air quality change at a more local scale, focusing on scientific research designed to allow TfL to better understand the processes underlying the expression of the air quality impacts of the scheme. It draws primarily on emerging information from seven high-specification air quality monitoring sites that have been developed specifically for this work.

- **Section 10** considers the impacts of the scheme outside Greater London. The changes to vehicles, emissions and air quality associated with the scheme are expected to have wider although less intense implications outside London. This is taken into account by the extension of key elements of the monitoring work to consider relevant trends and the air quality implications for the rest of Great Britain.
- **Section 11** considers how the air quality impacts of the scheme can ultimately be translated into an assessment of the impacts on public health.
- **Section 12** considers the economic and business impacts of the scheme, focusing on the costs of compliance to vehicle operators and the wider economic implications for the various road transport sectors.
- **Section 13** characterises aspects of both TfL and vehicle operator preparation during the run-up to the implementation of the scheme during 2007. It also reviews emerging data on the early impacts of the scheme, reflecting the first three months or so of operation following implementation of the first phase of the scheme on 4 February 2008.

1.6 The wider scientific and technical backdrop and the level of presentation for this report

This report is aimed at a general informed readership including stakeholders, air quality practitioners and the wider public. The material it deals with involves technical issues – the details of which cannot be fully articulated in a report of this nature.

This report therefore aims to present material at a level of detail that is likely to be most generally understood. Technical appendices to the report, published on the internet only[3] set out selected technical issues in greater detail than is possible in the main text, and readers are directed to these where appropriate. TfL is conscious, however, that specialist readers will require more detail on certain aspects of the monitoring work and, furthermore, will want to be sure that TfL's work and assumptions take due account of the wider scientific literature and best practice. To reflect this, the report is comprehensively referenced throughout. This will allow readers with particular interests to follow up aspects of the work as required.

A general consideration underlying the monitoring work for the scheme will be the diversity of other factors affecting air quality, public health and the economy. Consequently, it may be difficult to isolate effects and trends that are specifically due to the scheme. Over time, however, it is hoped that the material set out in this report and the work underlying it will build in to a comprehensive 'evidence base' from which a robust assessment of scheme impacts can be made.

2. Outline of the London Low Emission Zone Scheme

2.1 Introduction

This section outlines the main elements of the London Low Emission Zone scheme, prior to a more detailed consideration of the impacts monitoring work that is associated with the scheme. Full details of the scheme can be found on TfL's website[1].

2.2 Why a London Low Emission Zone?

Despite improvements in recent years, London's outdoor air pollution is the worst of any city in the UK and among the worst in Europe. Levels of two key pollutants – particulate matter (PM_{10}) and nitrogen dioxide (NO_2) – currently fail to meet national[2] and European[3] air quality objectives, particularly close to busier roads. High levels of air pollution can adversely affect the health and quality of life of a large number of Londoners[4].

Local authorities in Greater London have an obligation to work towards National and European air quality objectives. In 2003, London authorities along with the UK Government's Department for the Environment, Food and Rural Affairs (Defra) and Department for Transport (DfT), produced a joint feasibility study that investigated a range of options for a Low Emission Zone to address air quality in London[5]. Of the options considered, a zone that covered the whole of Greater London emerged as potentially the most effective in terms of making a difference to outdoor air quality.

A Low Emission Zone would target pollution from road traffic – one of the key contributors to poor outdoor air quality in London. The scheme would work by imposing area-wide minimum emissions standards on vehicles – targeting older, heavier diesel-fuelled vehicles that produce the most pollution. By substantially reducing emissions from these sources, a scheme of this nature could potentially deliver worthwhile overall air quality benefits, and contribute significantly to the wider suite of policies outlined in the Mayor's Air Quality Strategy[6].

2.3 Development of the current scheme

In 2005, following instruction from the Mayor of London, TfL completed a review of the 2003 Feasibility Study and concluded that a London Low Emission Zone, along the lines of that proposed in the study, would be the best option for improving outdoor air quality in London over the short to medium term[7]. TfL was then tasked by the Mayor with taking the development of the scheme forward.

Initial proposals for a Low Emission Zone scheme in London were published by TfL for public and stakeholder consultation in January 2006, in the form of proposed revisions to the Mayor's Transport and Air Quality Strategies[8]. The Mayor confirmed these revisions with minor amendments in July 2006. Detailed proposals for the current scheme were published for consultation by TfL in the form of a Scheme Order[9] in November 2006. Following consideration of responses received as part of the consultation and some further minor changes to the scheme proposals, TfL

reported to the Mayor of London[10], who then publicly confirmed the proposals on 3 May 2007[11].

2.4 Key elements of the London Low Emission Zone scheme

The London Low Emission Zone covers the large majority of Greater London, within which the most polluting diesel-engined heavy vehicles are required to meet specific minimum exhaust emissions standards. If they do not meet these standards and they travel within the zone, they are required to pay a daily charge. This charge is set at a level so as to discourage more than very occasional presence in the zone by vehicles that do not meet the minimum emissions standards.

The current scheme consists of four **phases**, the first two of which have now been successfully introduced – on 4 February and 7 July 2008.

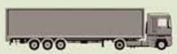
- **From 4 February 2008**, the specified minimum emissions standards have applied to diesel-engined lorries over 12 tonnes in weight. This requirement is referred to as **'phase 1'** of the scheme in the remainder of this report.
- **From 7 July 2008**, these requirements were extended to all lorries over 3.5 tonnes, as well as to buses and coaches. This requirement is subsequently referred to as **'phase 2'**.
- **From October 2010**, larger vans and minibuses will also be covered by the scheme. This requirement is subsequently referred to as **'phase 3'**.
- **From January 2012** the minimum emissions standards applying to vehicles affected by phases 1 and 2 will be tightened. This requirement is subsequently referred to as **'phase 4'**.

For vehicle operators to operate within the zone without paying the daily charge, their vehicles must meet a minimum exhaust emission standard. These standards are based on the **Euro Standards**, which are a set of requirements that define the acceptable limits for exhaust emissions for new vehicles purchased in member states of the European Union. The minimum Euro Standards applicable to the London scheme are:

- **From February 2008**, a minimum standard of **Euro III** for particulate matter (PM) for Heavy Goods Vehicles (HGVs) over 12 tonnes in weight. These are also referred to as **'N3'** goods vehicles.
- **From July 2008**, a minimum standard of **Euro III** for PM for goods vehicles between 3.5 and 12 tonnes in weight (also known as **'N2'** vehicles), and for buses and coaches (known as **'M3'** vehicles).
- **From October 2010**, a minimum standard of **Euro III** for PM for heavier Light Goods Vehicles (LGVs) and minibuses.
- **From January 2012**, the minimum standard will be tightened to **Euro IV** for PM for goods vehicles over 3.5 tonnes, buses and coaches.

These requirements are illustrated by Figure 2.1. **Appendix 1** to this report provides a technical summary of the Euro emission standards.

Figure 2.1 Guidelines for vehicle compliance with the requirements of the London Low Emission Zone scheme.

Vehicle type and definitions		Date affected	Required emissions standards
Heavier lorries. Heavy diesel-engined vehicles exceeding 12 tonnes Gross Vehicle Weight, including goods vehicles, motor caravans, motorised horseboxes and other specialist vehicles.		4 February 2008 Euro III for PM 3 January 2012 Euro IV for PM	**All Euro III vehicles meet the LEZ standard.** From 4 February 2008 the LEZ emissions standard is Euro III for particulate matter (PM). Vehicles first registered as new with the DVLA on or after 1 October 2001 are assumed to meet this standard. Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro III standard for PM. Vehicles not meeting the LEZ emissions standards will need to pay a daily charge if used within the LEZ. **From 3 January 2012 the required emissions standards are raised to Euro IV for PM. All Euro IV vehicles will meet the LEZ standards in 2012.** Vehicles first registered as new with the DVLA on or after 1 October 2006 are assumed to meet this standard. Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro IV standard for PM. Vehicles which do not meet the LEZ emissions standards would need to pay a daily charge if used within the LEZ.
Lighter lorries. Heavy diesel-engined vehicles between 3.5 and 12 tonnes Gross Vehicle Weight, including goods vehicles, motor caravans, motorised horseboxes and other specialist vehicles.		7 July 2008 Euro III for PM 3 January 2012 Euro IV for PM	
Buses and coaches. Diesel-engined passenger vehicles with more than eight seats, plus the driver's seat, exceeding 5 tonnes Gross Vehicle Weight.			
Large vans. Diesel-engined vehicles between 1.205 tonnes unladen and 3.5 tonnes Gross Vehicle Weight and motor caravans and ambulances between 2.5 tonnes and 3.5 tonnes Gross Vehicle Weight.		4 October 2010 Euro III for PM	**From 4 October 2010 the emissions standard is Euro III for PM.** Vehicles registered as new with the DVLA on or after 1 January 2002 are assumed to meet this standard. Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro III standard for PM. Vehicles which do not meet the LEZ emissions standards would need to pay a daily charge if used within the LEZ.
Minibuses. Diesel-engined passenger vehicles with more than eight seats, plus the driver's seat, below 5 tonnes Gross Vehicle Weight.			

N.B. The vehicle weight is a good guide as to when your vehicle is affected by the LEZ. If your type of vehicle does not appear here you should use the weight limits used for lorries and large vans as a guide and/or contact your vehicle manufacturer or Transport for London for guidance.

The London Low Emission Zone covers almost all of the area of Greater London (see Figure 2.2). Vehicles of the types described above travelling on public roads within the zone are subject to the requirements of the scheme. The M25 orbital motorway is not included in the scheme, irrespective of whether it lies inside or outside the Greater London boundary. This therefore provides a viable 'diversionary route' around London for traffic whose ultimate origin or destination is not in an area covered by the scheme. Additionally, in some locations, the scheme boundary deviates from the Greater London Authority boundary in order to allow for suitable diversion routes or turnaround points.

The scheme operates continuously: 24 hours a day, every day of the year. The requirements of the scheme are enforced using Automatic Number Plate Recognition (ANPR) cameras; a proven technology that has also been successfully used for the enforcement of congestion charging in central London. These cameras 'observe' vehicles travelling on the road network, and compare observations with databases that establish whether or not the vehicle is compliant with the requirements of the scheme.

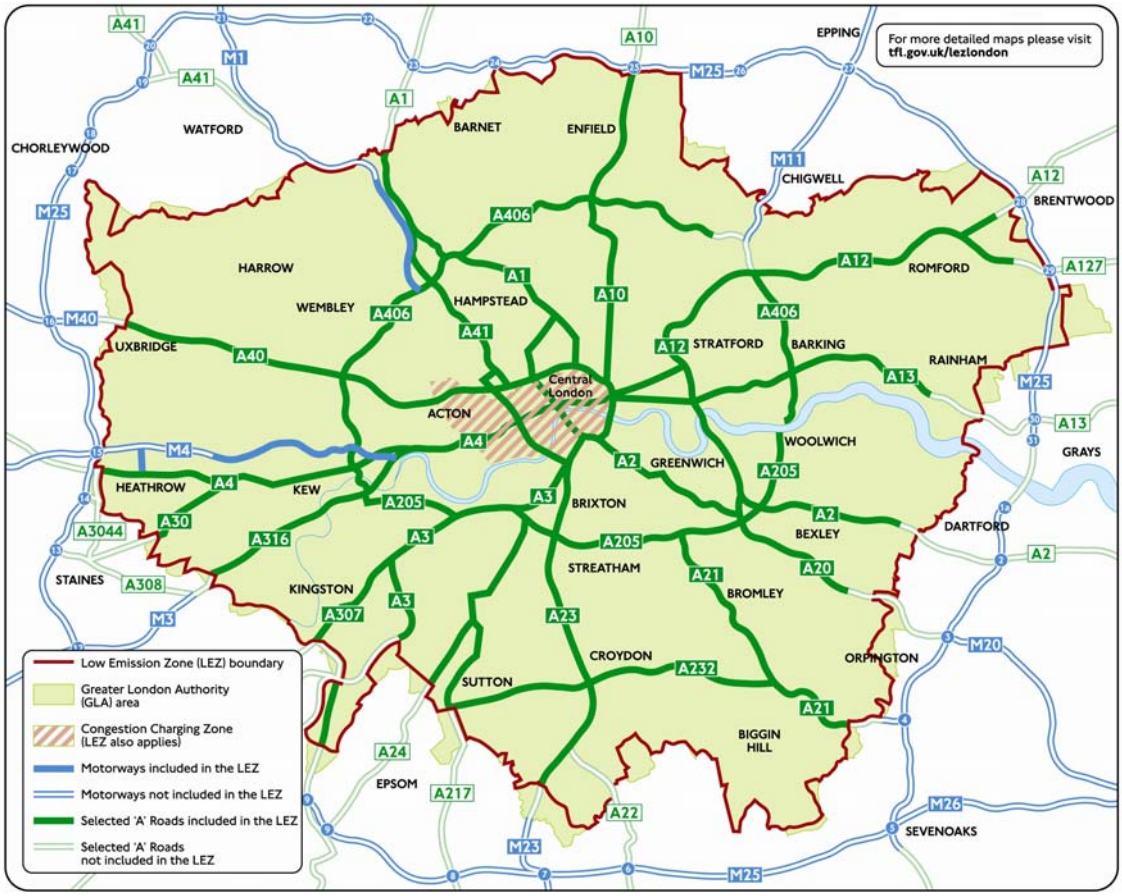
Vehicles that are not in-scope for the scheme (eg cars, lighter vans and motorcycles) will be unaffected. Vehicles that are in-scope according to the phased implementation timetable will be assessed for compliance by TfL. Vehicles in this category that are found to be compliant with the requirements of the scheme, or which have exempt or discount status, will be similarly unaffected. Exempted in-scope vehicles include UK registered military vehicles, UK registered historic vehicles and non-road going vehicles such as construction equipment. British and foreign registered Showman's Goods Vehicles need to register with TfL to receive a 100 percent discount.

Operators of vehicles that currently do not meet the requirements of the scheme have several options if they wish to drive within the zone. For example, they can purchase a newer vehicle that meets the required emissions standards; re-organise their fleet for journeys within the zone, modify their vehicles to meet the required standards, or pay a daily charge.

A daily charge of £200 is applied for non-compliant goods vehicles, buses and coaches and, from 2010, a daily charge of £100 will be applied for non-compliant light goods vehicles and minibuses that are in-scope for the scheme. Should an operator of a non-compliant vehicle not pay the daily charge on the day that it was incurred, or on the next working day, then a penalty charge applies. This is £1,000, reduced to £500 if paid within 14 days for heavy goods vehicles, buses and coaches; and will be £500, reduced to £250 if paid within 14 days, for light goods vehicles that are in-scope for the scheme, and for minibuses.

The London Low Emission Zone scheme is independent of the central London congestion charging scheme. Being compliant with the requirements of the London Low Emission Zone scheme does not affect the liability of a vehicle to pay the central London congestion charge for trips that take the vehicle into the extended central London congestion charging zone. Likewise, payment of the central London congestion charge does not affect the liability of a vehicle to comply with the requirements of the London Low Emission Zone.

Figure 2.2 The Greater London Low Emission Zone.



In Transport for London's Report to the Mayor in April 2007, following public consultation, scheme set-up costs were estimated at £50 million. Operating costs were estimated at £80 million (present value to 2015/16) while the scheme was estimated to generate £5m to £7m per year in revenues.

2.5 Overview of expected key impacts of the scheme

The key benefit arising from the scheme will be improved outdoor air quality, with improvements brought forward three to four years from when they would otherwise occur. The scheme will achieve this by reducing particulate matter (PM) and, to a lesser extent, oxides of nitrogen (NO_X) emissions from road traffic. It is expected that these benefits will bring London closer to achieving national[12] and European[13] air quality objectives. Net benefits are also expected to extend beyond the boundary of the zone, reflecting travel outside London by vehicles that comply with the requirements of the London scheme.

The following sections summarise the projections of scheme impacts that have been made as part of the scheme development process by TfL. However, it is important to note that they pre-date, and are separate from, the impact assessments described in the remainder of this report, which are based on observed data collected before and after the implementation of the actual scheme.

Emissions performance of vehicles travelling in London

TfL carried out a vehicle fleet operator survey in 2006[14] which generally corroborated indications from vehicle licensing data. This showed that, at that time and without any change in fleet management practices, roughly one-third of heavier goods vehicles and one-quarter of lighter goods vehicles would not – as a matter of course – be expected to be compliant with the respective requirements of the scheme by the relevant phase implementation date.

The 'natural' background process of vehicle technology development and the year-on-year renewal of the vehicle fleet would be expected to further reduce these levels of non-compliance over time, since newly-purchased vehicles would automatically be compliant with the relevant Euro emissions standard (and in many cases would reflect a Euro standard higher than the minimum required for compliance with the scheme). However, without further action, there would still be a large number of disproportionately-polluting vehicles contributing to London's air quality problems.

The introduction of the scheme would be expected to reduce these levels of non-compliance significantly – albeit at a cost to vehicle operators – thereby 'bringing forward' the natural background fleet turnover. In practice, because of the operation of a small range of discounts and exemptions, and the daily payment option, absolute (100 percent) compliance with the requirements of the scheme would be unlikely to be achieved in the medium term. Furthermore, because retrofitting of pollution abatement equipment will be a common means of complying with the requirements of the scheme, not all 'newly-compliant' vehicles will perform to the latest Euro standards as would be the case with newly-purchased vehicles.

On the other hand, operators who acquire or re-deploy the very latest vehicles would deliver substantially greater air quality benefits than would be the case for vehicles meeting only the minimum Euro Standard to ensure compliance with the scheme. Projections of the impacts of the scheme on emissions and air quality can therefore be made on the basis of assumed vehicle populations that reflect a near-100 percent compliance with the scheme, together with assumptions about wider vehicle fleet and emissions trends in 2008 and beyond.

Concentrations of PM_{10} in the atmosphere

In terms of the air quality objectives and on the basis of these anticipated vehicle fleet and emission impacts, phases 1 and 2 of the scheme are projected to result in a reduction in the proportion of the Greater London land area where concentrations of PM_{10} exceed the daily PM_{10} air quality objective by around 7 percent in 2008[17].

Figure 2.3 Illustrative impact of the Low Emission Zone on concentrations of PM_{10} across Greater London (2012 with scheme compared to 2012 without scheme).

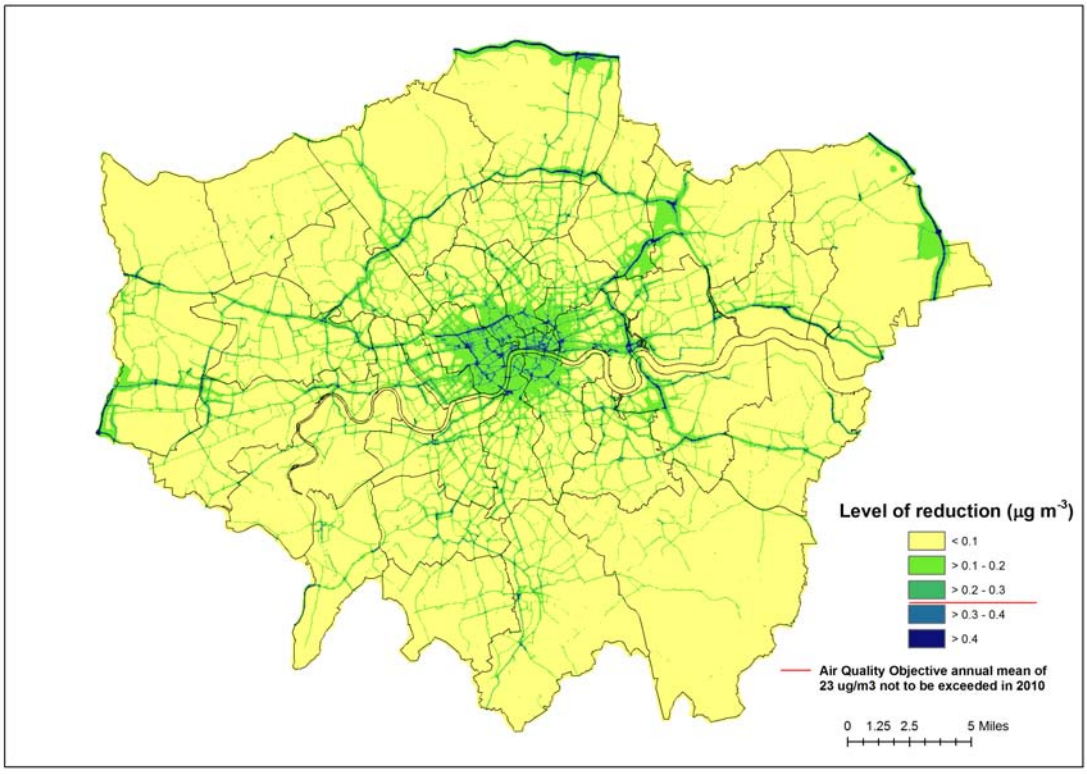


Figure 2.3 illustrates the general scale and nature of the projected impact of the scheme on concentrations of PM_{10} across Greater London. This illustration compares a 'business-as-usual' (no scheme) scenario for 2012 with conditions assuming implementation of all four phases of the scheme. Impacts are shown in terms of the degree of reduction to annual average PM_{10} concentrations expected from the scheme. The figure shows that:

- The beneficial effect of the scheme is widespread, albeit generally at relatively modest absolute levels. No parts of Greater London are projected to experience an adverse net impact from the scheme.
- The scale of the beneficial impact on PM_{10} concentrations increases in proximity both to central London and to individual major roads. The scheme therefore has the greatest impact where the air quality problems are most severe, and where the bulk of human exposure to poor outdoor air quality takes place.
- The M25 and some other sections of motorway within London are excluded from the scheme. However, these should experience reduced emissions and improved air quality overall, reflecting travel on roads that are not covered by the requirements of the scheme by vehicles that are nevertheless compliant with those requirements.

Emissions of particulate matter

Air quality and emissions modelling has indicated that the projected scheme impacts will result in a reduction in emissions of total road traffic PM_{10} in Greater London of just over 2 percent in 2008 and around 6 percent in 2012[15]. In considering these projected reductions, it is important to note that:

- They relate to emissions of PM_{10} from road traffic only. As shown in Section 4 of this report, road traffic PM_{10} accounts for about 70 percent of all primary PM_{10} emitted in Greater London. Changes to other sources of PM_{10} (the remaining 30 percent from sources such as industrial processes) are not included, and neither is the substantial contribution to typical ambient PM_{10} concentrations from secondary or imported PM_{10} (see Section 9).
- Around one third of the total 'road traffic' PM_{10} emission in London arises from non-exhaust sources, such as tyre and brake wear. These are not targeted specifically by the scheme and are therefore projected to remain substantially unchanged.
- Although these projected reductions are small in absolute terms, the air quality and health benefits should be proportionately greater. This is due to the non-linear relationship between emissions and air quality change, the concentration of the beneficial impacts of the scheme close to busier roads, and the differential impacts of the scheme on the various components of particulate matter emissions.

Improved public health

Poor outdoor air quality is recognised as a significant cause of poor health. It is estimated[16] that poor outdoor air quality is directly responsible for around 1,000 premature deaths in London annually. These are people who die earlier than would otherwise be expected, specifically as a result of either primary conditions caused by air pollution, or the exacerbation of pre-existing conditions. Moreover, many more people, particularly those with pre-existing heart or respiratory conditions, suffer exacerbated symptoms that reduce their quality of life. Improving public health is the primary motivation for the European and UK air quality objectives, and the London Low Emission Zone will contribute significantly to their achievement.

Projections of the scheme impact on health[17] over an illustrative ten-year period, using both the Defra's recommended Inter-Governmental Cost Benefit (IGCB) method[18] and the European Union Clean Air for Europe programme (EU CAFÉ) method[19] suggest that approximately 5,000 years of life that would otherwise be lost through poor air quality will be regained. In simple terms, some people who would otherwise die prematurely would gain additional life expectancy. In addition, lower levels of illness would deliver widespread benefits in terms of fewer 'restricted activity days' (about 250,000 over the same period) and there would be in excess of 300,000 cases where respiratory symptoms that would otherwise be more acute are reduced in severity. These projections are on a UK-wide basis, since the air quality impacts of the London scheme will have implications at the national level.

These benefits can also be valued in monetary terms, as shown in Table 2.1. The two sets of values refer to alternative methodologies for estimating and valuing the health benefits from the scheme (see Section 11 of the report).

Table 2.1 Valuation of health benefits from London Low Emission Zone using two alternative methodologies (£ millions) [20].

	IGCB method	EU CAFÉ method
Within London	£80-110m	£160-420m
Outside Greater London	£70-100m	£90-250m

2.6 Other impacts of the scheme

Although primarily directed at improving public health by reducing emissions of particulate matter, the scheme will have a range of other impacts – on air quality and more widely. These are summarised in TfL's Report to the Mayor on the London Low Emission Zone scheme[21].

Impact on other pollutants – Nitrogen Dioxide (NO_2)

Nitrogen dioxide (NO_2) is a second pollutant for which London currently fails to meet EU and UK air quality objectives. It is related to particulate matter in the sense that a large proportion of NO_2 in ambient air ultimately originates from road traffic, initially as a range of constituents collectively known as oxides of nitrogen (NO_X). But the chemical and physical properties of NO_X and NO_2 are quite different to those of PM. The scheme is expected to deliver overall benefits in terms of a 4 percent reduction in emissions of NO_X from road traffic in Greater London in 2010, and a 10 percent reduction in 2012. In terms of air quality concentrations, the scheme is expected to result in a reduction in the Greater London land area where concentrations exceed the annual mean NO_2 objective for 2010 by around 5 percent. In 2012, it is projected that the scheme would reduce the area exceeding the annual mean NO_2 objective by around 16 percent. All of these reductions are over and above what would be expected in the normal course of events without a scheme.

As with particulate matter, however, the pathways by which these projected overall reductions would be achieved are complex, and one goal of TfL's monitoring work for the scheme is to better understand and quantify the various mechanisms at work.

Carbon Dioxide (CO_2)

Carbon dioxide is a major contributor to climate change. Reflecting heightened concern about climate change, the Greater London Authority have produced a Climate Change Action Plan for London[22].

The London Low Emission Zone does not specifically target CO_2 emissions and it is not anticipated that it would have a significant overall impact on these emissions. There may be some small benefits from reduced CO_2 emissions through newer and more fuel-efficient vehicles being introduced into the fleet as a result of the scheme

(newer vehicles tend to be slightly more fuel efficient). However, these may be offset by greater fuel use relating to the fitment of particulate abatement equipment by vehicle operators choosing this route to comply with the requirements of the scheme as this can marginally reduce energy efficiency.

The scheme is not designed or expected to significantly affect either the numbers of vehicles in London, the traffic composition, vehicle kilometres driven, or average traffic speeds or congestion.

Impacts on business and the economy

The scheme will inevitably impose some additional costs on vehicle operators as they take steps to comply with the requirements of the scheme. These additional costs are expected to be small in relative terms, compared to the overall value of the road haulage sector. They would broadly have the characteristics of 'costs brought forward', ie reflecting earlier renewal of assets than would otherwise be the case and this would not be confined to London, owing to the nature of the road haulage industry. There would be an offsetting 'beneficial' impact – in economic terms – associated with the production of new vehicles and the production and fitment of pollution abatement equipment.

It is estimated[23] that in economic output terms the costs of 'compliance' associated with asset replacement and vehicle upgrade and retrofitting in response to the scheme would result in overall net economic 'loss' of some £80-110 million (present value to 2015/16).

Some two thirds of these additional **compliance costs** are expected to be passed directly to customers. However, given the overall geographical area impacted and the size of the economy affected, the consequences of these increased costs can be considered to be relatively minor in most cases. The final one third of the compliance costs are expected to be absorbed by the vehicle owners and operators.

In aggregate net terms the economic impact of the scheme is expected to be very small. The estimated range of increased costs represents around only one tenth of one percent (0.1 percent) of the total operating costs of the road haulage industry at the national scale[24].

Other impacts

- The scheme has the potential to have a beneficial effect on biodiversity within London and to reduce building soiling and decay due to dry deposition of air pollutants affecting cultural heritage assets in London, although this effect is not expected to be significant.
- There may be a small overall reduction in ambient noise levels as older, noisier vehicles are removed from the fleet, though the overall effects on the London noise climate are likely to be very marginal.

3. Technical approach to monitoring and understanding the impacts of the London Low Emission Zone

3.1 Introduction

This section describes the overall strategy and technical approach that TfL is adopting to monitor and understand the impacts of the London Low Emission Zone. The approach builds on previous monitoring work for TfL schemes, such as Congestion Charging in central London[1], in seeking to provide a range of definitive indicators that can be used to assess scheme impacts against expectations, as well as providing wider insights that help to place these indicators in context.

3.2 Objective of impacts monitoring

This can be defined as the provision of robust and timely measurement and understanding of key impacts from the scheme over its life-cycle, having regard to stakeholder aspirations, cost-effectiveness and scientific limitations associated with many of the quantities being measured.

Air quality is a complex subject and is sometimes misunderstood. The material in this report is therefore most profitably approached with an appreciation of the wider scientific backdrop to air quality assessment, as reflected in references throughout.

3.3 Key considerations for the monitoring work

Section 2 of this report summarised the expected impacts of the scheme. In summary:

- The scheme is expected to lead to reductions in emitted particulate matter (as PM_{10}) from affected vehicles across Greater London.
- These would be expressed as a series of tapering 'additional reductions' over and above what would be expected from 'background' vehicle fleet change without a scheme.
- The typical magnitude of this tapering reduction would be of the order of three to four years' **advancement** of emissions improvements over what would otherwise be expected from background change to the vehicle fleet.
- These emission changes should translate to general but small improvements in ambient concentrations of particulate matter (as PM_{10}) across Greater London, with higher localised improvements close to busier roads.
- There would be a range of 'secondary' impacts on other pollutants, such as oxides of nitrogen (NO_X), as well as a range of wider impacts on the economy and public health.

For the purpose of designing a monitoring programme, it is important to note the following distinguishing characteristics of the scheme:

- Relatively restricted range of 'observable' impacts, all deriving from a (primary) vehicle fleet change in emissions performance – involving a relatively small

proportion of the 'potentially-affected' vehicle fleet (vehicles that are already compliant are unaffected).

- Fixed quota of 'possible' impacts, with benefits primarily deriving from acceleration of an otherwise 'natural' process (the background renewal of the vehicle fleet).
- A phased implementation, with consequent longer-term uncertainties and overlapping baselines.
- Potentially confounding background trends in key indicators such as air quality, reflecting a wide range of other initiatives and policies, such as those contained in the Mayors' Air Quality Strategy[2].
- Potential impacts beyond the Greater London area.
- Technical difficulties associated with measurement of emissions impacts that are relatively small in scale, and in some cases poorly understood in scientific terms.
- Cost and other impacts on vehicle operators, with implications for the economy.

The remainder of this section identifies the key areas of activity for the monitoring work and summarises the overall strategy and technical approach being adopted by TfL in each case.

3.4 An impacts hierarchy

Conceptually, impacts from the scheme are best considered in terms of an 'impacts hierarchy', reflecting measurability, starting with the most immediate and measurable change that is expected to result from the scheme.

Primary impact

The **primary impact** is expected to be an improvement to the emissions performance of a sub-set of vehicles operating in London, most readily visible as a change in the population composition of these vehicles in terms of their emissions performance (ie their Euro Standard), reflecting vehicle operator compliance with the requirements of the scheme. The population of primary interest for this work is therefore the **total vehicle kilometres driven within Greater London by vehicles that are potentially affected by the various phases of the scheme**, for equivalent time periods before and after implementation. The primary measurement target is the **emissions performance**, or 'emissions profile' of this population.

Secondary impacts

This primary vehicle population change then leads to a range of **secondary impacts**, such as reduced overall road transport emissions and improved air quality (pollutant concentrations in ambient air). These impacts are less immediate and less directly-measurable, since they are potentially obscured and diminished in relative scale by other factors and trends unrelated to the scheme itself. Examples of these factors would be the effect on road traffic emissions from 'background' changes to other types of vehicles in London that are not affected by the scheme (eg cars), or the

influence of medium-run weather patterns (eg hot, dry summers) on measured outdoor air quality.

Tertiary impacts

Improved air quality, reflected in reduced ambient concentrations of key pollutants such as particulate matter would, in turn and over time, lead to a range of **tertiary impacts**, most obviously in this case improved public health. Here, the timescales required for full expression of the impacts of the scheme are measured in decades, and the range and scale of potentially confounding 'background' factors – such as the public places smoking ban of July 2007[3] – make detection and robust quantification of 'scheme-attributable' impacts very difficult over the medium-term.

Signal degradation and measurement noise

The above three groups of impacts all ultimately derive from the primary change to the emissions performance of vehicles operating in London, resulting from action by vehicle operators to comply with the requirements of the scheme. At each stage moving down the hierarchy, the time taken for the expected impact – the 'signal' reflecting the impact of the scheme – to become visible and measurable increases, as does the range and magnitude of potentially-confounding external factors (the measurement 'noise'). This has important implications for the ability of the monitoring work to detect and attribute change, particularly in relation to improved public health, which is the 'ultimate' goal of the scheme. It also follows that the best view of scheme impacts is obtained from concentrating the measurement effort on the most readily observable primary and secondary changes.

External impacts

An important but diverse fourth group of impacts, termed **external impacts**, cover various wider effects of the scheme:

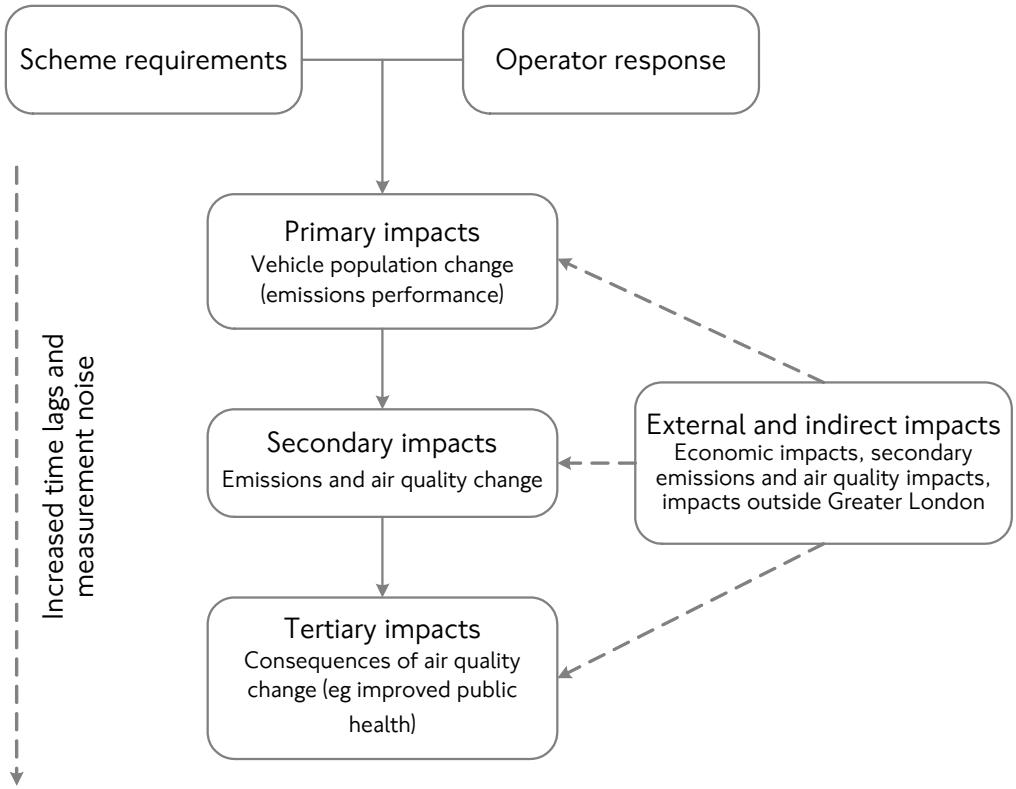
- These include the important area of business and economic impacts, such as the consequences on business performance of the additional costs imposed on the road haulage industry in meeting the requirements of the scheme, for example having to purchase new vehicles earlier than might otherwise be necessary.
- A second group of impacts under this heading relate to the consequences of the scheme outside London, whether being potential benefits arising from the wider use of cleaner vehicles outside London or possible dis-benefits arising from the reallocation by operators of dirtier, non-compliant vehicles to work outside London.
- Finally, there is a group of potential **indirect** effects, mainly relating to detailed aspects of traffic composition and vehicle emissions. Examples here include potential changes to the traffic mix and volumes (in terms of vehicle type), reflecting operator adaptation, albeit that this is not expected to be significant, and 'secondary' consequences on the emission of pollutants other than those directly targeted by the scheme.

This four-tier hierarchy, illustrated in Figure 3.1, forms the basis for the structure of this report. It also provides a framework for assigning priorities and resources

between the various elements of the monitoring work, based on technical feasibility and timescales. In considering Figure 3.1, note also that:

- Secondary impacts on emissions are calculated from the observed primary vehicle population change and not observed directly, whereas impacts on ambient air quality (pollutant concentrations) are both calculated from the secondary emissions change, and measured directly using air quality monitors.
- 'External' impacts cut across the hierarchy and will occur at each level.

Figure 3.1 Conceptual impacts hierarchy for the monitoring of the London Low Emission Zone scheme.



3.5 Primary impact: changes to the emissions performance of vehicles operating in Greater London

From a monitoring viewpoint, the most immediate and visible impact of the scheme would be a series of accelerated adjustments to the emissions performance of relatively small sub-sets of the potentially-affected vehicle fleet. Specifically this would involve only vehicles that are in-scope to meet the requirements of the scheme and that are not already compliant with them. This would have the nature of advancing changes that would be expected to take place in any case through 'background' fleet renewal, albeit over a longer timescale.

Figure 3.2 General nature of scheme impacts on the emissions performance of heavier diesel fuelled vehicles in London.

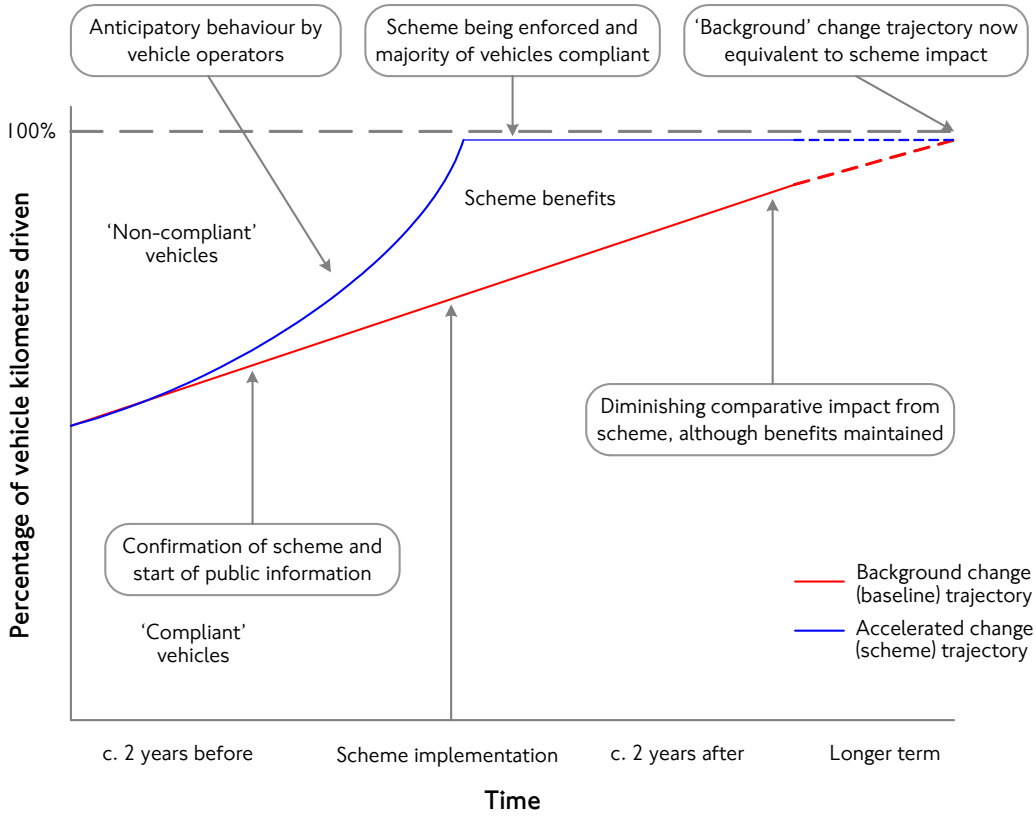


Figure 3.2 is an idealised representation of this change in relation to a single phase of the scheme (eg for N3 heavy goods vehicles over 12 tonnes in weight). Note that:

- The beneficial change arising from the scheme or phase starts to occur some time before the implementation date, reflecting anticipatory action by operators to knowledge of a future phase (for example in influencing decisions relating to the purchase of new vehicles).
- At the time of implementation of a scheme phase itself, and given effective public information and scheme enforcement, the large majority of vehicle kilometres driven in London by potentially-affected vehicle types are expected to be compliant with the requirements of the phase.
- There will be a small residual element of 'non-compliance' in terms of emissions performance. This primarily reflects certain specialist exemptions to the scheme. Effectively, from the phase implementation date, close to 100 percent of the vehicle kilometres driven by affected vehicles are expected to be compliant with the requirements of the scheme and delivering air quality benefits.
- As a proportion of new vehicles brought into the fleet in response to the scheme will conform to Euro emissions standards higher than the minimum required for scheme compliance, the overall beneficial impact of the scheme should be higher than that implied by the minimum Euro standards for compliance.
- Some years from implementation date, a point is reached where – had there not been a scheme – continuation of the 'background' change in the vehicle

population would have achieved an equivalent end-point to that achieved by the scheme or phase several years earlier.

These changes to the emissions performance of vehicles can be measured directly through camera-based observations of road traffic. As quantification of the secondary and tertiary impacts of the scheme will largely rely on calculations or estimates based on the observed vehicle population changes, robust measurement of these effects is essential, as is an understanding of the 'size' of the vehicle populations affected. TfL's approach to this element of the work is described in Sections 4 and 5 of this report.

3.6 Secondary impacts: changes to emissions

Changes to the emissions performance of vehicles affected by the scheme would result in reduced emissions of key pollutants from those vehicle types. In turn, changed emissions from these vehicles would combine with emissions from other sources, both traffic and non-traffic (which are probably also changing at the same time) to have a proportionate impact on ambient concentrations of key pollutants across the region. These changes in pollutant concentrations can either be calculated, using emissions and air quality models, or measured, using available data from air quality monitoring sites across the region.

It is not possible to directly measure the actual emissions from all vehicles driving within Greater London. Instead, an established methodology exists in the form of the London Atmospheric Emissions Inventory[4] that allows these to be estimated.

An emissions inventory is a numerical database that brings together relevant information, known as 'activity data', about activities in a region that give rise to polluting emissions. Alongside the activity data are 'emissions factors' which, for any given activity, quantify the emissions of pollutants of interest that can be expected.

For the London Low Emission Zone the key quantities are:

- Kilometres driven by each of the main vehicle types, and by each of the main Euro emissions standards and fuel usage categories (largely petrol or diesel) within each vehicle type, in the Greater London area over the course of, say, one year.
- A comprehensive set of speed-related emissions factors, again by main vehicle type, fuel usage and Euro emissions standard, corresponding to the disaggregate observations of vehicle kilometres driven.

The former will arise directly from the camera-based observations of traffic, described in Section 5 of this report. The latter already partly exist from established work, but require selective supplementation to more appropriately align with the requirements of the monitoring work.

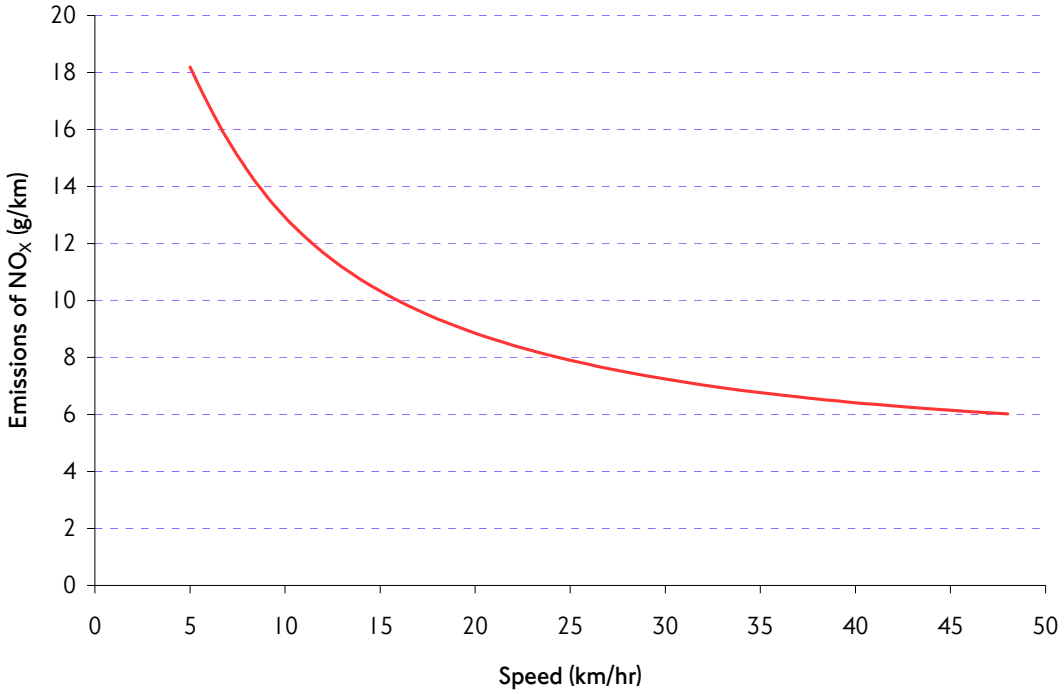
Figure 3.3 illustrates the general form of a speed-related emissions curve for road traffic. Note that:

- Emissions factors are not the same as Euro emissions standards. The former relate to 'real world' emissions from typical vehicles undertaking representative

drive cycles. The latter are primarily a legislative requirement for vehicle manufacturers.

- However, in general, vehicles of higher Euro emissions standards would have consistently and significantly lower emissions per kilometre operated than those of lower Euro emissions standards.

Figure 3.3 General form of a speed-related emissions curve for road traffic. Oxides of nitrogen (NO_X) from rigid heavy goods vehicles – Euro II standard.



Given a sufficiently comprehensive and disaggregate description of vehicle kilometres operated by each vehicle type, fuel usage category and Euro emissions standard, and a corresponding set of emissions factors, it is relatively straightforward to make successive estimates of emissions produced. These would be in terms of mass (weight) by location for each of the key pollutants of interest, corresponding to successive years, or phases, of the scheme. This approach also allows effects arising directly from the scheme to be identified separately to those arising from unrelated causes, for example changes to domestic and commercial fuel consumption. This element of the work is described in Section 6 of this report.

3.7 Air quality change: general approach

Reduced emissions are likely to lead to relative improvements in air quality, reflected in reduced concentrations of key pollutants in the atmosphere. However, as with emissions from road traffic, it is not possible to measure air quality at all locations across Greater London directly. Furthermore, air quality as measured by established monitoring sites across London reflects a very wide range of influences – most of which are entirely external to the scheme. These include chemical reactions in the

atmosphere, localised influences such as the presence or absence of industry near to monitoring sites, and the weather.

All of this means that data from air quality monitors is unlikely to give a clear picture of impacts from the scheme in the medium term. Nevertheless, these data will be the first point of reference for most commentators, and are the legal basis for establishing compliance with air quality objectives.

Therefore a dual track approach is required; a 'calculated' approach using air quality models, and a 'measurement' approach, making best use of the large quantities of measured air quality data available in London.

Air quality models

An air quality model uses mathematical relationships to transform disaggregate emissions estimates, such as the outputs from the atmospheric emissions inventory work described above, into estimated concentrations of pollutants in the atmosphere on a time-averaged basis (eg yearly). Spatially-disaggregate estimates of emissions of individual pollutants are transformed according to descriptions of local topography, representative meteorology and chemical reactions between various pollutants and other constituents of the atmosphere into representative concentration gradients, typically represented in map form. These 'predicted' concentrations can be compared with observed concentrations at points where air quality monitoring sites are located, thereby confirming or 'validating' the predictions of the model; or providing adjustment factors for model calibration if required.

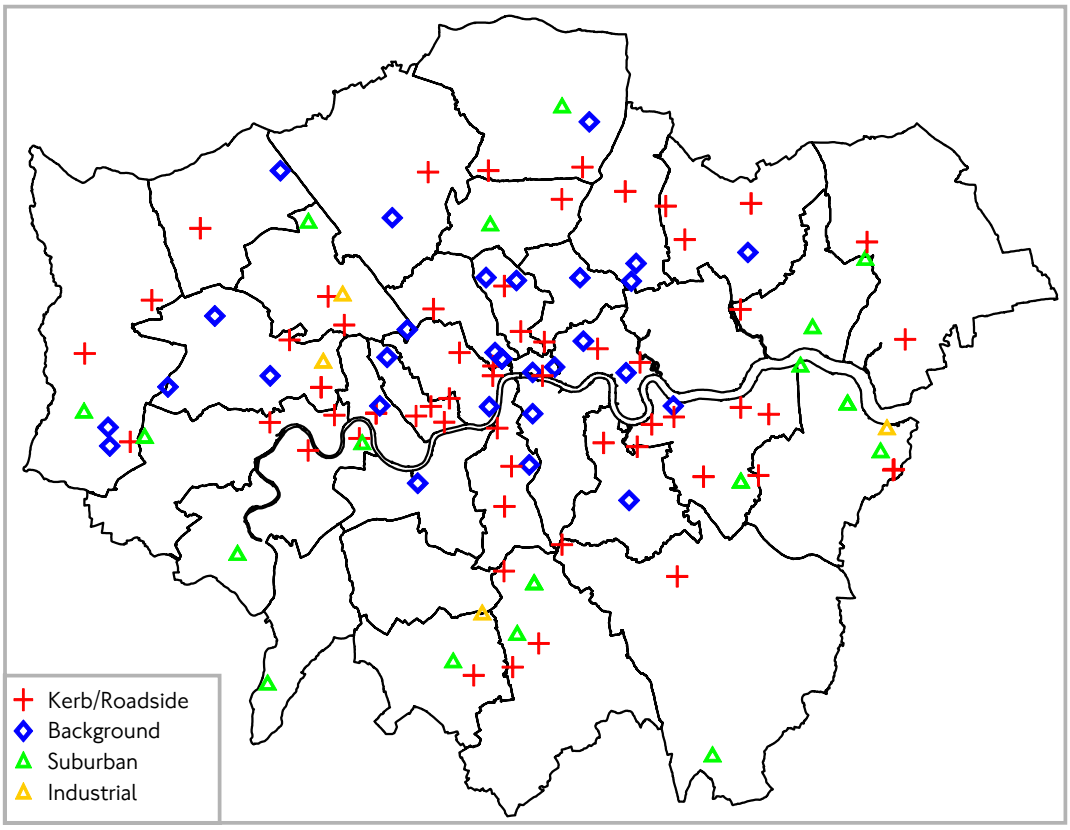
For scheme impacts monitoring purposes within Greater London, a small number of proprietary models are available. All of these are broadly compatible with the outputs from the London Atmospheric Emissions Inventory – and the key models have been proven over several years' experience with air quality reviews by the GLA and local authorities.

The basic approach to be adopted for this aspect of the monitoring work is therefore to use disaggregate emissions estimates to generate successive estimates of air quality concentrations for key pollutants representing the main stages in the life cycle of the scheme. From these it is possible to generate a range of descriptive statistics, such as changes to the percentage of the land area in Greater London that exceeds national air quality objectives, enabling the impacts of the scheme on air quality and public health to be assessed. Section 7 of this report considers this aspect of the work.

Measurement of pollutant concentrations in ambient air

Levels or concentrations of specific pollutants in ambient air are measured routinely at approximately 100 locations across Greater London under the auspices of the London Air Quality Network, known as the LAQN[5]. These are high-quality, continuous measurements from permanent sites that are operated to stringent technical quality standards.

Figure 3.4 Permanent air quality monitoring sites in and around Greater London affiliated to the London Air Quality Network, as of June 2008.



Monitoring sites are generally owned and operated by the host boroughs, but are maintained by King's College London who currently run the LAQN. They are divided into broad groups depending on whether they monitor air quality at the kerbside (ie directly adjacent to the road carriageway); at the roadside (ie on a street but set back from the kerb); or at 'suburban' or 'background' sites – these typically being in lower-density locations away from main roads[6]. For the foreseeable future, the general level of this third-party monitoring effort can be assumed to continue, and a 'ready-made' dataset therefore exists covering both an extensive period before the introduction of the scheme, and potentially the period afterwards.

Therefore, the essential task for this part of the monitoring work is to assemble relevant data and organise it so that it is possible to derive a series of indicators using statistical tools to track and characterise air quality trends across London following the introduction of the scheme. This aspect of the work is considered in Section 8 of this report.

There are two key areas where further work is necessary. The first reflects the fact that measured outdoor air quality trends tend to be quite variable. This particularly applies to the 'exceedence day' PM_{10} measurements used for assessing compliance with air quality objectives. Second, conventional concentration-based measurements are unlikely to reveal the more detailed nature of scheme impacts – for example differential effects on particulate matter by size, chemistry and potential toxicity – which can be important for health impacts. These mean that specialist analysis

procedures will need to be developed in order to understand scheme impacts of this type.

3.8 Enhanced air quality monitoring sites

To address some of these more technical issues, TfL has modified a small number of existing air quality monitoring sites to increase the range of pollutants measured, and to provide a full array of co-located traffic and meteorological monitoring equipment.

Described further in Section 9 of this report and fully operational from the start of 2007, these seven 'enhanced air quality monitoring sites' are purposefully located in roadside or kerbside locations adjacent to major roads. Model forecasts have suggested that these locations are likely to see the biggest changes in air quality from the scheme – in other words they are located at 'high-signal' sites.

It is important to clarify that the primary role of these enhanced air quality monitoring sites is to enable detailed study of the interrelationships between traffic and pollutant change, at locations where these changes are likely to be most readily observable. Their role is not primarily to 'detect' a scheme impact and, as they are both small in number and in specific, atypical locations. They should therefore be viewed as 'exemplar' sites, in the context of the broader picture on air quality trends provided by the LAQN, and will inform a range of statistical and scientific analyses designed to better understand the mechanisms at work in air quality change.

3.9 Tertiary impacts: impacts on public health

Improved public health through improved outdoor air quality is the primary objective of the scheme. As such, it will be proportional to the degree of change actually achieved in ambient air quality from the scheme, including secondary effects on pollutant composition, and the relative importance of these in terms of prevailing levels of morbidity and mortality from poor outdoor air quality and other causes more generally.

As with improved vehicle emissions performance, reduced emissions and, ultimately, improved air quality, the scheme will have the effect of 'bringing forward' beneficial changes that might otherwise have been expected to occur in the normal course of events, albeit over a longer timescale. However:

- Although important, the number of morbidity and mortality events directly affected by outdoor air pollution and therefore liable to be influenced by the scheme is small in the context of overall numbers of morbidity and mortality events.
- There are many other factors affecting trends in morbidity and mortality that are completely unrelated to the scheme – the public places smoking ban from July 2007 is a current relevant example.
- Formal health records, while improving, have limitations in this regard, particularly in making a link between diagnosis (for example of a respiratory disease being the immediate cause of death) and a possible life-long history of contributory factors (for example employment in a hazardous environment).

- People who are simply not ill when they would otherwise have been, or whose deaths are no longer 'brought forward' because of poor air quality will generally not recognise, or be recognised, as such, either by themselves or by the medical community.

All of these factors mean that it is difficult to directly 'measure' changed public health as a result of the scheme over the timescales of interest. The importance of this aspect of the monitoring does nevertheless mean that an approach needs to be developed to estimate these effects. TfL is pursuing the following initiatives:

- Although heath care records (both primary and acute) are unlikely to show clear scheme-attributable effects over the short to medium term, it is nevertheless necessary to examine them – both to validate this assumption and also to understand longer-term 'background' trends in public health.
- The health impacts of the scheme have been projected, in advance of the scheme being implemented, based on standard 'best available' methodologies. These projections can be revisited once actual observed data on the air quality impacts of the scheme are available. Using the same standard methodologies and assumptions, an estimate based on observed, as opposed to forecast, air quality changes can be generated.
- However, as with emissions and air quality models, it is possible that the standard assumptions on which the health impacts models are based are not optimal for estimating impacts from this particular scheme. It is therefore reasonable in the longer term to explore the sensitivity of calculated health impact outputs to changes in the model assumptions. This process will be informed by the wider scientific investigations associated with the monitoring work.
- Finally, it may be possible to detect a health 'change signal' associated with the scheme under more closely-controlled conditions than is possible for the general population. TfL is therefore building upon existing medical studies that have looked at respiratory function among schoolchildren by sponsoring collaborative research. This group are known to be especially sensitive to air pollution, given their relatively high exposure to outdoor pollutants and the immaturity of their lungs.

This collaborative research and the wider elements of the health impacts assessment work are described in Section 11 of this report.

3.10 Economic and business impacts

The scheme will impose additional costs on, in the first instance, goods vehicle and bus and coach operators who operate in London. These additional 'compliance costs' would largely have the nature of 'costs brought forward' – in other words requiring action in advance of when it would otherwise be necessary. Only those operators whose vehicles would not, through the normal course of events, comply with the requirements of each successive phase of the scheme at the implementation date are affected.

For phase 1 of the scheme, affecting heavier goods vehicles from February 2008, this 'default non-compliant' portion of vehicles operating in London has been estimated

at approximately one third. Vehicles in this group need either to be replaced, re-deployed or modified in order to become compliant with the scheme, with each of these courses of action having different 'supply side' cost implications.

- In the case of vehicle replacement, of an older vehicle with a newer one, there is the capital cost of the new vehicle, which can be discounted according to the residual 'value' of the existing vehicle. Many of these existing vehicles will be nearing life-expiry and will therefore have a comparatively low residual value, and in these cases the operator would face a correspondingly low 'additional cost brought forward'. Selling on the vehicle to the second-hand market is a viable option for operators, but this carries implications for air quality in the area to which the vehicle is re-deployed.
- In the case of fleet re-deployment, and assuming that operators have flexibility within their fleet or pattern of operations to make this a viable option, there would generally be only minor cost implications, although it should be recognised that for the majority of operators, with typically small fleets, this is unlikely to be a feasible option.
- In the case of modification to an existing vehicle, through the fitment of pollution abatement equipment, there would be an additional capital cost that, while relatively substantial, should be seen in the context of typical vehicle operating costs and the remaining natural 'life' of the vehicle.

Vehicles that are not compliant with the requirements of the appropriate scheme phase following implementation can pay a daily charge (£200 for vehicles in-scope for phases 1 and 2 of the scheme), set so as to discourage all but very occasional use of non-compliant vehicles in London.

In general, it can be assumed that operators would make the most rational economic choice in relation to their own particular circumstances. For the majority of vehicles operating in London, the direct impacts of the first two phases of the scheme will be small – both in absolute and relative terms. For some vehicles, and some operators, there is nevertheless the possibility of more specific or disproportionate impacts.

The monitoring priorities in this area are therefore to:

- Understand the profile of operators potentially affected by the scheme, in terms of their compliance status, options and choices – the 'supply side' impacts.
- Estimate the actual profile of additional operator costs incurred and compare these to pre-implementation projections.
- Understand the prevalence of specific or disproportionate operator cost-related impacts that might require a review of aspects of scheme operation.
- Understand the implications of the additional operator costs on aspects of business performance such as profitability and competitiveness.

There will also be further economic effects associated with the provision of new vehicles and emissions abatement equipment.

The most robust route to understanding these effects is through national-scale statistics, such as those produced by Government and by groups from the freight and

vehicle supply industry. Over time, and taking account of all of the other factors going on simultaneously that will affect business performance in these sectors such as recent fuel price rises, any differential trends that may be related to the scheme should become evident. There are two major limiting factors here. First, lags of two years or more are to be expected before 'official' data reflecting post-scheme conditions is published. Second, it may be the case that the magnitude of scheme-attributable impacts is small in relation to wider background trends, such that they are difficult to distinguish.

In view of this and in the interim, the initial monitoring work in this area will primarily be based on adapting the existing operator survey framework that has been used for the development of the scheme to measure post-implementation operator behaviour. Also available in the short term will be information from TfL's operational processes in relation to the scheme, such as vehicle registrations, observations of vehicles in the zone, payments, etc. The aim here is to verify initial expectations, more accurately dimension the operator cost impacts and their distribution across operators, and further investigate any specific issues that arise. Further details of this work can be found in Section 12 of this report.

3.11 Buses and coaches

Phase 2 of the scheme, from 7 July 2008, requires that bus and coach operators comply with the scheme. TfL is the operating authority for public service buses in London. Therefore, it has taken steps to ensure that all 'London' buses were compliant with the scheme by the required date. This considerably simplifies the monitoring work in relation to these vehicles.

However, the remaining vehicles in this category involve a wide range of operators. While the aggregate impacts on these vehicles will become evident from the camera-based data referred to above, identifying 'economic' impacts that might be operator-specific, or disproportionate, could be problematic. In this circumstance, and in addition to intelligence gathered during the preparation phase of the scheme, such as working with small operators to encourage and facilitate compliance, TfL will make use of stakeholder liaison and commentary following implementation to determine whether additional investigative work is required.

3.12 Impacts outside London

Most individual vehicles potentially affected by the scheme will operate both inside and outside London depending on business needs. Potential impacts of interest here are:

- Possible displacement or diversion of non-compliant vehicles to work outside London – potentially having negative air quality implications in those areas.
- Use of vehicles that have 'become' compliant (ahead of when they otherwise would have been) outside London – in this case delivering air quality benefits.
- The balance between the two, in terms of net air quality and health impacts.

Estimates of these effects have suggested that the overall balance for the earlier phases of the scheme will be significantly positive at the national scale. This is primarily because of the long distances typically travelled by heavier goods vehicles, the majority of which will be outside London, together with the more general 'fleet-wide' impacts of the scheme.

Quantifying this balance is one objective of the monitoring work. In principle, this can be achieved by extending aspects of the work outlined above to outside London, although clearly this has to be done on a selective basis. National and vehicle operator statistics will also assist in building a picture of changing vehicle populations that can ultimately be used as inputs to national scale emissions, air quality and health models to derive quantitative assessments. This aspect of the work is described in Section 10 of this report.

3.13 Advancing the science – some problems and opportunities

In considering the detailed measurement of emissions characteristics of vehicles travelling in London, and in using this information to derive estimates of emissions and air quality change, comparing them to observed air quality trends, attributing them to the scheme and calculating out-turn health benefits, the monitoring work needs to address several technical issues that have hitherto been relatively poorly understood. This section summarises TfL's aspirations in these areas.

- Firstly, the use of cameras to undertake statistically-representative measurement of the emissions profile of the London vehicle population offers new and potentially valuable insights. The emissions performance of vehicles in London has never been measured directly before. Previous estimates, including those used to project the impacts of the scheme, have been based on national vehicle fleet profiles - which may or may not prove to be ideally applicable to London.
- Second, previous emissions assessment and air quality modelling methodologies have largely been based on PM_{10} mass or concentration. Understanding the impacts of the scheme will require more detailed consideration of the individual components of particulate matter, particularly in relation to improved emission factors that more accurately reflect the impacts of the scheme. To this end, TfL has sponsored independent vehicle emissions tests, the results of which will be used in conjunction with other related material – for example from the enhanced air quality monitoring sites – to progressively improve the performance of the emissions assessment framework used for this work.
- Third, current emissions factors and air quality models are not optimal in the way they deal with secondary effects on other pollutants of the measures designed to tackle one 'target' pollutant – increased primary nitrogen dioxide (NO_2) from particulate abatement technology being an important case in point[7]. Similar shortcomings relate to understanding of the interaction between pollutants – an example being the role of ozone (O_3) in NO_2 formation. Understanding more about these is an important prerequisite of robust assessment, and again TfL hopes that insights gained from the monitoring work will have wider application.

All of these issues could result in 'monitoring based' estimates of scheme impacts that differ from those previously used to inform the design of the scheme. While this

may cause some practical issues in the short term, it also offers the potential for better knowledge and more accurate assessment of air quality issues by TfL and agencies across London going forward.

3.14 Summary of the work programme

The key elements of the monitoring work programme for the scheme are set out in **Appendix 2**.

4. Identifying the vehicle populations of interest

4.1 Introduction

The starting point for the assessment of scheme impacts is the measurement of the emissions characteristics of potentially-affected vehicles operating in Greater London. The first step is therefore to identify and define these 'vehicle populations of interest' and to establish their size and relative contribution to air quality problems. As these populations may well change in size from year to year, ultimately affecting emissions, it is also important to understand and monitor background traffic trends.

This section identifies and establishes the basic characteristics of the vehicle populations of interest for the monitoring work. This is a necessary preliminary to the work described in Section 5 of this report to measure the emission characteristics of these populations, and to Section 6, which assesses the impact of the scheme on emissions from these vehicles.

4.2 The vehicle population of direct interest

For the purpose of this report, the vehicle population of **direct** interest is that potentially affected by phases 1 and 2 of the scheme. This comprises:

- Goods vehicles and other specialist vehicles of 3.5 tonnes gross vehicle weight or over, also known as N2 and N3 heavy goods vehicles (HGVs).
- Buses and coaches with more than eight passenger seats and exceeding 5 tonnes gross vehicle weight, also known as M3 buses and coaches.

The area over which the scheme applies is broadly the whole of Greater London, with some small exceptions. Vehicles falling within each of the above two type and weight categories will be identifiable as conforming to one of the 'Euro' emissions standards, or a 'pre-Euro' class for older vehicles – see **Appendix 1**. From this Euro classification it is possible to assign emissions characteristics (in this case for PM_{10} and NO_X) to individual vehicles, which can then be used to assess the emissions and air quality impacts of the scheme.

The primary unit for assessment for monitoring purposes is therefore: total vehicle kilometres driven by vehicles in each of the above type and weight categories, by Euro emissions standard or class, within the area covered by the scheme, per nominal calendar year.

Note that:

- Vehicles 'based' in London, or having a registered keeper with an address inside the Greater London area, are not the same as the vehicle population of interest. Vehicles operating in London are based in a wide range of locations, including abroad. Similarly, vehicles licensed to an address in Greater London may or may not operate predominantly within the Greater London area.

- The staggered implementation timing of phases 1 and 2 of the scheme, together with the practical requirement for a significant degree of 'pre-adjustment' of operators to the requirements of the scheme ahead of the actual implementation date, mean that change in vehicle populations in response will be progressive in nature, and would mostly occur in the months before and immediately after the actual implementation date for each phase of the scheme.

4.3 Vehicle populations of indirect interest

Other vehicle types, not potentially affected by phases 1 and 2 of the scheme, are also of interest for this work. Phase 3 of the scheme will address light goods vehicles and minibuses (currently scheduled for October 2010), and it is desirable to closely monitor changes in the activity and emissions performance of these vehicles well ahead of the 2010 phase 3 implementation date.

Vehicles not in-scope to be affected by the scheme, such as cars and taxis, are also of interest in that better knowledge of the emissions characteristics of these vehicles will allow emissions from these 'non-scheme' road traffic sources to be more accurately represented, and therefore changes attributable to the scheme to be more robustly apportioned. While the monitoring work offers significant new longer-term opportunities in this respect, it is not a primary objective in the short term.

4.4 Global estimates of vehicle-kilometres driven in London

London benefits from established, comprehensive traffic monitoring programmes conducted by TfL, the Department for Transport (DfT) and various other organisations. These provide several long-term time-series datasets detailing comparative traffic volumes by main vehicle type, together with recent trends. The overall picture is however somewhat inconsistent, and it is important at the outset to definitively establish the size of the vehicle populations that the monitoring work will apply to.

The primary estimate of **vehicle-kilometres driven** within Greater London is that produced annually by the Department for Transport[1]. This is based on a large-scale programme of manual classified traffic counts, which allow the main vehicle types (cars, vans, lorries, etc.) to be separately identified. The counts are taken on a sample of roads designed to be statistically representative of traffic in Greater London.

London in this context is defined as the area within the Greater London Authority boundary, which includes certain small sections of the M25 orbital motorway. Vehicle counts obtained at count points are adjusted for seasonal effects and factored by the length of the road to which they apply. This gives an estimate – on an annual total basis – of vehicle-kilometres driven in the geographical area of Greater London. Table 4.1 shows the published estimates for 2006.

Note at this point that the vehicle categories used for traffic counting are not ideally aligned with those used for scheme operational purposes. However, in broad terms, the traffic count category 'heavy goods vehicle' aligns with those goods vehicles that are in-scope for phases 1 and 2 of the scheme; the count category 'bus and coach'

aligns with those vehicles that are in-scope for phase 2 of the scheme; and the count category 'light goods' aligns with vehicles that are in-scope for phase 3 of the scheme.

Table 4.1 Annual total vehicle-kilometres driven in Greater London (geographic area) by main vehicle type. Billion vehicle-kilometres. DfT published estimate for 2006. With national comparison.

Main vehicle type	Annual total kilometres (bn) 2006 - London	Percentage of total	Annual total kilometres (bn) 2006 - National	Percentage of total
Cars and taxis	26.4	80	402.4	79
Light goods vehicles (<3.5 tonnes)	4.1	13	64.3	13
Heavy goods vehicles (>3.5 tonnes)	1.1	3	29.1	6
Buses and coaches	0.6	2	5.4	1
Powered two-wheelers	0.8	2	5.2	1
Vehicles in-scope for scheme (phases 1 and 2 only)	1.7	5	34.5	7
Vehicles in-scope for scheme (phases 1, 2 and 3)	5.8	18	98.8	20
All motor vehicles	33.0	100	506.4	100

The 2006 DfT estimate for vehicle-kilometres driven in London for all motor vehicles of 33.0 billion compares to a national equivalent figure of 506.4 billion, ie London accounts for 6.5 percent of national total vehicle-kilometres.

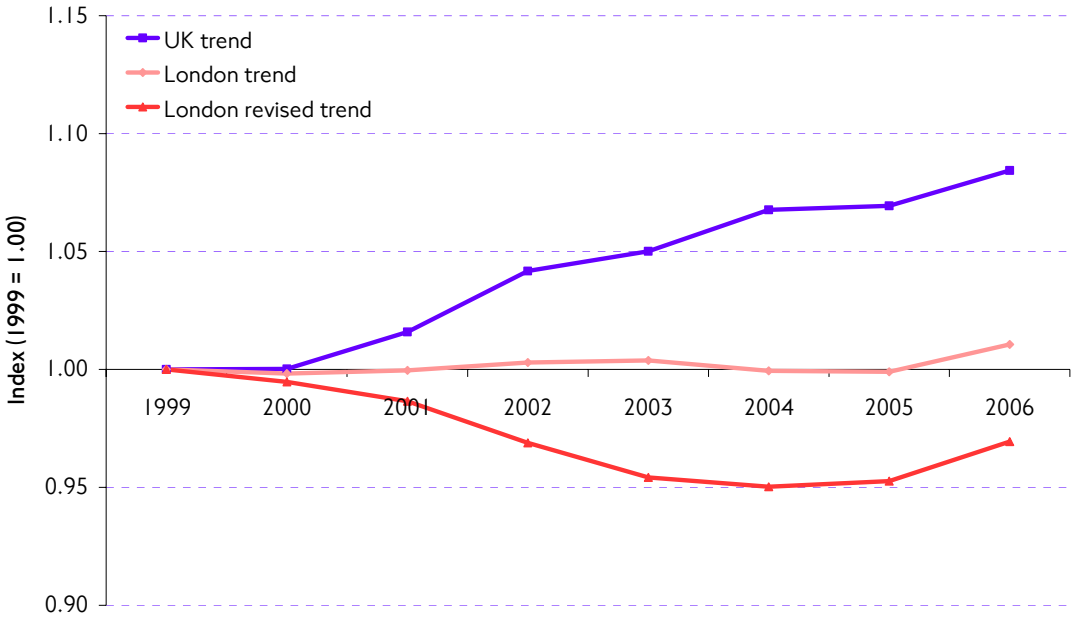
Table 4.1 also shows the proportion of total traffic (in terms of vehicle-kilometres) driven by each of the main vehicle types, from which it is seen that the vehicles in-scope to be potentially affected by the scheme account for relatively small proportions of total kilometres driven in London.

- Heavy goods vehicles, broadly corresponding to those vehicles that are in-scope for phases 1 and 2 of the scheme, account for 3 percent of traffic.
- Buses and coaches, in-scope for phase 2 of the scheme, account for 2 percent of traffic.
- Light goods vehicles, corresponding to those in-scope for phase 3 of the scheme from 2010, are however more numerous, accounting for 13 percent of traffic.
- The large majority of traffic is accounted for by cars (80 percent), which are outside the scope of the scheme.
- Proportionately, heavy goods vehicles account for a greater proportion of vehicle-kilometres nationally compared to London. The reverse applies to buses and coaches.

4.5 Issues with global estimates of vehicle-kilometres driven in London.

Figure 4.1 shows the recent historical trend for estimates of total vehicle-kilometres driven in London. Values have been indexed to 1999 for comparability. The pink line shows the published DfT estimate for London, as referred to above. This suggests that traffic has been effectively stable over the last five to seven years. The blue line shows the equivalent trend for national traffic. In contrast to London, this has grown steadily by around 1 percent per year. The third (red) line is a TfL 'adjusted' estimate for London, which indicates a general decline over the review period.

Figure 4.1 Annual total vehicle-kilometres driven in London (all motorised vehicles – indexed to 1999). With national comparison and TfL adjustment.



An issue to be tackled by this work is an apparent difference in absolute quantities and trends between the DfT global estimate of vehicle-kilometres in London (the pink line), and various other estimates available to TfL. Research has suggested that this is primarily a function of differing methodologies. The DfT estimate, in so far as it reflects traffic on the more minor roads in London, is oriented towards arriving at a robust estimate of national vehicle-kilometres, and therefore primarily reflects national traffic growth trends on these types of roads.

TfL, with assistance from the DfT, has recently produced revised estimates of total traffic in London, using a modified version of the DfT methodology. This is more closely aligned to particular conditions in London and has the effect of reducing the estimated total vehicle-kilometres by about 4 percent overall. Separate revised estimates are also available for each of the main vehicle types. These revised totals are sufficiently robust for them to be adopted as the basis for the scheme monitoring work (Table 4.2), but bearing in mind that they relate to a materially lower total

volume of traffic than those used previously by TfL to project the impacts of the scheme.

Table 4.2 Annual total vehicle-kilometres driven in Greater London (geographic area) by main vehicle type. Billion vehicle-kilometres. TfL adjusted estimate for 2006.

Main vehicle type	Annual total kilometres (bn) 2006 – London	Percentage of total
Cars and taxis	25.2	80
Light goods vehicles (<3.5 tonnes)	3.9	12
Heavy goods vehicles (>3.5 tonnes)	1.1	3
Buses and coaches	0.7	2
Powered two wheelers	0.8	2
Vehicles in-scope for scheme (phases 1 and 2 only)	1.8	6
Vehicles in-scope for scheme (phases 1, 2 and 3)	5.7	18
All motor vehicles	31.7	100

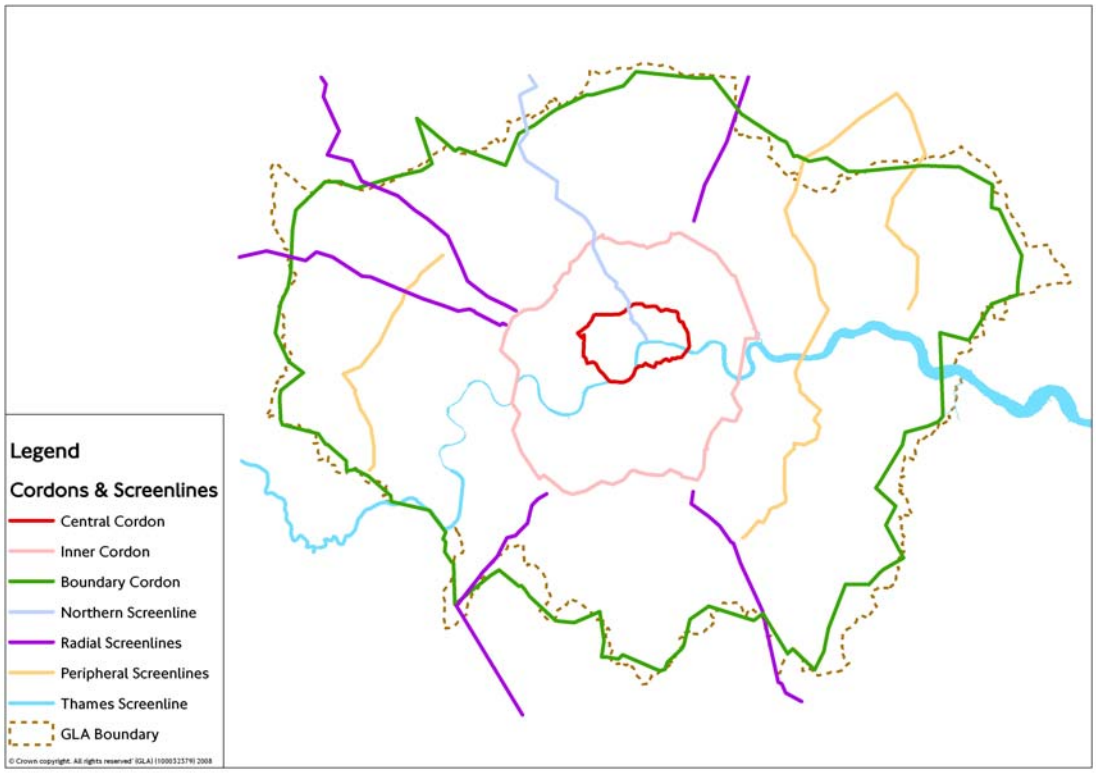
4.6 Recent trends by main vehicle type

Longer-run 'background' trends in the vehicle populations of interest for this work are important because they reflect fluctuations in the total and proportionate contribution to emissions. They also reflect wider 'background' trends in the vehicle market, economy, traffic management policy and driver/vehicle operator behaviour, against which the direct impacts of the scheme need to be set.

The scheme is not expected to materially affect the overall numbers and activity of the main vehicle types, although it is possible that there may be some small marginal effects, such as the preferential use of smaller vehicles that are not affected by the current scheme phase. Any such trends should become apparent in the general traffic monitoring work undertaken by TfL, subject to the usual statistical limitations.

Counts of traffic crossing a system of strategic cordons and screenlines (see Figure 4.2) conducted by TfL provide more information on these trends[2]. A 'cordon' typically encloses an area, such as central London and all vehicles crossing into and out of this area are counted. A 'screenline' is simply a line joining two points across which all traffic is enumerated. These provide estimates of traffic volumes 'at-a-point', rather than vehicle-kilometres driven, but the overall trends should be broadly representative of trends in vehicle-kilometres.

Figure 4.2 Key strategic traffic counting cordons and screenlines in London.



The following figures show recent trends for the main vehicle populations of interest across these cordons and screenlines. All values are indexed to 2001 and reflect 24-hour working weekdays only (ie weekend and bank holiday traffic is not included). Note that the absolute volumes of traffic represented by each of the individual cordons and screenlines will differ. Also, note again that the vehicle type definitions used for traffic counting are not identical to those used for scheme operational purposes.

Figure 4.3, covering all motorised traffic, shows a predominant slow downward trend for total traffic volumes, with the exception of the London boundary cordon and peripheral screenlines, which reflect traffic in outer London and show small increases. The overall pattern nevertheless closely aligns with the revised assessment of recent trends in total vehicle-kilometres within Greater London as described above.

In relation to the heavier goods vehicles that are in-scope for phases 1 and 2 of the scheme, a significant and long-standing background trend has been a move away from what are classified (for traffic counting purposes) as 'medium' goods vehicles, in favour of both heavier and lighter vehicles. Traffic counting methodology relies on vehicle body type and axle configuration to visually classify the various types of goods vehicle. Broadly, although the sum of both 'heavy' and 'medium' goods vehicles as recorded by traffic counts equates to those vehicles in-scope for phases 1 and 2 of the scheme, the individual components have changed significantly in recent years.

Figure 4.3 Traffic crossing strategic cordons and screenlines. All motor vehicle traffic. 24-hour working weekday only.

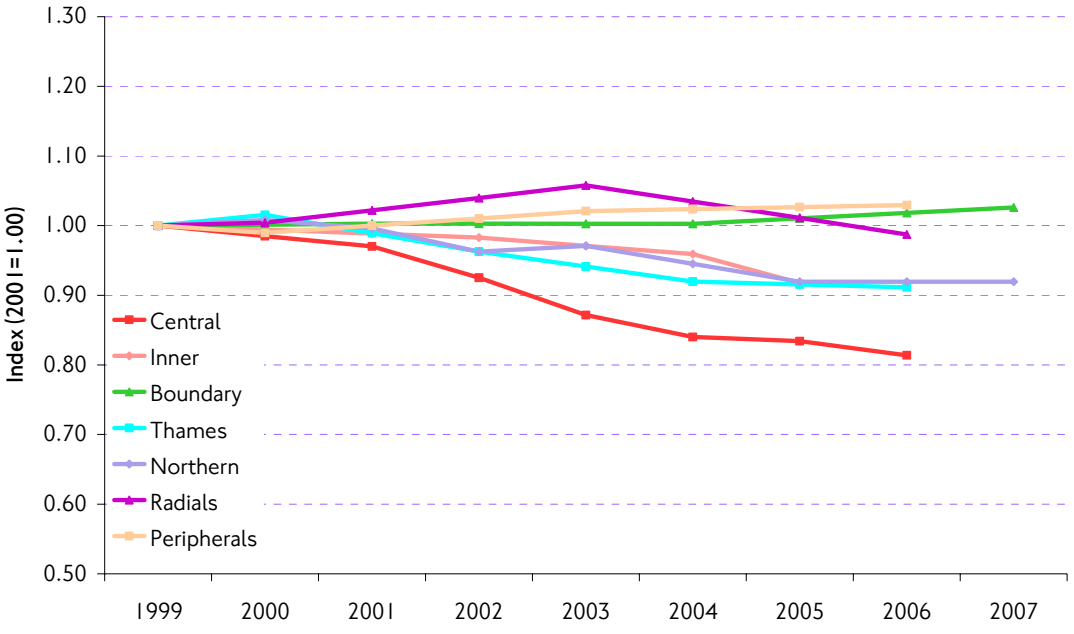
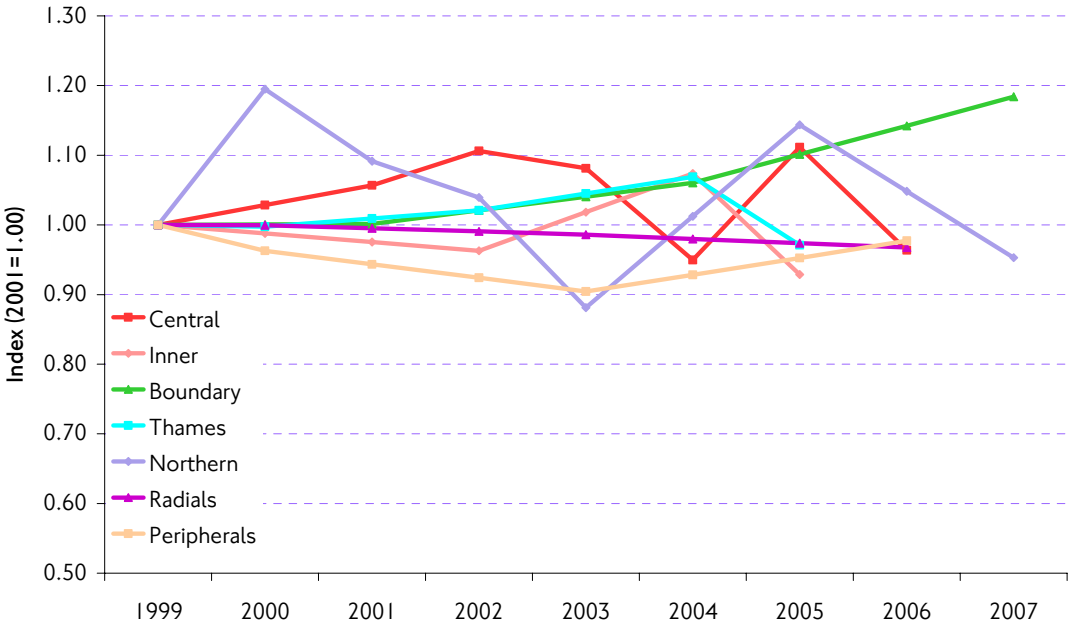


Figure 4.4 Traffic crossing strategic cordons and screenlines. Heavy goods vehicle traffic. 24-hour working weekday only.



Figures 4.4 and 4.5 show trends, respectively, for heavy and medium goods vehicles. Volumes of heavy goods vehicles have remained relatively constant over the past six to seven years, whereas numbers of 'medium' goods vehicles have declined sharply.

Figure 4.5 Traffic crossing strategic cordons and screenlines. Medium goods vehicle traffic. 24-hour working weekday only.

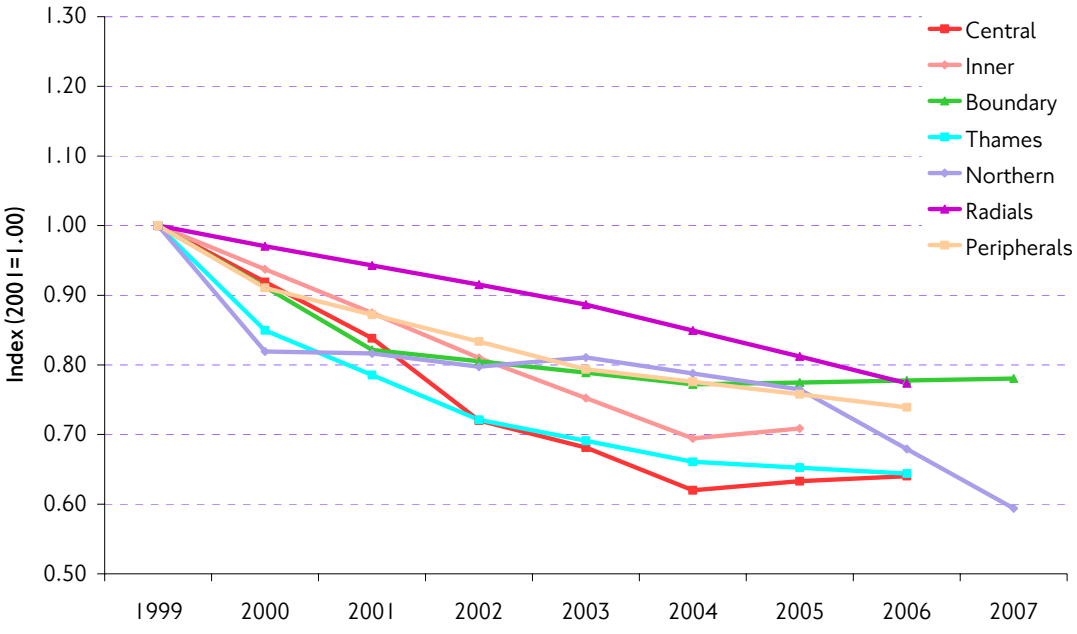
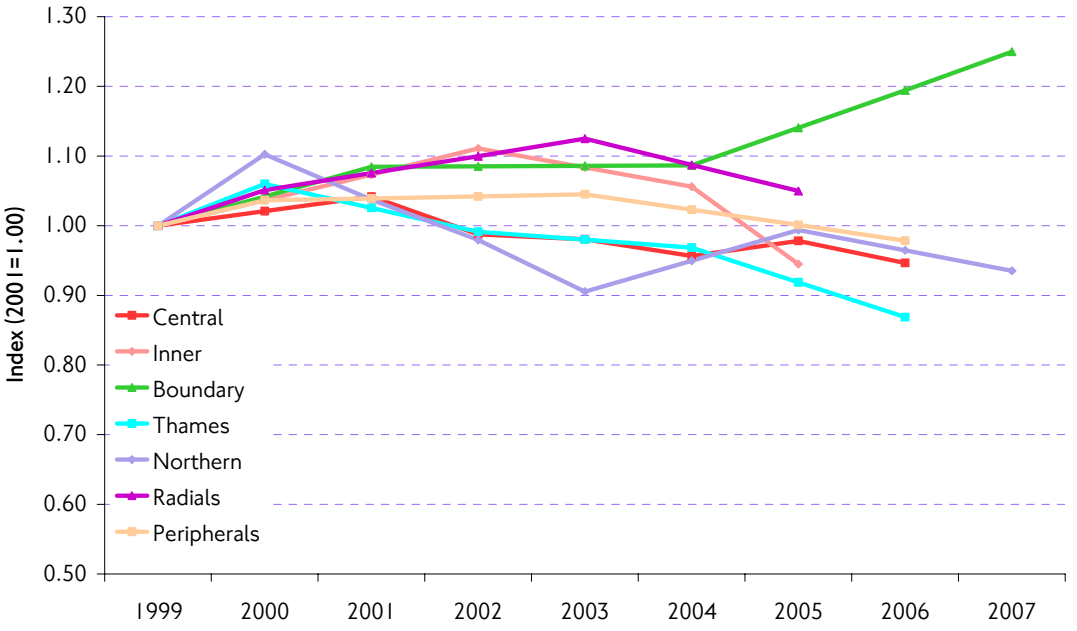


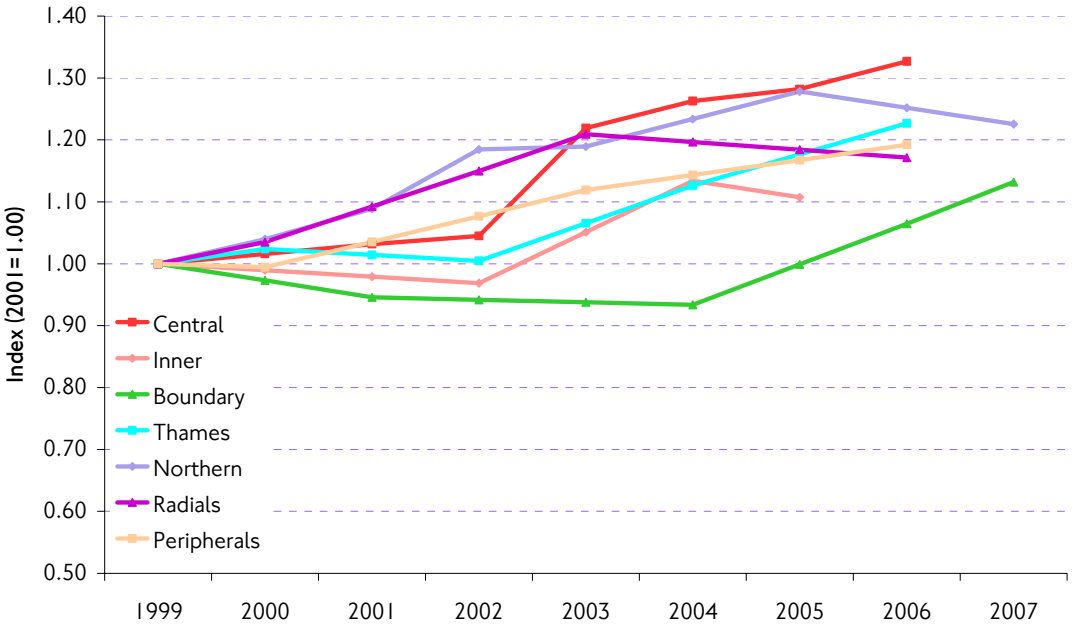
Figure 4.6 Traffic crossing strategic cordons and screenlines. Light goods vehicle traffic. 24-hour working weekday only.



Figures 4.6 and 4.7 show trends for light goods vehicles, broadly equating to those that are in-scope for phase 3 of the scheme from October 2010, and for buses and coaches that are affected by phase 2 of the scheme from July 2008. Volumes of light goods vehicles have again been broadly stable, with a tendency towards increased volumes in outer London and reduced volumes in central and inner London. Volumes

of buses and coaches have increased significantly and consistently, primarily reflecting recent TfL improvements to the London bus network.

Figure 4.7 Traffic crossing strategic cordons and screenlines. Bus and coach traffic. 24-hour working weekday only.



4.7 Implications for scheme assessment

These recently revised estimates of traffic volumes and trends in London, while still subject to further refinement, are considered to be sufficiently robust to justify their adoption as the best available estimates for scheme monitoring purposes. The emissions assessment work described in Section 6 of this report will therefore take the revised estimates of traffic volumes as a starting point for a series of emissions inventories tracking the impacts of the scheme. In so doing the monitoring work will depart from previous assessments of emissions, including those made and published by TfL as part of the scheme development.

4.8 Contribution to emissions

As well as accounting for differing proportions of traffic (vehicle-kilometres operated) different vehicles emit differing amounts of pollution. Despite representing relatively small proportions of overall vehicle-kilometres, heavier goods vehicles and buses/coaches contribute disproportionately to emissions of key pollutants. Tables 4.3, 4.4 and 4.5 illustrate this for, respectively, PM_{10}, NO_X and CO_2. Figures are given both at the national level, using the UK National Atmospheric Emissions Inventory, and at the Greater London level, using the 2004 London Atmospheric Emissions Inventory. Note that these estimates for London pre-date the monitoring work, and are therefore taken as the 'point of departure' for the emissions assessment work described in Section 6 of this report.

Table 4.3 Relative contribution to emissions of particulate matter (PM_{10}).

Source	UK National Atmospheric Emissions Inventory 2005				London Atmospheric Emissions Inventory 2004			
	tonnes	% total road traffic (exhaust)	% total road traffic (all)	% all sources	tonnes	% total road traffic (exhaust)	% total road traffic (all)	% all sources
All traffic	33,000	100%	100%	19%	1,950	100%	100%	69%
HGVs >12 tonnes	4,000	15%	11%	2%	280	18%	14%	10%
HGVs 3.5-12 tonnes	2,000	8%	6%	1%	120	8%	6%	4%
Buses/coaches >5 tonnes	1,000	3%	2%	0.5%	90	4%	5%	3%
LGVs 1.5-3.5 tonnes	11,000	45%	32%	6%	490	32%	24%	17%

Nationally, PM_{10} emissions from vehicles that are affected by phases 1 and 2 of the scheme (HGVs, buses and coaches combined) account for 19 percent of road traffic PM_{10}, equivalent to about 4 percent of total PM_{10} from all sources. In London, the equivalent percentages are higher, at 25 percent of road traffic PM_{10} emissions and 17 percent of total PM_{10} emissions. This largely reflects the relative importance of road traffic as a source of PM_{10} in London, with a smaller industrial contribution than is typical for the rest of the UK. Note that PM_{10} from tyre and brake wear (ie non-exhaust) is a significant component of total road traffic PM_{10} and this component will not be affected by the scheme.

Table 4.4 Relative contribution to emissions of oxides of nitrogen (NO_X).

Source	UK National Atmospheric Emissions Inventory 2005			London Atmospheric Emissions Inventory 2004		
	tonnes	% total road traffic (all)	% all sources	tonnes	% total road traffic (all)	% all sources
All traffic	549,000	100%	34%	26,400	100%	42%
HGVs >12 tonnes	151,000	27%	9%	7300	27%	11%
HGVs 3.5-12 tonnes	87,000	16%	5%	3100	12%	5%
Buses/coaches >5 tonnes	37,000	7%	2%	3600	13%	6%
LGVs 1.5-3.5 tonnes	58,000	11%	5%	3200	12%	5%

Tables 4.4 and 4.5 show equivalent figures for NO_X and CO_2 respectively. Neither of these pollutants are specifically targeted by the scheme, but the scheme is expected to have a significant beneficial impact on emissions of NO_X. Vehicles that are in-scope for phases 1 and 2 of the scheme contribute approximately 16 percent of total national NO_X emissions, with light goods vehicles (phase 3) contributing a further 5 percent. In London again the proportionate contribution to total emissions is higher, at 22 percent for vehicles affected by phases 1 and 2, but only 5 percent for light goods vehicles affected by phase 3 of the scheme from 2010.

In terms of CO_2, the overall contribution of vehicles potentially affected by the scheme to total emissions is much lower than for PM_{10} and NO_X, reflecting the dominance of other sources such as industrial combustion and commercial or residential heating. Typically, vehicles that are in-scope for the first three phases of the scheme account for between 6 (national) and 8 (London) percent of total CO_2 emissions.

Table 4.5 Relative contribution to emissions of carbon dioxide (CO_2).

Source	UK National Atmospheric Emissions Inventory 2005			London Atmospheric Emissions Inventory 2004		
	kilo tonnes[i]	% total road traffic (all)	% all sources	kilo tonnes[ii]	% total road traffic (all)	% all sources
All traffic	32,800	100%	18%	7,500	100%	25%
HGVs >12 tonnes	5200	16%	3%	900	12%	3%
HGVs 3.5 – 12 tonnes	2600	8%	1%	300	5%	1%
Buses/coaches >5 tonnes	1000	3%	0.5%	400	6%	1%
LGVs 1.5-3.5 tonnes	4600	14%	2%	900	12%	3%

[i] CO_2 as tonnes carbon.
[i] CO_2 as tonnes carbon dioxide.

4.9 Summary

Establishing the size and scale of the vehicle populations that are potentially affected by the London Low Emission Zone, and their relative contribution to emissions of key pollutants, is an essential preliminary to the work described in the following sections to measure the impacts of the scheme. Trends in the absolute numbers of vehicles circulating in London over the coming years will affect the scale of the potential impacts from the scheme, although they are not expected to be significantly influenced by it. These developments will be measured through TfL and DfT's ongoing strategic traffic monitoring work, as described in this section (see also **Appendix 2** to this report).

In summary, phases 1 and 2 of the scheme will potentially affect vehicles that account for about 5 percent of vehicle-kilometres in London, with phase 3 of the scheme potentially affecting vehicles that are responsible for a further 13 percent. In terms of emissions, phases 1, 2 and 3 of the scheme address sources that account for about one third of total primary PM_{10} emissions in London, and have the potential to significantly reduce PM_{10} emissions from these sources. There will be smaller proportionate impacts on other pollutants.

5. Emissions characteristics of potentially-affected vehicles within London

5.1 Introduction

Section 4 identified the vehicle populations of interest for the monitoring work. It described these populations in terms of **basic vehicle type** and **vehicle-kilometres driven** in Greater London. It examined recent volumetric trends in these populations, and outlined TfL's strategic traffic monitoring framework by which these trends will be measured over the life-cycle of the scheme. The section also characterises these vehicles in terms of their contribution to emissions of key pollutants, both in London and nationally.

This section describes how TfL is measuring the emissions characteristics of vehicles operating in London. TfL has devised a new approach using cameras that allow the emissions characteristics of vehicles in London to be directly inferred for the first time. TfL has obtained a complete calendar year of data for 2007 – the year before the introduction of the scheme. This 'baseline' dataset is presented, and comparisons made with vehicle registration ('licensing') data and with previous assumptions used for air quality analysis. Comparisons will later be made with similar measurements taken once the various phases of the scheme have been introduced to assess the degree to which the emissions characteristics of vehicles have changed in response to the scheme.

The basic impact of the scheme will be to encourage, for heavier diesel-engined vehicles operating in Greater London, a shift away from relatively heavily polluting older vehicles – those manufactured to the lower Euro emissions standards – towards relatively less polluting vehicles – those built to the higher Euro emissions standards. This change would be achieved either through direct replacement, of older vehicles with newer ones, retrofitting with pollution abatement equipment, or re-deployment of vehicles within operator fleets. The change should be visible as a shift in the Euro class profile of the affected vehicle fleets and of their 'on road' population, over and above that which would be expected from normal fleet renewal of life-expired vehicles (ie the 'background' change).

5.2 Key concepts and technical limitations

This section deals with the following views of the vehicle population:

- **Vehicle registration data** – looking at the emissions profile of vehicles registered (licensed) to addresses within a particular geographical area. Trends at the London, regional and national scale can be separately examined.
- **Vehicle population data** – looking at the emissions profile of vehicles that are observed (present) in the area covered by the scheme over a particular period of time, irrespective of their intensity of operation in that area. Corresponds to 'unique vehicles' observed to have been present in the zone on at least one occasion during the time period of interest.

- **Vehicle activity data** – looking at the emissions profile of vehicles that operate in the zone, according to the intensity of their operation, ie taking account of vehicle-kilometres operated. Data in this form is the key input to the emissions assessment work described in Section 6 of this report.

The following are the key components of change considered, applicable to all three 'views' of the vehicle population (above):

- **Gross fleet change** – the aggregate change to the emissions performance of the vehicle fleet over any one year, comprising both 'background change' and 'scheme-attributable change'.
- **Background fleet change** – the year-on-year improvement to the emissions performance of the vehicle fleet, reflecting the purchase of new vehicles and the removal of older ones from the vehicle stock. This would happen in the absence of a scheme.
- **Scheme-attributable fleet change** – the improvement to the emissions performance of the vehicle fleet that can be attributed to change in response to the scheme, ie over and above 'background' fleet change.
- **Scheme compliance** – whether or not a vehicle complies with the emission standards of the scheme or phase at a given date. This is broadly equivalent to Euro emissions standard III or above for particulate matter for phases 1, 2 and 3 of the scheme.
- **Established compliance** – the emissions profile or scheme compliance status of the vehicle fleet at a date considered not to reflect any significant impacts from the future scheme or phase, ie the 'default' emissions performance of the vehicle fleet.
- **Operator pre-compliance** – changes to the emissions performance of the vehicle fleet reflecting operator action to comply with the requirements of the scheme ahead of the actual scheme or phase implementation date.

There are two major technical limitations to the data considered in this section:

- First, the performance of the camera system in detecting and successfully classifying vehicles is less than 100 percent. This leads to an element of **camera non-detection bias** in the estimates. This means that measurements of absolute numbers of vehicles will tend to be systematically under-stated, although not generally to a material degree. The implications of this are however more significant when considering the frequency profile of vehicles present in the zone, the absolute degree of under-estimation **increasing** the more frequently a vehicle is actually present in the zone. Estimates of the emissions profile of the vehicle fleet are however unaffected.
- Second, the necessarily progressive development of the vehicle classification and business rules for the scheme during 2007 introduced some discontinuities into the data. Specifically, for the early part of 2007, DVLA tax classes were used to estimate vehicles with Reduced Pollution Certificates (and therefore compliant with the scheme requirements). From mid 2007, this was replaced by data from the Vehicle and Operator and Services Agency. This revealed that a proportion of operators had not maintained their certification (although they largely remained

compliant with the scheme), artificially reducing the assessed rate of compliance. This particularly affects the time series for vehicle type M3 buses and coaches.

The data considered in this section provides new and as yet not fully explored views of the vehicle population in Greater London. These data are still being investigated by TfL, and therefore much of the analysis presented in this section should be regarded as exploratory in nature at this early stage in the monitoring work.

5.3 The measurement task

The basic measurement task is to establish the **proportions** of either registered vehicles, unique vehicles or vehicle-kilometres operated, by vehicles in the different Euro emissions classes. This will identify vehicles that are either compliant or not compliant with the requirements of the scheme phase at a particular point in time.

In terms of the licensed vehicle fleet, this can be identified directly from databases established by TfL, based largely on vehicle licensing data from the Driver and Vehicle Licensing Agency (DVLA) but also including some additional information reflecting the registration process operated by TfL in relation to the scheme.

For vehicles present in the zone (unique vehicles), and for vehicle-kilometres operated, a means of measurement is required that:

- Provides estimates at the London-wide scale that are statistically-representative of the vehicle population and of vehicle-kilometres operated by the vehicles of interest within London.
- Provides information by which the basic vehicle type and Euro emissions class of vehicles can be robustly identified.
- Allows developing trends in vehicle emissions characteristics to be tracked over time, particularly over the short-term around the implementation dates of the various phases of the scheme.
- Generates outputs that are directly compatible with the input requirements of the London Atmospheric Emissions Inventory (see also Section 6).

5.4 Using Automatic Number Plate Recognition cameras

The approach adopted has been to measure vehicle emissions profiles using a representative statistical sample of semi-permanent Automatic Number Plate Recognition (ANPR) cameras across Greater London. Automatic number plate recognition technology has been successfully used by TfL for enforcement of Congestion Charging in central London. The technology works by recording the registration marks (the formal term for vehicle registration numbers) of vehicles passing camera sites. These registration marks (which are anonymised immediately for data protection purposes) can then be matched with similarly-anonymised datasets – in this case an enhanced sub-set of the DVLA vehicle licensing database. This contains details of the vehicle relevant to the scheme monitoring, such as body type, weight, wheel plan and fuel type. This establishes whether the vehicle seen is in-scope for the requirements of a particular phase of the scheme (ie whether it is a

car or a lorry), and provides other information, largely based on the TfL enforcement process for the scheme, that can be used to help determine Euro emissions class and scheme compliance status.

Figure 5.1 A typical semi-permanent automatic number plate recognition camera installation on a traffic signal head.

5.5 Statistical requirements and sampling approach: a summary

The key conclusions from a sample design exercise for the monitoring camera network were that:

- A sample of approximately 100 individual cameras, located across Greater London so as to be statistically representative of traffic (vehicle-kilometres) driven by vehicles that are in-scope for the first two phases of the scheme, would provide an optimal balance between statistical precision and spatial resolution, generating of the order of 40 million observations (all vehicle types) per year.
- The sample would be adaptable – at minimal cost – to cover vehicles that will be in-scope for phase 3 of the scheme from October 2010, and would also in due course provide good information on the emissions characteristics of other vehicles that are not in-scope to be affected by the scheme, such as cars and taxis.
- The key temporal target for trend tracking should be a four-week period at the lowest required level of spatial resolution for the most infrequent vehicle type of interest. There are thirteen four-week periods in a calendar year (see **Appendix 3**).
- Dividing the sample into 11 'regional' strata and three road flow (ie based on traffic volume) strata would provide a good compromise between the various competing sample priorities, giving 33 strata each consisting of three cameras (99 in total).
- Based on the projected sample rate, each stratum could be expected to capture about 1 million observations (all vehicles) per year, of which vehicles that are

in-scope (for the first two phases of the scheme) would typically comprise 5 percent (or roughly 50,000 observations per stratum per year).

While optimised to the intended purpose, the camera sampling arrangements have certain characteristics that should be taken into account when understanding the outputs from the monitoring work. The more important of these are that:

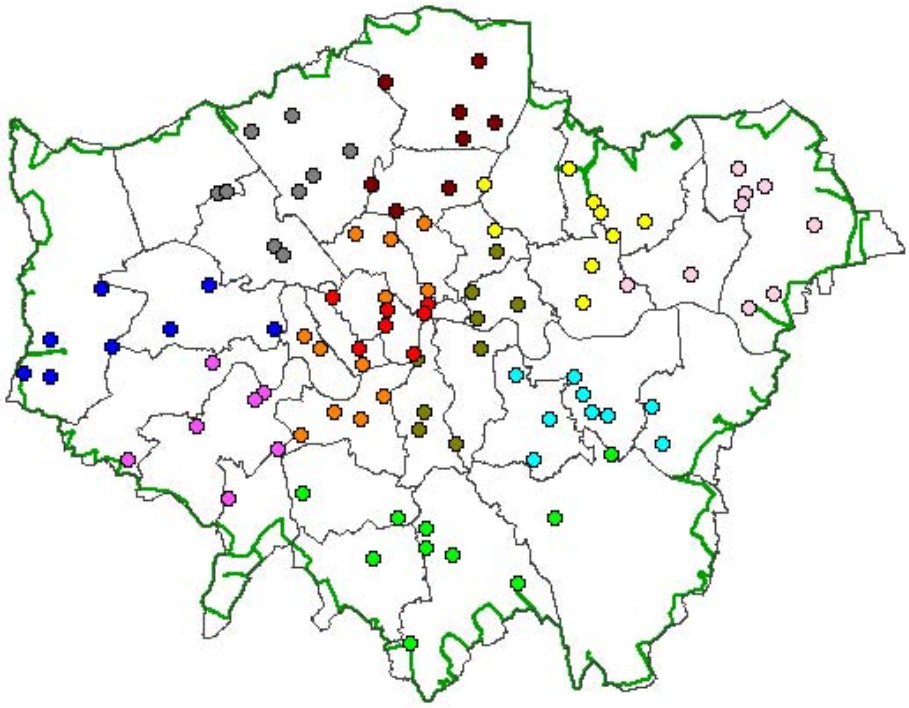
- There is one camera per site, monitoring only lane one of multiple-lane roads. This reflects a design prioritisation of representative London-wide coverage over completeness of coverage at any one site, and is organised to be statistically bias-free for the quantities of key interest.
- Traffic on motorways in Greater London is not sampled directly. However, for this purpose, their traffic is likely to reflect the requirements of the scheme, since it is not possible to join or leave a motorway in Greater London without travelling on roads that are subject to the requirements of the scheme.
- Minor roads are also excluded from the camera sample for both practical and sample optimisation reasons. Again, however, their traffic is likely – in terms of emissions performance – to closely reflect that on the more major road network.

In practical terms, the camera sample covers all non-motorway major and intermediate flow roads, mirroring the explicitly-modelled roads in the emissions inventory. Flows on minor non-sampled roads are estimated based on the proportions observed on sampled roads and following standard emissions inventory methodology.

This means that estimates of vehicle emissions profiles obtained from the cameras (percentage belonging to each Euro standard) can be applied directly to the corresponding traffic flow estimate in the emissions inventory. The traffic volumes information in the inventory will statistically 'weight' the raw camera-based estimate so as to be representative of vehicle-kilometres driven in London.

Figure 5.2 shows the camera sample, with cameras colour-coded by regional stratum. The map also shows the London borough boundaries (in black) and the scheme boundary (in green).

Figure 5.2 Automatic number plate recognition camera sample for scheme monitoring, showing regional stratification.



5.6 Determining the emissions characteristics of vehicles

Cameras operate continuously to correspond to scheme operational hours. Data from individual cameras are returned to a central hub using mobile telephone technology. Images of individual vehicles are not required for monitoring purposes and are discarded immediately by the cameras.

Encrypted registration details of all vehicles observed by the camera sample, whether in-scope or not for the requirements of the scheme, are processed through a bespoke software system developed by TfL. The basic processing task is to match the encrypted registration marks with a similarly encrypted version of TfL databases relating to the scheme. These contain selected details of all nationally registered vehicles including, progressively from late 2007, foreign domiciled vehicles that have registered their details with TfL. Details include basic vehicle characteristics, such as: body type, fuel type, wheel plan and date of first registration. This enables the 'basic vehicle type' of observed vehicles to be identified. The database also contains a set of 'business rules' for the scheme, which establishes the Euro emissions class and hence the scheme compliance status of each in-scope vehicle observed.

Therefore, at the aggregate level and for any sample stratum, the percentages of each vehicle (body) type accounted for by the various Euro emissions classes can be calculated, and changes in these percentages (ie the emissions profile of the vehicle fleet) tracked over the life cycle of the scheme.

The scheme compliance database and other related sources can also be used to examine global trends in the emissions characteristics of the national or London

registered vehicle fleet. This is not directly useful for estimating emissions, as traffic operating in London does not necessarily correspond to vehicles registered to an address there, but it does provide a key means of identifying global changes within vehicle populations, which corresponds to 'background' changes in emissions characteristics. It also offers opportunities for further understanding the relationship between vehicles licensed to addresses in London and those actually operating there.

5.7 Issues with the emissions classification

While innovative and proven to be relatively robust in tests, the system described has a number of features and potential shortcomings that need to be recognised, in addition to those already outlined in Section 5.2.

- First, the DVLA dataset used for monitoring purposes is only provided to TfL on a quarterly basis. This means that there will be some delay in the very newest vehicles being positively identifiable through the monitoring cameras. The raw monitoring camera data will consequently tend to slightly under-state the degree of compliance, and slightly over-state the corresponding emissions, at any particular point in time. This does not apply to the enforcement process for the scheme, which is carried out on a daily basis.
- Second, Euro emissions standards are defined in terms of individual pollutants, and it is therefore possible for a specific vehicle to belong to different Euro classes for different pollutants (see also **Appendix 1**). For scheme compliance purposes the relevant criterion is the emission of particulate matter – known as the 'PM Euro class'. This may be higher than the 'Base' Euro class, applicable to all pollutants and to which the vehicle was originally manufactured. This circumstance typically reflects the fitment of pollution abatement equipment for PM post-manufacture which is a common means of complying with the requirements of the scheme (see **Appendix 4** for further technical information).
- Third, assignment of a vehicle to a Euro emissions class for scheme enforcement purposes is not the same as determining the emissions of the vehicle for air quality assessment purposes. Further stages are required, as discussed in Section 6.

5.8 Database dimensions

Conceptually, TfL's monitoring database that contains camera data and scheme compliance information is set up as a multi-dimensional 'cube'. The user can choose to expand the database according to various dimensions, which may include attributes of individual vehicles or more global information, such as scheme compliance status. Table 5.1 summarises the most important of these dimensions.

Table 5.1 Summary of main dimensions for analysis in the TfL monitoring database for the scheme.

Key dimension	Description
National fleet (global input)	All vehicles in the DVLA dataset, whether captured by the cameras or not. This is used both as a look-up for ascribing emissions characteristics, and for national fleet-level analysis.
Total captures (global output)	Each incidence of a vehicle being seen by a camera – equivalent to one record in the database. Vehicles seen multiple times will have a corresponding number of multiple records. Used for establishing vehicle-kilometre equivalence.
Unique captures (global output)	A refinement of total captures, such that all unique vehicles seen over a period will have one record, irrespective of the number of times seen. Used for establishing fleet or vehicle population level compliance.
Four-weekly period (attribute)	Captures are grouped by four-weekly time period, from 1 January 2007. Periods run from 00:00 hours on the first Monday to 23:59 hours on the fourth Sunday. There are 13 four-weekly periods per calendar year. More disaggregate analysis is possible, as individual observations are date/time stamped.
Sample strata/ camera (attribute)	Observations are tagged with the identity of the camera that produced them, allowing arbitrary spatial aggregations for analysis.
Vehicle body type (attribute)	This is the European Vehicle Type Specification (see also **Appendix 3**). Classification occurs within each quarterly extract of DVLA data according to highly-specific scheme business rules involving vehicle weight, body class, seats, taxation class and other attributes. Possible values are: M1 cars; M2 minibuses; M3 buses and coaches; N1 Class I light goods, N1 Class II light goods; N1 Class III light goods; N2 heavy goods; N3 heavy goods and Hackney Carriages.
TfL bus type (attribute)	An additional classification that sub-divides buses operated on behalf of TfL into their primary body type (eg single deck, double deck, articulated).
Base Euro emissions class (attribute)	This is the Euro emission standard to which the vehicle was manufactured. It is established using scheme business rules. Possible values are I through V, with a 'pre-Euro' option for older vehicles manufactured prior to 1992. Generally, the higher the Euro class, the lower the emissions.
PM Euro emissions class (attribute)	This is the same as the Base Euro class, but can be uplifted to reflect alterations to the vehicle after manufacture, typically the fitment of pollution abatement equipment to reduce emissions of particulate matter. This is the primary indicator for determining compliance with scheme requirements.
Engine capacity (attribute)	A measure of the size of the vehicle engine provided by DVLA and used for sub-dividing observations for emissions inventory purposes.
Fuel use (attribute)	Also provided by DVLA and used for emissions inventory purposes.
Wheel plan (attribute)	This dimension describes the number and configuration of the wheels. Provided by DVLA and used for emissions inventory purposes.
Scheme phase (attribute)	This is a flag that signifies the liability of a vehicle to comply with the various phases of the scheme. The compliance status of individual vehicles can then be assessed.

5.9 Relationship to scheme enforcement cameras

Scheme enforcement uses a similar arrangement to the monitoring cameras, with automatic number plate recognition cameras detecting vehicles operating within the zone, and comparing their registrations with databases to establish their compliance with scheme requirements. The enforcement infrastructure is however completely separate from the monitoring infrastructure, as is the data processing involved, which occurs on a daily basis. Nevertheless, estimates of scheme compliance obtained from the two camera systems should be broadly comparable, given the comprehensive coverage of both camera networks. Data from the enforcement cameras following their installation at the end of 2007 will provide a cross-check on the information from the monitoring cameras and vice-versa.

5.10 Overview of baseline measurements

The following sections summarise key measurements from the cameras and licensing data for the 2007 'baseline' calendar year only. They do not cover the immediate implementation period for phase 1 of the scheme or the run-up to phase 2 – these are addressed in Section 13 of this report. In time, the baseline measurements for 2007 will be compared with equivalent measurements for 2008 (the first year of the scheme) and subsequent years. Differences can then be calculated, and attributed between direct impacts of the scheme, and wider background trends affecting the vehicle fleet.

It is nevertheless apparent that 2007 saw action by vehicle operators to progressively modify their vehicles and/or operations to ensure compliance with the requirements of the first phases of the scheme ahead of the actual implementation dates – referred to subsequently as **operator pre-compliance**. This means that 'average' values for 2007 are not ideal, and it is necessary to look in more detail at how trends have developed across the 13 individual four-week camera observation periods that are available for 2007.

The key 2007 baselines for the monitoring work are now identified and set out under three headings:

- **Vehicle-registration based** views of the vehicle population – based primarily on national fleet (DVLA) data and the TfL scheme compliance database. Both regional and London specific values are available.
- **Vehicle population based** views of unique vehicles present in London – based primarily on new data from the automatic number plate recognition cameras, reflecting the populations of vehicles affected by the scheme.
- **Vehicle activity based** views of the vehicle population in London – based on automatic number plate recognition camera data and reflecting vehicle-kilometres operated.

Appropriate comparisons are made between the above baselines and also between these new empirical estimates and previous assumptions used for air quality analysis, all of which can be used in conjunction to derive estimates of the key change

indicators of interest. A concluding section looks across these newly-available estimates for vehicles potentially affected by the scheme. It draws some preliminary estimates about the degree of 'background' change visible during the 2007 calendar year, and the degree of **scheme-attributable** change, reflecting operator pre-compliance during 2007 with the requirements of the scheme, ahead of the actual implementation date for the first two phases. These are subsequently used to develop initial monitoring based estimates of the impact of the scheme on vehicle emissions and air quality in 2007.

5.11 Vehicle registration based views of the vehicle population

This section examines registered vehicle populations at the national, London and regional scale, and their compliance status with phases 1 and 2 of the scheme during 2007 – the full year **before** the implementation of the scheme.

Baseline 1: The national registered vehicle fleet – absolute numbers and vehicle type composition

Table 5.2 shows the number of registered vehicles in each of the main vehicle type categories of interest at the national (Great Britain) scale. The four dates in the columns represent the specific date to which information in the TfL scheme compliance database relates. Note that it covers a period of only nine calendar months and that scaling is required to derive annual equivalent changes. Note also that development of the vehicle classification procedures associated with the scheme by TfL have affected the allocation of some classes of buses and light goods vehicles between the different rows between successive versions of the database.

Table 5.2 Vehicles registered in Great Britain. Thousands of vehicles, 2007 by quarter.

Vehicle type	As of 23 Mar 2007	As of 01 Jun 2007	As of 01 Sep 2007	As of 30 Dec 2007
Hackney Carriages	43	42	43	43
M1 cars	27,728	27,474	28,150	27,991
M2 minibuses	100	85	87	86
M3 buses & coaches	75	76	75	75
N1 Class I LGVs	803	719	787	813
N1 Class II LGVs	676	767	483	494
N1 Class III LGVs	1,592	1,491	1,829	1,838
N2 HGVs under 12 tonnes	241	287	234	235
N3 HGVs over 12 tonnes	293	290	296	295
All vehicle types	31,552	31,231	31,984	31,871

There are about 31 million individual vehicles registered in Great Britain, of which approximately 2 percent are in-scope for phases 1 and 2 of the scheme.

Baseline 2: The national registered vehicle fleet – compliance status with the requirements of the scheme

Table 5.3 takes the same registration data for those vehicles that are in-scope for the requirements of the first two phases of the scheme only. It identifies whether or not they complied, at that point in 2007, with the requirements of the phase that they will be affected by in 2008. In other words, this is a measure of the 'established compliance' of the national vehicle fleet with the then-future requirements of the London scheme.

Table 5.3 Compliance status of potentially affected vehicles with the requirements of phase 1 and 2 of the scheme during 2007. Numbers of vehicles, Great Britain.

Vehicle type	Category	As of 23 Mar 2007	As of 01 Jun 2007	As of 01 Sep 2007	As of 30 Dec 2007
N3 HGVs	All N3 HGVs	293,000	290,000	295,500	295,300
	Phase 1 compliant	193,000	189,000	202,000	212,000
	Percentage compliant with phase 1	66%	65%	68%	72%
M3 buses & coaches	All M3 buses	75,300	76,100	75,400	74,800
	Phase 2 compliant	30,100	29,800	31,400	33,000
	Percentage compliant with phase 2	40%	39%	42%	44%
N2 HGVs	All N2 HGVs	241,400	287,400	234,000	234,700
	Phase 2 compliant	109,600	134,300	112,700	119,700
	Percentage compliant with phase 2	45%	47%	48%	51%

- At the national scale, the level of established compliance during 2007 was relatively low at approximately two-thirds of N3 HGVs. The equivalent proportion for N2 HGVs and M3 buses and coaches was typically between 40 and 50 percent. The 8,000 TfL London buses also come under the M3 category, and they had a known compliance status of almost 100 percent (see Section 5.14)
- As would be expected, rates of compliance improved throughout 2007, but at a relatively slow rate.
- Although national in coverage, these statistics demonstrate a clear scope for potential improvements from the scheme. They also provide one indication of the scale of 'background' changes to the emissions characteristics of the UK vehicle fleet largely, although not wholly, independent of the influence of the scheme.

Baseline 3: The London registered vehicle fleet – compliance status with the requirements of the scheme

Table 5.4 shows the absolute numbers of vehicles in-scope for the first two phases of the scheme that are registered to an address in Greater London, as well as the numbers and proportions that were compliant with the requirements of phases 1 and 2 of the scheme, according to TfL's scheme compliance database during 2007. The data is directly comparable with the national scale estimates in Table 5.3.

Table 5.4 Compliance status of the London registered vehicle fleet (potentially affected vehicles only) with the requirements of phase 1 and 2 of the scheme during 2007. Numbers of vehicles, Greater London.

Vehicle type	Category	As of 23 Mar 07	As of 01 Jun 07	As of 01 Sep 07	As of 30 Dec 07
N3 HGVs	All N3 HGVs	18,400	18,200	17,900	17,700
	Phase 1 compliant	10,600	10,400	10,700	12,400
	Percentage compliant with phase 1	58%	57%	60%	70%
M3 buses & coaches	All M3 buses	9,900	9,900	10,000	9,900
	Phase 2 compliant	7,800	7,300	7,700	8,100
	Percentage compliant with phase 2	79%	74%	77%	81%
N2 HGVs	All N2 HGVs	19,800	23,900	18,500	18,500
	Phase 2 compliant	8,100	10,600	8,300	9,200
	Percentage compliant with phase 2	41%	44%	45%	49%

- Approximately 18,000 heavy goods vehicles over 12 tonnes (N3 HGVs) and 20,000 of those under 12 tonnes (N2 HGVs) are registered in London; approximately 6 percent and 8 percent of the national total for these vehicles types respectively. Note in this respect that Table 4.1 suggests that, in combination, both of these vehicle types account for only 3 percent of vehicle kilometres operated in London.
- For both categories of heavy goods vehicle, established compliance rates during 2007 for London registered vehicles were, perhaps surprisingly, lower than the national average. However, the rates of improvement observed during 2007 in London registered vehicles were correspondingly greater than those nationally.
- The reasons for these differences are not immediately clear. They do however suggest only a loose relationship between vehicles registered to addresses in London and those operating there. For example, London may 'artificially' host operator fleets deployed outside London but registered to head-office addresses in London.
- On the other hand, the higher observed rate of improvement appears to reflect a greater tendency for vehicles registered in London to be more directly affected by the requirements of the scheme. Of particular note is the comparatively much higher compliance rates for buses and coaches in London compared to nationally, reflecting the importance of the TfL bus fleet in the overall population of buses and coaches registered in London.

Baseline 4: Regional changes to the scheme compliance status of the registered vehicle fleet during 2007

This section looks at trends in regional compliance of the registered vehicle fleet during 2007 with the requirements of the first two phases of the scheme. Table 5.5 shows the percentage compliance for vehicles registered in the major regions of Great Britain for the four available quarterly DVLA extracts. Note that these span a period of approximately nine months only for 2007 (March-December).

As would be expected, the large majority of rows in the table show increasing levels of compliance – most vehicle types and regions showing an improvement in scheme compliance status during 2007. However again there is a clear tendency for established compliance rates among vehicles registered in London to be lower than elsewhere, and for rates of improvement during 2007 to be higher.

By making some reasonable assumptions it is possible to use these numbers to estimate the 'background' change in the vehicle fleet that is independent of the scheme. Furthermore, by assuming that operator pre-compliance ahead of the scheme only became a significant factor during the latter half of 2007, reflecting the TfL public information campaign for the scheme, the component of the aggregate annual change that may have been attributable to the influence scheme can also be estimated. These estimates (rightmost three columns – see also footnotes) suggest that:

- Estimated **background** improvement in scheme compliance during 2007 was of the order of 4 to 5 percentage points for N3 HGVs, 3 percentage points for M3 buses and coaches, and 5 to 6 percentage points for N2 HGVs. These rates of improvement are fairly consistent across the different regions.
- An element of **operator pre-compliance** is discernible across most regions, as might be expected, but the magnitudes are generally small. Significantly, the estimated operator pre-compliance for vehicles registered in London is systematically higher than other regions. For N3 heavy goods vehicles affected by phase 1 of the scheme from February 2008, the estimated rate of improvement in London is three times greater than that nationally.
- For N2 HGVs a differential 'London effect' is also visible, but at lower levels to that seen for N3 HGVs. This would be a reflection of the later phase 2 implementation date (July 2008).
- The picture for buses and coaches is inconsistent, the apparent negative background change in London reflecting known anomalies in the categorisation of these vehicles by type during 2007.

Table 5.5 Percentage compliance and percentage point improvement in compliance in respect of phase 1 and 2 of the scheme by region including London. 2007 by quarter – registered vehicles.

Vehicle type	Region	As of 23/03/07	As of 01/06/07	As of 01/09/07	As of 30/12/07	Gross Annual Change[i]	Inferred Background Change[ii]	Inferred Scheme Change[iii]
N3 HGVs (phase 1)	East Anglia	68.8%	68.2%	70.8%	74.0%	+6.2%	+4.0%	+2.3%
	London	57.9%	56.9%	60.0%	69.7%	+12.9%	+4.3%	+8.6%
	Midlands	66.7%	66.2%	69.0%	72.7%	+7.1%	+4.6%	+2.5%
	North East	70.7%	69.8%	72.9%	75.8%	+6.2%	+4.4%	+1.8%
	North West	69.1%	68.2%	71.0%	74.2%	+6.0%	+3.7%	+2.3%
	Scotland	66.1%	65.3%	68.5%	70.9%	+6.0%	+4.9%	+1.2%
	South East	65.0%	64.2%	67.2%	72.2%	+8.3%	+4.4%	+3.9%
	South West	62.0%	60.9%	63.5%	66.1%	+4.9%	+2.9%	+1.9%
	Wales	50.3%	49.5%	52.5%	55.8%	+6.5%	+4.4%	+2.1%
	All UK	**65.9%**	**65.1%**	**65.1%**	**71.9%**	**+7.1%**	**+4.4%**	**+2.7%**
M3 buses & coaches (phase 2)	East Anglia	40.7%	30.5%	33.3%	34.7%	+5.3%	+5.2%	+0.1%
	London	78.8%	73.8%	77.1%	81.5%	+1.8%	-3.5%	+5.3%
	Midlands	35.0%	35.0%	36.1%	38.7%	+4.2%	+2.2%	+2.0%
	North East	33.6%	33.1%	35.9%	37.0%	+4.6%	+4.7%	-0.1%
	North West	34.8%	33.8%	36.3%	37.8%	+3.6%	+2.9%	+0.8%
	Scotland	32.8%	32.2%	35.1%	37.6%	+6.0%	+4.7%	+1.3%
	South East	41.5%	42.6%	45.2%	48.2%	+8.5%	+7.3%	+1.2%
	South West	28.4%	27.3%	28.9%	31.1%	+2.9%	+1.0%	+1.9%
	Wales	27.2%	25.6%	27.6%	30.6%	+3.6%	+0.9%	+2.7%
	All UK	**40.0%**	**39.1%**	**41.6%**	**44.1%**	**+4.9%**	**+3.2%**	**+1.7%**
N2 HGVs (phase 2)	East Anglia	39.7%	41.3%	41.7%	44.7%	+6.1%	+4.1%	+2.0%
	London	41.0%	44.1%	45.0%	49.5%	+10.4%	+7.9%	+2.5%
	Midlands	51.7%	51.9%	54.9%	57.3%	+7.2%	+6.4%	+0.8%
	North East	50.8%	51.2%	53.3%	55.8%	+6.3%	+5.1%	+1.2%
	North West	50.4%	50.3%	53.0%	55.3%	+6.2%	+5.3%	+0.9%
	Scotland	45.8%	47.1%	49.1%	52.4%	+8.2%	+6.6%	+1.6%
	South East	42.0%	44.2%	44.1%	47.1%	+6.2%	+4.4%	+1.9%
	South West	38.6%	42.2%	40.3%	42.5%	+4.8%	+3.4%	+1.4%
	Wales	34.2%	36.7%	36.3%	39.4%	+6.3%	+4.2%	+2.0%
	All UK	**45.4%**	**46.7%**	**48.2%**	**51.0%**	**+7.0%**	**+5.5%**	**+1.4%**

(i) Scaled from nine months covered by licensing data to 12 months full year.
(ii) Linear extrapolation of observed improvement in compliance over first 8 months of 2007, ie 'background trend'.
(iii) Additional improvement over months 8 to 12, notionally attributable to scheme, over and above background change over that period.

5.12 Unique vehicle based views of the London vehicle population

This section makes use of the automatic number plate recognition camera data and looks at the vehicle populations observed within Greater London during 2007 in terms of **unique vehicles**. This means that, over any given analysis period, the vehicle populations of interest are enumerated on the basis of 'having been seen in the zone at least once'. Thus it is a 'population-based' view of the London vehicle fleet based on presence in the zone.

It is possible to extend this unique vehicles indicator to derive frequency distributions in terms of 'numbers of days seen' for individual vehicles. This enables features such as compliance with the requirements of the scheme to be examined in terms of frequency of daily presence in the zone.

Absolute number of unique vehicles operating in London

Table 5.6 shows the absolute number of unique vehicles observed for each of the main vehicle type categories over each of the 13 four-week monitoring periods during 2007. Note that camera non-detection bias (see Section 5.2) will be a factor in these estimates.

Table 5.6 Absolute observations of unique vehicles by monitoring cameras. 2007 calendar year by four-week period, thousands.

Vehicle type	Four-week period												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Hackney Carriages	22	22	22	22	22	22	22	21	22	22	21	22	22
M1 cars	2,270	2,290	2,510	2,510	2,520	2,680	2,550	2,260	2,380	2,070	1,930	2,370	2,570
M2 minibuses	10	10	11	11	11	10	10	8	8	7	7	8	8
M3 buses & coaches	11	12	13	12	13	14	14	13	12	12	10	13	12
N1 Class I LGVs	74	77	84	82	83	78	76	68	74	70	64	75	73
N1 Class II LGVs	67	69	75	74	76	88	86	77	51	48	44	51	50
N1 Class III LGVs	150	160	170	170	170	170	170	150	180	170	160	180	180
N2 HGVs	26	27	29	29	30	34	33	30	26	24	23	26	25
N3 HGVs	49	51	55	56	56	57	57	50	50	48	48	51	48
All	**2,690**	**2,720**	**2,970**	**2,970**	**2,990**	**3,150**	**3,020**	**2,680**	**2,810**	**2,470**	**2,300**	**2,800**	**2,980**

Table 5.6 shows that:

- Typically, between 2.3 and 3.1 million unique vehicles are observed by the cameras in each four-week period – with a mean of 2.8 million. A significant

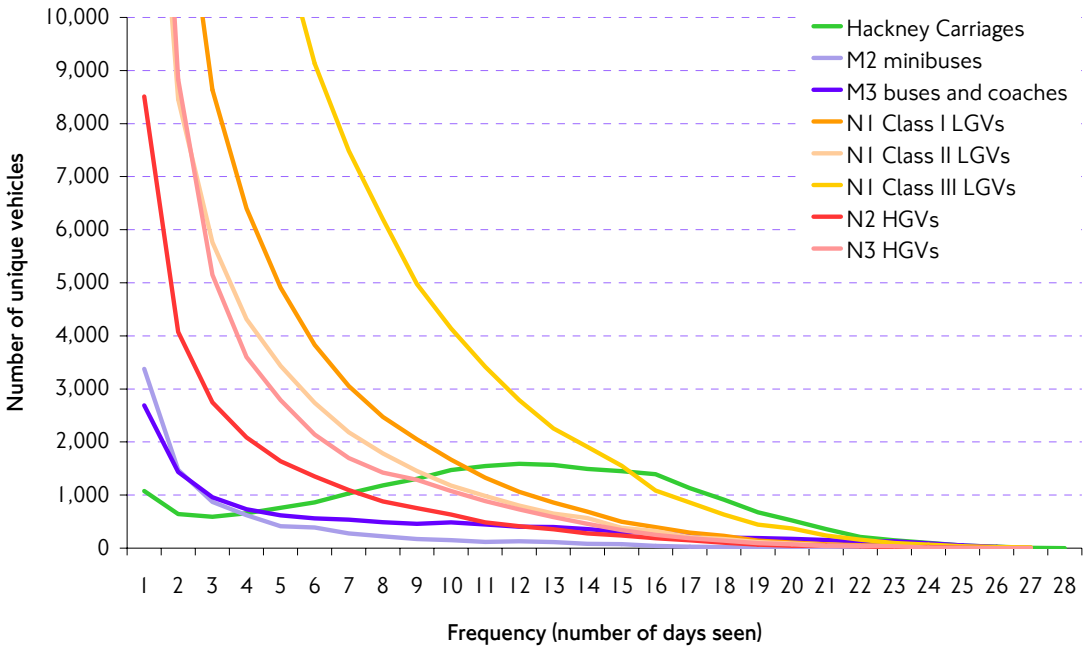
proportion of this variability will reflect various technical issues with the monitoring cameras during 2007.

- The large majority of these vehicles are unaffected by the scheme. Vehicles that are potentially affected by phase 1 of the scheme from February 2008 account for just under 2 percent of all vehicles (N3 HGVs). Those affected by phase 2 from July 2008 (N2 HGVs and M3 buses and coaches) account for approximately 1.5 percent. Those that will be affected by phase 3 from October 2010 (N1 Class II and III LGVs, and M2 minibuses) account for around 8 percent of all vehicles observed.
- The typical observation of 22,000 unique Hackney Carriages per period compares satisfactorily with a known independent estimate of the number of licensed taxis in London[1].

Frequency distributions of unique vehicles operating in London

Figure 5.3 shows frequency of presence (number of days observed by at least one camera) in the zone for an example four-week period. Higher frequencies have been truncated for clarity on the figure.

Figure 5.3 Frequency distribution of vehicle presence in the London Low Emission Zone (number of days seen). Example TfL four-week period, late 2007.



- As would be expected, the majority of unique vehicle types exhibit a progressively decaying frequency, with most being seen only infrequently. This indicates a relatively fluid vehicle population, with a large number of infrequent visitors and only a small core of vehicles that are present in the zone on most days.
- Thus, approximately 77 percent of all unique N3 HGVs and 72 percent of all N2 HGVs observed during the 28 day period are seen on five days or less. Less than

one percent of N3 HGVs and N2 HGVs were seen in the zone on 20 or more of the possible 28 days.

- Frequency profiles for buses and coaches are noticeably different. As would be expected, the proportion of all observed buses that are seen infrequently is less than for other vehicle types, and a greater proportion are seen on many of the days in the period. This reflects a relatively small 'captive' bus population.
- The pattern for licensed taxis (Hackney Carriages) is quite distinct, in that many unique vehicles are seen on most days. Again, this is a logical reflection of the largely 'captive' licensed taxi fleet, with individual vehicles operating on most days.

The choice of four-week period for the above analysis is convenient but also potentially misleading. For example, while it can be fairly safely assumed that most licensed taxis in London will be operating on at least one of the days during the period in question, this may not be the case for other vehicle types. This approach can therefore be extended to examine the frequency distributions that are associated with the different vehicle types over the whole 2007 calendar year. It is also possible to develop this analysis to look at profiles of compliance with the requirements of the scheme in terms of unique vehicles operating in London. A complicating factor in doing this is that fleet change and vehicle turnover during the year will affect the aggregate statistics, which are of necessity annual averages.

Baseline 5: Annual populations of unique vehicles in London and compliance with the requirements of the scheme in 2007

Figures 5.4 to 5.7 show annual frequency distributions for the three vehicle types subject to phases 1, 2 and phase 4 (from January 2012) of the scheme. The equivalent distribution for licensed taxis is shown for comparison, although they are unaffected by the scheme.

For vehicles subject to the scheme, proportions of each frequency class that are compliant with the requirements of the relevant 2008 or 2012 scheme phase are also shown. Note that the compliance indicator is based on successive quarterly DVLA extracts. Therefore, a proportion of unique vehicles will have changed compliance status – but not frequency class – during the course of the year (this is not shown in the graphs).

In each figure only those vehicles shown as being non-compliant for either phase 1 or 2 of the scheme are required to take action to comply with the requirements of the scheme before the relevant scheme phase implementation date (the darker red portion of the bars). Frequency classes have been grouped for clarity.

Figure 5.4 Annual frequency distribution for 2007 calendar year, N3 heavy goods vehicles. Showing established compliance with requirements of phases 1 and 4 of the scheme.

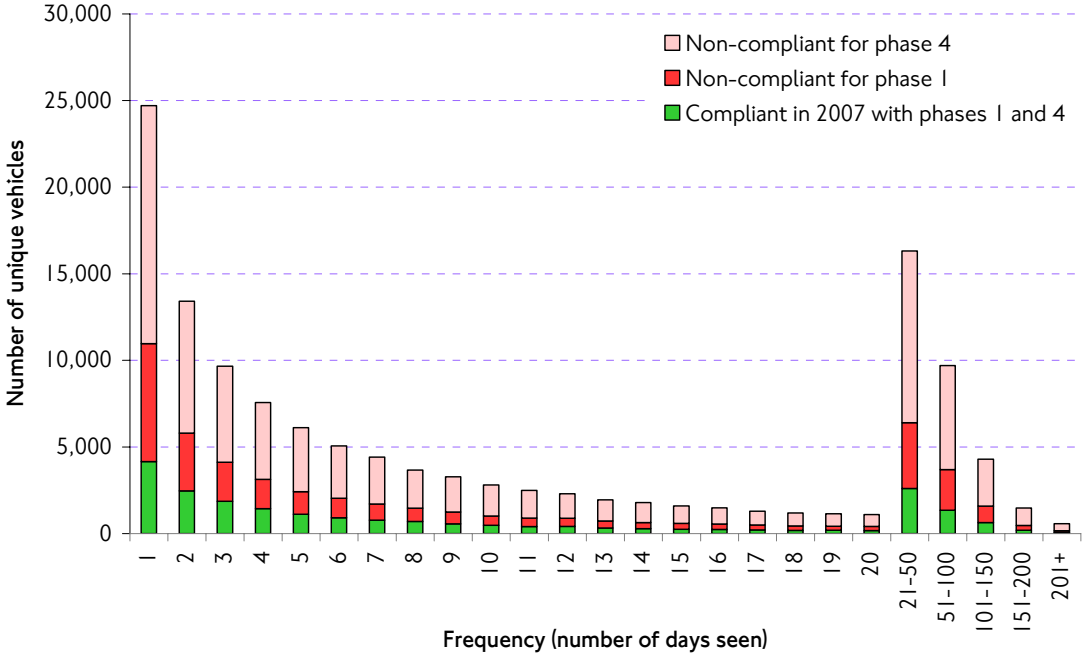


Figure 5.5 Annual frequency distribution for 2007 calendar year, N2 heavy goods vehicles. Showing established compliance with requirements of phases 2 and 4 of the scheme.

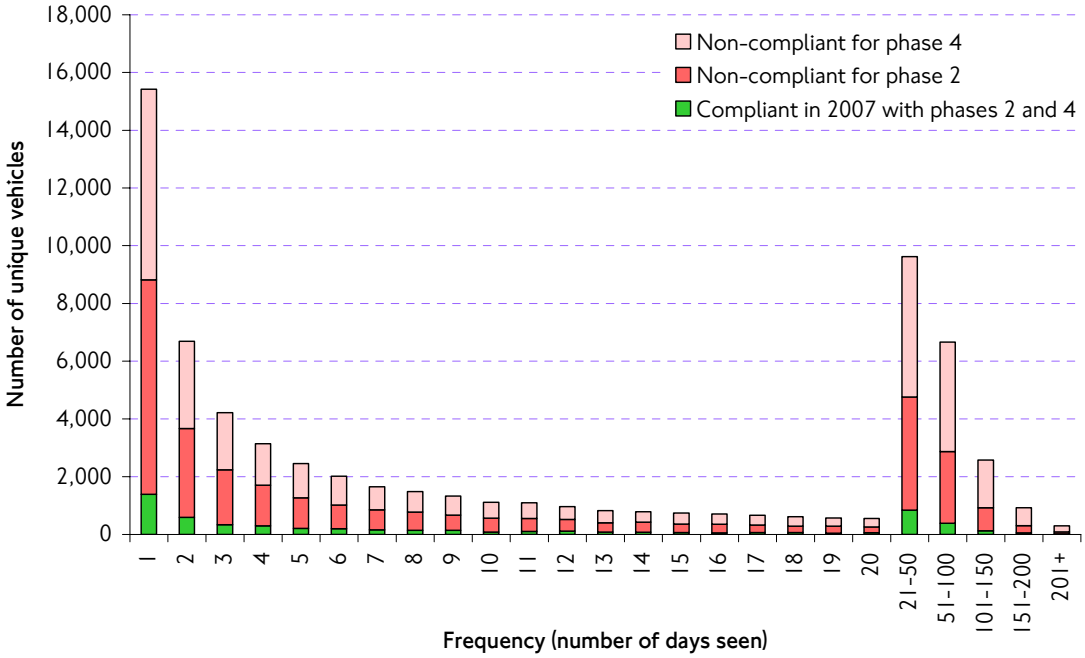


Figure 5.6 Annual frequency distribution for 2007 calendar year, M3 buses and coaches. Showing established compliance with requirements of phases 2 and 4 of the scheme.

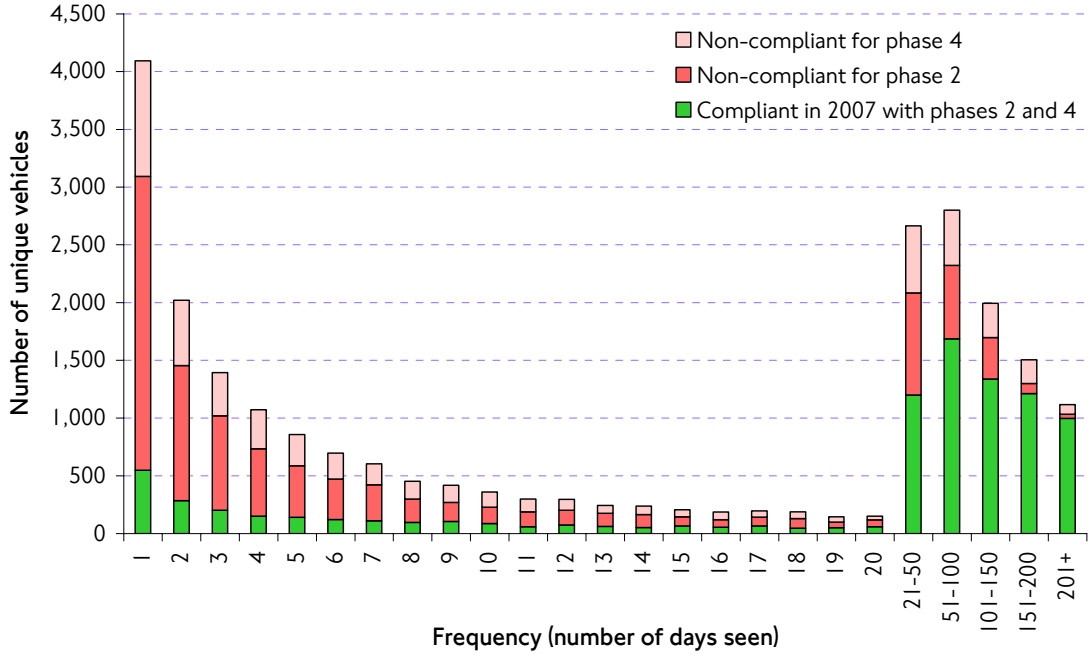
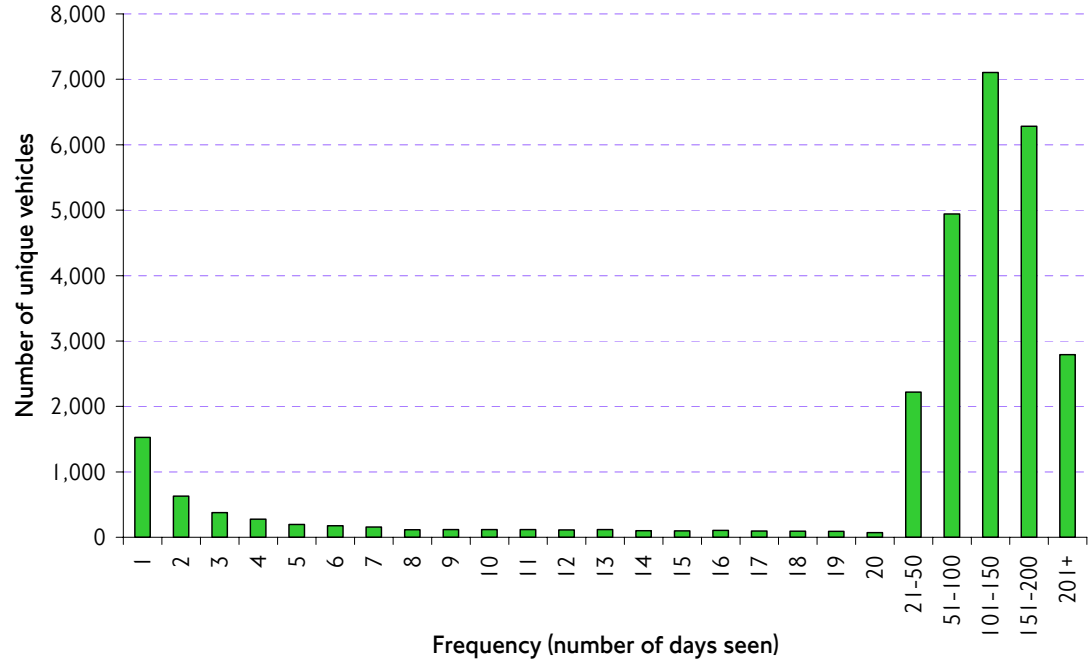


Figure 5.7 Annual frequency distribution for 2007 calendar year, London licensed taxis (Hackney Carriages).



Looking across these distributions:

- The predominance of infrequent visitors in the daily vehicle population of London is again apparent. Bearing in mind the important caveat about camera non-detection bias (Section 5.2), the majority of both types of goods vehicle (about 75 percent of N3s and 70 percent of N2s) are observed in the zone on less than 5 percent of the days in the year. Daily traffic, however, is dominated by the 25 percent or so of vehicles that operate in the zone on more than 5 percent of the days in the year.
- There is also a core of very frequent visitors, typified by around 1 percent of N3 and N2 HGVs that are present in the zone on more than 200 days of the year, although this frequency class will suffer proportionately the most from camera non-detection bias and will therefore tend to be underestimated.
- Buses and coaches (Figure 5.6) show different characteristics, with a higher representation of very frequent or 'captive' vehicles (ie specific to one operator or route within London), although again it is important to note that camera non-detection bias will artificially reduce the number of unique vehicles in the highest frequency classes in relation to those in the lowest.
- Taxis are again characteristically unique, the distribution reflecting operation on the majority of days by a largely captive vehicle fleet.

It is possible from these data to estimate – on an indicative basis – the number of unique vehicles in 2007 operating in London that will have been potentially affected by the requirements of the scheme. This can be thought of as the 'total vehicle population' addressed by the scheme. Note that camera non-detection bias is not a significant factor in these estimates.

- For N2 HGVs and N3 HGVs the estimated range from the camera data would be 160,000-190,000 unique vehicles in 2007. This compares to an equivalent estimated range used by TfL for the scheme design of 138,000-186,000 vehicles.
- For M3 buses and coaches, the estimate is 24,000. This compares to a known value for the TfL bus fleet of 8,000 unique vehicles, implying a combined non-TfL bus and coach fleet of 16,000 unique vehicles. This is higher than the corresponding estimated range used for scheme design of 8,000-10,000 vehicles (not including the TfL bus fleet).
- For licensed taxis (Hackney carriages), the central estimate is 28,000. This compares to an independent estimate of 22,000; the difference probably reflecting an element of fleet turnover during 2007. This will also affect the corresponding estimates for the other vehicle types, and cause them to be slightly over-estimated relative to the earlier TfL estimates.

In terms of compliance with the requirements of the scheme during 2007:

- There is a clear tendency, as might be expected, for heavy goods vehicles (N2s and N3s) that are present in London more frequently to be more likely to be compliant with the requirements of the scheme than those that are seen less frequently.

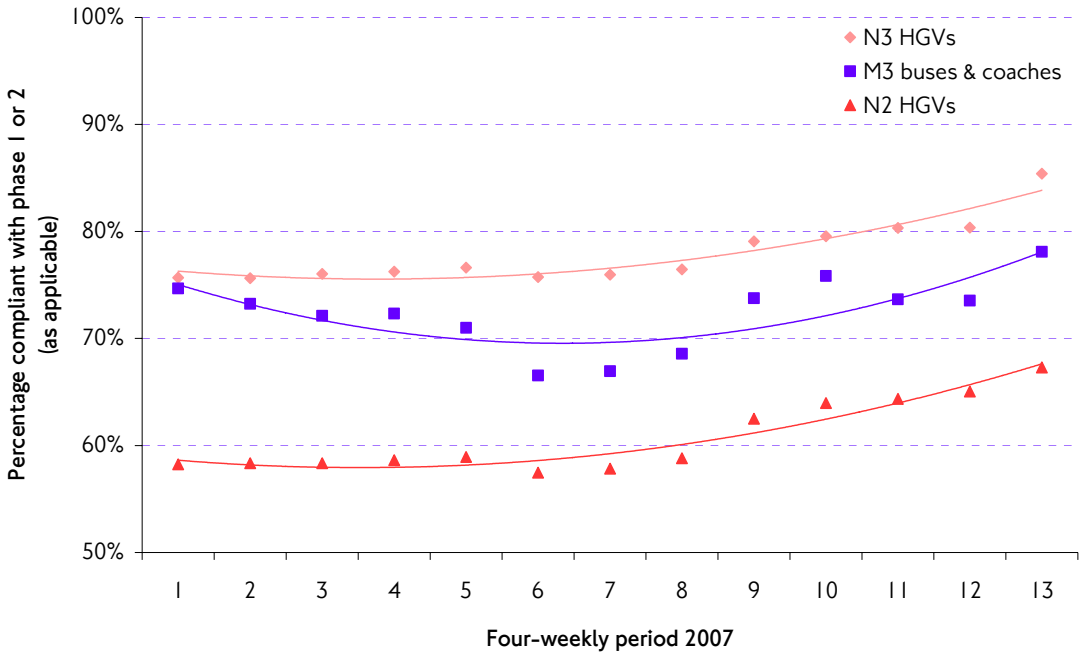
- Aggregate compliance rates for buses and coaches are more skewed, with much higher degrees of compliance typical of those vehicles that are present in the zone more frequently.

Assessing how these distributions change following introduction of the scheme will provide valuable insights into both the impacts of the scheme and vehicle operator behaviour. Key indicators will include the degree to which operators re-deploy mixed fleets so as to ensure that only vehicles that are compliant operate in London (visible as increased average frequencies in Figures 5.4 to 5.6); and the extent to which compliance rates shift between the 'infrequent' and 'frequent' elements of the vehicle populations.

Baseline 6: Trends in vehicle compliance with the scheme during 2007 – vehicles present in London

Figure 5.8 is a development of this 'vehicle population-based' view of the scheme compliance. It shows the trend in compliance – in terms of unique vehicles observed in the zone – during the 2007 calendar year. Only vehicle types that are in-scope for the first two phases of the scheme are shown. Best fit polynomial trend lines have been added.

Figure 5.8 Trend in scheme compliance during 2007. Unique vehicles, 13 four-week periods, phases 1 and 2 of the scheme. ANPR camera data.



For all categories of vehicles, the trend is of increasing compliance during the year. This reflects both 'background' change (fleet turnover) and an element of operator pre-compliance. Also evident is an increased degree of improvement in the latter part of the year, reflecting TfL advance publicity and increased operator action as the implementation date for the scheme approached.

More specifically:

- Compliance rates for N3 HGVs (phase 1 from February 2008) increase from typically 75 percent at the start of the year to more than 85 percent at the end of the year. This is an aggregate improvement in compliance of approximately 10 percentage points – comparable to the equivalent indicator from the vehicle licensing data.
- Compliance rates for N2 HGVs (phase 2 from July 2008) were typically much lower than for N3 HGVs, reflecting the later phase implementation date. Nevertheless, an aggregate annual improvement of approximately 9 percentage points is observed. This again comparable to, albeit slightly lower than, the equivalent indicator from the vehicle licensing data.
- Once again the picture for buses and coaches is less clear. The inconsistencies with the data referred to in Section 5.2 have clearly affected the integrity of the time series, but typical compliance rates across all M3 vehicles increased from approximately 75 percent at the start of 2007 to approximately 80 percent at the end. Again, this implied improvement of just under 5 percentage points is consistent with the equivalent indicator from the vehicle licensing data.

5.13 Vehicle activity (kilometres) based views of vehicles operating in London

This section uses automatic number plate recognition camera data to look at the vehicle populations observed within the zone during 2007 in terms of **vehicle activity**. As described in Section 5.5, the statistically-representative nature of the camera sample gives the ability to derive estimates of emissions performance that are representative of vehicle-kilometres operated. This means that, over any given analysis period, the vehicle populations of interest are enumerated on the basis of 'number of times seen'. This will be statistically proportional to the distance driven in the zone, and thus it is an 'activity-based' view of vehicles operating in London. Vehicles that are driven longer distances, in terms of aggregate vehicle-kilometres, within the zone will 'count' proportionately more in the analysis and air quality assessments than vehicles that drive shorter distances. These estimates are therefore the primary input to the emissions assessment work described in Section 6.

Composition of London traffic from cameras

Table 5.7 shows an activity-based view of the composition of traffic circulating in London in terms of main vehicle type. The traffic composition profile in Table 5.7 compares well with the revised TfL estimate described in Section 4 (Table 4.2). There is a slight tendency to systematically over-represent goods vehicles in relation to the manual traffic volume counts – an expected result of the camera sample optimisation.

Table 5.7 Composition of traffic in Greater London. Camera capture-based view equivalent to vehicle-kilometres. 2007 calendar year by four-week period. Percentage share of total vehicle-kilometres by main vehicle type.

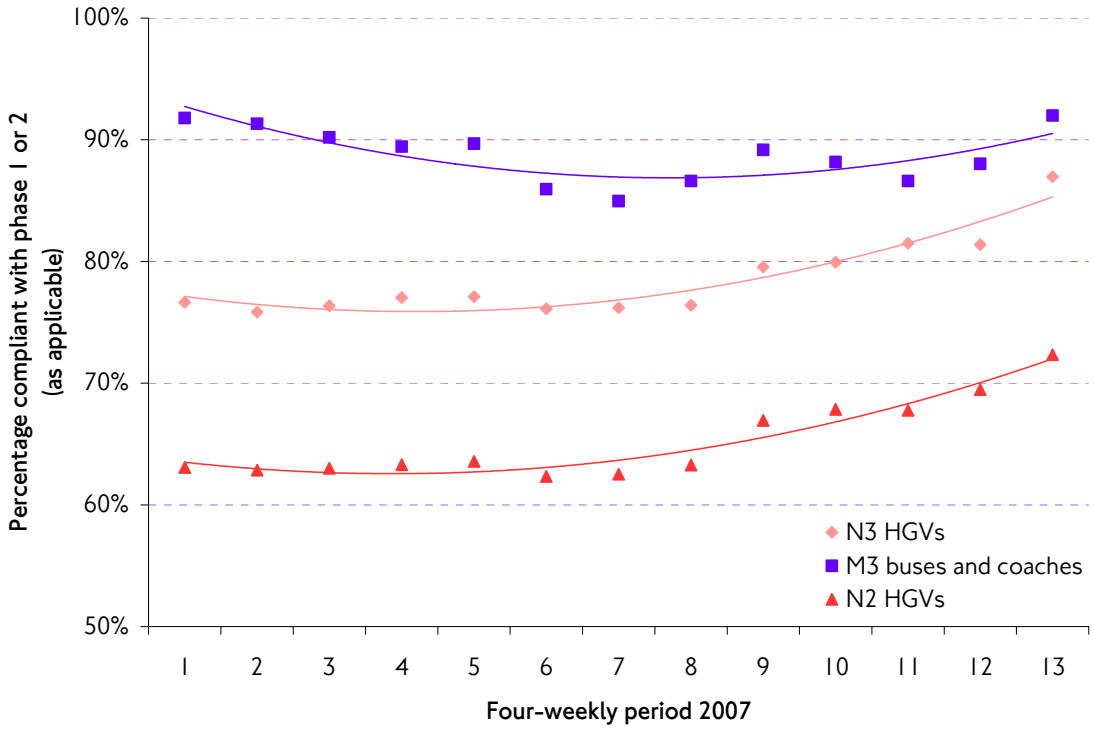
Vehicle types	Four-week period													Average 2007
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Hackney Carriages	3.5	3.4	3.3	2.7	3.4	3.4	3.4	3.7	3.8	3.6	2.0	3.2	3.5	**3.3%**
M1 cars	78.0	77.4	77.5	78.6	77.2	77.8	77.0	76.5	77.7	76.9	79.7	78.7	79.9	**77.9%**
M2 minibuses	0.4	0.4	0.5	0.4	0.5	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3	**0.4%**
M3 buses & coaches	2.4	2.3	2.2	2.0	2.2	2.2	2.2	2.4	2.3	2.0	1.6	2.0	2.2	**2.1%**
N1 Class I LGVs	3.0	3.1	3.1	3.0	3.1	2.7	2.8	2.8	2.9	3.1	3.0	2.9	2.6	**2.9%**
N1 Class II LGVs	2.8	2.9	2.9	2.9	2.9	3.3	3.4	3.4	2.1	2.3	2.1	2.1	1.9	**2.7%**
N1 Class III LGVs	6.6	6.9	6.9	6.8	7.0	6.7	6.9	7.0	7.6	8.1	7.6	7.5	6.7	**7.1%**
N2 HGVs	1.2	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.2	1.3	1.2	1.1	1.1	**1.3%**
N3 HGVs	2.1	2.2	2.3	2.4	2.4	2.3	2.4	2.3	2.1	2.4	2.5	2.1	1.9	**2.3%**
All	100	100	100	100	100	100	100	100	100	100	100	100	100	**100%**

Baseline 7: Vehicle-kilometre based estimates of scheme compliance in London during 2007

Figure 5.9 is a development of the trend in scheme compliance during 2007 shown in Figure 5.8. It is based on aggregate camera captures and not unique vehicles, and is therefore representative of kilometres driven. In comparison with Figure 5.8, several things stand out:

- Most obviously, the general level of established compliance is seen to be higher than the equivalent trend based on unique vehicles. So, compliance rates for N3 HGVs range from 75 percent at the start of 2007 to 87 percent at the end. Compliant N2 HGVs range from 63 percent at the start of 2007 to 73 percent at the end. Most strikingly, compliance rates for M3 buses and coaches reach around 93 percent at the end of 2007 – a much higher rate of compliance than the equivalent unique-vehicle based estimates.
- These differences imply that newer, scheme-compliant vehicles tend to be used more intensively than older, non-compliant vehicles. For buses and coaches in particular, it reflects the intensive daily operation of 'London' buses and longer distance scheduled coaches, which were almost all compliant with the requirements of the scheme during 2007. It also suggests that there is a long 'tail' of non-compliant coaches that operate in London only very occasionally.
- As would be expected, rates of change are also higher using this view of the data, particularly towards the end of the year, with an apparent strong scheme-related pre-compliance effect from period 9 (September) onwards.

Figure 5.9 Trend in scheme compliance during 2007. Vehicle activity based estimate, 13 four-week periods, phases 1 and 2 of the scheme. ANPR camera data.



Using a similar estimation method to that outlined in Section 5.11, it is possible to derive estimates of implied **background** fleet change and **scheme-attributable** changes from these data. This makes use of simple relationships to separate the accelerated compliance during the latter part of 2007 with the established 'background' trend over the earlier part of the year. These estimates are considered further in Section 5.15.

Baseline 8: Variations in scheme compliance levels across Greater London and the effect of sample weighting

The aggregate compliance trends considered above can also be examined at the regional level within London. There is little reason to expect that the emissions performance of goods vehicle traffic would differ significantly from one part of Greater London to another and effects reflecting the small regional samples will be a factor in any observed variation. Disaggregating the sample regionally (at a level corresponding to the 11 sample strata) also allows the effect of sample weighting to be illustrated.

Figures 5.10, 5.11 and 5.12 show scheme compliance levels for potentially affected vehicles (in terms of vehicle-kilometres) for, respectively, four-week periods 1 (start 2007), 6 (mid 2007) and 13 (end 2007). Values are given for each of the 11 regional sample strata. The left-most value in each case is the London-wide percentage compliance figure. The solid lines represent the weighted equivalent London-wide values. Weighting was in this case undertaken at the regional strata level, on the basis

of proportion of the actual vehicle-kilometres in London represented by each of the individual sample strata.

Figure 5.10 Compliance by region and weighted mean London compliance levels. 2007, period 1. Vehicle-kilometre equivalent data.

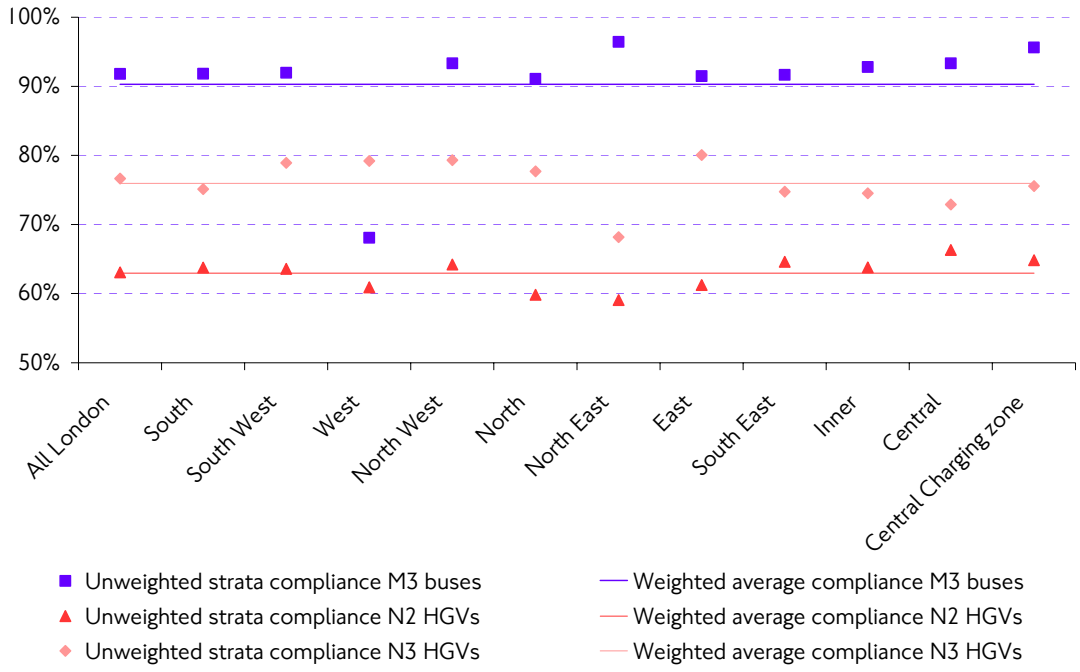


Figure 5.11 Compliance by region and weighted mean London compliance levels. 2007, period 6. Vehicle-kilometre equivalent data.

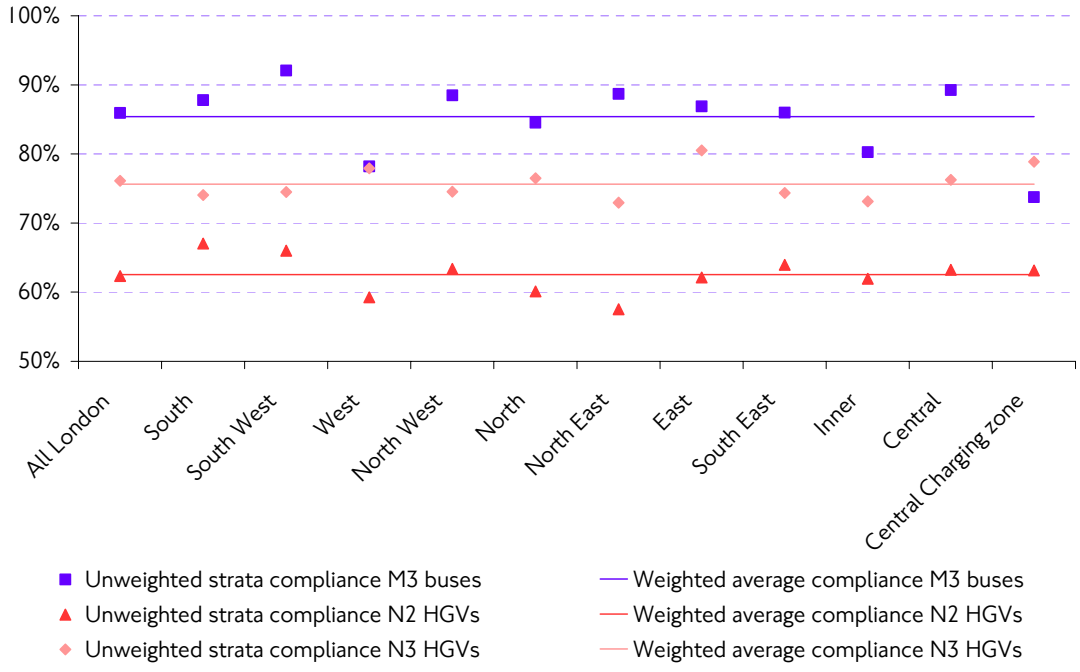
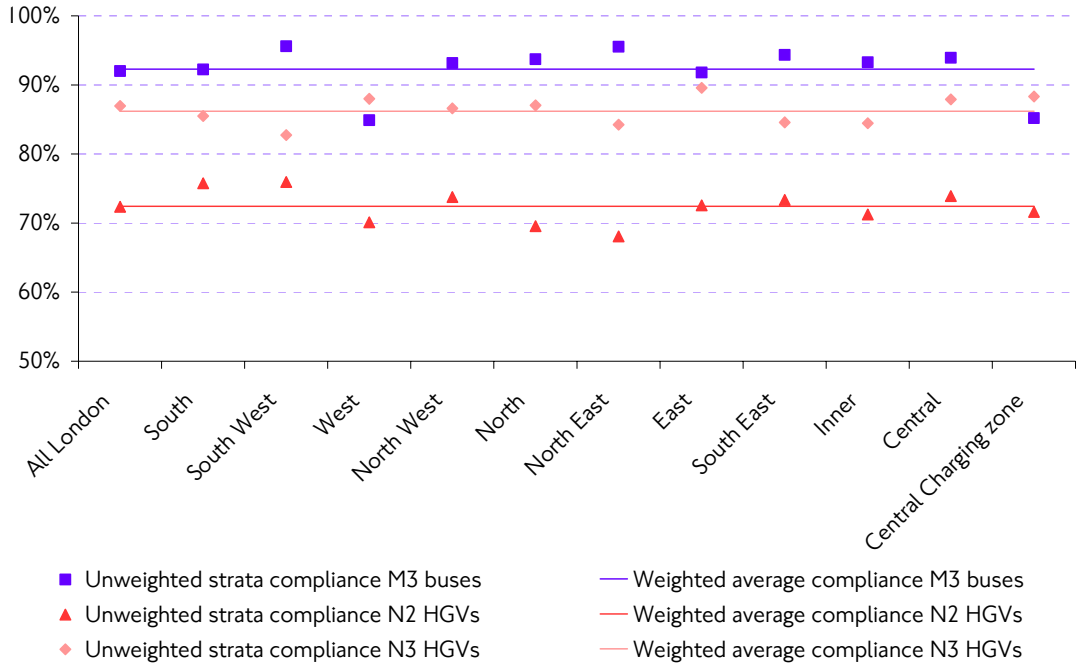


Figure 5.12 Compliance by region and weighted mean London compliance levels. 2007, period 13. Vehicle-kilometre equivalent data.



There are three key features of interest:

- First, there is an element of variability in compliance rates across the different regions of London. Comparing individual strata values with the weighted average lines gives a notional 'deviation from the average' at the regional level. For example, the large deviation for M3 buses and coaches in the 'west' region could reflect a specific 'captive' bus or coach fleet operating frequently on roads covered by cameras in this area. These deviations tend to be within a few percentage points and are not generally material to the analysis, although they will be reflected spatially in the estimated emissions impacts.
- Second, as 2007 progressed, compliance rates improved, but not steadily. So, for N3 heavy goods vehicles, affected by phase 1 of the scheme from February 2008, average weighted compliance in both periods 1 and 6 was about 76 percent, increasing to 87 percent in period 13. For N2 heavy goods vehicles, affected by phase 2 of the scheme from July 2008, average weighted compliance rates in both periods 1 and 6 were about 63 percent, increasing to about 72 percent in period 13. For M3 buses and coaches, affected by phase 2 of the scheme from July 2008, average weighted compliance rates in period 1 were about 90 percent, apparently decreasing to about 85 percent in period 6, but increasing again to about 93 percent in period 13.
- While the general trend of increased compliance over the year is visible, it is nevertheless again evident that the available emissions classification data available to TfL up to mid-2007 was inconsistent in some respects.
- Third, the effect of sample weighting – to compensate for the distorting effect of the comparatively small camera sample and in this case applied at the regional stratum level – on the London-wide totals is consistently very small. This

suggests that the camera sample is providing a good and representative view of vehicles circulating in Greater London.

5.14 The TfL bus fleet

The TfL bus fleet is known, from internal sources, to have been wholly compliant with the emissions requirements of the scheme from December2005 – well ahead of the phase 2 scheme requirements. As previously noted, issues relating to the certification process in respect of Reduced Pollution Certificates have introduced some distortions into the monitoring data during 2007.

Table 5.8 Euro (PM) Class status of TfL London bus fleet, by bus type. 2007 mid-year estimate. Based on certification status – all buses comply with the actual emissions requirements of the scheme.

Euro (PM) class	Articulated	Double Decker	Single Decker	All
0	0.0%	0.0%	0.0%	0.1%
I	0.0%	0.0%	0.2%	0.1%
II	0.0%	3.1%	13.8%	6.4%
III	2.1%	3.3%	10.2%	5.5%
IV	0.0%	31.8%	42.5%	33.7%
V	97.9%	61.8%	33.3%	54.2%

Table 5.8 shows the PM (particulate matter) Euro standard status of the TfL London bus fleet at mid-2007, based on internal TfL data. PM Euro classes of III and above indicate compliance with the requirements of phase 2 of the scheme, effective from July 2008.

Almost 95 percent of the TfL London bus fleet were certificated to Euro III for PM or above. Equivalent figures for 2008 should show 100 percent compliance, the difference for 2007 mainly reflecting delays to the certification process. For the emissions calculations described in Section 6, TfL internal data for the London bus fleet is used in preference to observed camera/vehicle licensing data.

5.15 Summary

Estimates of the emissions and air quality impacts of the London Low Emission Zone require good data describing the changes to the emissions performance of affected vehicles operating within Greater London. As these data have not previously existed, TfL has put in place a network of 100 automatic number plate recognition cameras optimised to measure these characteristics, and located across Greater London so as to be statistically representative of traffic activity. TfL has also developed a bespoke database describing the 'business rules' for the scheme, on which basis the basic vehicle type, Euro emissions class and scheme compliance status of vehicles

observed by the cameras or registered to London or other regions of the United Kingdom can be assigned.

These data are new and not yet fully investigated by TfL and the available data during 2007 also suffers from a degree of inconsistency, reflecting TfL preparations for the scheme. The statistics presented in this section should therefore be regarded as indicative in nature at this early stage of the monitoring work. Nevertheless, the camera system is generally functioning well – and data from it, relating both to vehicles that will potentially be affected by the scheme, as well as other vehicles (such as cars) not subject to the scheme, is providing valuable new insights into the emissions performance of vehicles in London.

Table 5.9 Estimates of change in compliance with the requirements of the scheme during 2007. Percentage point change, synthesis of various sources.

Data source/vehicle type	Gross annual change 2007	Estimated background change 2007	Estimated scheme-attributable change 2007
N3 HGVs			
- UK national fleet (licensing data)	+7%	+4%	+3%
- London registered fleet (licensing data)	+13%	+4%	+9%
- Camera data unique vehicles (annual)	+10%	+5%	+5%
- Camera data vehicle-kilometres (annual)	+10%	+4%	+6%
- LAEI projected (on national fleet turnover)	+8%	n/a	n/a
N2 HGVs			
- UK national fleet (licensing data)	+7%	+6%	+1%
- London registered fleet (licensing data)	+10%	+8%	+3%
- Camera data unique vehicles (annual)	+9%	+6%	+5%
- Camera data vehicle-kilometres (annual)	+9%	+6%	+4%
- LAEI projected (on national fleet turnover)	+8%	n/a	n/a
M3 buses and coaches			
- UK national fleet (licensing data)	+5%	+3%	-2%
- London registered fleet (licensing data)	+2%	-4%	-5%
- Camera data unique vehicles (annual)	+3%	-1%	+3%
- Camera data vehicle-kilometres (annual)	0%	+4%	-4%
- LAEI projected (on national fleet turnover)	c. +2%	n/a	n/a

Both the vehicle licensing data underlying TfL's scheme compliance database and the camera data give several complementary but different views of the emissions characteristics of vehicles in London. These can be used in combination to derive estimates of **established compliance** with the requirements of the scheme, annual background fleet turnover (**background change**) and **operator pre-compliance**, reflecting operator action to upgrade their vehicles in advance of the scheme implementation date.

Table 5.9 summarises the available inferences that it is possible to draw from the data so far – in terms of percentage point change in compliance status with phases 1 and 2 of the scheme during the 2007 calendar year. Also given for comparison is an existing estimate based on assumptions used for air quality assessment work. This is the projected change for the 2007 calendar year in the London Atmospheric Emissions Inventory, assuming a 'business-as-usual' scenario with no scheme. Table 5.9 shows that:

- For N3 heavy goods vehicles the camera data suggest a 10 percentage point overall improvement in scheme compliance during 2007. Corresponding vehicle license based estimates are lower at the national scale, and higher at the London scale. Both camera and licensing data suggest that 'background fleet change' component during 2007 was of the order of 4 to 5 percentage points. This is somewhat lower than the gross annual change projection, with no scheme, assumed by the London Atmospheric Emissions Inventory. Camera-based estimates suggest that operator pre-compliance ahead of phase 1 of the scheme during 2007 was responsible for an improvement in scheme compliance of between 5 and 6 percentage points – representing valuable air quality benefits achieved during 2007 ahead of the actual implementation date of the first phase of the scheme.
- For N2 heavy goods vehicles the camera data suggest a gross annual improvement in scheme compliance (phase 2 from July 2008) of around 9 percentage points, assessed to comprise about two-thirds 'background' fleet turnover and a one-third element of operator pre-compliance.
- For M3 buses and coaches the camera and licensing data are inconsistent – for reasons previously discussed. In taking forward the emissions assessment work TfL will therefore use in-house estimates of the emissions profile of the London bus fleet alongside existing (emissions inventory based) estimates of change for coaches.

In conclusion, the data so far available is tending to suggest lower rates of 'background' improvement to vehicles than has previously been assumed. It has also identified clear accelerated improvements during the second half of 2007 that can reasonably be attributed to the scheme. Both of these findings will be used by the emissions assessment work described in the next section.

Looking across the data it is nevertheless clear that there were still relatively large numbers of vehicles that remained non-compliant with the requirements of phases 1 and 2 of the scheme at the end of 2007. Section 13 of this report extends this analysis into the first months of 2008, covering the actual implementation of phase 1 of the scheme and the run-up to phase 2 over the first four months of 2008.

6. Estimating the impact of the London Low Emission Zone on emissions

6.1 Introduction

Section 5 described how TfL is measuring the impact of the scheme on the emissions characteristics of vehicles operating in Greater London. It set out a series of 'baseline observations' describing the scheme compliance profile of vehicles in-scope to be affected by the scheme in 2007 – the year immediately prior to the introduction of phases 1 and 2 of the scheme. This section describes how TfL is using these observations to estimate changes to the emissions of key pollutants – oxides of nitrogen (NO_X) and particulate matter (as PM_{10} and $PM_{2.5}$) resulting from the scheme.

This section first summarises the main technical features of the London Atmospheric Emissions Inventory (LAEI) – the key tool used for this part of the monitoring work. It then outlines certain technical enhancements that TfL is making to the basic inventory to allow it to better reflect the detail of the impacts that are likely to arise from the scheme. The section then proceeds to describe how successive versions of this enhanced inventory are being used, in conjunction with parallel estimates of traffic change, to track developments, focusing for this report on changes during 2007.

The results are estimates of both **background change** to emissions, reflecting the natural process of renewal of the vehicle fleet, in the notional absence of the scheme, and **scheme-attributable change**, in this case reflecting operator pre-compliance with the requirements of the scheme during 2007.

6.2 The London Atmospheric Emissions Inventory

The London Atmospheric Emissions Inventory was developed in the early 1990s as one of a series of urban-scale inventories to facilitate local air quality management by local authorities under the requirements of the Environment Act, 1995[1]. It has since been updated to an approximately annual cycle, and the current version of the inventory[2], produced by the Greater London Authority, was released to local authorities in March 2008. This reflects conditions in the year 2004 and provides forecasts of emission estimates to 2010.

An emissions inventory is a computer database that contains spatially-resolved details of all identifiable sources of polluting emissions to the atmosphere across a region. These sources, or 'activities', fall into four groups:

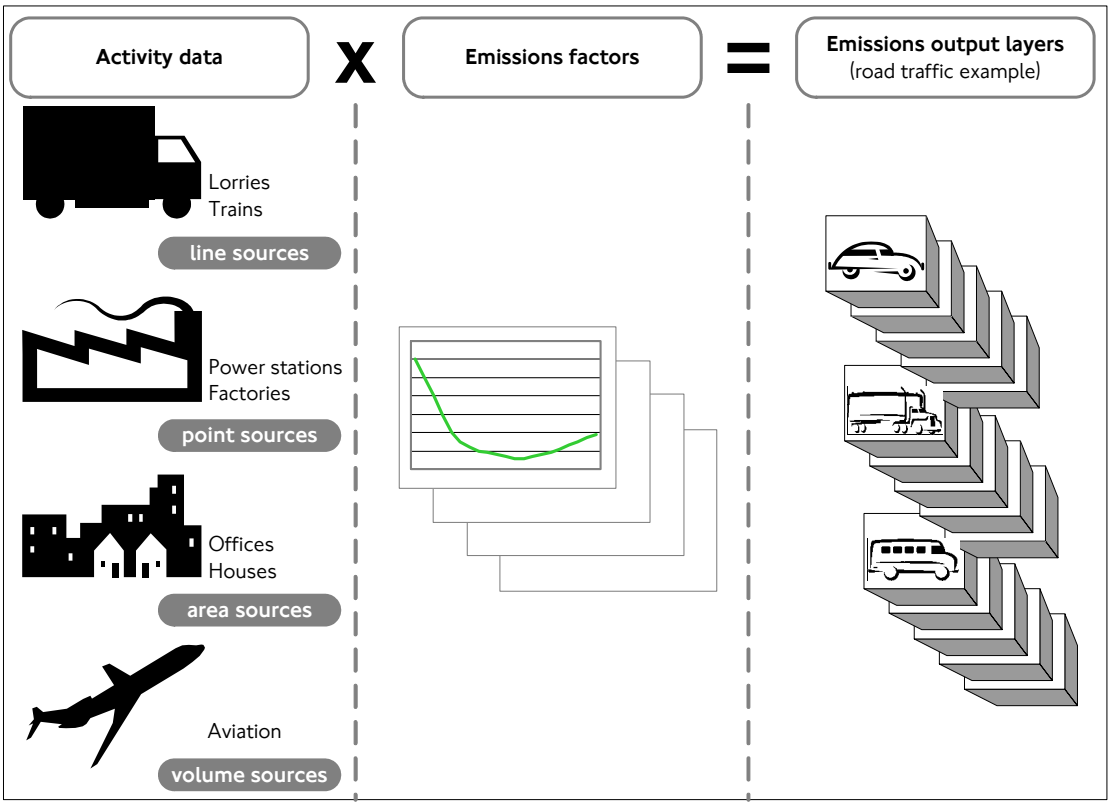
- **Point sources** – such as factory flues associated with industrial activity.
- **Line sources** – typically roads and railways.
- **Area sources** – typically emissions from diffuse activities such as commercial or domestic heating, which are not spatially resolved on an individual basis.
- **Volume sources** – reflecting a height dimension, typically airports and associated low-level flight paths.

In parallel with this comprehensive inventory of source or activity data, the inventory contains relationships describing the emissions of key pollutants to be expected from the various types and intensity of activity. These 'emissions factors' are empirically-derived[3], and are applied to the activity data in the inventory in order to estimate emissions, ie:

Activity [Rate] * Emissions Factor = Emissions

Typical **activities** include power generation, domestic gas consumption, and vehicles driving around a road network. Applicable **activity rates** for these activities would be tonnes of coal burned (for coal-fired power generation), units of gas consumed (for domestic consumption) or – most relevant for this context – vehicle-kilometres driven and hence fuel consumed. Refinements to emissions factors allow the impact of features such as the fitment of emissions abatement equipment, the type of vehicle (body type, fuel use) and vehicle speed to be resolved. In this way it is possible to arrive at calculated estimates of emissions to air across an area, on either a total (eg emissions from all sources), sub-total (eg emissions from road traffic in general) or individual activity (eg emissions from heavy goods vehicles over 12 tonnes belonging to Euro emissions class IV) basis.

Figure 6.1 Conceptual model of an emissions inventory.



The typical output from an emissions inventory is map-based, reflecting spatial variation of emissions across an area, and is conceptually analogous to slices in a loaf of bread, where individual slices reflect emissions from one particular group of activities, and total emissions reflect the sum of all of the individual slices. It is possible to vary emissions estimates relating to one or more of the slices (eg those

relating only to vehicles that are affected by the scheme), while holding others constant or varying them in a controlled way. In this way it is possible to quantify change from specific activities that are targeted by a particular policy intervention, and to set this against change from other activities that are unaffected.

In scheme monitoring terms this means that it is possible, given appropriately-resolved input or 'activity' data as described in Section 5, to quantify changes to emissions resulting specifically from the scheme, and to isolate this from wider changes to emissions reflecting other factors or background trends. Figure 6.1 illustrates these ideas.

6.3 Customising the inventory for scheme monitoring

The 2004 version of the London Atmospheric Emissions Inventory currently in general use needs to be modified in four key respects to make it appropriate for monitoring the impacts of the scheme.

- First, the current inventory reflects conditions as they were in 2004. This time lag is usual, reflecting the time taken to accumulate activity data for the 'most recent' year. In order to replicate conditions across the lifetime of the scheme it is therefore necessary to update the inventory to reflect either more recent observed activity data where available, or reasonable projections where these can be made.
- Second, the inventory methodology is not ideally suited to reflect some of the more detailed aspects of scheme impacts. Examples include differential impacts by particle size, and emissions factors reflecting the different types of particulate emissions abatement technology for road vehicles. As part of the wider monitoring work, TfL is investigating these matters and will make appropriate methodological improvements to the inventory calculations where this can be done robustly.
- Third, as described in Section 4, recent work by TfL and DfT has resulted in a reduced estimate of total vehicle-kilometres driven in London, which will reduce the absolute and relative proportion of emissions assessed to arise from road traffic sources compared with previous estimates.
- Fourthly and finally, all previous versions of the London Atmospheric Emissions Inventory have relied upon national-scale estimates of the emissions characteristics of vehicles in London, albeit modified to reflect better locally-derived information where available (relating to London buses and taxis). The scheme monitoring work using automatic number plate recognition cameras actually measures these characteristics for the first time, and therefore some re-basing of previous inventory assumptions is to be expected.

This means that the 'base case' inventory for scheme monitoring will be different from that used previously by TfL to forecast the impacts of the scheme, and defining this base case and identifying the differences is an important point of departure for the monitoring work.

6.4 Inventory assessment horizons for scheme monitoring

In using this 'custom' inventory for scheme monitoring and isolating the specific impacts of the scheme, there are four categories of change that need to be separately accounted for. These are:

- Updating the inventory from year-to-year, involving assumptions about changes in polluting activities unrelated to the scheme.
- Updating the road traffic volumes to reflect recently-available improved traffic flow data for London (see Section 4).
- Updating certain methodological features of the inventory (eg NO_X/NO_2 emissions ratios) and emissions factors, reflecting improved knowledge for those vehicles affected by the scheme.
- Impacting the effects of the scheme itself, broadly replicating the various scheme phases through a series of inventory 'horizons'.

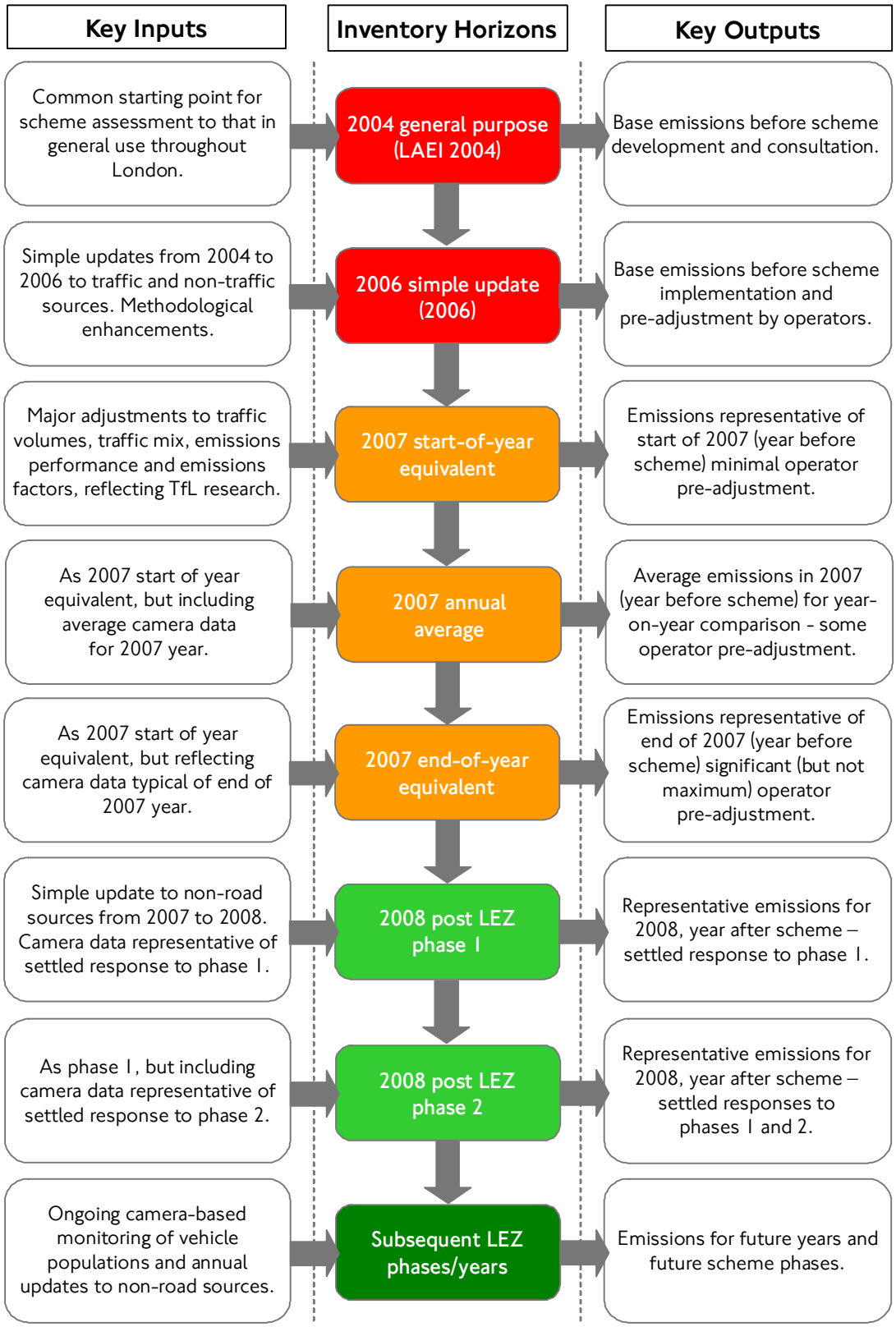
All of this means that an incremental series of scheme monitoring inventories will be required, 'stepping through' the various adjustments that are necessary in a controlled way. To represent the impact of part-year changes, multiple versions of the inventory referenced to the same calendar year can be developed, each having characteristics that represent the specific scenario under consideration.

This leads to the work programme illustrated by Figure 6.2. Comparisons between the various versions of the inventory, and the resulting air quality model outputs, will allow the 'settled' impact of each phase of the scheme to be identified, and the impact of both background, methodological and scheme-related change on the resulting emissions estimates to be separately accounted for.

A note on precision

In this section and in section 7 which follows, modelled estimates of emissions and pollutant concentrations are shown with several significant figures; an apparently high level of precision. This is to allow the reader to more readily appreciate where estimates are changing as a result of revised model inputs. However, the real level of precision of individual absolute modelled estimates is much lower.

Figure 6.2 Emissions assessment horizons for scheme impacts monitoring.



Given the technical background in Sections 6.3 and 6.4, the monitoring work has two elements:

- Starting from the 'common' 2004 London Atmospheric Emissions Inventory, and including the various technical enhancements identified above, derive an equivalent '2008 base case', equivalent to 2007 'end of year' in terms of how the emissions characteristics of the vehicle fleet is characterised, replicating conditions in the absence of a scheme.
- Working from this 'revised' 2008 non-scheme base, include the observed changes resulting from the various phases of the scheme, alongside other changes (subsequent years, changes to other sources), to give successive estimates of emissions change due to the scheme.

A complication relates to 'operator pre-compliance' during 2007, as reflected in Section 5, as operators modified their vehicles to comply with the first two phases of the scheme ahead of actual implementation. This will mean that multiple versions of the 2007 inventory will be required.

6.5 Emissions factors

Emissions factors are fundamental to emissions assessment as they specify the amount of pollution that is emitted for a given polluting activity and activity rate. Emissions factors for road traffic sources are comparatively good – in that they are available for most of the more common vehicle types, and are usually disaggregated by vehicle speed. From a scheme monitoring viewpoint there are nevertheless several shortcomings. These are:

- The diversity and detail of the vehicle types, Euro emissions standards and the various emissions abatement equipment configurations covered by the scheme are much less well provided for in terms of emissions factors. Some key configurations are not covered in the currently-available dataset, and some pragmatic assumptions have to be made at this stage, pending the availability of improved data.
- Emissions factors are usually derived from dynamometer tests of 'typical' vehicles, executing various 'representative' drive cycles. This means that there are usually issues of applicability to conditions in London (eg slower, more congested traffic), and relating to the – usually small – sample of vehicles tested.
- Finally, as emissions factors are so fundamental to the emissions calculation, relatively small changes to them can have a disproportionate effect on the resulting assessment. While it is desirable to improve upon existing emissions factors where this would allow scheme impacts to be quantified more accurately, this also has to be done carefully and in a robust manner.

TfL has recently carried out some vehicle emission tests to address some of these issues and will continue to explore how emission factors, particularly for heavier vehicles can be improved as part of the monitoring work during 2008. TfL is also aware of Defra's intention to consult on a revised set of emissions factors for general use in late 2008.

6.6 Summary of 2008 'base case' TfL scheme projections

This section summarises the key point of departure for the emissions monitoring work; this being the latest projection of a **2008 base case** for the scheme. This work dates from November 2007 which was just ahead of the implementation date for the first phase of the scheme. The significance of this **projected base case** – representing hypothetical conditions in 2008 without a scheme – is that it can be compared to the equivalent **observed base case** for 2008 without a scheme, thus isolating the component of change due to methodological improvements, ahead of the assessment of impacts due to the scheme. By definition the 2008 non-scheme projection does not include any operator pre-compliance during 2007.

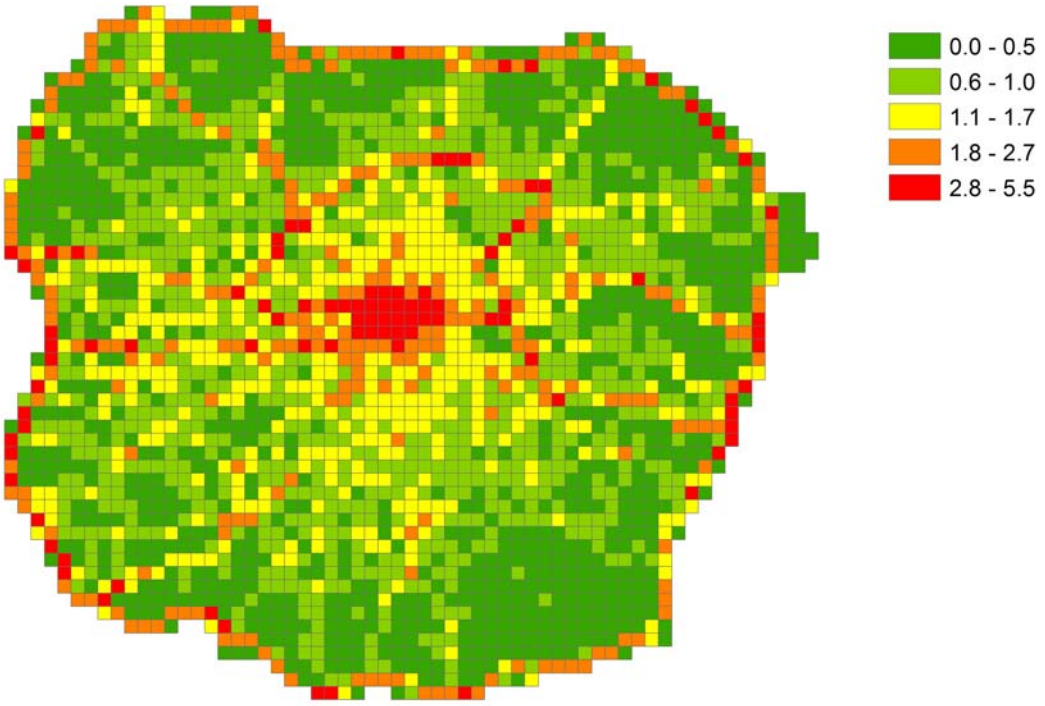
Table 6.1 Emissions of key pollutants from TfL base case. 2008 (end 2007 vehicle stock), no scheme, tonnes per annum.

Area	NO_X	NO_2	Total PM_{10}	PM_{10} tyre/brake	CO_2 (ktonnes)
Central charging zone[i]	922	208	71	24	262
Rest of Inner London	6,525	1,265	552	241	2,315
Outer London	14,047	2,539	1,139	528	5,178
External (incl. M25)[ii]	12,358	2,005	691	259	3,820
Total	33,851	6,017	2,453	1,053	11,574

(i) The extended central London congestion charging zone.
(ii) The area between the Greater London boundary and the outer edge of the M25 orbital motorway.

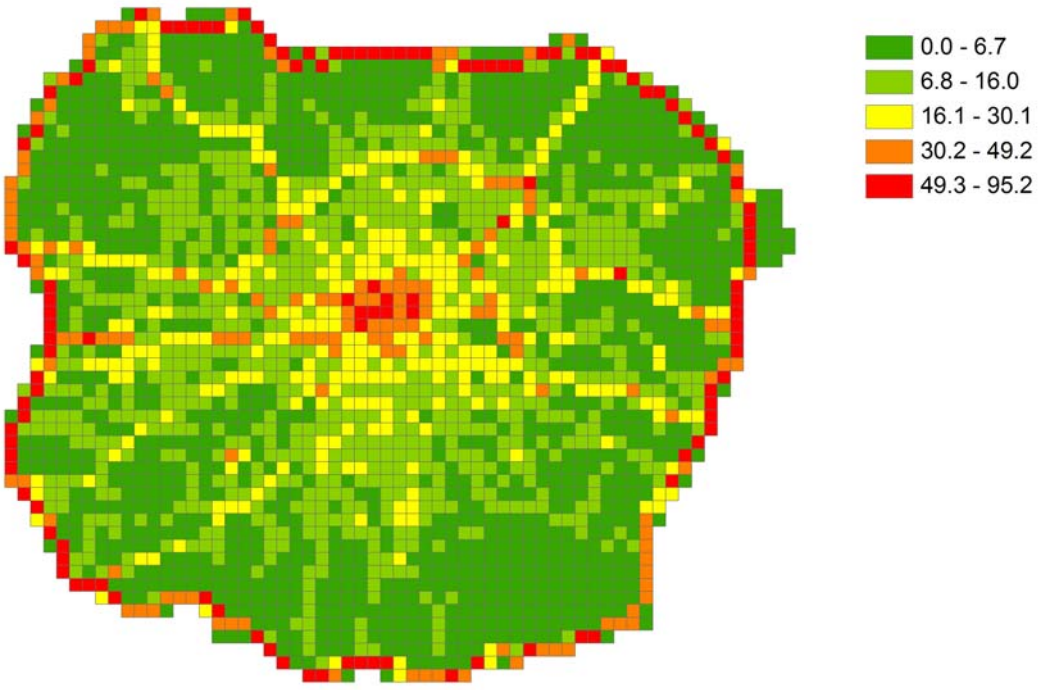
Figures 6.3 and 6.4 show spatial variations in the intensity of emissions across London in 2008, according to this non-scheme scenario. As would be expected the highest emissions are closely associated with busy roads and central London. Note also that the area covered by the inventory extends outwards from Greater London to include the M25 motorway – the 'external' area.

Figure 6.3 Emissions of PM_{10} from TfL base case. 2008, no scheme, tonnes per annum per kilometre grid square.



Source: Environmental Research Group, Kings College London.

Figure 6.4 Emissions of NO_X from TfL base case. 2008, no scheme, tonnes per annum per kilometre grid square.



Source: Environmental Research Group, Kings College London.

6.7 Summary of projected emissions impacts of the scheme

Table 6.2 is taken from the most recent TfL projections of the impacts of the various phases of the scheme. It uses projected estimates of the emissions performance of vehicles operating in London (ie it does not use the newly-available camera data).

Table 6.2 Most recent TfL projections of vehicle fleet change and scheme impacts. Emissions (tonnes) from road traffic sources only and percentage change.

Scenario/location	NO_X	NO_2	Total PM_{10}	PM_{10} tyre/brake	CO_2
2008 no scheme (2007 vehicle stock)					
Greater London	21,490	4,010	1,760	794	7,755
External	12,360	2,010	690	260	3,820
2008 no scheme (2008 vehicle stock)					
Greater London	20,010	3,850	1,680	790	7,725
External	11,410	1,910	650	260	3,812
% diff to 2008 base: Greater London	-6.90%	-3.96%	-4.82%	-0.76%	-0.37%
% diff to 2008 base: External	-7.66%	-4.99%	-6.22%	0.00%	-0.21%
2008 scenario1 (2007 vehicle stock – scheme effects only)					
Greater London	20,800	4,010	1,730	790	7,751
External	11,800	2,010	670	260	3,817
% diff to 2008 base: Greater London	-3.23%	-0.02%	-1.82%	0.00%	-0.03%
% diff to 2008 base: External	-4.48%	-0.05%	-3.04%	0.00%	-0.07%
2008 scenario 2 (2008 vehicle stock – includes background change for all vehicles, 2007-2008)					
Greater London	19,430	3,840	1,650	790	7,723
External	10,940	1,900	630	260	3,810
% diff to 2008 base: Greater London	-9.59%	-4.21%	-6.47%	0.00%	-0.40%
% diff to 2008 base: External	-11.44%	-5.39%	-9.12%	0.00%	-0.26%
2015 all scheme phases (2014 vehicle stock)					
Greater London	13,420	2,960	1,470	840	8,002
External	6,890	1,380	520	270	3,944
% diff to 2008 base: Greater London	-37.58%	-26.35%	-16.86%	-5.42%	-3.20%
% diff to 2008 base: External	-44.26%	-31.12%	-25.47%	-5.79%	-3.26%

The first two sets of figures are alternative 'base cases', assuming no scheme, varying in terms of whether they use stock profiles relating to the end of 2007 or the end of 2008. The table summarises the percentage changes expected to arise from phases 1 and 2 of the scheme only, at this stage, controlling for the background turnover of the vehicle fleet between years. An 'ultimate' scenario, relating to 2015 and including all four phases of the scheme, is also shown for comparison. Note the three variant scenarios for 2008, detailing the impacts of phases 1 and 2 of the scheme (combined) in 2008 against, respectively, vehicle stock assumptions reflecting both the end of 2007 and the end of 2008. An 'end-2008' vehicle stock scenario with no scheme is also given for comparison.

Phases 1 and 2 of the scheme were expected to lead to an attributable reduction of about 1.8 percent to total road traffic emissions of PM_{10} across Greater London, assuming end-2007 vehicle stock. Including the benefits of 'background' vehicle fleet turnover between 2007 and 2008 gives a total reduction of about 6.5 percent, in this case against and end-2008 vehicle stock profile – both on an annual total basis for 2008. Proportionately larger reductions were expected for emissions of NO_X. Note how the contribution from background fleet turnover is estimated at approximately 2.5 times the magnitude of that attributable to the scheme in 2008. This primarily reflects changes to the large majority of vehicles in London that are unaffected by the scheme (see Table 5.6).

In 2015, assuming implementation of all four phases of the scheme and accumulated 'background' turnover in the vehicle fleet, aggregate reductions of up to 17 percent in emissions of total PM_{10} and up to 37 percent in emissions of NO_X were projected, although only a proportion of this would be directly attributable to the scheme itself. Note that PM_{10} arising from vehicle tyre and brake wear (not directly affected by the scheme) is separately identified and is assessed to reduce only marginally over the period of interest.

The remainder of this section outlines the emissions scenarios developed for the monitoring work to date covering the 2007 calendar year – reflecting the key assessment stages identified in Figure 6.2.

6.8 Monitoring inventories step 1: 2004 annual average to 2006 annual average emissions

This section describes the first step in the monitoring inventory series (see Figure 6.2). This involves a simple 'rolling forward' of the 2004 London Atmospheric Emissions Inventory to represent a 2006 year, using default assumptions that underlie conventional LAEI-based projections of future conditions. Specifically; traffic volume and composition (vehicle type) is considered not to change between 2004 and 2006, taking a pragmatic view of the traffic volume evidence described in Section 4 of this report. Vehicle stock is assumed to change between 2004 and 2006 in line with default London Atmospheric Emissions Inventory projections[4].

The impact of these changes is summarised in Table 6.3. Not surprisingly, road traffic emissions reduce across the board, reflecting the beneficial effects of background fleet change (vehicle turnover) on vehicles circulating in London between 2004 and

2006. Indicative annual emissions reductions (half the two-yearly values shown in the table) to road traffic emissions from vehicle turnover of about 7 percent per annum for NO_2, 6 percent per annum for PM_{10} and 7 percent per annum for $PM_{2.5}$ are suggested. It is important to note the wider context into which the London Low Emission Zone is being introduced is one of significant year-on-year 'background' reductions in emissions from road traffic in general, and that the scheme will only affect a relatively small proportion of total road traffic.

Table 6.3 Emissions impact of moving from 2004 annual average conditions to 2006 annual average conditions (year end vehicle stock profiles). Total road traffic emissions only, tonnes per annum, Greater London area only unless otherwise stated.

Emissions category	NO_X	NO_2	Total PM_{10}	Total $PM_{2.5}$	CO_2 (ktonnes)
2004 annual average					
Phase 1 affected vehicles	7,951	1,113	296	243	838
Phase 2 affected vehicles	6,854	1,569	221	169	859
Total phase 1 and 2 affected vehicles	14,806	2,682	517	412	1,697
All road traffic – Greater London	27,680	4,392	2,012	1,396	8,115
External road traffic	16,293	2,317	820	626	3,748
All sources – Greater London	63,162	n/a	2,822	n/a	29,827
2006 annual average					
Phase 1 affected vehicles	7,205	1,009	256	208	835
Phase 2 affected vehicles	6,182	1,524	175	128	854
Total phase 1 and 2 affected vehicles	13,388	2,533	432	336	1,690
All road traffic – Greater London	23,964	4,268	1,777	1,207	7,890
External road traffic	14,018	2,189	730	549	3,671
All sources – Greater London	60,077	n/a	2,636	n/a	30,019
Difference road traffic emissions – Greater London	**-13%**	**-3%**	**-12%**	**-14%**	**-3%**
Difference road traffic emissions – External	**-14%**	**-6%**	**-11%**	**-13%**	**-2%**

6.9 Monitoring inventories step 2: 2006 annual average emissions to 2007 'no scheme' annual average emissions.

This section describes the second step of the monitoring inventory series (see Figure 6.2). This involves moving from the 2006 inventory, as described above, to a 2007 inventory that does not include any impacts (in the form of operator pre-compliance) from the scheme. This involves applying further standard London Atmospheric Emissions Inventory assumptions relating to national vehicle stock turnover between 2006 and 2007. It also involves impacting the changes relating to traffic volumes (ie the amount of traffic circulating in Greater London) as described in Section 4.

The impact of both of these changes is summarised in Table 6.4. The effect of simply 'rolling forward' the default London Atmospheric Emissions Inventory vehicle stock

turnover assumptions from 2006 to 2007 is that emissions again reduce across the board, the reductions being typically half the size of those illustrated in Table 6.3 (above), reflecting in this case just one year of vehicle stock turnover (ie background change). The impact of the vehicle-kilometre (traffic volume) changes is less straightforward to interpret.

Table 6.4 Emissions impact of moving from 2006 annual average conditions to 2007 annual average conditions with revised traffic volumes. Total road traffic emissions only, tonnes per annum, Greater London area only unless otherwise stated.

Emissions category	NO_X	NO_2	Total PM_{10}	Total $PM_{2.5}$	CO_2 (ktonnes)
2006 annual average					
Phase 1 affected vehicles	7,205	1,009	256	208	835
Phase 2 affected vehicles	6,182	1,524	175	128	854
Total phase 1 and 2 affected vehicles	13,388	2,533	432	336	1,690
All road traffic – Greater London	23,964	4,268	1,777	1,207	7,890
External road traffic	14,018	2,189	730	549	3,671
All sources – Greater London	60,077	n/a	2,636	n/a	30,019
2007 annual average – original traffic volume, end of year vehicle stock (annual update only)					
Phase 1 affected vehicles	6,635	929	224	179	822
Phase 2 affected vehicles	5,864	1,463	158	112	854
Total phase 1 and 2 affected vehicles	12,498	2,392	382	292	1,676
All road traffic – Greater London	22,167	4,111	1,672	1,122	7,750
External road traffic	12,991	2,094	687	511	3,660
All sources – Greater London	58,535	n/a	2,543	n/a	30,115
Difference road traffic emissions – Greater London	**-7%**	**-4%**	**-6%**	**-7%**	**-2%**
Difference road traffic emissions – External	**-7%**	**-4%**	**-6%**	**-7%**	**0%**
2007 annual average – revised traffic volume, end of year vehicle stock (traffic volume change)					
Phase 1 affected vehicles	6,487	908	219	175	804
Phase 2 affected vehicles	6,116	1,568	161	114	887
Total phase 1 and 2 affected vehicles	12,603	2,476	380	289	1,691
All road traffic – Greater London	21,796	4,113	1,602	1,072	7,440
External road traffic	12,975	2,091	685	509	3,652
All sources – Greater London	58.164	n/a	2,473	n/a	29,806
Difference road traffic emissions – Greater London	**-2%**	**0%**	**-4%**	**-4%**	**-4%**
Difference road traffic emissions – External	**0%**	**0%**	**0%**	**0%**	**0%**

The following are the key points:

- As the revised vehicle-kilometre totals only apply to the Greater London area, emissions estimates for the external area are unchanged.
- Emissions of NO_X for the Greater London area are assessed to reduce by 2 percent from this change – less than the traffic volume correction factor applied. Emissions of NO_2 for the Greater London area are unchanged, despite the volume reductions. These outcomes primarily reflect the increase to buses (see Tables 4.1 and 4.2), partly cancelling out reductions to other vehicle types – and bearing in mind both that these changes have been applied to the TfL vehicle stock profile for London buses and the national stock profile for coaches.
- Emissions of PM_{10} and $PM_{2.5}$ for the Greater London area reduce by around 4 percent – roughly equivalent to the overall traffic volume correction factor applied. Importantly, reduced tyre and brake wear from the reduced vehicle-kilometres accounts for about two-thirds of this change – a significant adjustment that will affect comparability with the corresponding TfL base case (see Section 6.12).
- The same 4 percent reduction applies to emissions of CO_2, although in this case the reduction is more directly reflective of the reduced vehicle-kilometres.

6.10 Monitoring inventories step 3: impacting automatic number plate recognition camera fleet profiles and assessing scheme pre-compliance impacts during 2007

All of the changes outlined so far reflect essential methodological updates to the emissions inventory and do not include any impacts from the scheme itself. As Section 5 of this report demonstrates, there was a clear element of pre-compliance by vehicle operators with the requirements of the scheme during 2007. This reflects a period of time from May 2007, when TfL started the public information campaign for the scheme, during which operators had the opportunity to either purchase newer vehicles, or otherwise bring their fleet to a state of compliance, for example to retrofit pollution abatement equipment. This **operator pre-compliance** is visible as a progressive acceleration to the normal background process of vehicle fleet turnover (see Figure 3.2), and the difference between the two is a legitimate and attributable impact of the London Low Emission Zone scheme during 2007.

Data from the monitoring cameras provides a 'measured' view of the emissions profile of vehicles operating in London. A further necessary methodological step here is therefore to replace the projection-based emissions profiles in the inventory for those components of the vehicle fleet that are affected by the scheme. This means moving from the default (national-level) assumptions previously used in the inventory to new observed profiles based on camera data. There are several complications here:

- First, the cameras would – irrespective of any scheme effect – be expected to reveal differences in the observed emissions profile of vehicles against the previous assumptions. This gives rise to a component of change in the resulting emissions estimates that reflects the changed methodology.

- Second, camera data is at this stage imperfect in several respects. Most important is that TfL processes are optimised to establish compliance with the requirements of the scheme rather than disaggregate Euro class, although in most cases good inferences can be made.
- Finally, operator pre-compliance occurred throughout 2007 at a progressively accelerating rate. This means that average values for 2007 are misleading, and that a series of discrete steps are required to isolate the various components of change during 2007.

Five such 'steps' are relevant for 2007:

- A 2007 **default stock** scenario, based on national-scale projections of the emissions performance of the vehicle fleet for 2007. In terms of emissions profile this reflects conditions at the end of the 2007 calendar year. This is identical to the third group of figures in Table 6.4.
- A 2007 **start of year** scenario, based on camera data (not projections) for TfL four-week periods 1 to 3 in 2007 (see **Appendix 3**) and thereby reflecting a minimal operator pre-compliance scenario.
- A 2007 **end of year** scenario, based on camera data for TfL four-week period 13 (only), reflecting the maximum expression of operator pre-compliance during the 2007 calendar year.
- A 2007 **annual average** scenario, based on automatic number plate recognition camera data reflecting conditions mid-way through the 2007 calendar year.
- A 2007 **end of year camera background change** scenario – having the effect of removing the identified pre-scheme compliance during 2007 and thereby being comparable with the original TfL projected baseline for quantifying scheme impacts (2008 no scheme with end 2007 vehicle stock) as described in Section 6.6 and set out as the first set of figures in Table 6.2.

The incremental impact of these various changes is set out in Table 6.5.

Table 6.5 Scheme monitoring inventories during 2007. Road traffic emissions only, tonnes per annum.

Emissions category	NO_X	NO_2	Total PM_{10}	Exhaust PM_{10}	Total $PM_{2.5}$	CO_2 (ktonnes)
2007 – default stock (non-camera), reflecting an end-of-year position						
Phase 1 affected vehicles	6,487	908	219	163	175	804
Phase 2 affected vehicles	6,116	1,568	161	87	114	887
Total phase 1 and 2 affected vehicles	12,603	2,476	380	250	289	1,691
All road traffic – Greater London	21,796	4,113	1,602	873	1,072	7,440
All external road traffic	12,975	2,091	685	418	509	3,652
2007 – camera start of year						
Phase 1 affected vehicles	6,746	945	234	178	189	807
Phase 2 affected vehicles	6,665	1,074	183	108	133	889
Total phase 1 and 2 affected vehicles	13,411	2,019	417	287	322	1,696
All road traffic – Greater London	23,491	3,681	1,695	966	1,147	7,554
All external road traffic	14,065	2,194	735	468	553	3,697
2007 – camera end of year						
Phase 1 affected vehicles	6,334	887	216	161	173	804
Phase 2 affected vehicles	6,454	1,043	172	97	123	887
Total phase 1 and 2 affected vehicles	12,789	1,930	388	258	296	1,691
All road traffic – Greater London	21,982	3,567	1,610	881	1,079	7,440
All external road traffic	12,968	2,084	688	421	513	3,652
2007 – camera annual average						
Phase 1 affected vehicles	6,571	920	228	173	184	805
Phase 2 affected vehicles	6,621	1,068	181	107	132	889
Total phase 1 and 2 affected vehicles	13,192	1,988	410	279	316	1,694
All road traffic – Greater London	22,385	3,625	1,632	903	1,098	7,443
All external road traffic	12,982	2,086	689	422	513	3,652
2007 – end of year camera background change						
Phase 1 affected vehicles	6,500	910	225	169	181	805
Phase 2 affected vehicles	6,540	1,055	177	103	128	888
Total phase 1 and 2 affected vehicles	13,040	1,965	402	272	309	1,692
All road traffic – Greater London	22,233	3,602	1,624	895	1,091	7,442
All external road traffic	12,977	2,085	689	422	513	3,652

6.11 Interpretation of emissions changes during 2007

Considering firstly the transition from default London Atmospheric Emissions Inventory vehicle emissions (ie 'vehicle stock') profiles to observed profiles based on camera data, it is apparent that the general picture is for scenarios based on camera data to compare reasonably well with those using the default profiles in terms of aggregate emissions. This aggregate correspondence however conceals two opposing effects.

Bearing in mind that the 2007 'default stock' scenario includes a vehicle fleet profile that is representative of conditions at the end of 2007, camera-based profiles for the start of 2007 show higher relative emissions across the board. A more appropriate comparison is with the camera-based profile for the end of 2007. Here, emissions tend to be lower across the board, although only marginally so for PM_{10} and $PM_{2.5}$. Again, this would not be unexpected, but the camera data for end 2007 now includes observed operator pre-compliance with the scheme during the latter part of 2007.

Therefore the net effect is that the camera-based vehicle emissions profiles are tending to slightly over-state emissions relative to the default London Atmospheric Emissions Inventory assumptions. Importantly, this relative over-statement largely offsets the reductions to emissions arising from the adoption of the revised TfL traffic volume estimates.

Note that particulate matter emissions from tyre and brake wear (not separately shown) remain unchanged for all of the 2007 scenarios, since traffic volumes are assumed to be constant during the year and neither 'background' or 'scheme-attributable' change affects emissions from this source.

Table 6.6 identifies the key comparisons from Table 6.5. Note that:

- The 'background change' is assessed to be the major factor contributing to the overall emissions reduction in 2007, accounting for broadly three quarters of the total change. This reflects change to all vehicles, of which those affected by the scheme are only a small part.
- Consequently, the component of the overall change that is attributable to operator pre-compliance is smaller at about one quarter, but still represents a significant contribution to overall change, and is a legitimate attributable impact of the scheme.

Table 6.6 Selected difference analysis of 2007 emissions scenarios. Percentage change to total road traffic emissions across Greater London.

Scenario comparison	NO_X	NO_2	Total PM_{10}	Exhaust PM_{10}	Total $PM_{2.5}$	CO_2 (ktonnes)
Default stock vs. camera start of year. Equivalent to 'method change' less stock turnover during 2007.	+7.8%	-10.5%	+5.8%	+10.7%	+7.0%	+1.5%
Camera start year vs. camera end year, scaled to 12 months. Equivalent to gross annual change.	-8.6%	-4.1%	-6.7%	-11.7	-7.9%	-2.0%
Camera end year background vs. Camera start year. Equivalent to 'background change' – no scheme, ie stock turnover during 2007.	-7.1%	-2.9%	-5.6%	-9.8%	-6.5%	-2.0%
Scheme pre-compliance effect in 2007 – gross annual change less background change.	-1.4%	-1.3%	-1.1%	-1.9%	-1.4%	0%
Scheme pre-compliance effect in 2007 – phase 1 affected vehicles only	-3.3%	-3.2%	-5.1%	-6.0%	-5.6%	-0.2%
Scheme pre-compliance effect in 2007 – phase 2 affected vehicles only	-1.7%	-1.5%	-3.6%	-7.4%	-5.0%	-0.1%

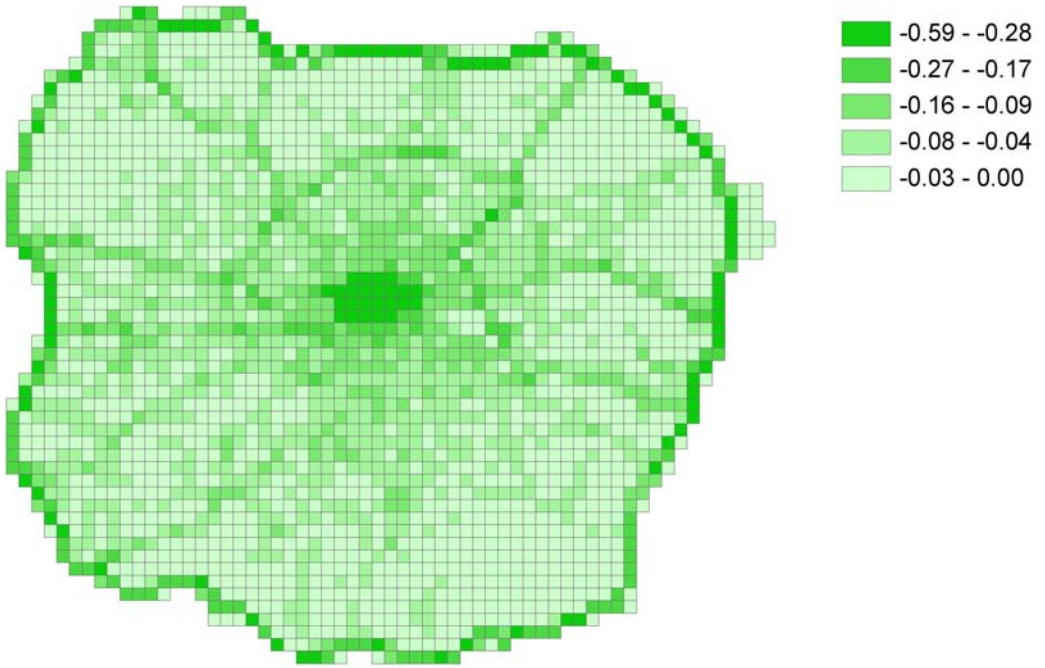
Figures 6.5, 6.6 and 6.7 illustrate the impact of these changes on emissions of PM_{10} from road traffic only across Greater London. Note that the scales on each map are not identical.

Figure 6.5 shows the total annual emissions change for 2007, including both **background** and **scheme-attributable** components of change. It is seen that the highest emissions reductions occur in central London and close to major roads – corresponding to areas having the highest emissions in the base case.

Figure 6.6 shows the component of total change that is attributable to **background change** in the emissions performance of the vehicle fleet. A similar but less intense pattern is seen. Both Figures 6.5 and 6.6 show significant emissions reductions on the M25 orbital motorway. This wholly reflects background change to the vehicle fleet, and does not include any scheme-attributable effects (these are present, but are not estimated here).

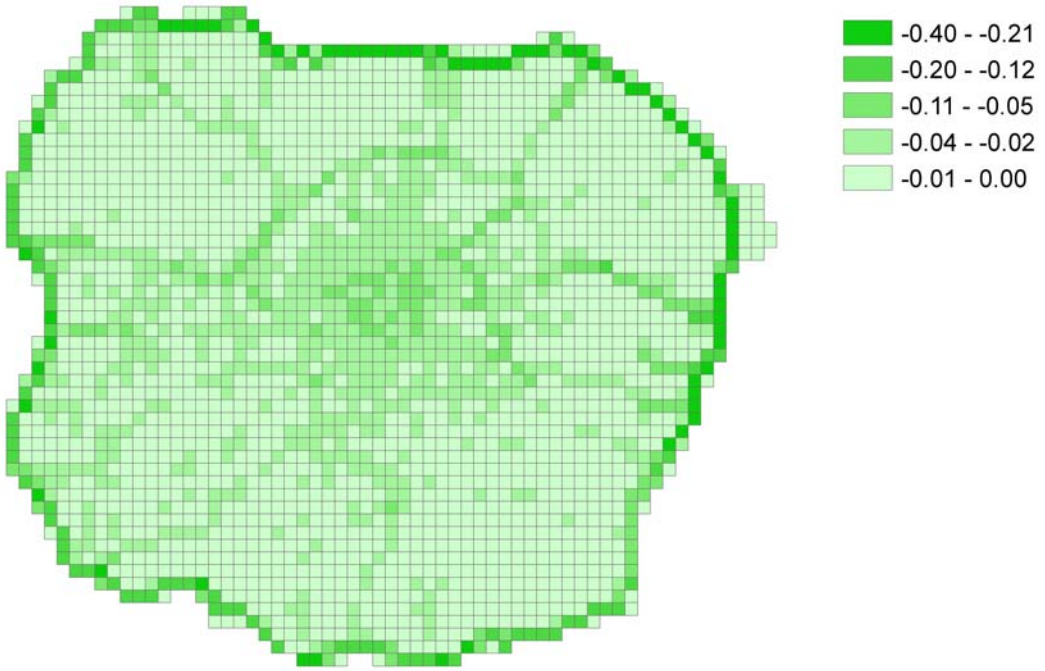
Figure 6.7 shows the component of total change that is attributable to **operator pre-compliance** with the scheme during 2007. In this case no impacts are shown for the M25, although again they are present (see Section 10 of this report).

Figure 6.5 Reduction in emissions of PM_{10} during 2007. Road traffic sources only, total annual change (start vs. end of 2007). Tonnes per annum.



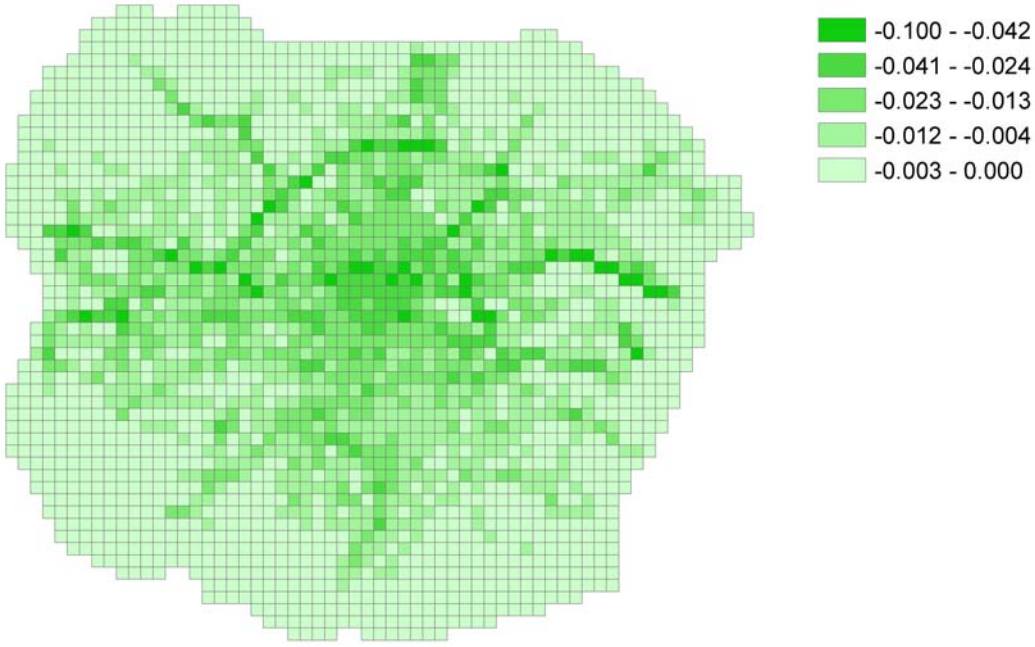
Source: Environmental Research Group, Kings College London.

Figure 6.6 Reduction in emissions of PM_{10} during 2007. Road traffic sources only, 'background' change for vehicles affected by phases 1 and 2 of the scheme (start vs. end of 2007). Tonnes per annum.



Source: Environmental Research Group, Kings College London.

Figure 6.7 Reduction in emissions of PM_{10} during 2007. Road traffic sources only, scheme-attributable change for vehicles affected by phases 1 and 2 of the scheme (start vs. end of 2007). Tonnes per annum.



Source: Environmental Research Group, Kings College London.

6.12 Comparison with previous TfL projections of scheme impacts.

Finally, it is necessary to revisit the most recent set of TfL projections of scheme impacts (Table 6.2), and compare them with the equivalent scenario arising from this emissions assessment work. This equivalent scenario is 2007 'end of year camera background' change from Table 6.6. This differs from the TfL projection in the following key respects:

- The starting point is 2004 general purpose London Atmospheric Emissions Inventory, compared to 2003 version of the inventory used for TfL projections (ie general method improvements to the London Atmospheric Emissions Inventory).
- Revised (reduced) vehicle-kilometres.
- Observed (camera) vehicle emissions profiles as opposed to national fleet-based assumptions.
- Observed (camera) estimates of vehicle stock turnover (background change) as opposed to default London Atmospheric Emissions Inventory assumptions.

Operator pre-compliance with the requirements of the scheme is excluded in both cases. Table 6.7 sets out the comparison.

Table 6.7 Comparison of TfL 'projected' base case for the scheme and equivalent TfL 'monitoring' base case. 2007 end of year projected/observed vehicle stock Annual total emissions (tonnes). All road traffic sources.

Scenario/location	NO_X	NO_2	Total PM_{10}	PM_{10} tyre/brake	CO_2 (ktonnes)
TfL projection base					
Greater London	21,493	4,012	1,762	794	7,754
External	12,358	2,005	691	259	3,820
TfL monitoring base					
Greater London	22,233	3,602	1,624	729	7,442
External	12,977	2,085	689	267	3,652
Difference – Greater London	**+740**	**-410**	**-138**	**-65**	**-312**
Difference – External	**+619**	**+80**	**-2**	**+8**	**-168**

6.13 Summary

The impact of the London Low Emission Zone on emissions in London is being assessed using an emissions inventory. This allows selective manipulation of input data relating to vehicle flows and emissions characteristics, reflecting both background change to the emissions performance of the vehicle fleet and the specific impacts of the scheme itself. TfL is developing a series of 'custom' inventories, based on the widely-used London Atmospheric Emissions Inventory, to quantify emissions impacts over the lifetime of the scheme.

Defining a 'baseline' set of emissions estimates for 2007, against which the emerging impacts of the scheme can be set, involves incorporating new data and insights arising from the wider monitoring work. These include significant revisions to previously-used traffic volume and composition estimates, and newly-available measured data from cameras describing the emissions characteristics of vehicles operating in Greater London. These changes mean that the 'scheme monitoring' baseline for emissions will not be directly comparable with that previously published by TfL for scheme consultation purposes, as shown by Table 6.9. Finally, operator pre-compliance during 2007 with the requirements of the scheme – an expected and observed effect during the second half of 2007 – needs to be accounted for separately as a legitimate impact of the scheme, albeit ahead of the actual implementation date of the first phase of the scheme.

The net effect of the methodological changes to the inventory is to reduce the estimated emissions of PM_{10} and NO_2, by 8 and 10 percent respectively, and increase estimated emissions of NO_X, by 3 percent, in relation to previous equivalent 'no scheme' assessments produced by TfL.

During 2007, it is estimated that **background change** to the emissions performance of vehicles operating in Greater London reduced emissions of NO_X in Greater London by 7.1 percent; of NO_2 by 2.9 percent; of PM_{10} by 5.6 percent; of $PM_{2.5}$ by 6.5 percent, and of CO_2 by 2.0 percent – all with reference to this revised 'monitoring' base case. These empirically-based estimates of background change tend to be smaller than would otherwise be assumed using national-level projections – a potentially important finding that will be further investigated.

Over and above this background change, it is estimated that **operator pre-compliance** with the requirements of the scheme reduced emissions in Greater London of NO_X by 1.4 percent; of NO_2 by 1.3 percent; of PM_{10} by 1.1 percent; and of $PM_{2.5}$ by 1.4 percent. Emissions of CO_2 remained largely unaffected by the scheme, as would be expected.

These estimates will be carried forward into the model-based assessments of pollution concentration change in relation to developments during the 2007 calendar year. These are considered in the next section.

7. Estimating the impact of the London Low Emission Zone on air quality

7.1 Introduction

Section 6 described how the impacts of the changes to vehicle emissions brought about by the scheme are being measured through an incremental series of emissions scenarios, in the context of continuous background change to the vehicle fleet. This allows a 'step-by-step' assessment of the impact of the various phases of the scheme, controlling for both background changes to emissions from unaffected sources and necessary methodological improvements to the inventory itself.

This section looks at how these emissions changes translate to changes in ambient air quality ie changes to the concentration of pollutants in the outdoor atmosphere that are experienced by people. It firstly reviews the nature of the relationship between changes to emissions and changes to air quality, which is both complex and indirect. It then briefly describes the air quality model being used by TfL, and proceeds to set out a series of incremental ambient air quality scenarios that correspond directly to the emissions scenarios described in the previous section.

7.2 Relationship between emissions and air quality change

Successive emissions assessments will give a good, quantified indication of the impact of the scheme on emissions of key pollutants across London. However, changes to emissions do not translate to equivalent changes in ambient air quality. In fact, the relationship is often quite indirect, for the following key reasons:

- The scheme only affects emissions from one source (road traffic) and then only a small proportion of that source – those vehicles that are affected by the scheme.
- The processes by which emissions from discrete sources are transformed into pollutant concentrations in ambient are both complex and diverse. This involves processes such as dispersion and chemical transformation in the atmosphere, and mixing of locally-produced emissions with similar pollutants from further afield.
- In this respect, the influence of the weather is crucial. A hot, dry summer, characterised by easterly winds and 'continental' air masses will tend to have much poorer ambient air quality than a cool, wet summer – for equivalent locally-generated emissions.

In practical terms this means that:

- What may be a substantial proportionate impact on one source of emissions will diminish in significance when considered in the context of all sources, and in the context of pollution that is generated outside the region of interest, which can be a major contributor to poor outdoor air quality.
- A calculated reduction in emissions may or may not translate in the short term to observable improvements in ambient air quality – depending primarily on year-to-year weather patterns.

- However, irrespective of whether the impacts of the scheme are immediately detectable in air quality measurements or not, reduced emissions should nevertheless give rise to **relative** improvements in air quality against equivalent conditions had local emissions not been reduced, albeit usually on a significantly smaller proportionate scale to the initial emissions change.

These important considerations underlie the interpretation of the material described in this section, and also the relationships between **calculated estimates** of air quality change, and the equivalent **measured** indicators of air quality change, as described in Sections 8 and 9 of this report.

7.3 The King's College London Air Quality Model

TfL has adopted the air quality model developed by the Environmental Research Group at King's College London for this work. This is a well-established model that is widely used for air quality assessment in London, including the Mayors' Air Quality Strategy[1]. Key features of this model include its ability to interface directly to the detailed and disaggregate emissions estimates as described in Section 6, and the finely-resolved spatial resolution at which air quality forecasts can be made. The model is kept up to date with general developments in air quality science. Recent examples include incorporating new knowledge about NO_X/NO_2 emissions relationships and NO_X atmospheric chemistry; the ability to predict 'true' gravimetric concentrations of PM_{10} (see Sections 8 and 9), and an ability to model concentrations of $PM_{2.5}$. The model is validated using the large dataset of observed concentration data produced by the London Air Quality Network.

7.4 Using the air quality model for scheme assessment purposes

For the purposes of this report, the version of the model used is identical to that used for TfL's most recent set of projections for the scheme impact. This allows like-for-like comparison, and makes use of previous enhancements to the model – largely specified by the Greater London Authority and TfL – to make it more optimal for assessing scheme impacts. Nevertheless, as with the emissions inventory, the basic air quality model is not yet fully optimised for reproducing some of the more subtle effects of the scheme, and some additional technical enhancements remain to be taken forward as the monitoring work progresses.

The air quality model has an important role in controlling, and accounting for, the impact of extraneous variables such as the weather and non-locally-generated emissions on the successive estimates of scheme impacts. In terms of the weather, standard practice is to calibrate the model to reflect an 'idealised' meteorological year, and to test the various scenarios on the basis of this (constant) meteorology. It is usual to select a recent year that was free from extreme weather, and for which full meteorological data are available. The year that is currently in use for this is 2002, as opposed to more recent years that have tended to be more prone to climatic extremes. This means that the resulting pollution (concentration) estimates can be taken as being close to long-run average conditions for a given year's emissions. It is important to emphasise that the particular 'meteorological year' chosen is selected simply to derive standardised and representative meteorological conditions, and

carries no other implications for the comparative assessment of different air quality scenarios.

It follows that actual experienced pollutant concentrations in any given year may well differ considerably from the projections, but this would almost wholly reflect the impact of yearly weather on pollutant concentrations, and not changes to the emissions inputs. This is a very important consideration when assessing modelled projections of air quality change and equivalent measured pollution concentrations, which may not correspond directly. A similar process accounts and controls for the impact of emissions from outside Greater London on estimated pollutant concentrations, which again will vary in intensity from year to year depending primarily on the weather.

7.5 Air quality model outputs

The air quality model will operate on the available emissions scenarios described in Section 6, producing successive pollutant concentration scenarios at a fine level of spatial resolution, assuming constant (2002 equivalent) meteorology and standardised non-locally-generated pollution inputs. As with emissions scenarios, air quality model outputs are best viewed as maps, and it is usually readily possible to pick out the more important pollution sources (such as traffic using major roads) on these maps. Maps corresponding to two different emissions scenarios can be overlaid, and differences between the scenarios calculated. In this way the impact of a specific change can be quantified, and 'difference maps' produced, illustrating how the impacts vary spatially.

Model outputs are most conventionally expressed in terms of the UK national air quality objectives, using measures such as 'annual average concentrations' or 'number of days on which a specific concentration is exceeded' (see Table 8.1). In this way it is straightforward to identity areas or locations that, according to the projections, will fail to meet the applicable air quality objective.

For scheme monitoring purposes this is not ideal, as some of the relationships involved are non-linear, and reductions in pollution in areas that are densely-populated are more significant in terms of impacts on public health than equivalent reductions in areas that are lightly populated. Therefore, TfL has also used measures based on percentage changes to the **land area** of London projected to exceed air quality objectives, and these can potentially be further developed for health impacts assessment purposes into equivalent **population exposure based** measures of change.

7.6 Summary of TfL's most recent projections of scheme impacts

The vehicle emissions assessments underlying TfL's most recent projections of the impacts of the various phases of the scheme were summarised in Section 6.6. This section summarises the corresponding air quality scenarios, as projected by TfL in November 2007 ahead of the implementation of the first phase of the scheme. Table 7.1 shows two different projection scenarios of the full 'settled' impact of phases

1 and 2 of the scheme in 2008 compared with the equivalent 'no scheme' scenarios. Note that impacts of the scheme in subsequent years are not shown in this table.

Table 7.1. Summary of TfL's air quality impacts projections for phases 1 and 2 of the London Low Emission Zone scheme. Average absolute concentrations from all sources, whole Greater London area.

Scenario/location	2008 no scheme (2007 stock)	2008 with phases 1 and 2 (2007 stock)	2008 no scheme (2008 stock)	2008 with phases 1 and 2 (2008 stock)
Mean NO_2 ($\mu g\ m^{-3}$)	32.533	32.326	31.583	31.405
NO_2 difference ($\mu g\ m^{-3}$)	n/a	-0.207	n/a	-0.178
Mean PM_{10}	20.529	20.496	20.104	20.075
PM_{10} difference ($\mu g\ m^{-3}$)	n/a	-0.032	n/a	-0.029
PM_{10} exceedence days	2.046	2.014	1.574	1.55
PM_{10} exceedence days difference	n/a	-0.032	n/a	-0.025

The appropriate basis for comparison is between pairs of columns in the table with the equivalent vehicle stock profiles (2007 or 2008). Note that the values refer to average concentrations across the whole of the Greater London area. Actual scheme impacts close to busy roads and in central London would be significantly more intense. Key points, looking at the projected **scheme-attributable** impact of phases 1 and 2 of the scheme in 2008, are that:

- In 2008, reductions of about 0.2 $\mu g\ m^{-3}$ are projected for annual average concentrations of NO_2 against both scenarios – about 0.6 percent of prevailing average concentrations across Greater London. These scenarios are not additive, but can be thought of as two different 'sensitivity tests' reflecting, respectively, 2007 and 2008 'no scheme' vehicle stock (emissions profile) assumptions.
- In 2008, reductions of about 0.03 $\mu g\ m^{-3}$ are projected for annual average PM_{10} concentrations against both vehicle stock scenarios – these representing overall reductions of about 0.15 percent to prevailing average concentrations.
- The average number of days per year on which mean PM_{10} concentrations across the region are projected to exceed the national objective of 50 $\mu g\ m^{-3}$ are reduced – by typically 0.03 of a day.
- Although relatively small in absolute magnitude, these projected outcomes apply to total concentrations from all emissions sources, including non-traffic sources and those external to Greater London, and are annual averages across the whole of Greater London.

Global mean-based impact estimates such as these are potentially misleading, as pollutant concentrations vary considerably over the region. The actual impact of the scheme at the local scale will be broadly proportionate to the absolute scale of local pollution concentrations, and in particular to the relative contribution from road traffic sources.

Therefore, locations close to busy roads that have much higher prevailing concentrations of NO_2 and PM_{10} will experience a proportionately higher impact from the scheme. This effect is evident from Figure 2.3 where it is noted that the large majority of the land area of Greater London is projected to show little or no change to annual average concentrations. There are, however, more significant reductions close to major roads.

Indeed, the propensity of locations to exceed the PM_{10} annual mean objective varies enormously across Greater London. Particularly heavily-polluted locations may register in excess of 100 exceedence days per year, compared to a London average value of about 2 days. The scheme would tend to deliver the highest intensity reductions in these more polluted locations, and therefore area-average based statistics such as these should be viewed in that context (see Figures 7.1 and 7.2).

Note also that:

- Because the vehicle stock in general would be expected to become cleaner between 2007 and 2008, irrespective of the scheme, the pair-wise comparisons for 2008 in Table 7.1 yield slightly lower estimates of change attributable to the scheme than those for 2007.
- Note that the magnitude of the values for average PM_{10} exceedence days across Greater London, in those scenarios involving a 2008 vehicle stock profile, are substantially less than those for 2007 – illustrating the non-linear nature of the relationship between average PM_{10} concentrations and PM_{10} exceedence days, referred to previously.

7.7 Modelled air quality scenarios from the monitoring work

Subsequent to these pre-scheme projections, air quality model assessments have been made for the key 'scheme monitoring' emissions scenarios – reflecting the stages described in Section 6 of this report. These are:

- A 2007 annual average scenario based on 'default' emissions inventory vehicle stock profiles – equivalent to **'2007 default stock'** in Table 6.5.
- A 2007 start of year scenario based on camera data – equivalent to **'2007 camera start of year'** in Table 6.5.
- A 2007 end of year background change scenario based on camera data – **'2007 end year camera background change'** in Table 6.5.
- A 2007 end year total change scenario – including both background and scheme-attributable change – equivalent to **'2007 camera end of year'** in Table 6.5.

Table 7.2 sets out these scenarios in terms of change in annual mean NO_X, NO_2 and PM_{10} concentrations and PM_{10} exceedence days across the whole of Greater London. Table 7.3 highlights the key differences between these scenarios, in terms of changes in annual mean concentrations. Note here that these results also apply to average concentrations across the whole of the Greater London area. As with the projected scenarios above, the reductions attributable to the scheme in locations close to busy roads will be of considerably greater magnitude.

Table 7.2 Modelled annual mean concentrations (µg m^{-3}) of key pollutants, reflecting 2007 emissions scenarios. All sources, Greater London area averages.

	NO_X	NO_2	PM_{10}	PM_{10} exceedence days
2007 default stock	49.39	32.80	20.47	1.98
2007 camera start of year	51.40	33.60	20.57	2.08
2007 End of year background change – camera data	49.49	32.75	20.42	1.95
2007 camera end of year	49.29	32.67	20.41	1.94

Table 7.3. Changes in modelled annual mean concentrations of key pollutants (µg m^{-3}) during 2007. All sources, Greater London area averages.

	Background change 2007	Total change 2007	Scheme-attributable change (pre-compliance) during 2007	Most recent TfL projection of impact of scheme phases 1 and 2 in 2008
NO_2	-0.85	-0.93	-0.083	-0.21
PM_{10}	-0.15	-0.17	-0.014	-0.03

Key points to note are:

- Modelled average concentrations of PM_{10} are assessed to reduce 0.17 µg m^{-3}, in terms of total change. This however includes the vehicle stock or 'background' change inferred from the camera data during 2007. Isolating the 'scheme-attributable' change gives a reduction of 0.014 µg m^{-3}. This is about one-tenth of the estimated total change but compares to a value of 0.03 µg m^{-3} from the appropriate comparisons in Table 7.1.
- In other words, the camera-based assessments are suggesting that up to one-half of the total projected PM_{10} impact from the full implementation of phases 1 and 2 of the scheme (combined) in 2008 has in fact been achieved by operator pre-compliance with the requirements of the scheme during 2007, ie before implementation.
- This is an encouraging result but does need to be seen in context. Operator pre-compliance was mainly evident during the latter part of 2007. The model estimates strictly relate to a nominal full calendar year. It is therefore more appropriate to view the comparison as the 'maximum expression of operator pre-compliance' at the end of 2007, rather than a true annual average result.
- Furthermore, as previously described, the adoption of camera data in place of previous emissions inventory projections of the emissions performance of vehicles operating in Greater London means that the 'monitoring' assessments will not be strictly comparable with the equivalent TfL pre-scheme projections.
- A similar picture emerges for NO_2. Here, the total change (from all vehicles) in 2007 is estimated at 0.93 µg m^{-3}, while the scheme-attributable change is estimated at 0.083 µg m^{-3}. This is about 10 percent of the total change, but is again almost half of the equivalent projected scheme-attributable change - for full implementation of phases 1 and 2 if the scheme in 2008 suggested by the TfL

projections in Table 7.1. Similar caveats about comparability apply, but again it is clear that substantial progress was made during 2007 towards achieving the ultimate air quality improvement objectives for phases 1 and 2 of the scheme.

As with the projections described in Section 7.6, these outcomes are London-wide averages. The intensity of the impacts will vary considerably depending on the prevailing pollution levels in specific locations. Close to busy roads, where absolute levels of pollution are considerably higher than the average, and where the reductions to road traffic emissions brought about by the scheme would be most apparent, the achieved reductions will be much higher.

Across the 60 roadside air quality measurement sites to which the air quality model is calibrated, the average reduction in PM_{10} as a result of the scheme is estimated at 0.054 µg m^{-3}, ie about four times the London-wide average scheme-attributable reduction. Again, however, these are averages and the most heavily polluted road-traffic-influenced sites might well see reductions of considerably larger magnitude.

Across 47 'background' air quality monitoring sites, the average PM_{10} reduction attributable to the scheme is estimated at 0.023 µg m^{-3}. This is slightly higher than the London-wide average, reflecting the lower contribution of road traffic emissions to total PM_{10} in these locations. Note in this context that 'background' sites are not reflective of the areas of London that have the very lowest pollution concentrations, such as semi-rural areas with little housing development and hence little human exposure. A similar pattern also applies to projections of scheme impacts on concentrations of NO_2.

This differential impact is illustrated by Figures 7.1 and 7.2. These show, for PM_{10} and NO_X respectively, the observed scheme-attributable reduction (only) for each of the air quality monitoring sites against which the air quality model is calibrated. The figures show that, in relation to the vehicle operator pre-compliance impact during 2007, a substantial number of these sites are projected to benefit from reductions to both PM_{10} and NO_X that are substantially higher than the average (shown by the horizontal lines on the graph).

Figure 7.1 Estimated scheme-attributable reductions in PM_{10} at individual air quality monitoring sites, reflecting vehicle operator pre-compliance with requirements of phases 1 and 2 of the scheme during 2007 (µg m^{-3}).

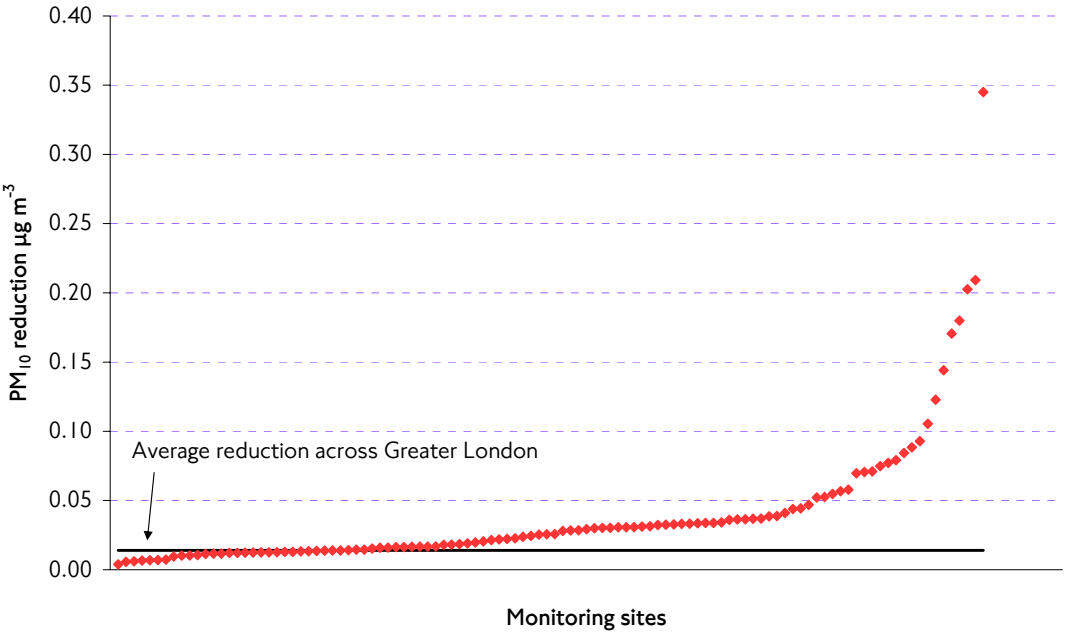
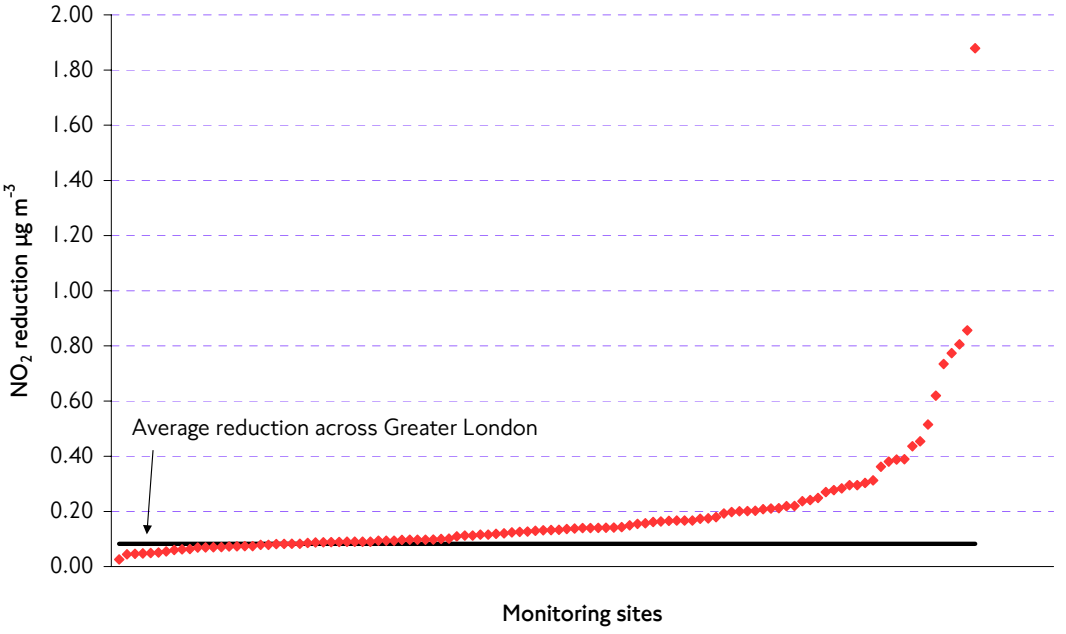


Figure 7.2 Estimated scheme-attributable reductions in NO_2 at individual air quality monitoring sites, reflecting vehicle operator pre-compliance with requirements of phases 1 and 2 of the scheme during 2007 (µg m^{-3}).

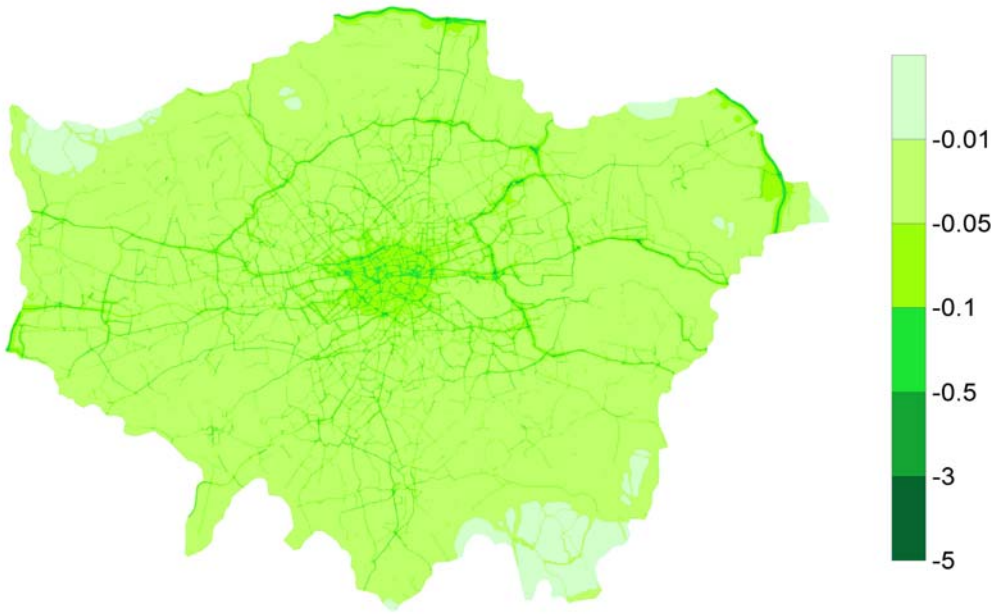


Figures 7.3 to 7.6 are examples of the maps that can be generated from this work. They illustrate the scale and nature of these impacts in terms of estimated concentration changes across the Greater London area for both PM_{10} and NO_2.

The first map in each pair shows the **projected scheme-attributable change**, as projected by TfL ahead of scheme implementation. The second map in each pair shows the estimated impact of operator pre-compliance with the requirements of the scheme during 2007, ie the **observed scheme-attributable change** during 2007. Generally it is seen that the observed maps in each case show reductions of about one half of the magnitude of the equivalent projected maps – clearly showing the **operator pre-compliance effect** during the latter part of 2007.

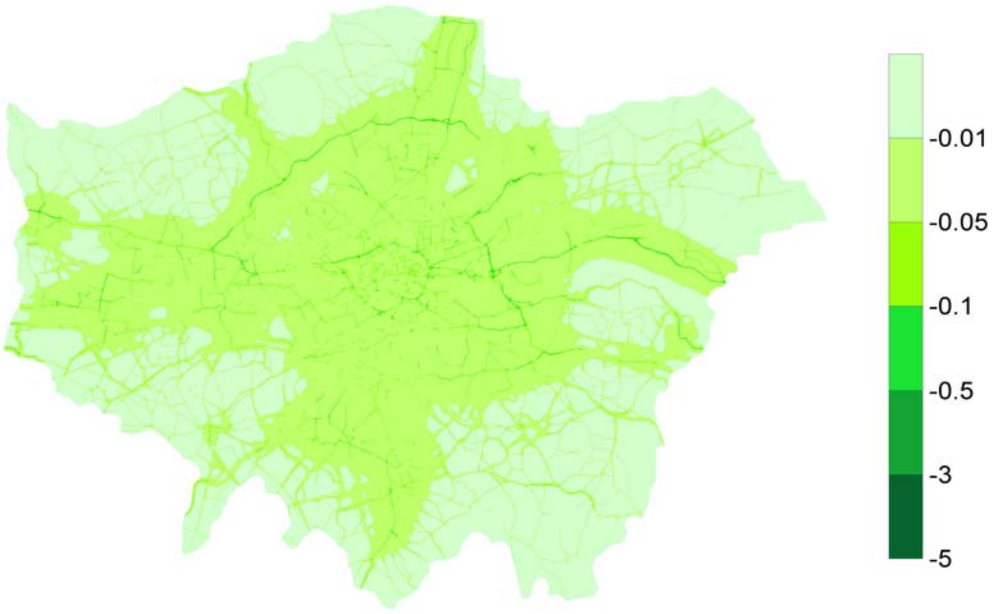
Note that all four maps assume that emissions from all other sources, apart from those directly affected by the scheme, are constant. It is also important to note that the reductions in concentrations can be several orders of magnitude higher in some areas (especially near major roads) than the Greater London average reductions, as illustrated by the visibility of the road network and central London on the maps.

Figure 7.3 Projected scheme-attributable changes in PM_{10} annual mean concentrations ($\mu g\ m^{-3}$). TfL pre-scheme projection for 2008 with 2007 vehicle stock.



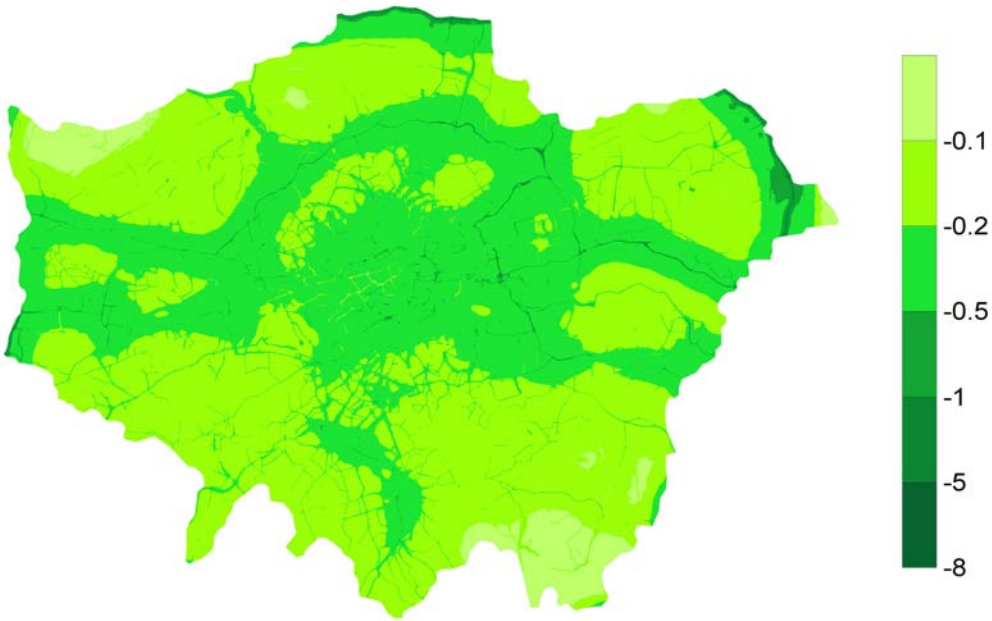
Source: Environmental Research Group, Kings College London.

Figure 7.4 Observed scheme-attributable changes in PM_{10} annual mean concentrations ($\mu g\ m^{-3}$). Start to end of 2007 with observed 2007 vehicle stock.



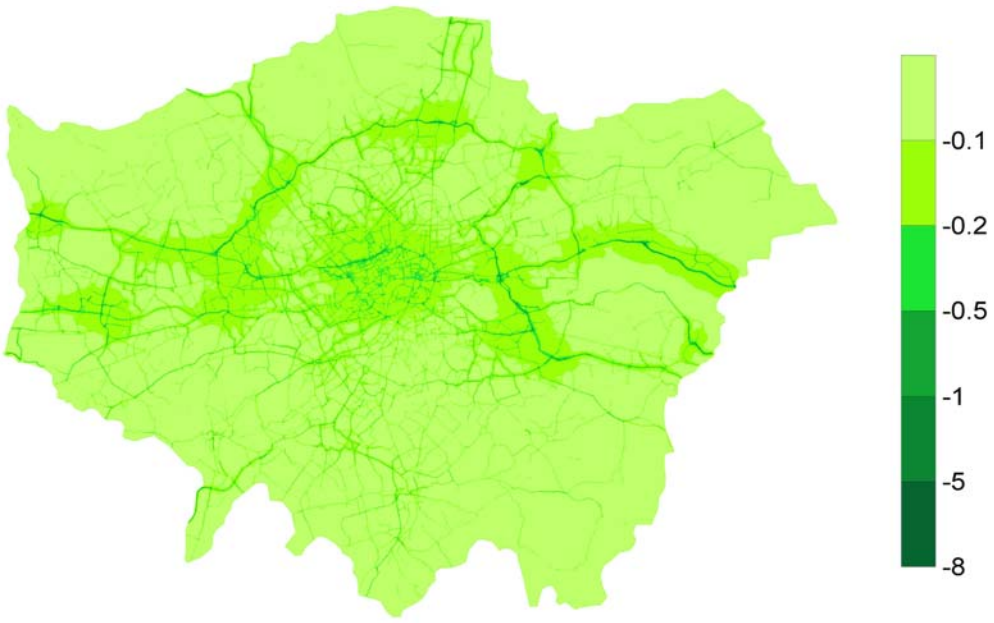
Source: Environmental Research Group, Kings College London.

Figure 7.5 Projected scheme-attributable changes in NO_2 annual mean concentrations ($\mu g\ m^{-3}$). TfL pre-scheme projection for 2008 with 2007 vehicle stock.



Source: Environmental Research Group, Kings College London.

Figure 7.6 Observed scheme-attributable changes in NO_2 annual mean concentrations ($\mu g\ m^{-3}$). Start to end of 2007 with observed 2007 vehicle stock.



Source: Environmental Research Group, Kings College London.

A useful way of quantifying these changes is in terms of the change in the land area of Greater London that is projected to exceed the relevant national air quality objectives. Table 7.3 shows selected exceedence statistics, reflecting these observed outcomes. Note that the exceedence areas for PM_{10} are expressed in terms of the erstwhile 2010 national objective for PM_{10} of 23 $\mu g\ m^{-3}$, which has recently been abandoned by Defra. The reason for this is that, given prevailing annual average PM_{10} concentrations, the 2005 annual average objective of 40 $\mu g\ m^{-3}$, which is consistently met across most of Greater London (see Section 8), would not show any significant impact – as few areas exceed it. On this basis, the scheme pre-compliance impact measured during 2007 would reduce the area of Greater London that exceeded the nominal 2010 objective by 4 percent. The equivalent value for the current annual mean NO_2 objective is a reduction of 3 percent.

Table 7.4 Impact of 2007 emissions and air quality scenarios on area of London exceeding nominal air quality objectives.

	Exceedence area km^2					
	Default 2007 stock	**Camera start of year**	**2007 end background**	**Camera end of year**	**Gross annual change**	**Scheme-attributable change**
PM_{10} (annual mean > 23 μg per m^3)	73	80	70	68	-20%	-4%
NO_2 (annual mean > 40 μg per m^3)	175	209	172	168	-26%	-3%

7.8 Summary

TfL is using an established air quality model to translate the emissions scenarios generated by the scheme monitoring work into estimates of pollutant concentrations across London. The emissions scenarios set out in Section 6 of this report lead to corresponding estimates of pollutant concentration change, reflecting changes to vehicle emissions performance during 2007. These changes will reflect the background process of improvement to the general vehicle fleet (both affected and not affected by the scheme), and an element of operator pre-compliance with the requirements of phase 1 in particular, of the scheme, ahead of implementation. These changes can be represented as maps of pollution concentration gradients (either absolute concentrations or changes to concentrations), and can be quantified in terms of national air quality objectives.

Selected air quality model runs have been undertaken for NO_2 and PM_{10}, based on new camera data that quantifies changes to the emissions performance of vehicles affected by the scheme during 2007. These can be compared to equivalent projections made by TfL shortly before implementation of the first phase of the scheme, based on default assumptions about the emissions performance of vehicles operating in Greater London.

These 'monitoring' estimates are generally of comparable absolute magnitudes to the previous projections. They show that the **maximum expression** of operator pre-compliance with the requirements of phases 1 and 2 of the scheme, as measured by the monitoring cameras at the end of 2007, reached **approximately half** of the maximum scheme effect for phases 1 and 2 combined as previously projected by TfL. Given the continuing trend of increased compliance during the first half of 2008, it seems that the scheme is well on track to achieving at least the full emissions and air quality benefits that are expected from the first two phases of the scheme.

In considering this finding, it is necessary to recognise that operator pre-compliance was a progressive trend during the second half of the year only, and that many other differences arising from the adoption of a camera-based view of vehicles circulating in Greater London will mean that the two sets of estimates will not be directly comparable. It is also necessary to recognise that area-wide average pollutant concentration statistics are potentially misleading, in that the scheme will have a proportionately much greater effect close to busy roads. It is precisely in these areas that air quality problems are most acute and where the bulk of human exposure to poor air quality occurs.

Further model-based estimates of change will be made as the scheme progresses, reflecting changes to the emissions performance of vehicles as detected by the monitoring cameras, and the corresponding emissions change scenarios. However, on this basis, and given the developments to compliance levels seen in the first few months of 2008 following the introduction of phase 1 of the scheme (see Section 13), it seems that the long-run air quality impacts of the scheme should readily meet TfL's expectations.

8. Concentrations of pollution in ambient air: recent air quality trends in London

8.1 Introduction

The principal aim of the London Low Emission Zone is to improve the quality of the air breathed outdoors by the people of London – especially by reducing concentrations of particulate matter, as these are the most damaging to health.

By reducing emissions from road traffic, the scheme should have a positive impact on measured concentrations of particulate matter which will ultimately feed through to positive impacts on public health. However, it is likely to be difficult to demonstrate a real attributable change in the concentration of particulate matter from the scheme. This is because the effect of the scheme on measured concentrations is relatively small and may be obscured by other factors that influence air quality, ranging from changing meteorological conditions which affect dispersion to the effects of wider local, national and international policies that affect emissions.

The Environment Act 1995 requires local authorities to work towards achieving air quality objectives. The objectives are specified as target concentrations measured in ambient air, as summarised in Table 8.1[(1)]. Concentrations of PM_{10} and NO_2 in many areas of London currently do not meet the air quality objectives and so the introduction of the Low Emission Zone should help London move towards compliance with these objectives. In order to monitor progress towards these objectives, there is an extensive network of pollution monitoring sites in London. TfL will use this monitoring network as part of its assessment of long term trends in measured air pollution and to help assess the impact of the scheme.

In addition to local authority monitoring sites, there are two long standing air quality monitoring networks within London; the London Air Quality Network (LAQN) and the national Automatic Urban and Rural Network (AURN). These are described in more detail in **Appendix 5**. Both networks work to a high level of quality control and assurance; from site maintenance to data collection and ratification, to guarantee high quality data.

Table 8.1 Summary of national air quality objectives for the protection of health.

Pollutant	Objective	Concentration measured as	Date to be achieved and maintained
PM_{10}	50 μg m^{-3} not to be exceeded more than 35 times a year	24 hourly mean	31 December 2004
	40 μg m^{-3}	Annual mean	31 December 2004
$PM_{2.5}$	25 μg m^{-3}	Annual mean	2020
NO_2	200 μg m^{-3} not to be exceeded more than 18 times a year	1 hour mean	31 December 2005
	40 μg m^{-3}	Annual mean	31 December 2005
Ozone	100 μg m^{-3} not to be exceeded more than 10 times a year	8 hour mean	31 December 2005
Sulphur Dioxide	266 μg m^{-3} not to be exceeded more than 35 times a year	15 minute mean	31 December 2005
	250 μg m^{-3} not to be exceeded more than 24 times a year	1 hour mean	31 December 2004
	125 μg m^{-3} not to be exceeded more than 3 times a year	24 hour mean	31 December 2004
Polycyclic Aromatic Hydrocarbons	0.25 mg m^{-3}	Annual mean	31 December 2010
Benzene	5 μg m^{-3}	Annual mean	31 December 2010
1,3-butadiene	2.25 μg m^{-3}	Running annual mean	31 December 2003
Carbon monoxide	10 mg m^{-3}	Max daily running 8 hour mean	31 December 2003
Lead	0.25 μg m^{-3}	Annual mean	31 December 2008

8.2 Overview of air quality trends

This section provides an overview of recent air quality trends in Greater London, focusing on concentrations of PM_{10}, $PM_{2.5}$, NO_X, NO_2 and ozone (O_3). The following analysis will establish a baseline for ambient air quality that describes temporal and spatial trends over a period of several years before the introduction of the scheme. These trends will also be compared against the relevant air quality objectives. The data will continue to be collected after the introduction of the scheme, with the intention of identifying and quantifying developments that may reflect scheme impacts. The trends in London will be compared to trends in other UK towns and cities, to help isolate the effects of the scheme on London's air quality.

In addition, Paris has been chosen as a European comparator city as it has a well established monitoring network and is a large enough conurbation to allow a

comparison of inner and outer city pollution. Paris is also unlikely to be affected by scheme related changes in the vehicle fleet that may affect the rest of the UK. By taking account of data from other cities, external influences or confounding factors, the impact of the scheme should be more clearly identifiable.

The data presented in this section has been collected and aggregated from monitoring networks in London. This aggregation has been necessary as there are too many sites to present on an individual basis. The site aggregation is based on geographical and traffic characteristics, and the data has been averaged across all sites in a group. This provides a wider spatial perspective of concentrations, although suppresses the typically large variation in measured concentrations between sites; for example some individual sites may have particularly high or low pollution concentrations. The site aggregations used in this analysis are summarised below:

Geographical location:

- **Inner** – sites located within the North and South Circular roads.
- **Outer** – sites located outside the North and South Circular roads, but within the Greater London Authority boundary.

Traffic conditions:

- **Roadside (low flow)** – sites located within five metres of roads with an annual average daily traffic flow of less than 1,000 heavier vehicles. The term heavier vehicles includes buses and coaches as well as heavy goods vehicles.
- **Roadside (medium flow)** – sites located within five metres of roads with an annual average daily traffic flow of between 1,001 and 3,500 heavier vehicles.
- **Roadside (high flow)** – sites located within five metres of roads with an annual average daily traffic flow of over 3,501 heavier vehicles.
- **Background** – sites located further than five metres from roads, but less than 35 metres.

Where available, this section includes data from 2002 to 2007, including only sites with a minimum of 75 percent data capture. A six year period has been chosen to illustrate and take account of year-on-year variability in average pollution concentrations. This variability largely reflects seasonal and other meteorological factors which are recognised complications in analysing air quality trends over time. The data takes the form of a continuous time-series of hourly averaged pollutant concentrations. As a continuous dataset from 2002 is not available for $PM_{2.5}$ and ozone, data has been analysed from 2004 onwards for these two pollutants. In addition, due to the low number of sites which measure this pollutant, the roadside sites for these pollutants have not been disaggregated by traffic intensity.

8.3 Summary of pollutants of interest

The pollutant directly influenced by the scheme is particulate matter. Particulate matter is predominantly measured on a mass basis, as PM_{10}, particles with a diameter less than 10 micrometers in size. This is the size fraction that can penetrate into the airways and lungs and is associated with adverse health effects. Increasing concern

over the health impacts being predominantly affected by the smaller size fraction ($PM_{2.5}$, particulate matter smaller than 2.5 micrometers in diameter) has led to inclusion of this particle size fraction in the legislation and thus a requirement to also measure this size range.

Particulate matter has a multitude of natural and anthropogenic sources. The physical and chemical properties of particles are as variable as their sources. Particles differ according to their size, shape, density and chemical composition but are highly associated with exhaust from diesel-engined road vehicles, as well as from brake and tyre wear from vehicles more generally and through the re-suspension of particulates on the ground. The finer particles ($PM_{2.5}$) are predominately emitted from combustion processes, whereas the coarse fraction ($PM_{10} - PM_{2.5}$) are more typically generated through mechanical processes such as tyre and brake wear. This fraction will be much less affected by the scheme, so any changes to exhaust emissions will primarily affect only a proportion of the overall PM_{10} concentration.

It is not clear whether the adverse effects of particulate matter are associated mainly with the mass of particles, their number or their chemical composition. Research suggests that particle number is a better measure than mass for particles associated with adverse health effects. Particle number is especially relevant for the smaller size fraction as the majority of the 'number count' of particles is associated with that size fraction whereas the main mass concentration is associated with the larger size fraction. There is very little monitoring data on particle numbers as the air quality objectives relate to mass. As part of the monitoring work for the scheme, TfL has installed particle count equipment at several enhanced monitoring sites (see Section 9).

Although the scheme initially targets particulate emissions, the improvements to the vehicle fleet will mean that other pollutants will also be influenced. Therefore analysis of measured concentrations will also be carried out to examine changes in NO_X and ozone (O_3) concentrations. NO_X is a collective term for oxides of nitrogen, made up of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_X is associated with road traffic but is mainly released by combustion of petrol engines. The main component of NO_X is NO, which is oxidised in the atmosphere to form NO_2. NO_2 is the only component which is subject to air quality objectives and both the hourly and annual objectives are frequently exceeded in London. A reduction of NO_X emissions is not an explicit aim of the scheme but it is nevertheless important to investigate the impact of the scheme on this pollutant.

Another area of concern for future roadside monitoring within London is that of direct emissions of NO_2 [2]. This is the proportion of NO_X that is emitted in the form of NO_2, and which therefore is not constrained by conversion in the presence of O_3. These emissions are currently not fully understood, but there is some evidence to suggest that abatement technology for particulate matter might lead to an increase in direct NO_2 emissions. An effective way of assessing the contribution of directly emitted NO_2 from ambient concentrations at the roadside is by co-locating NO_2 and O_3 analysers[3]. However, due to NO_X 'scavenging', O_3 concentrations at the roadside are typically below the air quality objectives, which has meant that monitoring of O_3 in London had been historically focused in background and suburban locations and very little roadside monitoring exists. Additional O_3 monitoring has therefore been

included at the enhanced monitoring sites. Ozone also has adverse effects on respiratory health and a shift in balance with NO_X could mean increases in O_3 concentrations at background sites, thus causing an increase in NO_2 as there is more ozone available for NO_X conversion.

8.4 Analytical methods

Details of the air quality monitoring sites in London that have been used for this analysis are given in **Appendix 5**. Air quality data from these sites has been analysed to compare concentrations against the relevant air quality objectives for each pollutant and to calculate exceedences of the objectives. In addition to this, 30 and 90 day running annual means have been determined to help detect any specific trends that may be more difficult to identify from the annual means, such as seasonal differences between sites. The following sections present examples of the data analysis, providing a 'baseline' for each pollutant of interest for the period before the introduction of the scheme.

8.5 Baseline 1: Running annual average PM_{10} concentrations

The UK national air quality objectives are based upon measurements carried out using the European transfer reference sampler, or equivalent gravimetric sampler. However the most widely used particulate monitoring method used in the UK is the Tapered Element Oscillating Microbalance (TEOM). Due to the elevated operating temperature of the TEOM, the instrument can lose semi-volatile material and thus under-estimate concentrations. A recommended correction factor of 1.3 is conventionally applied to TEOM based data to convert it into gravimetric equivalent to compare against the air quality objectives[4].

However, recent field research commissioned by Defra has shown that the data from TEOMs do not meet the EU PM_{10} reference method, even with this correction factor, although other types of monitoring equipment such as the Beta Attenuation Monitor (BAM) and the Filter Dynamics Measurement System (FDMS) do meet the equivalence tests[5]. This has significant implications into the way local authorities monitor and report PM_{10} concentrations in the future and it may mean a change in measurement technique or use of a new correction factor.

Until Defra publish their recommendations on future guidelines, TfL has presented TEOM data corrected by 1.3 in this section and in Section 10, and this is given the term 'gravimetric equivalent'. Note that for this report only PM_{10} data from TEOMs is presented. Further consideration in the use of FDMS as a method to measure particulates is given in Section 9.

Figure 8.1 shows rolling annual averages of daily PM_{10} concentrations. It can be seen that average concentrations at roadside site groups are higher than at background sites, reflecting closer proximity to traffic at these sites. However, the concentrations tend to follow the same trend across the sites and show little overall decline over the last six years. As this graph shows rolling annual averages, the slight increase shown around October 2003-January 2004 was due to the increased levels of pollution during the hot summer of 2003.

In Defra's recent revision of the UK Air Quality Strategy, the tighter annual mean objective of 23 µg m^{-3} was dropped from the regulations, keeping the original objective of 40 µg m^{-3}. Figure 8.1 demonstrates that when concentrations are averaged over many sites, they collectively meet this objective.

Figure 8.1 Running annual means of daily PM_{10} concentrations (gravimetric equivalent).

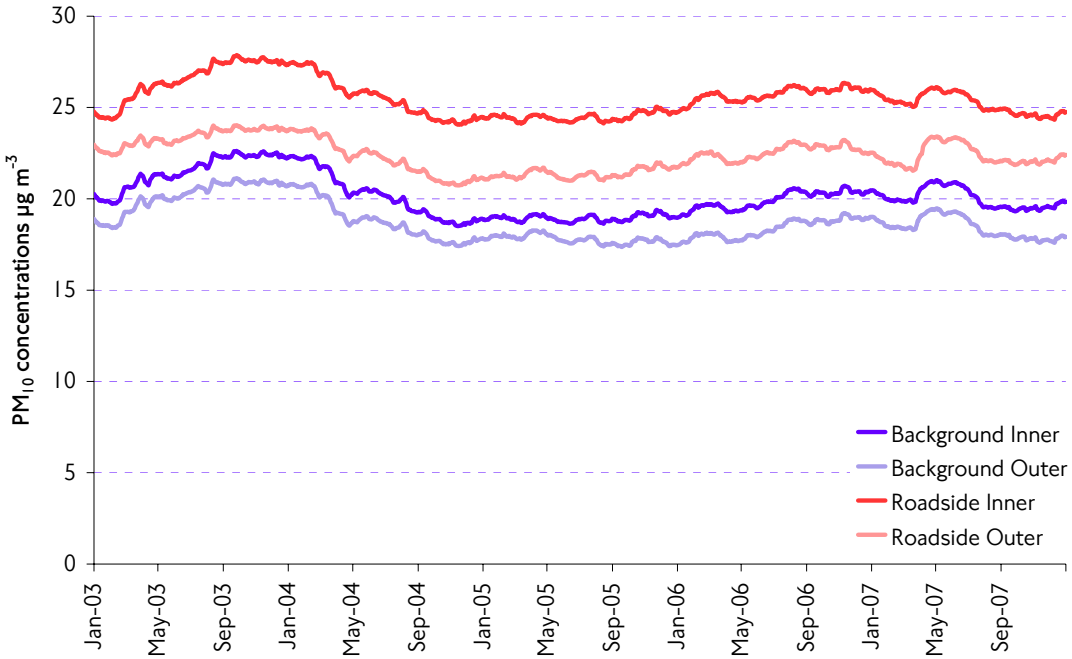


Figure 8.2 Daily mean PM_{10} concentrations and running annual means at two selected sites (gravimetric equivalent).

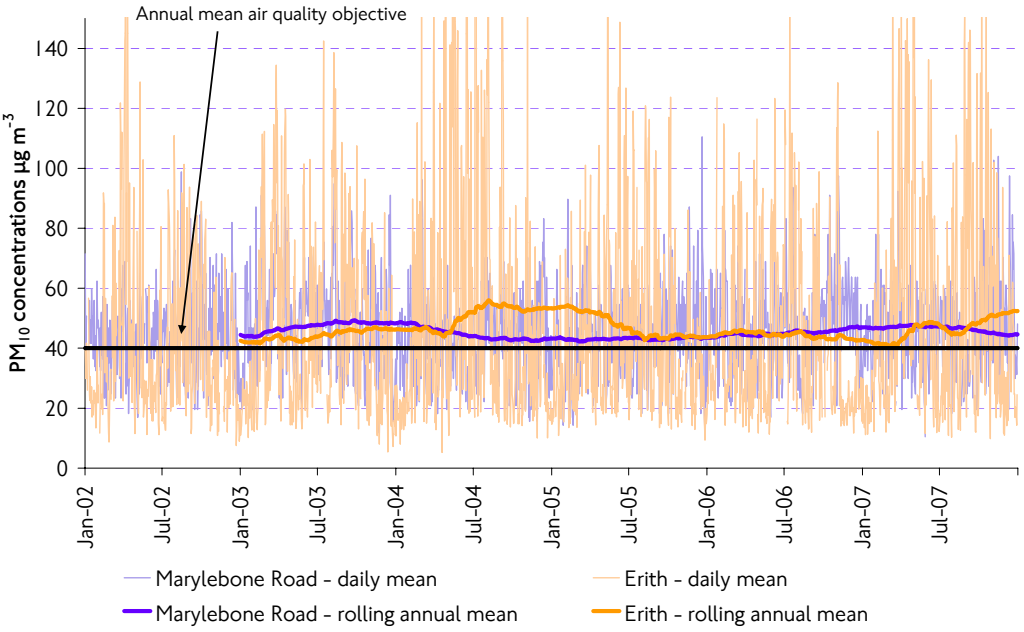


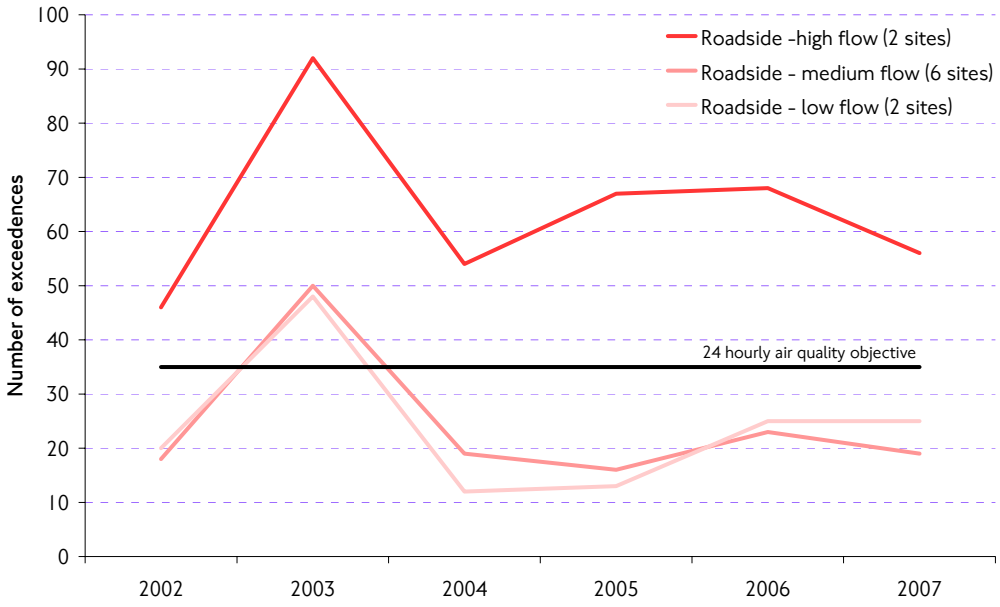
Figure 8.1 masks the large variation in pollution levels across London, but Figure 8.2 illustrates this variability at two sites, one a busy roadside site in central London (Marylebone Road) and one in outer London close to a waste transfer station. The

graph clearly shows that daily mean concentrations vary immensely at these sites and the annual mean concentrations exceed the UK national objective at both. The scheme should therefore provide disproportionate benefits to some of these most polluted sites, such as Marylebone Road, but would be expected to have much less influence on sites where high PM_{10} is mainly from local industrial sources.

8.6 Baseline 2: Exceedences of the daily mean PM_{10} objective

There is also a daily average PM_{10} objective of 50 µg m^{-3} that is set in air quality Regulations. This should not be exceeded more than 35 times in a calendar year. Figure 8.3 shows the numbers of exceedences of this objective each year at the aggregated roadside monitoring sites. The data presented has been further divided into roads with different volumes of heavy duty vehicles to further investigate the trends. Figure 8.3 shows that only those sites designated as being on high flow roads exceed the objective every year. 2003 was a particularly poor year for air pollution, and exceedences at all types of roadside sites were seen.

Figure 8.3 Exceedences of the daily mean PM_{10} objective at inner London roadside sites.

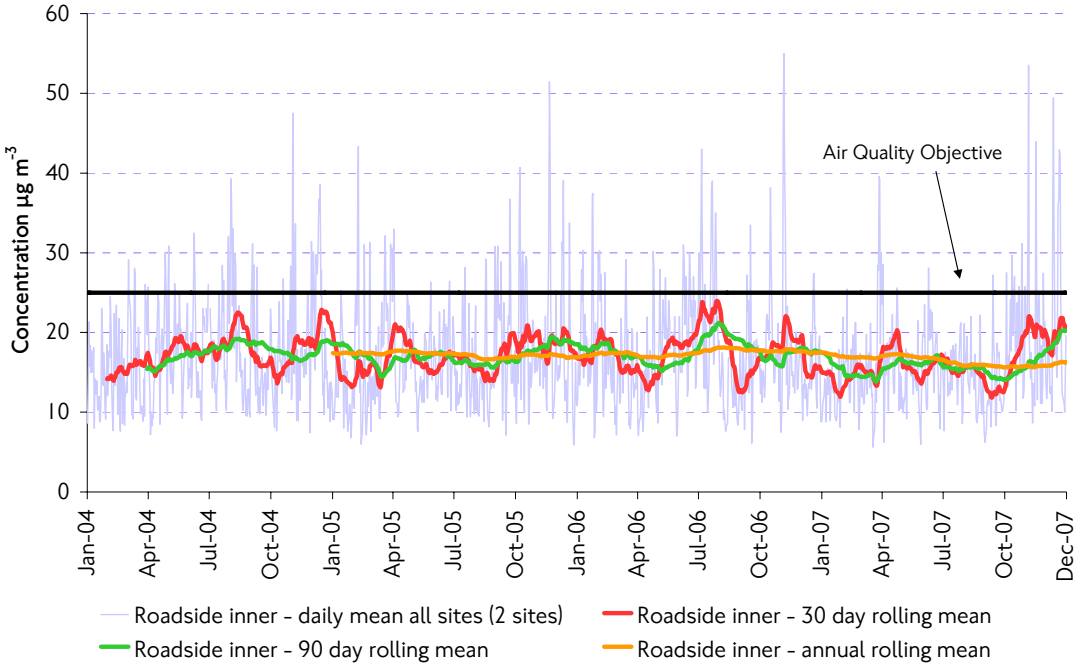


8.7 Baseline 3: Running annual average $PM_{2.5}$ concentrations

The recent revision of Defra's Air Quality Strategy included an annual average target objective for $PM_{2.5}$ of 25 µg m^{-3} to be met by 2020. Figure 8.4 shows the daily mean $PM_{2.5}$ concentrations as well as rolling averages over various time periods. The orange line shows that although the daily means vary substantially, annual average concentrations are already well below the target level. The analysis shows that there has been a downward trend in the concentration of $PM_{2.5}$ at inner roadside locations, in contrast to the trend in PM_{10}, which has slightly increased. In contrast, concentrations of $PM_{2.5}$ at inner background sites are slowly increasing.

This analysis illustrates the importance of considering individual components of particulate matter separately in traffic-related air quality studies.

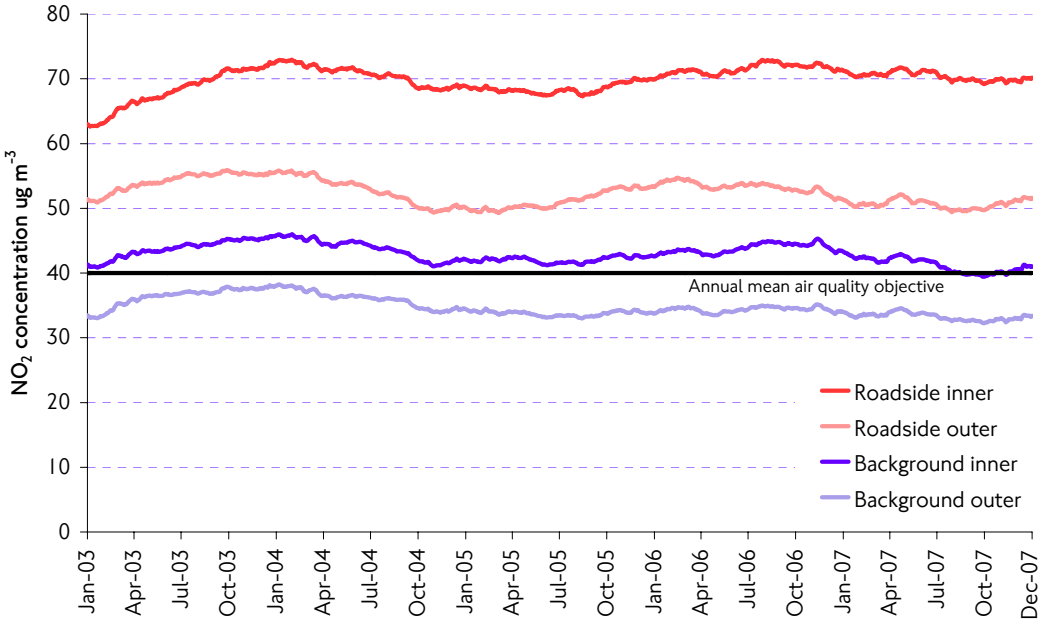
Figure 8.4 Running means of $PM_{2.5}$ daily concentrations, roadside sites.



8.8 Baseline 4: Running annual average NO_2 concentrations

Figure 8.5 shows that over all six years considered, annual average NO_2 concentrations exceeded the UK national objective of 40 µg m^{-3} across all site types, except at the background sites in outer London, which are just below the objective. Concentrations at roadside sites in inner London are noticeably higher than outer London, by over 10 µg m^{-3} and are at least 20 µg m^{-3} above the objective.

Figure 8.5 Running annual means of daily NO_2 concentrations, all site types.

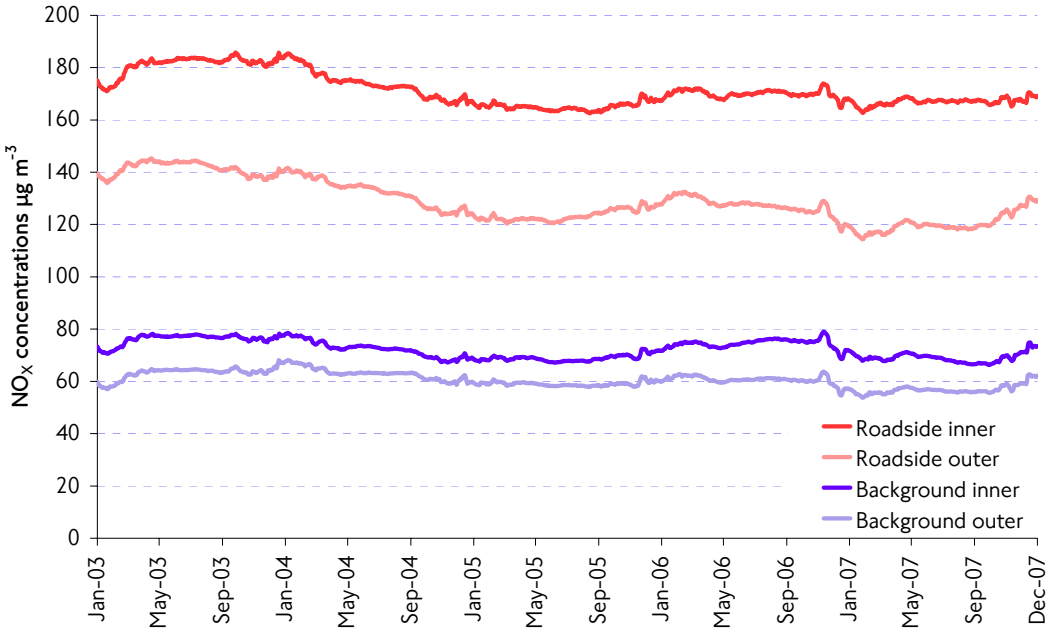


NO_2 concentrations at the inner roadside locations have actually increased over this time period, whereas background concentrations have remained almost stable. This increase suggests an increase in emissions sources at these roadsides. This evidence corroborates findings from research that has shown that the amount of direct NO_2 emitted from diesel vehicle exhausts and those vehicles fitted with abatement technology has been increasing [2].

8.9 Baseline 5: Running annual average NO_X concentrations

Figure 8.6 shows that in contrast to the increasing levels of NO_2 at many roadside sites, NO_X has decreased over this time period, particularly at the roadside sites.

Figure 8.6 Running annual means of NO_X concentrations, all site types.



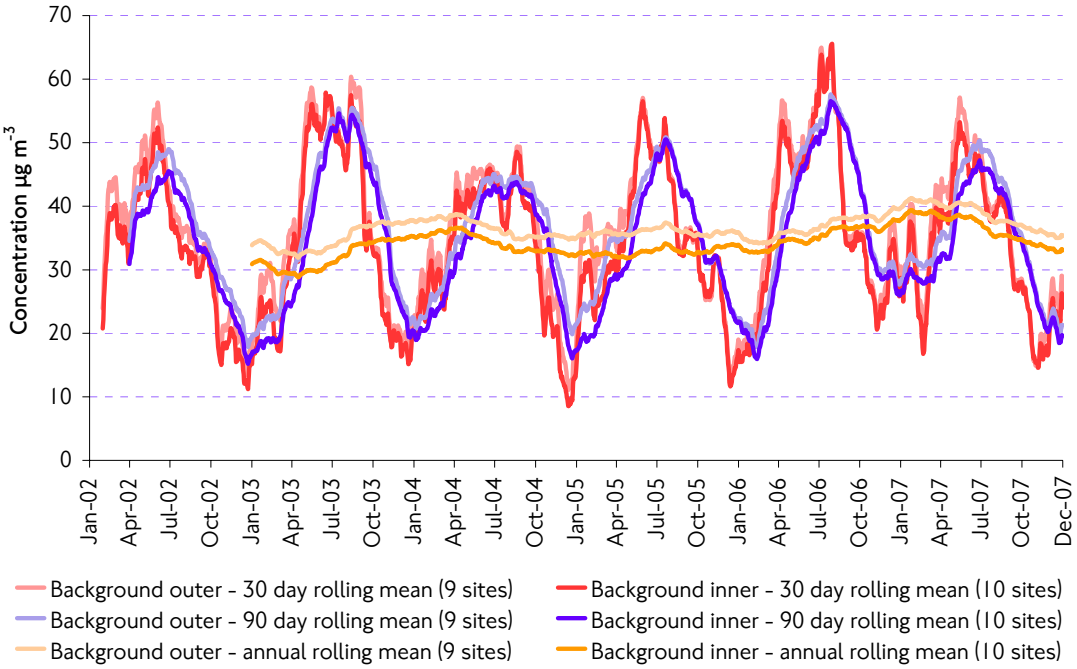
8.10 Baseline 6: Ozone concentrations

Ozone is quickly depleted close to sources of NO due to chemical reactions that form secondary NO_2 concentrations. This means that concentrations are typically lower close to roads with high traffic flow and for this reason, O_3 measurements are more commonly made at background and rural sites, rather than at roadsides.

Figure 8.7 provides data on rolling means at background sites in inner and outer London. It can be seen that concentrations in outer London are slightly higher than those measured in inner London and the annual trend shows a slight increase until early 2007, when there was a slight decline in concentrations.

O_3 concentrations show distinct seasonal patterns, as they are typically higher during the hotter summer months, as sunlight is one of the key components of the atmospheric chemistry involved.

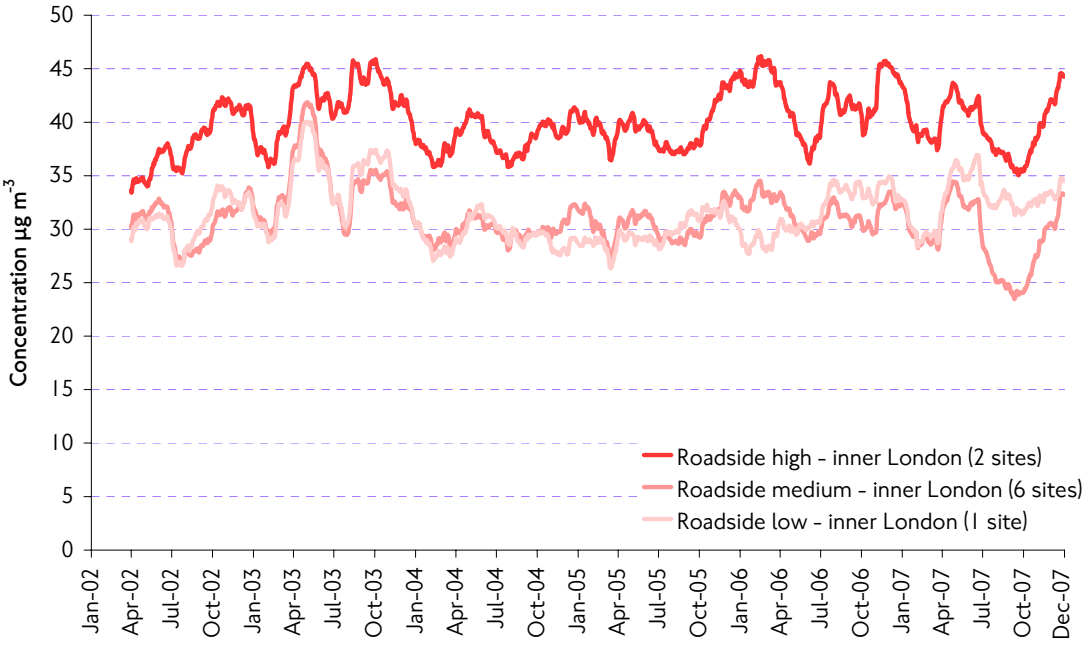
Figure 8.7 Running means of daily O_3 concentrations, background sites.



8.11 Detailed analysis of roadside sites

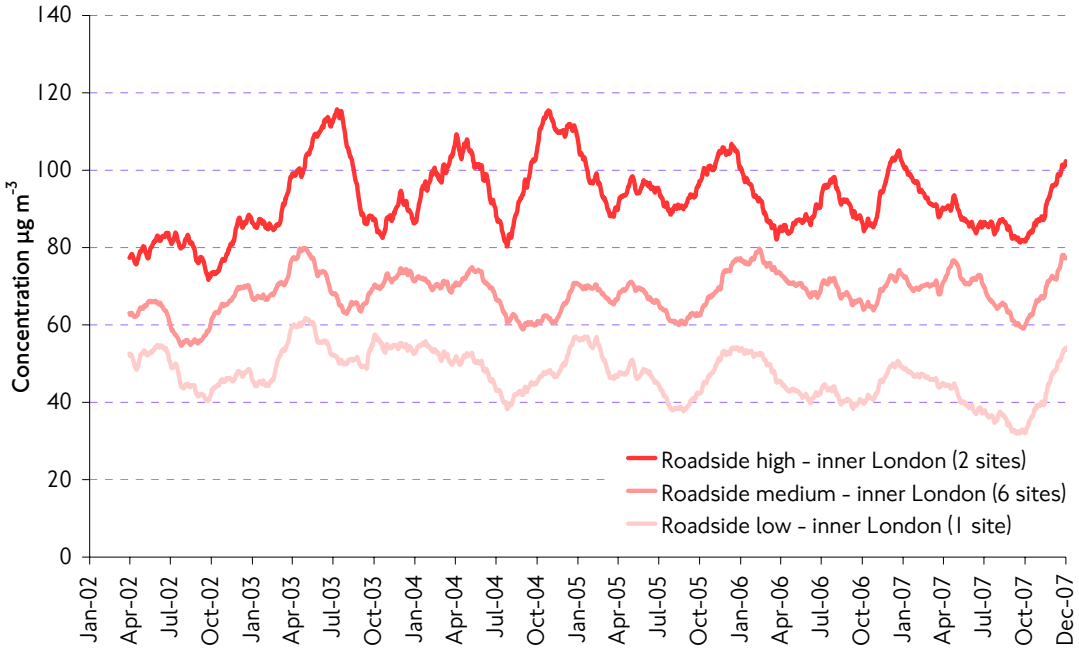
To be able to look in more detail at the PM_{10} and NO_2 concentrations at roadside monitoring sites, these sites were further divided according to the traffic flow of heavier diesel vehicles (ie HGVs, buses and coaches). This was done in the same manner as for the camera sample, described in Section 5.

Figure 8.8 Rolling 90 day mean PM_{10} concentrations, roadside sites.



As seen in Figures 8.8 and 8.9, the roads with the highest flow of heavier vehicles have the highest concentrations, typically 10 µg m^{-3} higher for PM_{10} and up to 20 µg m^{-3} higher for NO_2. However, as all site types follow a comparable pattern over the six measurement years, background pollution still makes a large contribution to the overall measured concentration.

Figure 8.9 Rolling 90 day NO_2 concentrations, roadside sites.



8.12 Summary

This section describes TfL's approach to assessing measured air quality data for trends that reflect the impacts of the London Low Emission Zone scheme. It sets out a comprehensive time-series of air quality trend data describing conditions in the years before the scheme was introduced.

The data shows that pollution concentrations of particulate species and NO_2 are higher at roadside sites, reflecting the fact that traffic emissions are the main source of these pollutants. In contrast, concentrations of ozone are higher at outer London background sites, due to chemical reactions that occur at roadside sites. It is clear that NO_2 concentrations widely exceed the annual average objective but that when averaged over all available sites in London, annual average PM_{10} is below the objective. Such averaging is highly misleading, however, as many locations, particularly close to busy roads, do exceed the PM_{10} objective, and it is precisely in these locations that the scheme would deliver most benefit.

This analysis will continue over the life cycle of the scheme, ideally at the same monitoring sites in order to provide a consistent assessment. The results will be used alongside findings from the other analytical techniques in the wider monitoring programme to help identify effects on air quality that are attributable to the scheme. Future analysis will need to take into account any changes in regulations or guidance on the use of measurement methods, in particular in the context of PM_{10}.

9. Air quality trends and interrelationships at the local scale

9.1 Introduction

The previous section considered trends in air quality at the London-wide scale. This level of analysis is appropriate for obtaining the most robust view of background trends and longer-term scheme effects at the London-wide level in relation to national air quality objectives, and for comparison with the results of the emissions and air quality model assessments described earlier. It is less appropriate for several other key objectives of the monitoring work. These include assessing scheme impacts over the shorter term, as well as several more fundamental 'research' issues, important to the wider monitoring work, that are best approached at the local (ie site-specific) scale.

This section describes how TfL is using a small number of specifically-enhanced air quality monitoring sites to explore these issues. With reference to selected examples of the types of analysis that will be possible, it demonstrates how these 'enhanced air quality monitoring sites' will help inform TfL's understanding of the factors determining local air quality change and scheme impacts going forward. Findings from these sites will be particularly useful in the event that external factors such as the weather obscure the expression of scheme impacts in the aggregate air quality trends (see also Sections 3.7 and 3.8).

9.2 Approach

Focusing on air quality change at the local level means that it is economically feasible to co-locate measurements of all key quantities of interest at a limited number of sites. This allows inter-relationships between key variables to be explored in detail, and in the context of a fixed set of local environmental determinants that would otherwise fundamentally influence the nature of the air quality measurements from each individual site. The key quantities in this context are:

- the full range of pollutants of interest (NO_X, NO_2, O_3, PM_{10}, $PM_{2.5}$ – and others as locally appropriate);
- comprehensive traffic volume and composition data (manual and continuous automatic traffic counts, camera based Euro Class profiling);
- local meteorological data.

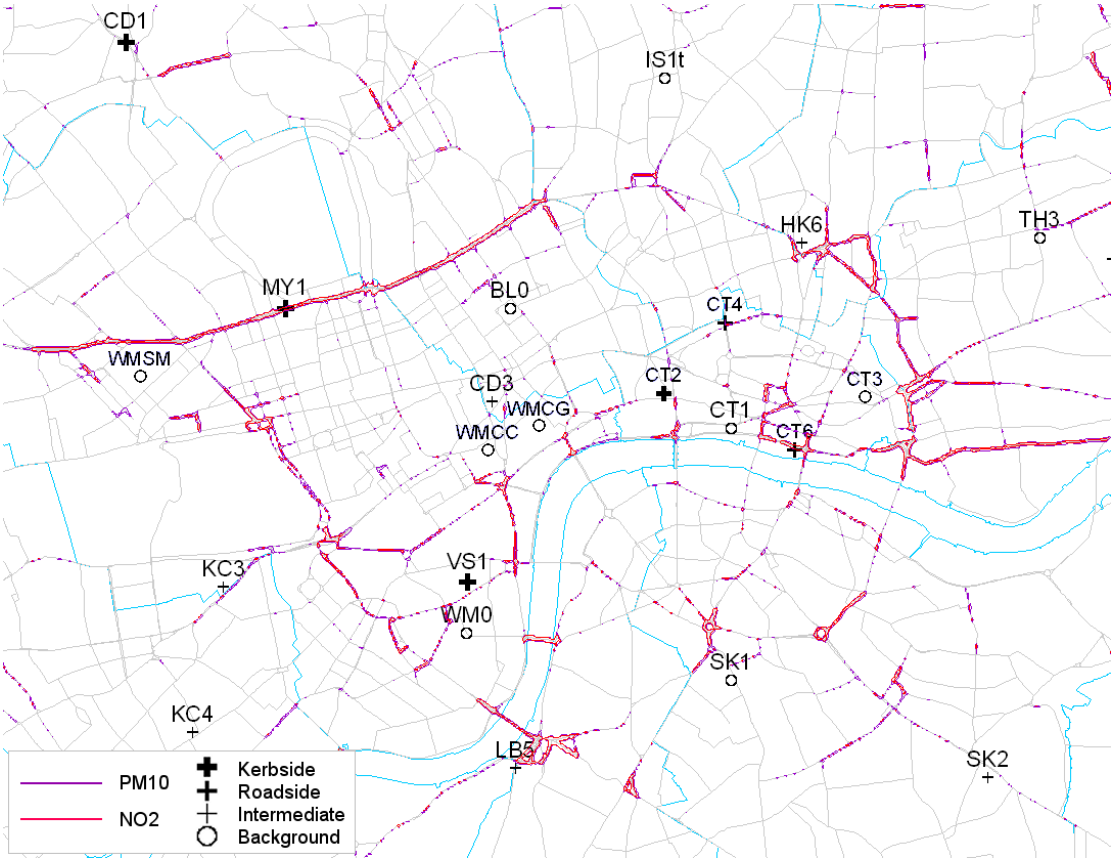
The site-specific determinants include proximity to roads, local building topology, predominant wind direction, the contribution of 'background' sources to local pollution levels and, in the case of PM_{10}, the composition and chemistry of the local particulate matter. All of these will affect, to some extent, the expression and probability of detection of scheme impacts.

9.3 Criteria for site selection

To maximise the insight gained from these sites, it is most appropriate to choose sites that are located close to busy roads, as this is where a change in air quality from the scheme would be most readily detectable. Furthermore, it is advantageous to

build on the facilities already existing at established sites, as these will usually provide an existing longer-term trend for at least some of the pollutants of interest. These basic selection criteria were further refined by reference to maps showing projected changes to local concentrations of key pollutants that are expected to arise from the scheme. These highlight roads on which the 'change signal' from the scheme is projected to be of the greatest magnitude, ie those carrying particularly high volumes of goods vehicles. Figure 9.1 shows an example of this approach for Central London, displaying the road network, projected concentration change gradients and existing monitoring sites.

Figure 9.1 Map of central London showing roads projected to experience the highest magnitude of air quality change from the Low Emission Zone scheme.



Note: NO_2 difference contours are coloured in red, PM_{10} difference contours in purple. The 2002 road network is coloured in grey and the London borough boundaries in light blue.

The result of this exercise was that six existing air quality monitoring sites lying within the 'high change' contour were selected for enhancement. Additionally, the maps projected a particularly high 'change signal' along the axis of the A12 road (Blackwall Tunnel Northern Approach) in east London – a route on which there were no existing air quality monitoring sites. It was therefore advantageous to establish an entirely new monitoring site here – in collaboration with the London Borough of Tower Hamlets. The resulting seven 'enhanced air quality monitoring sites' are:

- **Marylebone Road** (MY1). A Defra-operated kerbside site belonging to the national AURN (Automatic Urban and Rural) Network in central London (London Air

Quality Network (LAQN) affiliated). This was established in 1997 and is the most comprehensively-equipped monitoring site in London.

- **Brent** (BT4). A borough-owned monitoring site affiliated to the London Air Quality Network on a busy part of the A406 North Circular Road. This site was established in 2003.
- **Hackney** (HK6). A well established (since 2000) borough-owned London Air Quality Network site within inner/central London near to the Old Street roundabout.
- **Greenwich** (GR8). A London Air Quality Network roadside monitoring site located on a roundabout beneath the Woolwich flyover and established in 2004.
- **Greenwich** (GR9). A London Air Quality Network roadside monitoring site, established in 2004 near to the A2 Rochester Way.
- **Bexley** (BX7). A 2004 established London Air Quality Network site on the A206 near the Greater London boundary.
- **Tower Hamlets** (TH4). A newly established TfL-owned London Air Quality Network site (2006) adjacent to the A12 Blackwall Tunnel Northern Approach road.

At this stage it is important to note the following key points in relation to these sites:

- Although the sites are deliberately located in locations that projections suggest would experience the largest magnitude of air quality change from the scheme, their primary function is not to 'detect' a scheme impact, as such. Rather, it is to maximise the insights gained from the study of inter-relationships by examining them in a context where they are likely to be most clearly visible.
- The sites do not constitute a representative sample of air quality in London, or representative selection of existing air quality outdoor monitoring sites. This means that findings from specific sites cannot automatically be generalised to the London-wide scale. A specific example is the exclusion of sites measuring 'background' air quality – although these are amply represented in the regional-scale analysis.
- The enhanced sites are part of the London Air Quality Network and measurements from them will be processed and published through normal LAQN channels[1]. Measurements from each site are ratified to recognised Quality Assurance/Quality Control standards, and equipment at the sites is also subject to independent UK Accreditation Service audits. These processes are the same as those used on the UK national monitoring networks.

9.4 Characteristics of the enhanced monitoring sites

Table 9.1 provides a summary of the pollutants measured at each of the enhanced sites, including details of the method used. All sites were fully operational from late 2006, giving at least one clear calendar year in advance of the implementation of the scheme for pre-scheme data to be collected, although many have longer-term datasets for at least some pollutants.

Table 9.1 Pollutants measured at enhanced air quality monitoring sites.

Site code	Site name, borough and location	Parameters monitored
MY1	Marylebone Road, Westminster, Central London	TEOM PM_{10}, FDMS PM_{10}, $PM_{2.5}$, P_{NUM}, BC, NO_X, O_3, Hydrocarbons, meteorology
HK6	Old Street, Hackney, Central London	TEOM PM_{10}, NO_X, O_3, $PM_{2.5}$
BX7	A206 Cray, Bexley, East London	FDMS PM_{10}, $PM_{2.5}$, NO_X, O_3, meteorology
GR8	Westhorne Avenue (A2 / South Circular Interchange), Greenwich, South East London	FDMS PM_{10}, $PM_{2.5}$, NO_X, O_3, meteorology
GR9	Woolwich Flyover (A2), Greenwich, South East London	TEOM PM_{10}, $PM_{2.5}$, NO_X, O_3
BT4	North Circular (Ikea), Brent, North West London	TEOM PM_{10}, $PM_{2.5}$, NO_X, O_3, P_{NUM}, BC, meteorology
TH4	Blackwall Tunnel Northern Approach, Tower Hamlets, East London	FDMS PM_{10}, $PM_{2.5}$, P_{NUM}, BC, NO_X, O_3, meteorology

Note: all sites also have continuous automatic traffic counters, periodic manual classified traffic counts and automatic number plate recognition camera sampling of Euro Class profiles.

9.5 Guide to pollutants measured

The following provides a brief explanation of the key parameters measured at the enhanced sites.

PM_{10} and $PM_{2.5}$ as a mass concentration

The pollutant most directly targeted by the scheme is particulate matter, most commonly expressed as PM_{10} in terms of a mass concentration. Particulate matter is a highly variable assemblage of suspended solids and liquids, spanning a wide size range. The PM_{10} measurement refers specifically to the mass of suspended particles with an aerodynamic diameter of less than ten microns (μm). Other measurements are also used for particulate matter, most notably $PM_{2.5}$, which refers specifically to smaller particles of less than 2.5 microns in diameter (ie $PM_{2.5}$ is a subset of PM_{10}). There are corresponding national air quality objectives for PM_{10} and $PM_{2.5}$.

Particle number (P_{num})

It is also possible to measure the size range and the numbers (as opposed to mass) of particles. The particulate present at different sites is influenced by specific sources – and understanding these relationships can assist understanding of the diversity of factors affecting each specific site. For example, a variable but usually significant proportion of PM_{10} recorded at roadside sites is from background sources that will be unaffected by the scheme. If this 'background' component is largely composed of larger particles, for instance, then any changes to it could have a disproportionate impact on the PM mass-based measurements.

Black carbon (black smoke)

Black smoke monitoring as an air quality indicator is now rare in the UK. The only operational roadside/kerbside black smoke analyser in London is at Marylebone Road. However, many health studies, particularly in the United States, have utilised black smoke measurements as a health-relevant indicator of diesel emissions. The aethalometer, a continuous black carbon analyser, has been shown to produce measurements that are analogous to traditional black smoke analysers[2]. This presents an opportunity for this indicator to be re-established, for use in the health-related work described in Section 11, and aethalometer instruments have now been installed at three of the enhanced monitoring sites.

Nitrogen oxides (NO_X) and ozone (O_3)

NO_X and NO_2 are also key pollutants in relation to the scheme, and conventional chemiluminescent analysers are provided at all sites. The relationship between NO_X and NO_2 is of particular interest, reflecting recent observations of an increase in direct emissions of NO_2 from diesel vehicles, and the possible implications for the impacts of the scheme. Because levels of available ozone in the vicinity of the air quality site have an important role in this relationship, co-located O_3 measurements at these sites should allow detailed examination of changes in NO_X/NO_2 levels, and their relationship to causative factors.

Meteorology

Local wind patterns and other meteorological variables will have a great effect on the intensity and nature of pollution arriving at a monitoring site. Most of the enhanced monitoring sites are provided with a full array of meteorological monitoring equipment to include; wind speed and direction, ambient temperature and pressure and relative humidity.

9.6 Traffic flow monitoring at enhanced monitoring sites

A key feature of the enhanced air quality monitoring sites is detailed, co-located monitoring of traffic flows adjacent to the site. This is essential so that the levels, mix and changes to pollutants observed at the sites, can be related to changes to traffic arising from the scheme, as well as traffic trends more generally. Perhaps surprisingly, few established roadside sites in London benefit from these arrangements, and enhanced monitoring sites open up several new possibilities for better understanding the relationship between traffic and local pollution. For scheme monitoring purposes, four key traffic parameters are of interest:

- **Traffic volumes:** the numbers of vehicles passing the site.
- **Traffic mix:** the make-up of traffic – in terms of vehicle types.
- **Euro Class profile:** the Euro Class (emissions) profile of vehicles potentially affected by the scheme.
- **Traffic speed:** at the point adjacent to the site.

Three complementary methods of traffic monitoring are provided at each site:

- **Permanent (loop-based) automatic traffic counter.** This is an established method using inductive loops buried in the carriageway. All-lane coverage is provided at the nearest feasible location on the carriageway adjacent to the monitoring site. All vehicles with four or more wheels are recorded, on a continuous time-stamped basis. Counters can be set to provide a level of vehicle type resolution that approximates to those that are affected by the scheme, and to give an estimate of individual vehicle speed at the point where it activates the counter. This method therefore primarily provides continuous, disaggregate traffic volume information.
- **Periodic manual classified count.** This is also an established method, involving periodic counting, usually on one day per year, by human observers. Passing vehicles are visually classified by main body type and enumerated separately by category. This method primarily provides a cross-check on automatic traffic count vehicle classification and also longer-term traffic trend/composition information.
- **Automatic number plate recognition camera based Euro Class emissions classification.** At each enhanced site traffic on one lane (only) is monitored continuously by automatic number plate recognition camera. This uses the same methods as described in Section 5 and is designed to provide information on the Euro Class mix of vehicles passing the site – on a sample basis. This method primarily provides Euro Class profiles from which emissions can be estimated.

Used in combination, these data should facilitate the detailed and innovative exploration of the relationships between observed pollution and observed traffic change, in the context of the developments expected to result from the scheme.

9.7 Enhanced sites in the context of wider air quality monitoring in London

Data from the seven enhanced sites will be analysed in the context of data from the wider London Air Quality Network, numbering approximately 100 sites across London. It is not expected that the two types of site would give a fundamentally different picture of scheme impacts or wider prevailing trends, although the enhanced sites are deliberately placed to reflect heavily-trafficked locations and will therefore, to some extent, be atypical.

Figures 9.2 and 9.3 characterise the enhanced monitoring sites in terms of typical traffic flows and typical measured pollution levels in relation to other locations across London. Not surprisingly, the enhanced sites are characterised by relatively high flows of vehicles affected by the scheme (Figure 9.2). The locations with the very highest flows (extreme right of the graphics) tend to be motorway sites and other high-flow roads in locations where there is no established air quality monitoring.

Figure 9.2 Distribution of flow density of heavy goods vehicles and relative position of enhanced monitoring sites (LAQN site identification codes).

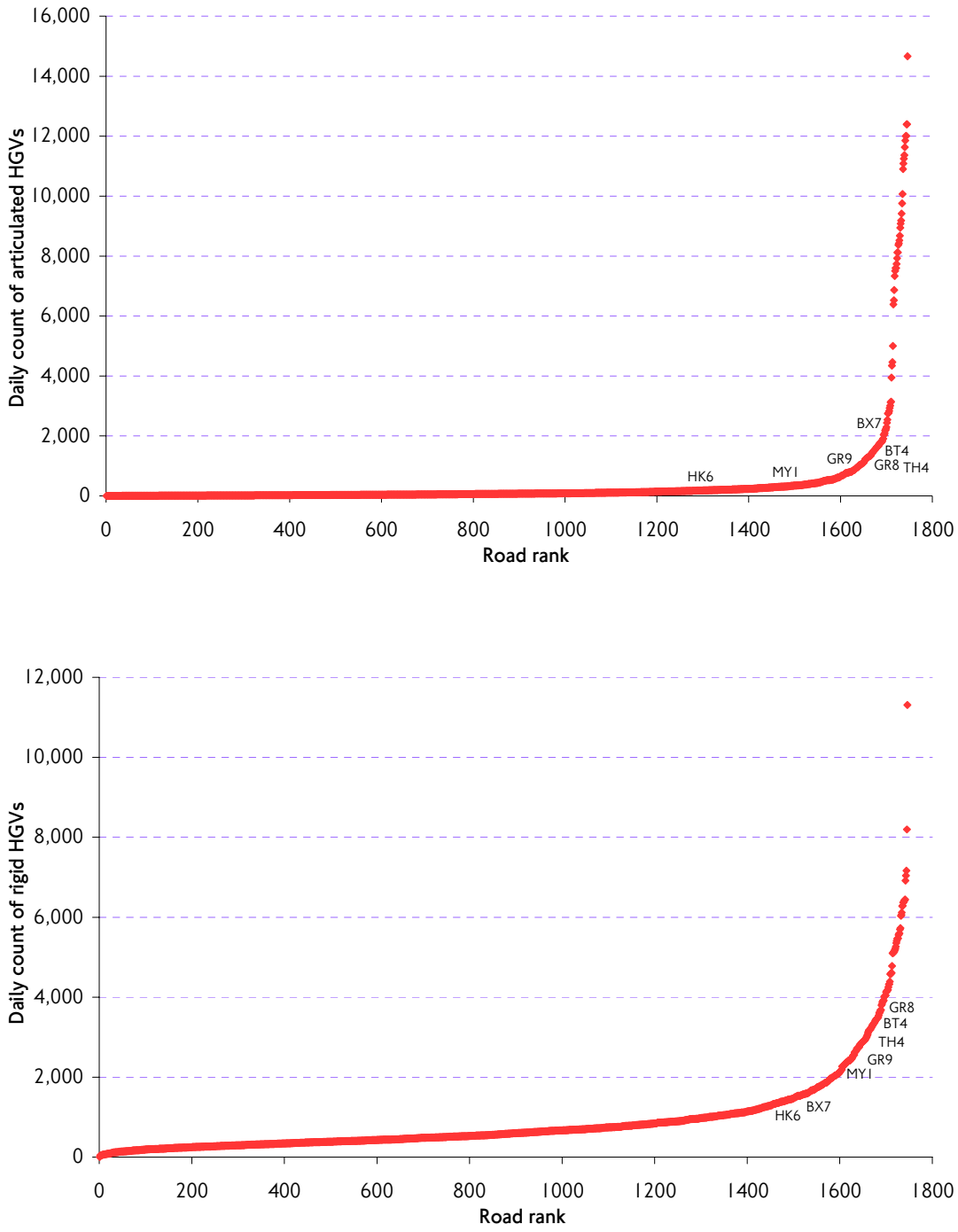
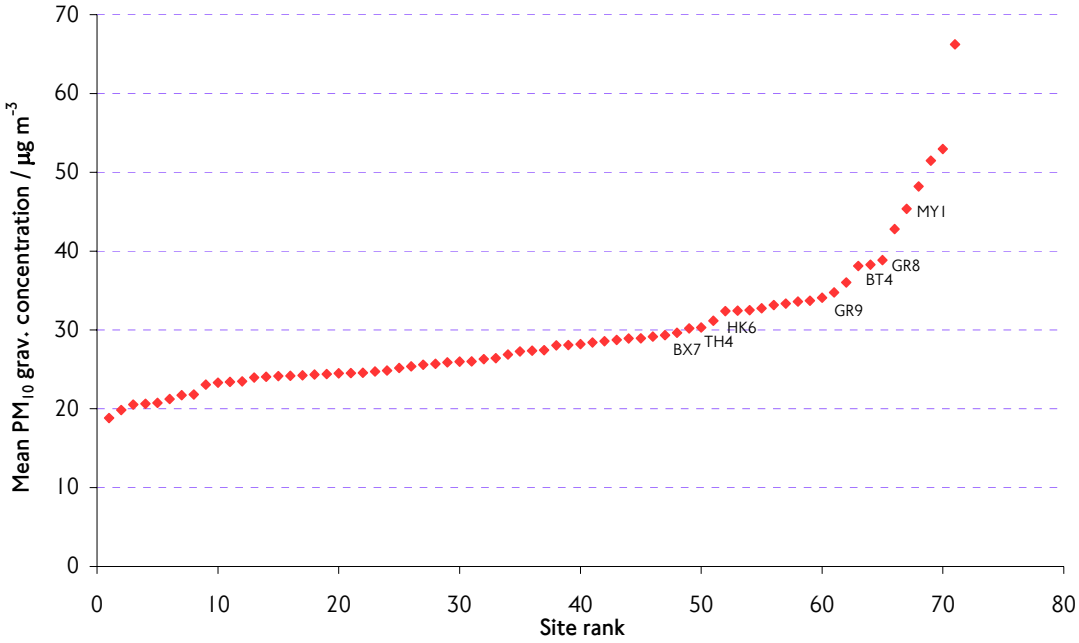
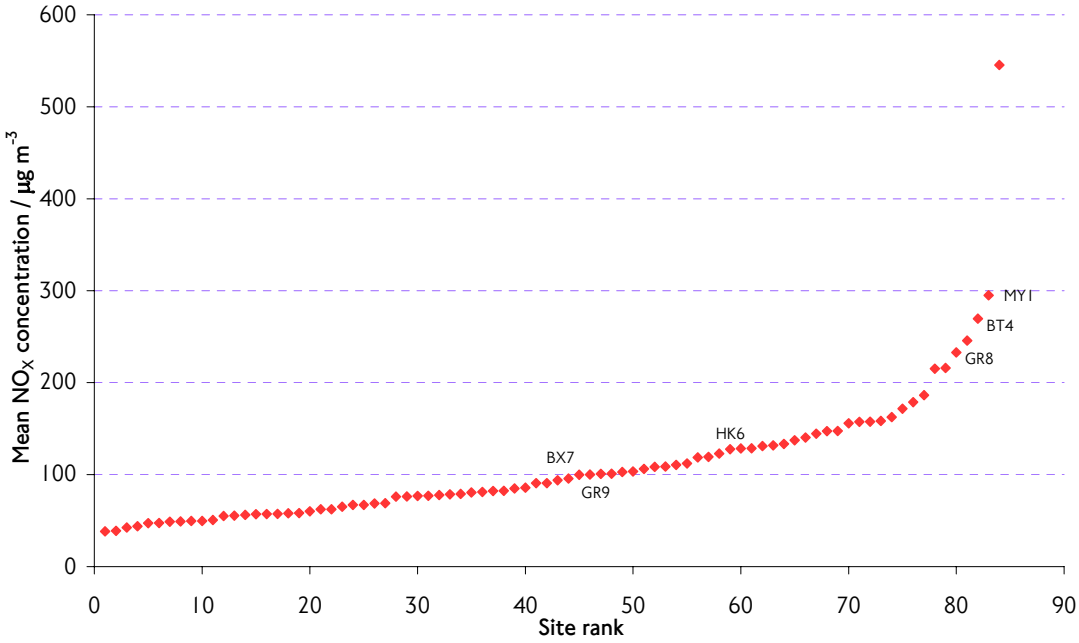


Figure 9.3 similarly ranks the enhanced sites in terms of indicative typical pollution levels measured by established air quality monitoring sites across London. For PM_{10}, most of the enhanced sites lie in the top quartile of PM_{10} concentrations. For NO_X the distribution is more variable – largely reflecting the peculiarities of local traffic composition and site geography.

Figure 9.3 Distribution of typical measured pollution levels at established air quality monitoring sites and relative position of enhanced monitoring sites (LAQN identification codes).





9.8 Exploratory analyses using enhanced air quality monitoring sites

Each of the enhanced monitoring sites is unique – and this property is fundamental to their use in this context. Each site has a unique geographical character and traffic flow and mix. Each will therefore have a unique response to a 'change signal' – such as that initiated by the scheme. A more detailed understanding of the local characteristics affecting air quality at each individual site should therefore allow the scale and nature of this change signal to be identified more clearly.

This approach is complementary to the London-wide scale analysis described in Section 8 in that, while this regional approach is more representative, it is more difficult to account for the impact of local influences or external factors in determining air quality change. These external factors, such as year-to-year variations in the prevailing weather, can fundamentally influence air quality to a degree several times greater than the 'signal' from even a quite significant intervention. It is therefore important to look below the regional scale to understand in more detail how these factors may be affecting wider air quality measurements. New insights gained from these sites into relationships between traffic and local air quality, and between pollutants themselves, will also add to our ability to represent the impacts of air quality initiatives going forward.

9.9 An example enhanced monitoring site: Marylebone Road

This section looks in a little more detail at the characteristics of one particular enhanced air quality monitoring site – Marylebone Road. Equivalent details for the other enhanced sites can be found in **Appendix 6**. Marylebone Road is an established 'flagship' air quality monitoring site located immediately adjacent to the Inner Ring Road surrounding the central London congestion charging zone.

Basic site details and key air quality statistics

Table 9.2 shows basic site details for Marylebone Road, alongside a selection of air quality statistics for 2006, in relation to the national air quality objectives.

Table 9.2 Basic site details and air quality statistics for 2006 at London Marylebone Road air quality monitoring site.

Name: Marylebone Road	**LAQN Code: MY1**
Class: Inner London Kerbside	**Distance to kerb:** 1m to 4m
Address: Marylebone Road, Westminster	**Sample inlet height:** 2.5m
Grid ref: 528120, 182000	
Pollutants monitored:	NO_X, TEOM PM_{10}, FDMS PM_{10}, $PM_{2.5}$, P_{NUM}, Black Carbon (BC), O_3, Hydrocarbons

Key air quality statistics for 2006 – in relation to National Air Quality Strategy

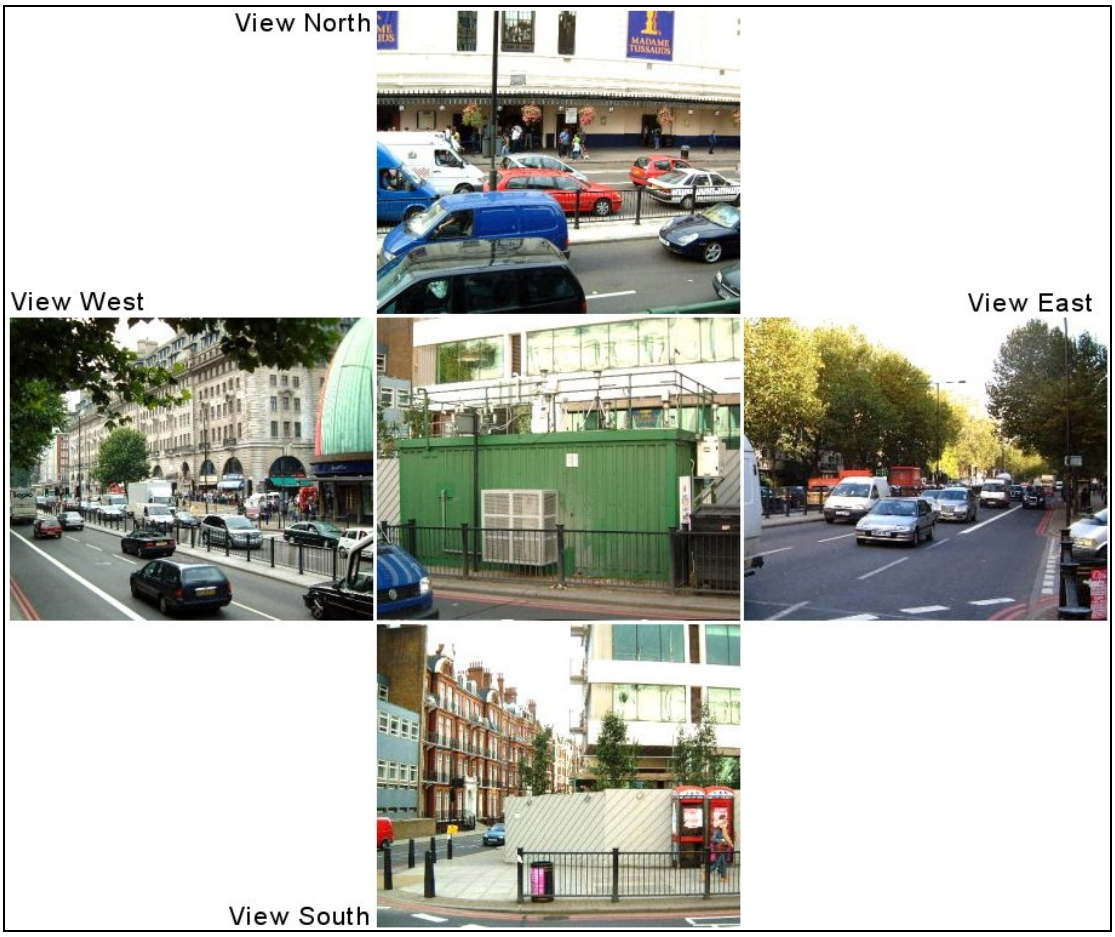
Pollutant	Objective	Result	Achieved?
Nitrogen dioxide	Annual mean not exceeding 40 µg m^{-3}	112 days	No
Nitrogen dioxide	No more than 18 occurrences of hourly mean >200 µg m^{-3}	676 µg m^{-3}	No
PM_{10} particulate	Annual mean less than 40 µg m^{-3} (gravimetric equivalent)	47 µg m^{-3}	No
PM_{10} particulate	No more than 35 days where daily mean >50 µg m^{-3} (gravimetric equivalent)	151 days	No

Geographical characteristics

The Marylebone Road monitoring site is located adjacent to the kerb on the southern side of Marylebone Road, a six-lane trunk route with the kerbside lane in both directions designated as a strictly enforced bus lane (since August 2001). It is within a street canyon approximately 32 metres wide with maximum building heights of approximately 25 metres on either side of the road.

There is a major signalled junction approximately 160 metres to the west (Baker Street) and a pedestrian crossing 60 metres to the west. Photographs of the monitoring cabin and compass point views are shown in Figure 9.4. This is a 'kerbside' monitoring site, with sample inlets placed approximately 1.5 metres from the kerb. Note that the $PM_{2.5}$ monitoring inlet is placed two metres further back from the kerb than the PM_{10} inlet – and direct comparison of these two size fractions should therefore be made with care.

Figure 9.4 '360 degree' photographs of the London Marylebone Road enhanced monitoring site.



Local traffic volumes

Figure 9.5 shows the daily (within week) and diurnal (within day) variation in traffic flow at Marylebone Road – averaged over the first six months of 2007. Automatic traffic counters are used to classify vehicles into their main vehicle body types using a measurement of vehicle length (derived from the time that the vehicle takes to transit the inductive loop). This classification should be regarded as approximate as vehicles with a length of up to 5.2 metres equate to cars, vehicles with a length between 5.2 and 6.3 metres equate to smaller light goods vehicles, and vehicles with a length between 6.3 and 12 metres are equivalent to larger light goods vehicles and smaller buses. Vehicles with a length greater than 12 metres correspond to heavier goods vehicles and larger buses (ie broadly those vehicles that are in-scope for phases 1 and 2 of the scheme).

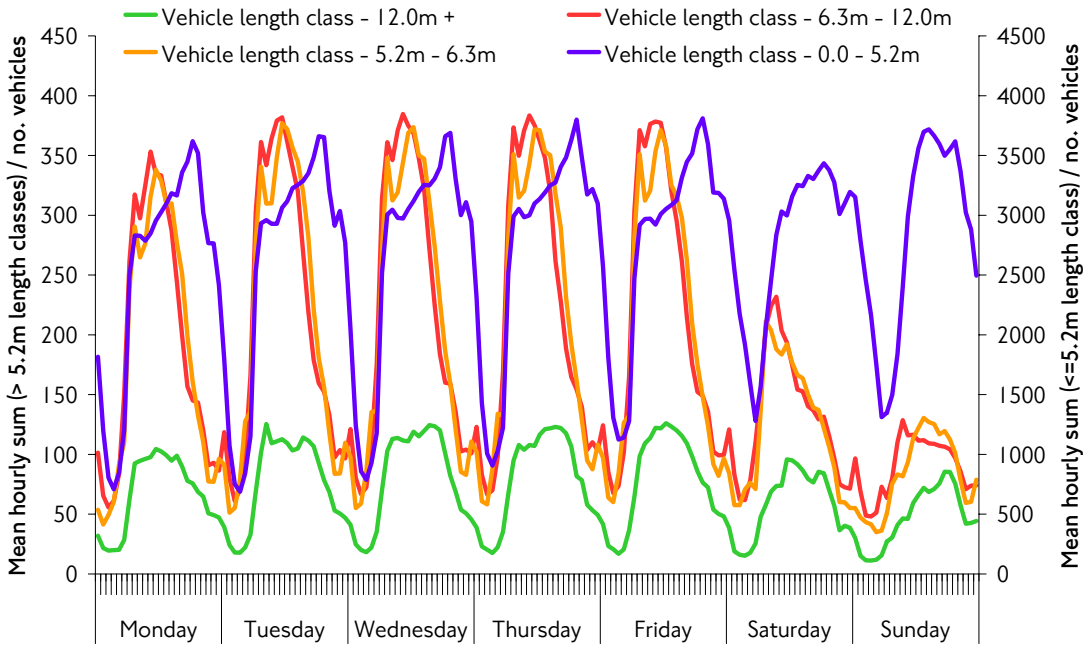
Figure 9.5 shows what might be regarded as a fairly typical daily and diurnal traffic profile for central London, but there is much of interest at the more detailed level. Of particular note are:

- The relative proportions of the various vehicle types (length classes) – with the longest vehicles typically accounting for around 10 percent of the total flow.

- Distinct differences between the traffic profiles for weekdays and the two weekend days at the site, with a particular fall-off in the volumes of vehicles in the intermediate length classes (largely light goods vehicles) at weekends.
- The different shape of the weekday profiles for cars and other vehicles, with the highest volumes for goods vehicles recorded in the early morning, with a rapid fall off in volumes during the middle of the afternoon.

All of these features can potentially be related to pollution data at an equivalent level of disaggregation.

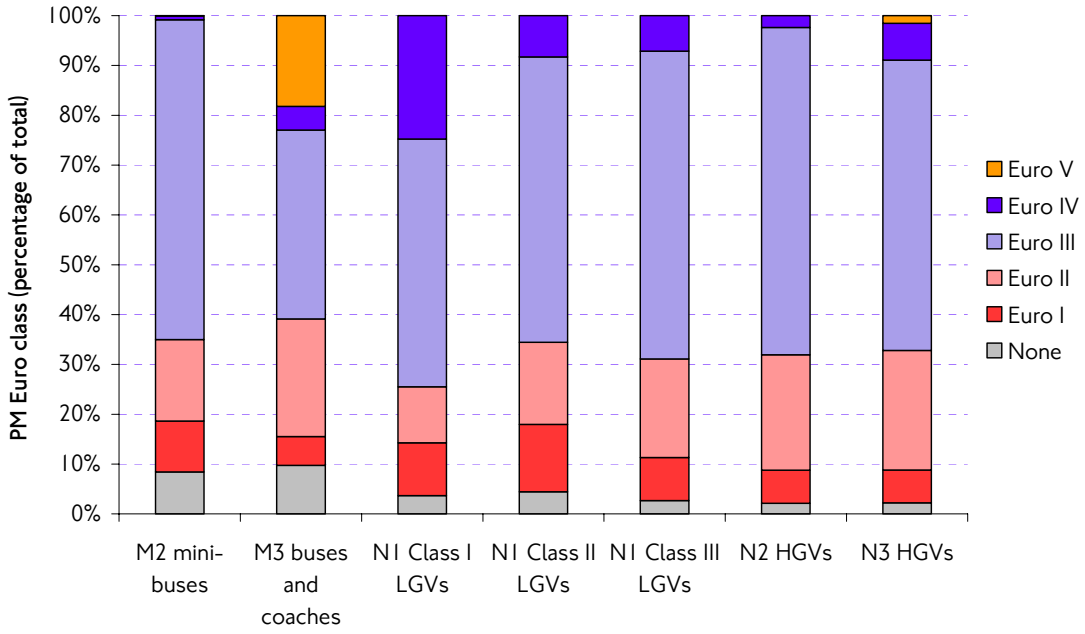
Figure 9.5 Automatic traffic counter summary data at Marylebone Road from January to July 2007 showing weekly diurnal variation by vehicle length class (mean hourly sum, all lanes).



Emissions characteristics of local traffic

Marylebone Road is frequently characterised by large volumes of slow moving traffic, including relatively high proportions of buses and taxis. Figure 9.6 shows the traffic composition at this site, in terms of Euro Class, obtained from the monitoring camera over the period January to July 2007. The figure shows that over this time period, approximately one-third of heavier goods vehicles over 12 tonnes (N3s) passing this site did not meet the phase 1 scheme emissions standard of PM Euro III during this period. This proportion is similar to the London wide estimates discussed in Section 5. Some 40 percent of buses and coaches did not meet the same emissions standard as required for phase 2 of the scheme. This proportion rose to 91 percent for the stricter phase 4 scheme emission standard of PM Euro IV, to be introduced in 2012.

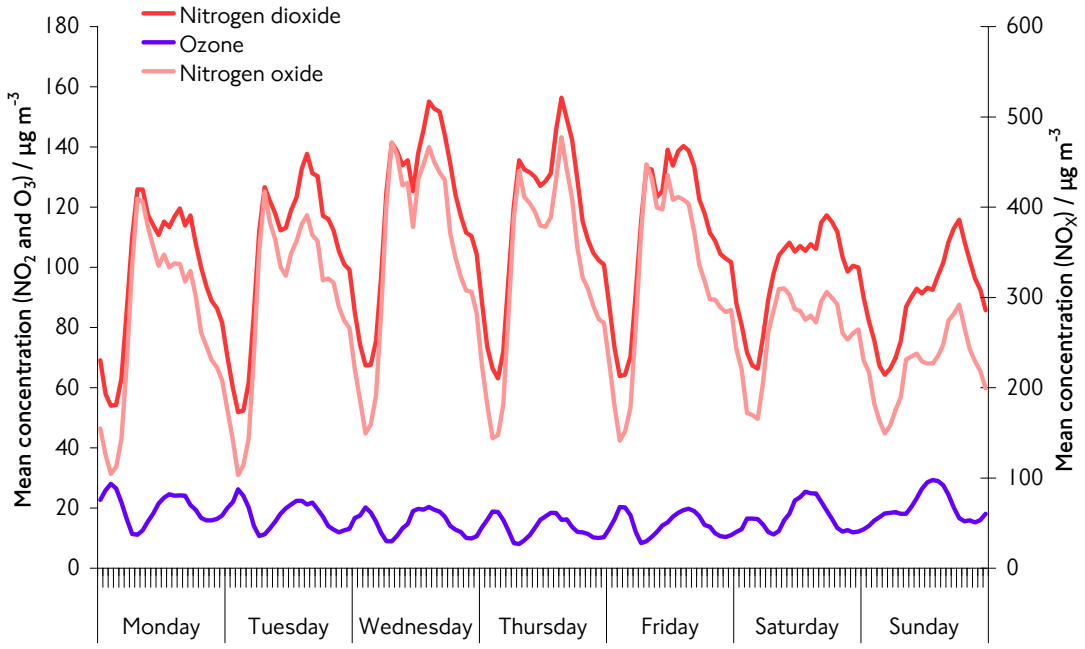
Figure 9.6 Euro Class by vehicle type at Marylebone Road. January to July 2007.



Variation in pollution concentrations

Daily average concentrations of pollutants at this site are shown in Figure 9.7, illustrating daily and hourly variations.

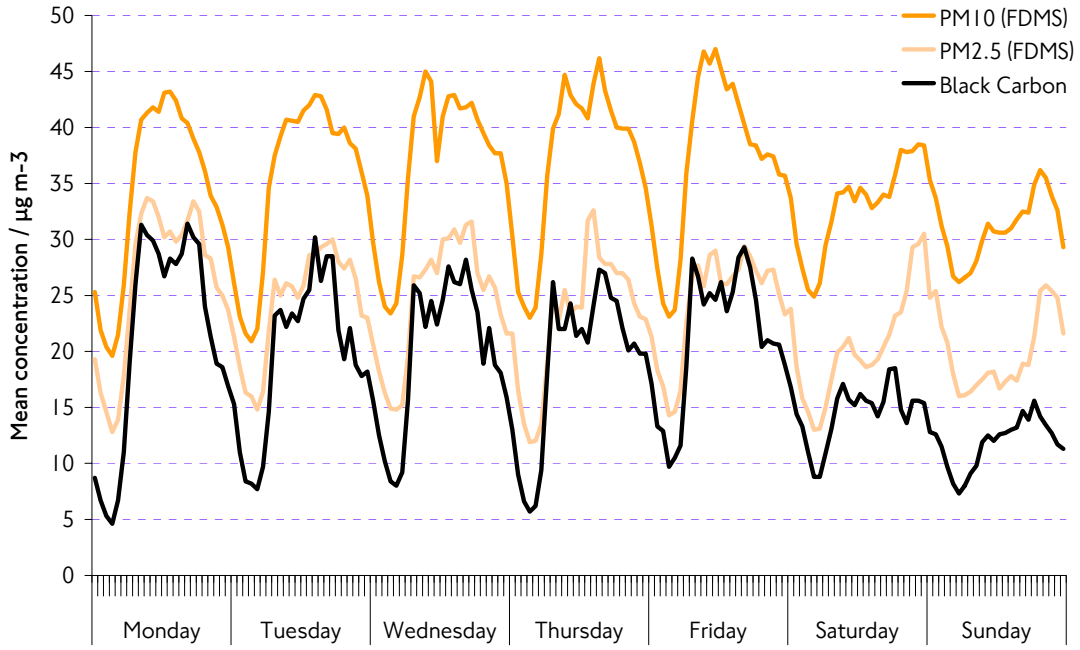
Figure 9.7 Marylebone Road. Weekly diurnal plots showing mean concentrations of NO_X, NO_2 and O_3. (October 2006 to October 2007 data).



This figure corresponds to equivalent traffic flow data and the overall patterns are similar, with local concentrations of both NO_X and NO_2 showing a close relationship with aggregate traffic volumes. Again, however the primary interest here is in the details of the relationship. Features such as the daily 'double peak' in NO_X/NO_2 concentrations (perhaps reflecting the distinct 'car' and 'light goods' vehicles peaks in Figure 9.5), and the similar daily 'double peak' in local O_3 (in this case reflecting a more complex daily cycle of events at the site) are highly characteristic of roadside sites.

Figure 9.8 is a similar plot showing local concentrations of PM_{10}, $PM_{2.5}$ and black carbon. In this case there is less evidence of a daily 'double peak' in PM_{10} concentrations, but there is a steady increase in PM_{10} concentrations at equivalent times of day from Monday to Friday which reflects aggregate traffic volumes. It is noticeable that concentrations of both $PM_{2.5}$ and black carbon tend to decrease as the week progresses – a different pattern than that seen for PM_{10}.

Figure 9.8 Marylebone Road. Weekly diurnal plots showing mean concentrations of PM_{10}, $PM_{2.5}$ and Black Carbon (October 2006 to October 2007 data).



The following sections illustrate an extension of this local analysis approach to two other issues that are key to understanding scheme impacts: the influence of local weather on pollutant concentrations and source apportionment for measured PM_{10}.

9.10 Example exploratory analysis 1: the influence of wind speed and direction on pollution concentrations

Pollution measurements at roadside monitoring sites tend to reflect local traffic conditions. However, the extent to which this is true can vary considerably, both in terms of the nature and location of other nearby pollution sources, and also in terms of variability in weather conditions – most notably the prevailing wind direction. Bivariate polar plots provide a graphical representation of the wind speed and

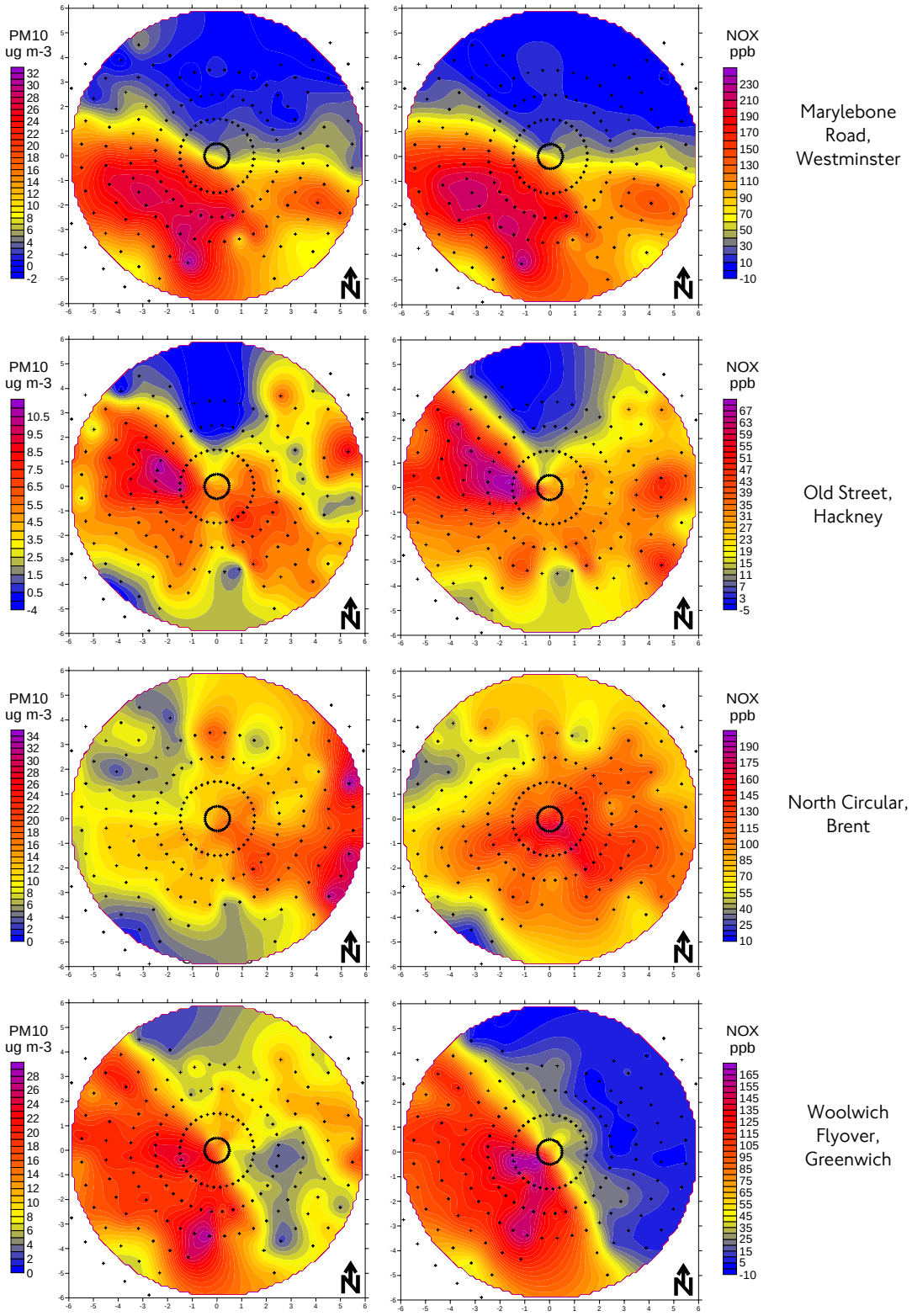
direction dependence of any measurement at a particular monitoring site, thereby allowing identification of the characteristics of primary emission sources and their likely significance relative to overall mean pollutant concentrations to be identified.

Figure 9.9 shows some example plots from the enhanced monitoring sites for NO_X and PM_{10}. They combine measurements of regional wind direction, wind speed and pollutant concentration into a 360 degree 'surface'. The 360 degrees correspond to compass points, representing the direction from which the wind blows, with North at the top. Distance from the centre of the plot corresponds to wind speed, with higher speeds being further from the centre. Pollutant concentrations are shown by colours on the plot, corresponding to the scale shown. The data have been treated to remove non-local (ie 'background') pollution, to allow clearer illustration of key local influences on site measurements. So, for example, NO_X concentrations are lowest at Marylebone Road during strong northerly winds, and highest during moderate south westerly winds of between three and five metres per second.

It is apparent in Figure 9.9 that there are considerable differences between the sites. This means that, given similar regional weather conditions, the measurements from individual monitoring sites would be expected to differ. For instance, wind from the north would lead to relatively low measured concentrations at Marylebone Road and the other example sites, but moderate concentrations at the Brent North Circular site. The plots for Marylebone Road are particularly interesting since they show the reverse of what might be expected. The monitoring site is actually located on the south side of the road, but is within a deep street canyon which gives rise to conditions at ground level where the wind direction is the reverse of that at rooftop level, due to recirculation of air within the canyon.

Comparisons between the two pollutants shows a more consistent pattern at each monitoring site, suggesting that similar sources in similar locations largely determine local concentrations, eg winds from the east at Brent North Circular would tend to be associated with elevated concentrations of both NO_X and PM_{10}. The position at Woolwich Flyover is the reverse of this, reflecting the location of a major road junction immediately to the south-west of the site, and there is clearly a significant secondary source of PM_{10} (but not NO_X) to the north and east of the site. Interestingly, wind speed is seen to be a much less-significant determinant of concentrations than wind direction at all sites.

Figure 9.9 Bivariate polar plots for PM_{10} and NO_X at selected enhanced air quality monitoring sites, showing influence of wind speed and direction on pollutant concentrations.



9.11 Example exploratory analysis 2: comparative source apportionment for PM_{10}

In order to understand the factors driving changes in PM_{10} concentrations in London, it is necessary to be able to disaggregate the PM_{10} arriving at air quality monitors according to its source. One way of doing this uses a 'source apportionment' model derived from NO_X and PM_{10} measurements across London. This method recognises three broad categories of PM_{10} source:

- **Primary PM_{10}** – directly emitted PM_{10} associated with NO_X from stationary sources and both tail-pipe and non tail-pipe road transport emissions.
- **Secondary and natural PM_{10}** – PM_{10} arising from regional sources and not associated with NO_X. Secondary particles are formed from the reactions of gases in the atmosphere and include compounds such as ammonium sulphate. Natural sources of PM_{10} make up of the majority of the coarse fraction of PM_{10} (ie larger particles in the PM_{10} size range) and arise from processes such as the wind blown re-suspension of dust.
- **Other local sources of PM_{10}** – PM_{10} arising from local sources and not associated with NO_X. These sources will include non-combustion sources such as dust generated by demolition or road works.

For the purpose of this analysis, the portion of total PM_{10} mass attributable to regional secondary and natural sources is considered to be uniform across the whole of south-east England. The portion attributable to primary PM_{10} and other local sources is dependent on local emissions and therefore varies across London. By separating these components of total PM_{10} mass, trends in PM_{10} due to changes in local vehicle emissions may be separated from those attributable to changes in regional and unrelated local sources.

Figure 9.10 shows apportionment results for annual mean concentrations at the Marylebone Road kerbside monitoring site. Here, the contribution from primary PM_{10} was approximately twice that from regional sources. At this kerbside location, local sources, principally vehicle emissions, dominate total PM_{10} mass measurements. There was no statistically significant local source of PM_{10} that was not related to NO_X at this site.

Figure 9.11 shows equivalent results from the roadside enhanced monitoring site at Woolwich Flyover. While annual mean PM_{10} concentrations were similar to those at Marylebone Road, source apportionment highlighted a substantially lower contribution from primary sources of PM_{10}. In conjunction with the bivariate polar plots for this site (Figure 9.9), the remaining 10 to 15 percent of total PM_{10} mass measured at this site can be associated with a strong independent source of PM_{10} to the east of the monitoring site.

Figure 9.10 Source-apportioned PM_{10} concentrations for London Marylebone Road (annual mean concentrations).

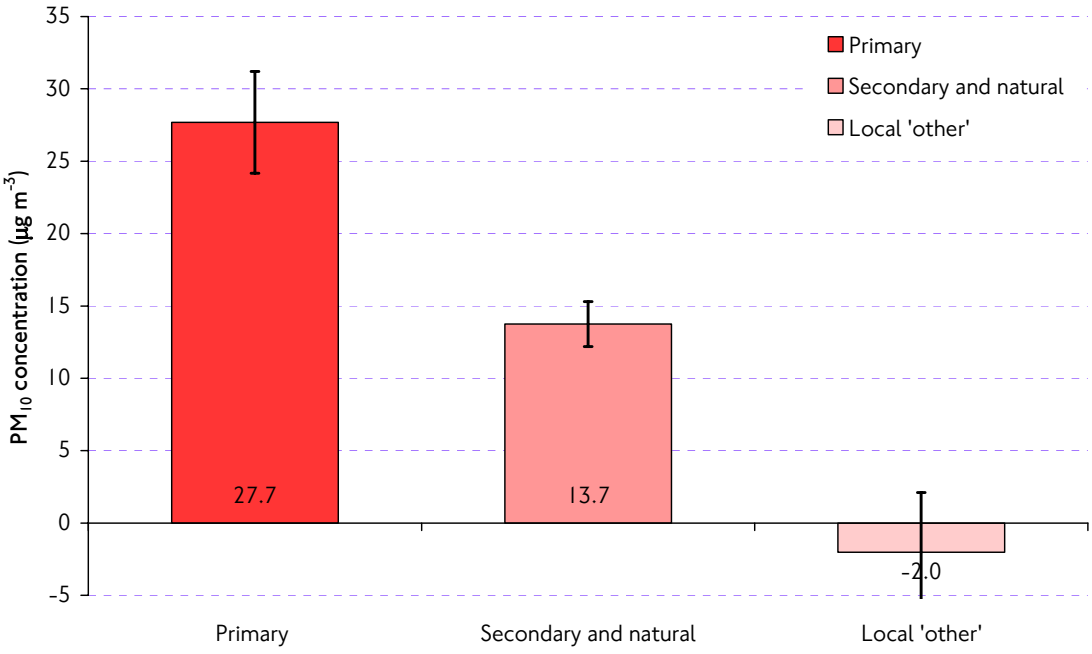
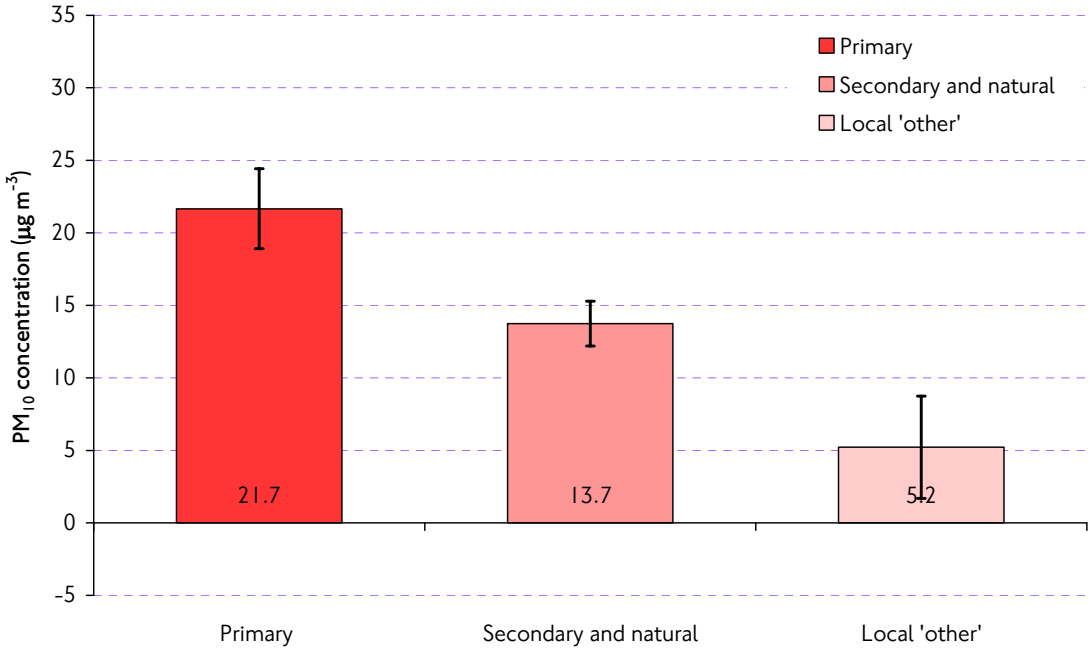


Figure 9.11 Source-apportioned PM_{10} concentrations for Woolwich Flyover (annual mean concentrations).



The same model has also been applied at a daily mean time resolution to apportion total PM_{10} on each day during 2005. Figure 9.12 and 9.13 show source-apportioned time-series charts for Marylebone Road and Woolwich Flyover. The EU Limit Value of 50 µg m^{-3} is also shown on each chart. An 'instrumental offset' (with a constant value of 3.9 µg m^{-3}) is applied to all TEOMs. This value has been included in these figures.

Figure 9.12 Source-apportioned PM_{10} concentrations for London Marylebone Road (daily mean concentrations)

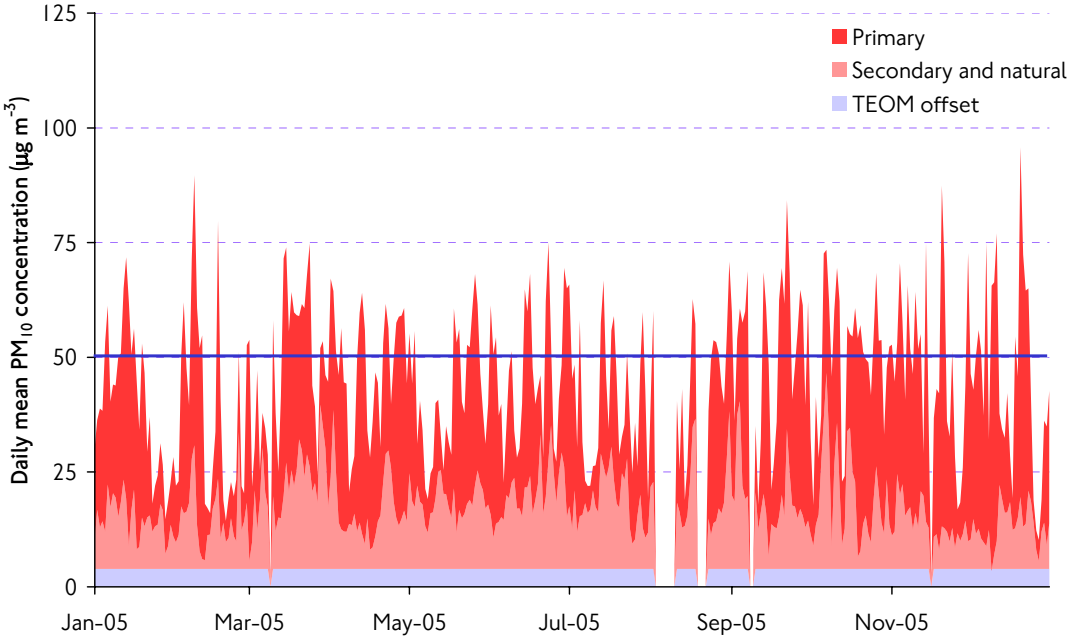
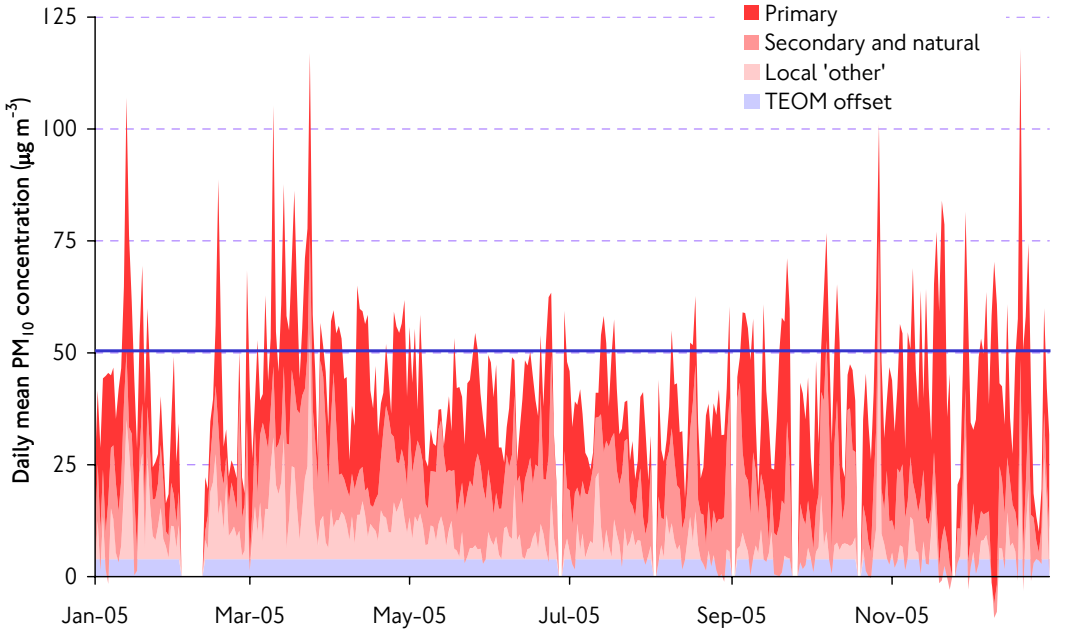


Figure 9.13 Source-apportioned PM_{10} concentrations for Woolwich Flyover (daily mean concentrations).



As with the annual mean charts, the regional secondary and natural component was approximately the same at each site. However, this component varied throughout the year, depending primarily on meteorological conditions. Peak concentrations of regional PM_{10} are usually recorded during prolonged periods of high pressure (anti-cyclonic) weather, as easterly winds transport a continental air mass over the UK. Troughs in concentrations typically occur during wet and windy low pressure (cyclonic) weather conditions which bring fresh maritime air from the Atlantic. While this component of PM_{10} was not itself the cause of any exceedences of the EU limit value in isolation at either site, the peak recorded during October was near to the limit. These regional and secondary PM_{10} would not be directly affected by the London Low Emission Zone, and this analysis illustrates the important role of these 'background' sources in determining pollutant concentrations.

Concentrations attributed to the local primary PM_{10} source at each site were found to depend on weather conditions and local emissions. It is noticeable that PM_{10} from local primary sources did not mirror the regional source. For example, breaches of the EU limit value were recorded at both sites on the day that the lowest daily mean secondary and natural source concentration was recorded (9 December). The polar plots revealed that the highest local PM_{10} concentrations were recorded during south westerly or westerly winds at Marylebone Road and Woolwich Flyover – weather conditions typical of relatively low concentrations of secondary and natural PM_{10}.

Figure 9.12 does not indicate a local 'other' source for Marylebone Road as this was found to be non-significant. However, the daily mean time series analysis illustrated in Figure 9.13 for the Woolwich Flyover site showed that this other source was evident throughout the year to some degree, although it appeared to be strongest in the first half of the year. This source had a very significant effect on peak concentrations on certain days; each incidence of daily mean concentrations greater than 80 µg m^{-3} included a proportionally large contribution from the local 'other' source. Concentrations arising from the non-transport related local source plus those from the regional source were greater than 50 µg m^{-3} on a number of days throughout the year. This means that, even if all road traffic emissions were removed from the adjacent road, this site would still have recorded breaches of the EU Limit Value.

9.12 Summary

Robust characterisation of scheme impacts would benefit from additional research into air quality trends and their relationship to traffic change and monitoring site characteristics at the local scale. TfL has implemented a small number of 'enhanced air quality monitoring' sites mainly by adding additional equipment to existing sites. These sites are at locations where a high 'air quality change signal' from the scheme is projected. This will enable these relationships to be observed in a context where changes arising from the scheme are likely to be most apparent.

A variety of analyses will be possible using these enhanced sites, depending on emerging priorities as the monitoring work progresses. These sites are part of the London Air Quality Network and data from them will be published through normal LAQN channels.

10. Regional emissions and air quality impacts of the London Low Emission Zone

10.1 Introduction

The London Low Emission Zone is likely to have impacts outside Greater London, ultimately leading to reduced pollutant emissions and improved air quality. Around one-third of the total national stock of heavy duty vehicles enter London each year. If the scheme reduces the emissions of vehicles used in London, this could have a material impact on the emissions performance of the national fleet. Although some operators may transfer their older, non-compliant vehicles to routes and cities outside London, it is likely that the scheme will result in overall benefits throughout the country as a whole.

This section outlines how TfL will assess the impacts of the scheme on emissions and air quality outside Greater London. Two approaches will be taken to achieve this. The first is to build on the emissions modelling that has already been carried out as part of the consultation for the scheme, using observed data reflecting actual scheme impacts. The second approach is to analyse measured air quality data in selected UK and European cities, as opposed to the projections previously used, which can act as regional comparators to the measured air quality trends in Greater London, which were discussed in Section 8.

10.2 Modelled emissions and air quality

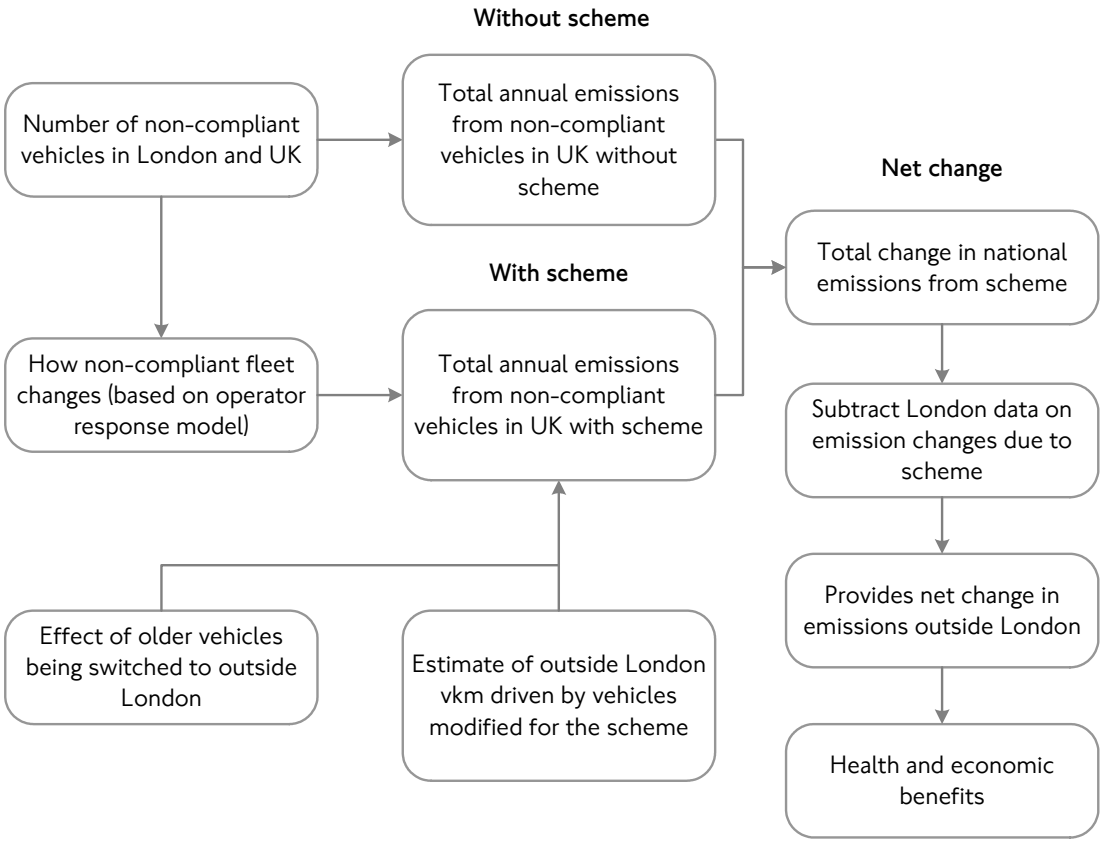
There is no one data source that will give a comprehensive view of the scheme related emission changes outside Greater London. This section sets out how various different data sources can be used to model the impact of the scheme on emissions of air pollutants outside London.

Forecast impacts from the operator response model

As part of TfL's health impact assessment for the scheme consultation, an estimate was made of the impact of the London Low Emission Zone on the health of people living outside London[1]. Data from TfL's vehicle operator response model was used as the basis of these estimates, in terms of how operators would change their fleet once the scheme was introduced. The effect this would have on changes to the vehicle fleet driven outside London was estimated, including the numbers of kilometres driven by different vehicle types.

The main emissions data source was the National Atmospheric Emissions Inventory, which was used to estimate emissions on the UK scale from vehicles subject to the scheme. Projections of the effect of the scheme in London were then obtained from the London Atmospheric Emissions Inventory, to give a net change in emissions. A summary of this approach is provided in Figure 10.1.

Figure 10.1 Methodology to estimate emissions impacts of the scheme outside Greater London.



Observed scheme compliance outside London

TfL has analysed various data sources for areas outside Greater London to try to better understand the actual emissions profile of the vehicle fleet outside London before the introduction of the scheme.

Table 10.1 provides a summary of these data across the various available sources, giving estimated proportions of vehicles that comply with the scheme. This includes data from automatic number plate recognition camera surveys on roads just outside the M25 motorway and in South Yorkshire, as well as DVLA data on registered vehicles (both nationally and by region). This data is also compared with the emissions profile of the vehicle fleet from the monitoring cameras within London.

On initial inspection, the data from the cameras in South Yorkshire and just outside the M25 are comparable with the fleet within London at the time of the survey. For example, the proportion of compliant vehicles for phase 2 of the scheme in these areas is around 70 percent. However, it is important to note that the camera data from South Yorkshire and from around the M25 are from one-day surveys. The numbers of vehicles captured are therefore low, so are likely to have a wide range of statistical uncertainty.

Another way of comparing the fleet is by looking at the DVLA data, by region of registration. It should be noted that vehicle registration in a particular region does not necessarily mean that it is driven there.

Table 10.1 Percentage of compliant vehicles in different areas of UK, various indicative observations.

Area and data source	Proportion of compliant vehicles (N3 HGVs, phase 1)	Proportion of compliant vehicles (N2 HGVs phase 2)	Proportion of compliant vehicles (M3 buses, phase 2)	Proportion of compliant vehicles (All, phase 2)
South Yorkshire camera (Oct 07)	68%	77%	70%	71%
London average camera (Oct 07)	80%	64%	74%	77%
Annulus around M25 average camera (Jan 08)	90%	n/a	n/a	72%
London average from cameras (Jan 08)	86%	69%	79%	72%
National DVLA fleet (Jan 2008)	72%	51%	44%	49%
DVLA fleet registered in London (Jan 08)	70%	49%	81%	41%
DVLA fleet registered in the South East (Jan 08)	72%	77%	48%	47%
DVLA fleet registered in the North East (Jan 08)	76%	56%	37%	51%
DVLA fleet registered in Wales (Jan 08)	56%	39%	33%	37%

Table 10.1 shows that, typically, the registration data has a much lower scheme compliance rate than that observed by the cameras, particularly for vehicles affected by phase 2 of the scheme. This was observed in London (see Section 5) and most probably reflects the prevalence of newer vehicles in the operational fleet, as opposed to the total registered vehicle stock.

Note that the DVLA data shows a high compliance of M3 buses and coaches registered in London, similar to that from the cameras. This probably reflects the importance of the TfL bus fleet in London.

Ongoing monitoring of scheme compliance outside London

TfL plans to put in place a programme of ongoing camera surveys in different regions of the UK following the introduction of the scheme, both in an annulus around the M25 and in cities distinct from London. This will allow TfL to detect relative changes in the proportion of different Euro classes and in vehicle compliance with the scheme, for the different areas. These data will then be used to revise estimates in the national stock profile and update the emissions modelling methodology that was carried out to forecast the emissions impacts outside London, based on observed changes following the introduction of the scheme.

10.3 Measured pollutant concentrations

The second approach to assessing the impacts of the scheme outside Greater London is to focus on changes in measured air quality in other cities. Although the scheme may result in a reduction in total emissions both in and outside London, these will be widely dispersed, so it may be very difficult to observe any clear impacts on measured pollutant concentrations. However it is still worthwhile analysing long term trends for cities outside London as this data is readily available and can act as a 'control' to help identify and isolate any differential changes to air quality that do occur in London as a result of the scheme. A selection of towns and cities in the UK and Europe were chosen to assess these background trends. The data analysis has been performed in a similar manner to that described in Section 8 and this regional data is compared to the London wide trend data later in this section.

Choice of comparator areas

The following towns and cities have been chosen as regional comparator sites.

- **Towns in Kent/Medway** – to provide a regional annulus around London.
- **Oxford** – a substantial town within a 50 kilometre radius of London.
- **Manchester** – regional capital about 300 kilometres from London.
- **Paris** – continental European capital city.

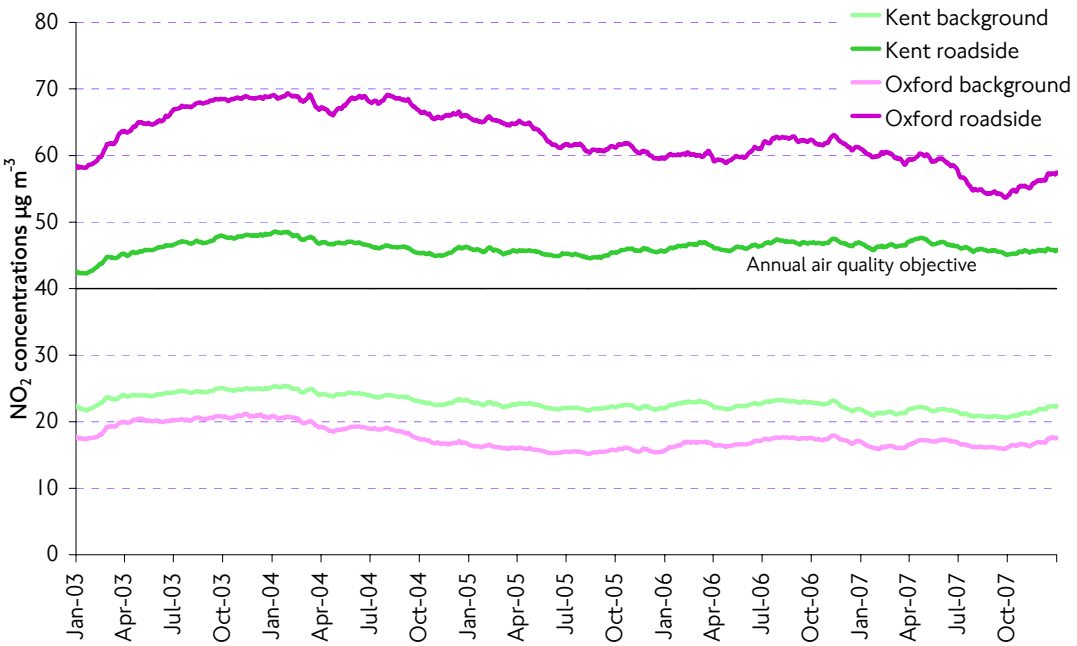
Representative monitoring sites, with a continuous and good quality dataset have been chosen for each area, and detailed data analysis has been conducted. Selected examples of the results are presented below to provide a baseline for each area and to illustrate the analytical methods that are possible.

Pollutant concentrations in areas close to London

The characteristics of vehicles operating in Kent have previously been shown to be comparable to those in London (Table 10.1), so any changes in emissions to the vehicle fleet that result from the scheme may be more noticeable in this region than others. This region also has a well established air quality monitoring network (KentAir) that is maintained by AEA Energy and Environment on behalf of the local authorities. Data from Oxford has also been included in this analysis, as it is close enough to London to be potentially affected by vehicles that regularly travel to and from London. A summary of the monitoring sites selected in Kent and Oxford for this analysis is provided in **Appendix 5**.

Figure 10.2 provides an example of pollutant data from these regions. The figure shows that the running annual average NO_2 concentrations at roadside sites in Kent and Oxford has been above the annual objective over the last five years, whereas background concentrations are well below the objective. Concentrations of NO_2 averaged across all Kent roadside sites actually increased over this time.

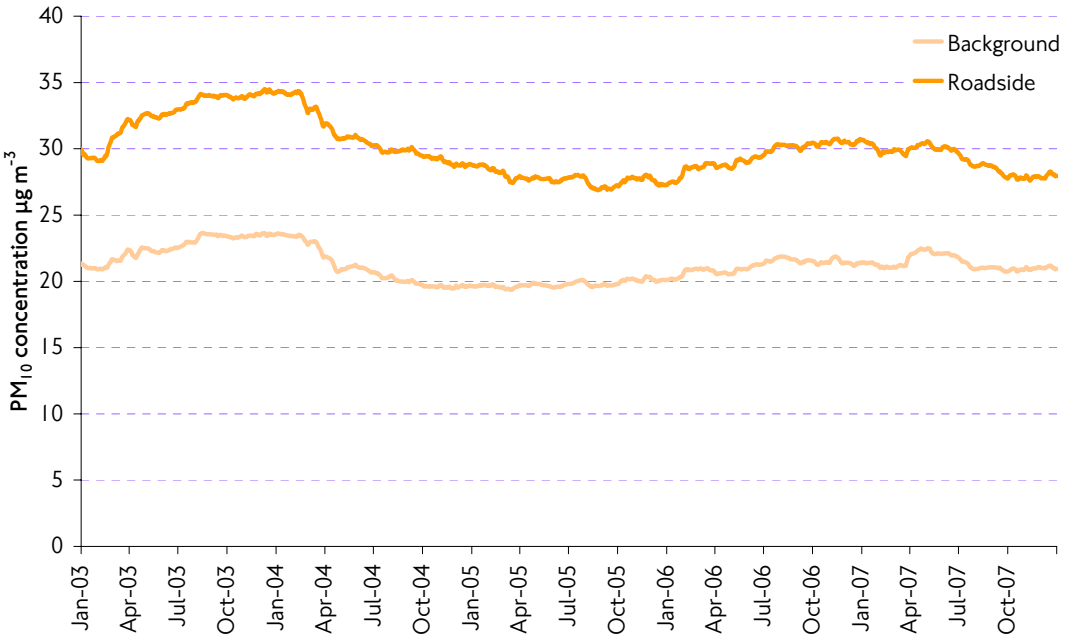
Figure 10.2 Running annual average NO_2 concentrations in Kent and Oxford.



Pollutant concentrations in Manchester

Manchester was chosen to provide an example of a major city in the UK that has high levels of air pollution, but is unlikely to be significantly affected by the London scheme. **Appendix 5** provides a list of the monitoring sites in Manchester for which data analysis has been undertaken.

Figure 10.3 Rolling annual average PM_{10} concentrations (gravimetric equivalent) in Manchester.



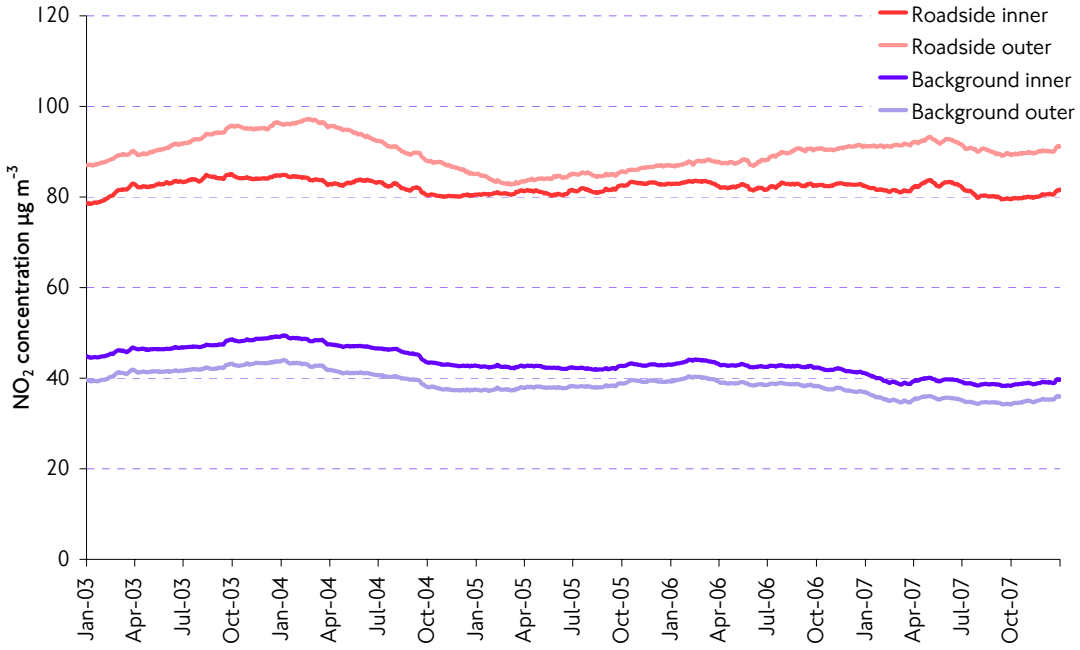
Average concentrations of both PM_{10} and NO_X are similar to those measured at London sites, as seen for PM_{10} in Figure 10.3, as an example. These comparable levels may help isolate changes in concentrations that occur in London as a result of the scheme. In future analysis, it will be important to take account of any local transport policies in Manchester and other comparator areas that may affect pollutant concentrations.

Pollutant concentrations in Northern Europe: Paris

Paris was chosen as a city of comparable size and function to London. As Paris is outside the UK, it is very unlikely to be affected by any scheme influenced changes to the national vehicle fleet. Paris has a well established monitoring network called Airparif which has approximately 46 monitoring sites over a 100 kilometre radius, in both inner and outer Paris. Concentrations measured at Paris roadside sites are noticeably higher than those in London and other UK cities.

For example, Figure 10.4 shows that NO_2 concentrations at roadsides were above 80 µg m^{-3}; where as concentrations at inner London roadside sites were typically around 70 µg m^{-3}. The most likely reason for the very high concentrations at Paris roadsides is that the data presented is an average of only two roadside sites, both of which have high traffic flows. In contrast, the inner London roadside site data is an average of more than ten monitoring sites, which include both busy and less busy roads.

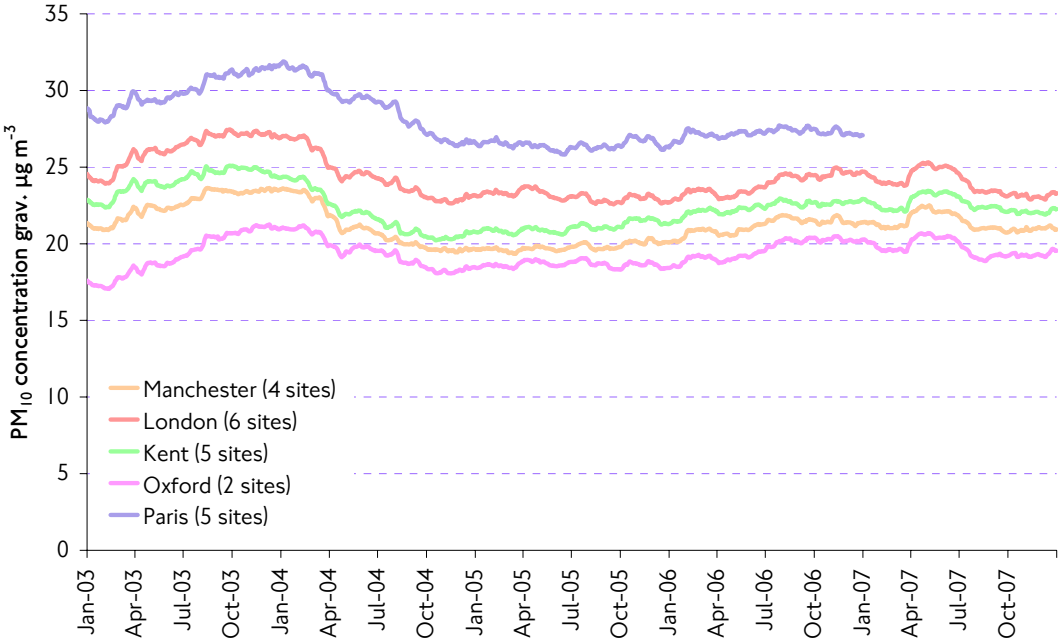
Figure 10.4 Rolling annual average NO_2 concentrations, Paris.



Comparison to London

The air quality data presented in this section has been compared to the concentrations measured in London. Background pollution concentrations of PM_{10} across these locations are of a similar magnitude and follow a similar trend across the time period considered, demonstrated by Figure 10.5.

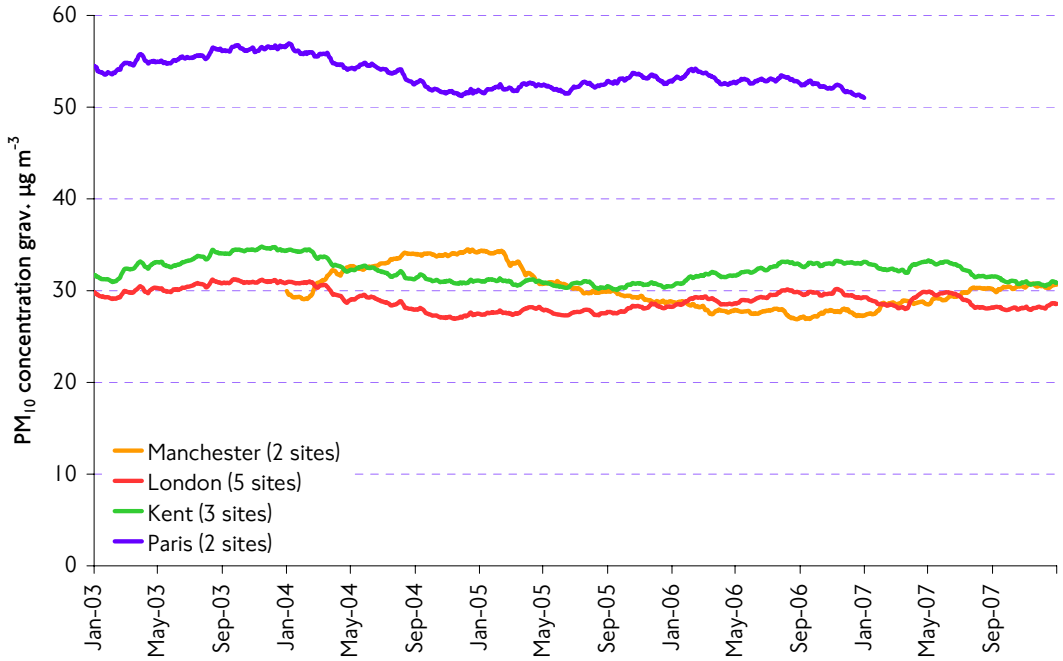
Figure 10.5 Background rolling annual average PM_{10} concentrations (gravimetric equivalent), all locations.



Note: 2007 data is not shown for Paris due to changes in the monitoring from TEOM to FDMS.

In contrast, Figure 10.6 shows that the average PM_{10} concentrations at the two roadside sites in Paris are much higher than the other cities.

Figure 10.6 Roadside rolling annual average PM_{10} concentrations (gravimetric equivalent), all cities.



Annual average NO_2 concentrations at background locations are below the objective of 40 µg m^{-3} in all cities (see Figure 10.7), whereas roadside concentrations tend to

be much higher and exceed the objective (Figure 10.8). As is the case with PM_{10}, concentrations of NO_2 in Paris are higher than in the other areas.

Figure 10.7 Rolling annual average NO_2 concentrations at background sites, all locations.

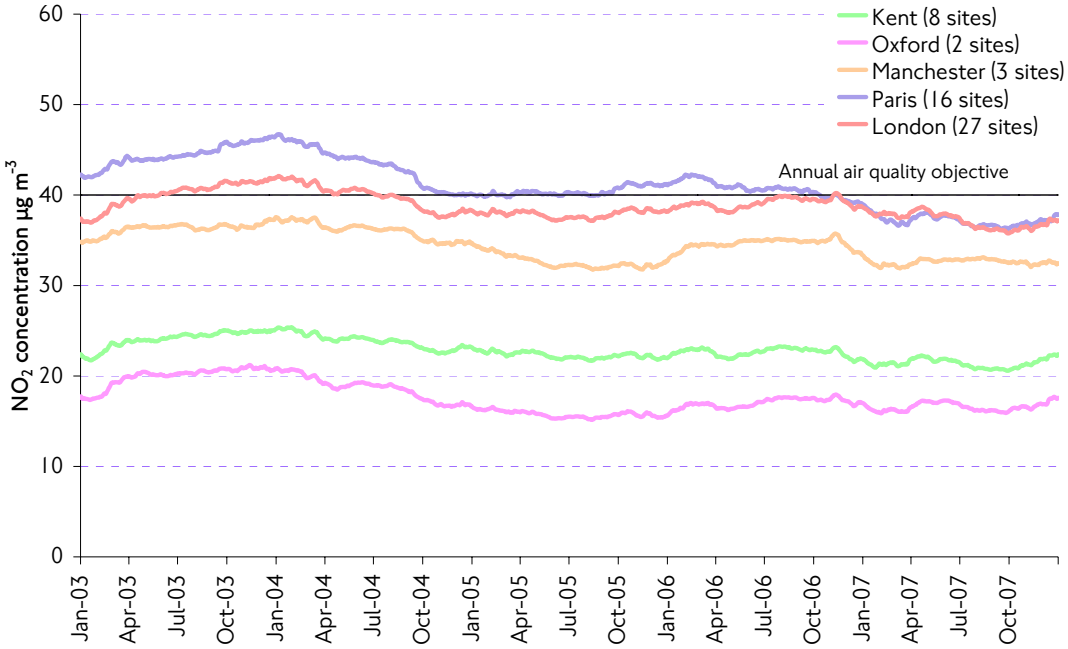
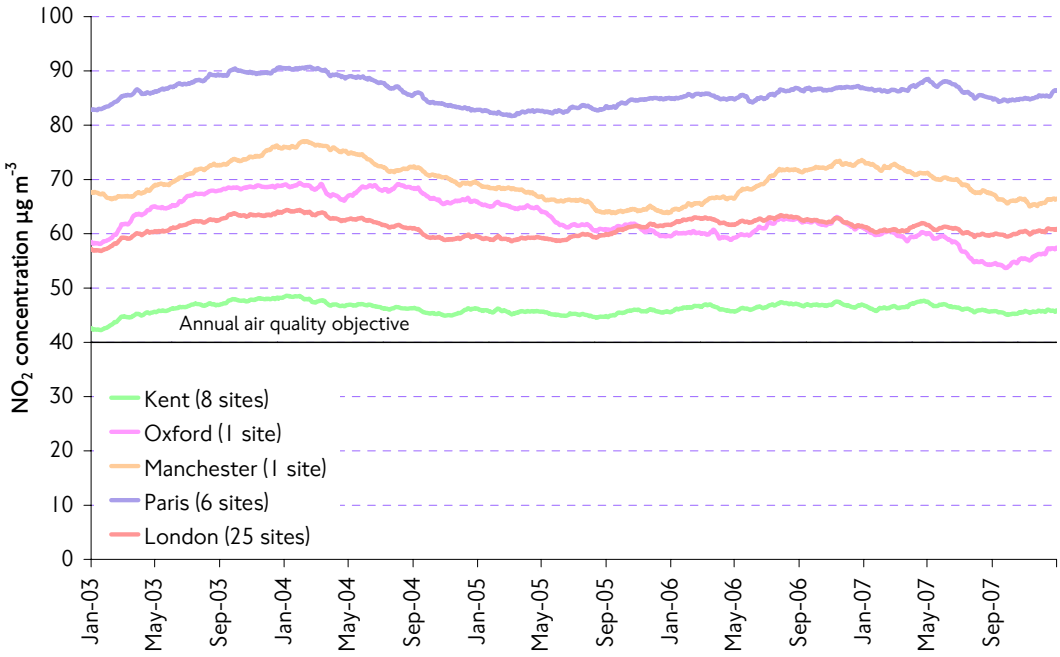


Figure 10.8 Rolling annual average NO_2 concentrations at roadside sites, all locations.



Despite this apparent similarity in the pattern of trends over the six years considered, the relative changes in annual average concentrations at each site are quite different when compared between cities. Table 10.2 gives the percentage change in roadside concentrations from 2002 to 2007. The data shows that concentrations of PM_{10} and NO_X have reduced across all locations but by the most in Manchester. However,

NO_2 concentrations have increased over time in most of the cities, except in Oxford and Manchester. These trends will be progressively updated going forward to help identify any specific effects of the scheme in London.

Table 10.2 Percentage change in annual mean concentrations from 2002-2007, roadside sites.

Pollutant	London inner	London outer	Paris inner	Paris outer	Manchester	Kent	Oxford
PM_{10}	-0.3	-4.3	-5.7*	n/a	-7.4	-2.8	n/a
NO_X	-3.3	-7.3	-18.4	-11.6	-20.3	-0.4	-14
NO_2	+11.5	+0.4	+3.8	+5.0	-2.2	+7.1	-2.2

* 2002-2006

The data can also be analysed to determine exceedences of the short term objectives for both PM_{10} and NO_2. This analysis showed that exceedences of the daily PM_{10} objective were similar across the different areas, but that exceedences of the hourly NO_2 objective were much greater at the inner roadside sites in Paris and London, which may make it less easy to detect differential changes in trends in future years.

10.4 Summary

In influencing the emissions characteristics of vehicles operating in London, the Low Emission Zone may have secondary impacts outside London. Because heavier goods vehicles typically operate only a small proportion of their total annual vehicle-kilometres travelled in Greater London, beneficial impacts on emissions and air quality might be expected at the national scale. On the other hand, it is possible that the London scheme will lead to an element of operator fleet displacement as non-compliant vehicles are relocated to work outside London. Assessment of these effects by TfL has suggested that the net effect at the national scale will be beneficial, albeit relatively small in terms of the overall scale of all UK emissions.

It is not possible to directly measure these effects as part of the monitoring work for the scheme. For national-scale emission impacts, an assessment method has been developed that is based on the established national atmospheric emissions inventory, but that uses actual observations of vehicle change corresponding to the various phases of the scheme. For air quality trends, an approach looking at trends in pollutant concentrations in selected comparator cities should, over time, allow any differential trends in London that might be associated with the scheme to be detected. This approach would also place London wide air quality trends in a wider geographical context.

11. Health impacts

11.1 Introduction

Benefits to public health are the ultimate aim of the London Low Emission Zone scheme. By reducing emissions from the most polluting diesel vehicles, air quality should improve, which will in turn improve public health.

There is substantial evidence to link outdoor exposure to air pollution to a range of adverse health effects[1]. Research has demonstrated a causal association between short-term and long-term exposure to ambient levels of particulates and respiratory and cardiovascular illness and mortality. There is currently no threshold concentration below which there are deemed to be no health effects. It is the general consensus that fine particles, primarily emitted from larger diesel vehicles such as heavy goods vehicles are the most damaging component of outdoor air pollution. At high ambient levels, NO_2 can also be associated with adverse health effects, causing inflammation of the lungs and exacerbating responses to allergens. Long term exposure may also lead to respiratory problems in some individuals.

The scheme would therefore be expected to confer a benefit on the health of people living and working in London. However, it is likely that its effect would be small in comparison to other major factors that affect respiratory and cardiovascular health (such as deprivation and smoking), which will make it very difficult to directly measure any health benefits from the scheme.

As part of TfL's public consultation, a health impacts assessment was undertaken to model the health benefits of the scheme[2]. In principle, this assessment could be revised once actual observed data reflecting the impact of the scheme on emissions and air quality has been accumulated.

A task of the impacts monitoring work will therefore be to consider whether this method is fully sufficient and appropriate to identify the health effects of the scheme, or whether there are other methods that are better suited to isolate and take into account differential effects of the scheme on particulate sizes and composition. This section summarises the process of the health impact assessment, but also outlines other approaches that TfL will take to assess the health impacts of the scheme.

11.2 Health Impacts Assessment

This section describes the main elements of a health impact assessment (HIA) and outlines some of the projected health benefits from the scheme.

What is a health impacts assessment?

An HIA is a recognised method of assessing the health impacts of a scheme such as the Low Emission Zone. To conduct an HIA, a range of methods and approaches are used to identify and consider the potential, or actual, health and equity impacts of a proposal on a given population. Health impacts may include both positive benefits (eg reduction in respiratory illness due to improvements in air quality) and negative (eg a

possible increase in stress and anxiety due to loss of employment). An HIA considers a range of factors that are known health determinants, such as age, sex and hereditary factors, lifestyles, living and working conditions and socio-economic and environmental background. It is important to recognise the complexity of the interactions between the different determinants of health that lead to a specific state of individual health (or the health of the population in an area). Given these influences, this makes it almost impossible to use any empirical monitoring methods post-implementation to 'measure' or attribute impacts.

Methodology to forecast the impacts of the London Low Emission Zone

The HIA process involves collecting a wide range of evidence in order to interpret health risks and potential health gains. The core stages of a typical HIA include:

- **Screening** – to decide whether an HIA is the best means of ensuring that health and equity concerns are addressed effectively.
- **Scoping** – to decide how an HIA should be undertaken in the context of the proposal, in this case the London scheme.
- **Appraisal of evidence** – to identify and consider the evidence for potential impacts on health and equity.
- **Development of recommendations** – to provide policy makers with an understanding of the key health impacts, and the means of enhancing positive effects and minimising any negative impacts.
- **Monitoring and evaluation** – it is important that the actual impacts of the scheme are monitored where possible to understand whether the implementation has led to the predicted health outcomes.

TfL initially carried out a screening phase and decided that an HIA exercise for the proposed scheme was required. Following this, a scoping phase was undertaken as part of the Scheme Order consultation. This took into account other impact assessments, such as those on the environment, economic and business and equalities impacts of the scheme. At the appraisal stage, the following four key elements were considered important:

1. Literature review

This review considered the latest evidence on the health impacts of the two main air pollutants from road traffic; NO_X and PM_{10} as well as considering other changes to health that may result from the scheme. These included perception of improved environmental quality, reduced noise and the influence of employment and socio-economic status.

2. Stakeholder engagement

As part of this HIA process, the views of interested stakeholders were sought to help identify the different health impacts arising from the proposed scheme to prioritise the significance of such impacts, and to consider how positive impacts could be maximised and any negative impacts minimised. Two stakeholder engagement meetings were held. The overall opinion of stakeholders was that the air quality

benefits of the scheme and the perceived improvement in environmental quality would be beneficial. The benefits could be maximised by integrating the introduction of the scheme with other measures to encourage participation in walking and cycling, and to create a perception of improved environmental quality. The potential negative impacts of greatest concern was the impact on community transport and the potential for increased social isolation of vulnerable individuals including the elderly and disabled.

Some stakeholders felt that these potential negative impacts could be appropriately managed by making modifications to the scheme such as providing exemptions for community transport, allowing a longer timescale for compliance or providing assistance with the cost of retrofitting pollution abatement technology to the vehicles. There was a concern that if the unintended consequences of the scheme such as the potential impact on community transport were not properly managed, then the overall impact of the scheme on health could potentially be damaging rather than beneficial.

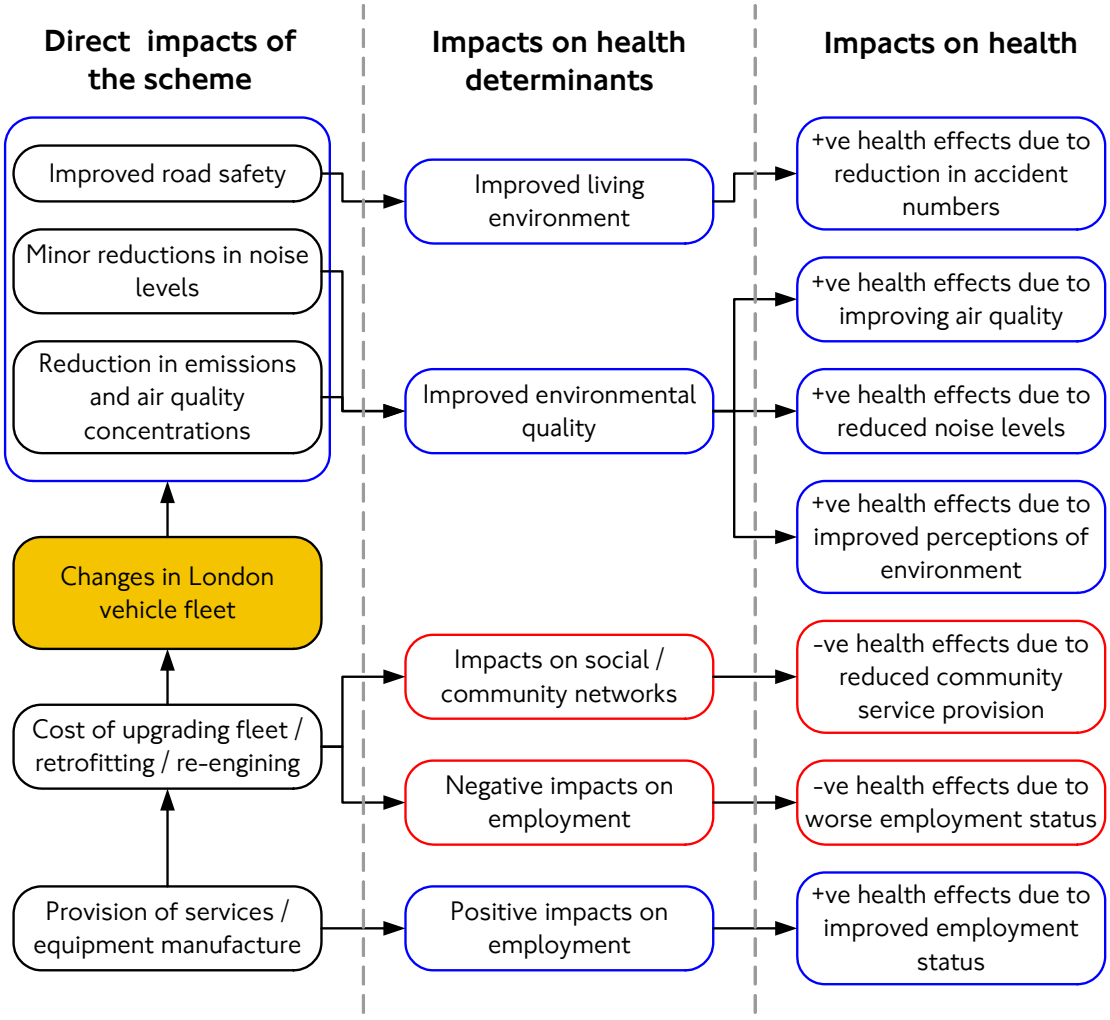
3. Community profile

A community profile was compiled to get a better understanding of the socio-economic and health characteristics of people living in Greater London to identify where the health benefits from the scheme could be most significant. Data such as measured air quality concentrations, population distribution, health statistics and changes in employment were considered in developing this community profile.

4. Assessment of impacts

Information from the literature review, stakeholder engagement, and community profile was collated to provide a full assessment of the potential effects of the scheme on the health of the London population. TfL evaluated each impact to prioritise them in terms of significance before evaluating whether the scheme should be implemented. Figure 11.1 summarises this process.

Figure 11.1 Process to identify the health impacts of the proposed scheme.



The following sub-sections summarise the forecast health impacts of the scheme, in terms of improved air quality, perception of environmental quality, socio-economic and other impacts.

11.3 Key impacts of the London Low Emission Zone on public health

Air quality and health impacts

The HIA modelling produced net beneficial outcomes from the scheme in terms of improved emissions reduced areas of exceedences of air quality objectives and a reduced proportion of the population living in areas of exceedence. Table 11.1 summarises some examples of these outputs.

Table 11.1 Examples of forecast air quality benefits of the scheme, from TfL's Health Impact Assessment[2].

Scenario	Population living in area exceeding annual average NO_2 objective	Reduction in population exceeding objective (%)	Population living in area exceeding annual average PM_{10} objective*	Reduction in population exceeding objective (%)
2008 no scheme	1.37 million		495,000	
2008 with scheme	1.29 million	6%	464,000	6%
2015 no scheme	443,500		46,000	
2015 with scheme	407,600	8%	43,000	8%

*For this modelling, the provisional objective for annual average PM_{10} concentration of 23 μg m^{-3} for 2010 was used.

Based on the projected emission reductions, the effect on health was calculated using two methodologies, the IGCB (Inter-Governmental Cost Benefit) method recommended by Defra, which was used in their Air Quality Strategy Review; and another method as used by the EU in the CAFÉ programme. Table 11.2 shows the results from the most recent evaluation. This replaces the evaluation used in the public consultation on the scheme as it is now recognised that some Euro I and Euro II vehicles were manufactured and type approved with Euro III requirements for particulate emission levels without necessitating modification.

Table 11.2 Forecast monetised health benefits from the scheme, present value to 2015/16[3].

	IGCB / Defra	EU CAFÉ
London Benefits	£80m–£110m	£160m-£420m
Outside London Benefits	£70m–£100m	£90m–£250m
Total benefits	**£140m–£210m**	**£250m–£660m**

Across London, there would be significant differences in the distribution of these benefits, for example, central London boroughs appear to experience the highest level of benefit, as this is where the air quality problems are most acute. These are the boroughs that also have the highest proportion of deprived communities; therefore, it is the most deprived communities that on average experience the most significant improvements in air quality. Although the relative improvements in air pollution are modest, they are important given that such communities are thought to be more vulnerable to air quality impacts on health.

Economic impacts on public health

TfL's economic and business impact assessment for the scheme[4] to support the scheme consultation estimated a small net cost to the London and South East economy, and a small loss in employment across certain sectors once the activity in ancillary sectors had been taken into account. Based on this analysis, it is assumed that there would be a resulting small negative impact on health specifically due to

adverse impacts on employment. It appeared to be the smaller businesses and those that are less able to pass costs through to the consumer that would be potentially most affected, such as those in construction and transport, storage and communications industries.

The compliance costs associated with replacing vehicles or retrofitting abatement technologies could have an impact on the ability of voluntary and public sectors to maintain community services. Access to services is a particular issue for vulnerable groups, such as the elderly, disabled or most deprived communities and any reduction in these services could potentially have implications for health, in terms of physical health (eg provision of healthcare or healthy food), and mental health and well being (eg participating in the community and use of local amenities).

Other impacts

There is evidence that perception of the environment can affect the health of the population, particularly in terms of well being, associated with how people view their quality of environment and its impact on their quality of life. Measuring this is difficult, particularly as perceptions within and between communities will differ significantly. On balance, it is likely that the health benefits from a changed perception of the environment would be relatively small.

The evidence suggests that exposure to noise can have important effects on health. The scheme has potential benefits to noise, as it removes older noisier vehicles from the fleet. However, it has been estimated that the scheme would lead to only very small reductions in ambient noise levels; therefore, health benefits are likely to be marginal. Newer vehicles tend to be safer, and are part of the reason why road safety in the UK has improved in recent years. An increase in newer vehicles could lead to some small improvements in road safety, and a resulting small benefit to health.

11.4 Methodological improvements to health benefits modelling

As part of the monitoring work, TfL will consider where the HIA can be further refined to make it more accurate. Areas of potential improvement are:

- **Emission estimates.** The improved emissions inventory outlined in Section 6 acts as the basis for assessing the impact of changes to air quality in health impacts modelling. Improvements to this method and availability of actual observed scheme impacts as opposed to forecast ones will ultimately lead to different health benefit estimates than were forecast during the consultation exercise.
- **Pollution monitoring.** By expanding the pollution monitoring network, TfL will have more data on other pollutants, such as ozone and different types of particulate measurement. This could provide a more sensitive way of measuring the impact of the scheme on air quality and it may be possible to use this data to undertake a more refined assessment of the health impacts of the air quality changes from the scheme (eg differential impacts of particle size) in due course.
- **Health benefits method.** The health benefits model could also be refined over the next few years as part of the monitoring work by selectively incorporating new insights from the programme where this can be done robustly.

11.5 Case study to investigate respiratory health of school children

School children have been identified by the World Health Organisation as a group that is particularly sensitive to air pollution. This is because their lungs are not mature and they are exposed to relatively high levels of outdoor pollution – mainly reflecting the increased time spent in the outdoor environment. Previous studies have shown that, over time, traffic related pollutants can damage the growth and development of children's lungs and it is also know that children living in inner cities can have high hospital admission rates for respiratory problems which may, in part, be connected with poor outdoor air quality.

As part of the assessment of the London Low Emission Zone, TfL has co-sponsored an academic case study into the effect of the scheme on respiratory health of school children. This study focuses on the London Borough of Tower Hamlets to examine the relationship between measured pollution levels near schools and the rates and incidences of respiratory and allergic diseases, lung growth and respiratory infections in children attending the schools. A large dataset, collected between 2002-2005, already exists for over 30,000 children in this borough. This dataset contains information on respiratory health as well as demographic, school and social data and is ideal as a baseline, representing conditions before introduction of the scheme.

The main aims of this study are to determine the effects of the scheme on:

- Incidence of new diagnoses of asthma (primary outcome).
- Asthma severity in those with an existing asthma diagnosis.
- Health care use attributable to asthma and to respiratory illness.

The study will be conducted in two phases. Firstly, health data for the 30,000 children will be linked to individual emissions exposure for 2002-2005, modelled on school and home addresses. This modelling will take into account relevant confounding factors such as deprivation and passive smoking. Secondly, new pollution and health data will be gathered for 2008-2010 to see whether reduced exposure to traffic pollution improves health, by reducing the number of children getting asthma, the severity of asthma in those with asthma, and numbers of hospital admissions for asthma and chest infections. From September 2008, a series of measurements will be taken on a group of 150 children aged eight years to provide data on lung function, respiratory symptoms and specific diagnostic markers of inflammation and oxidative stress. In conjunction with this work, particulate filters from monitoring sites in Tower Hamlets and at the seven monitoring sites enhanced specifically for scheme monitoring will be collected and samples analysed for their oxidative activity, which is linked to health effects.

11.6 Health Effects Institute study

The above case study is part of a wider international collaborative study, led by Kings College London, in association with St George's Hospital and the London School of Hygiene and Tropical Medicine, funded by the US-based Health Effects Institute. A baseline report for the study was completed in 2007[5]. This specifically considered

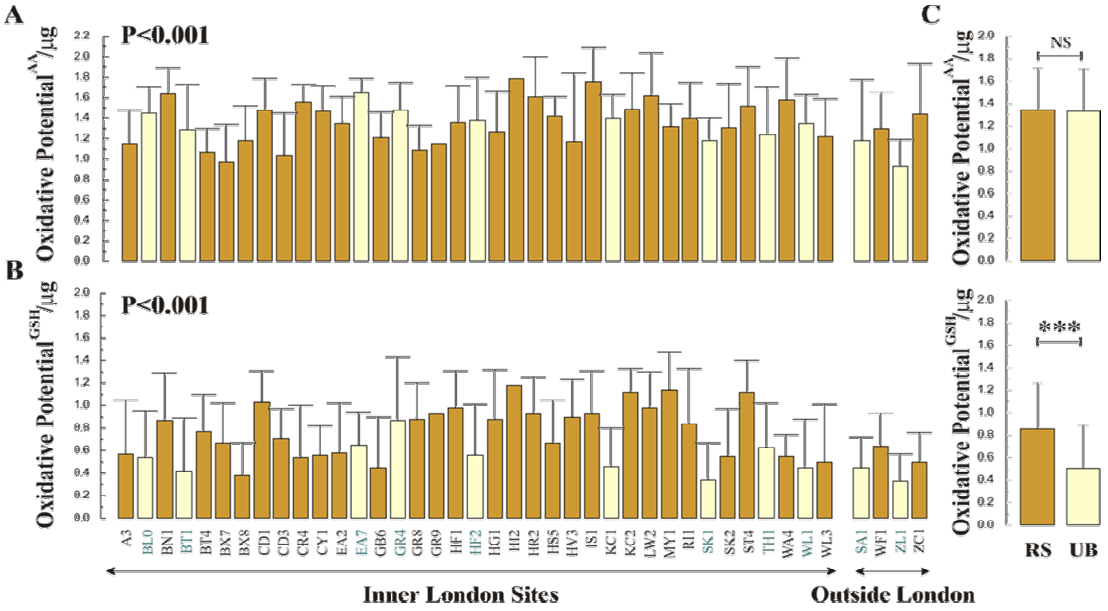
the potential of innovative methodologies for investigating the health impacts of schemes such as the London Low Emission Zone.

Oxidative proprieties and metal content of ambient particulate matter

The London Low Emission Zone has the potential to not only alter the concentration of particulates in the air, but also affect their composition. Particulates are made up of many components, including metals, organic and inorganic elements, which can all affect oxidative activity, ie the ability of the particulate to cause 'oxidative stress' to the lining of the lung. The oxidative potential of measured PM_{10} and $PM_{2.5}$ was measured for the study prior to the introduction of the scheme, focusing on analysing the components associated with road traffic. The components of the particulate matter on filter papers recovered from 41 air quality monitoring sites were analysed in the laboratory using various synthetic substances to represent the surface of the lung.

Figure 11.2 shows that the recovered particulate matter had considerable variability in its oxidative capacity across monitoring sites in London. There was some evidence that particulates collected at roadside sites are more active than those of background sites for both of the synthetic substances – ascorbate and glutathione. There was little indication that $PM_{2.5}$ activity was stronger relative to PM_{10}, but overall PM_{10} oxidative potentials were stronger relative to $PM_{2.5}$. This indicates that the coarse PM fraction ($PM_{10-2.5}$) had components with considerable oxidative capacity.

Figure 11.2 PM_{10} oxidative capacity at 41 monitoring sites (expressed per m^3 of air).



Source: Environmental Research Group, Kings College London.

Across all sites, a significant proportion (60-70 percent) of the total oxidative activity was attributed to metals. The active particulates at roadside locations had elevated concentrations of copper, barium, molybdenum and bio-available iron, largely associated with the coarse PM fraction. Some of these metals, such as iron, may arise from sources such as brakes, or other mechanical wear processes.

Overall, there was clear evidence that the oxidative potential of particulate matter tended to be greatest at sites close to busy roads in London.

Analysis of primary health care records and development of methodology

This work aimed to establish the feasibility, in ethical and operational terms, of using the UK's electronic primary care records to evaluate the effect of the London Low Emission Zone on health outcomes such as incidence and exacerbations of asthma, respiratory tract infections and heart diseases. The feasibility study created a dataset from a group of pilot general practices for which ethics committee approval was obtained. Individual primary care records were linked (via postcode) to these modelled concentrations.

The initial study found that a wide range of individual NO_X exposure profiles existed across London, as well as within and between the practices examined. While there was little observed association between exposure and smoking status, a positive relationship between exposure and increased deprivation was found. However, no cross-sectional positive association between exposure to NO_X and any of the health outcomes selected were found, and some associations were negative.

This work has proven that it is feasible to gain approval to use primary care data in this way, and that this could provide a good foundation for future evaluation of the scheme. Further investigation into the use of an online primary care database with over 100 practices is now being carried out.

11.7 Summary

The Health Impacts Assessment modelling has projected that the Low Emission Zone scheme will benefit the health of the population both in and outside London. It is likely that the actual health benefits arising from the improvements in air quality would be greater for certain vulnerable groups, such as those living in more deprived areas. However, these benefits will not be directly measurable and analysis of trends in health outcomes would be unable to isolate the impact of the scheme from the wide range of other confounding factors.

The focus of the ongoing monitoring work is therefore two fold. Firstly to explore and selectively update the existing HIA framework in the context of emerging data from the wider monitoring work on the actual impacts of the scheme. Secondly by investigating other approaches to assessing health impacts, such as collaborative case studies of respiratory health among school children and investigations into the changing chemical properties of particulate matter in London.

12. Business and economy impacts

12.1 Introduction

This section is presented as two parts. The first part of this section focuses on the assessment to explain the scale and distribution of the business impacts of the scheme in terms of economic output and employment. The scale of the business impacts will be determined by the costs of compliance, the numbers of non-compliant vehicles during the implementation of the various phases of scheme, and the responses of vehicle operators.

The second part focuses on data relating to freight and passenger transport activity. The data include historical trends in the level of business activity, numbers of operators, operator fleet sizes and end use sectors. Potential economic impacts of the scheme would be indicated if the amount of freight moved, for example, showed a fall after the introduction of the scheme due, for instance, to non-compliant vehicles being taken off the road. Such effects would need to be considered in the context of background trends across the industry and whether similar trends were reported elsewhere outside Greater London.

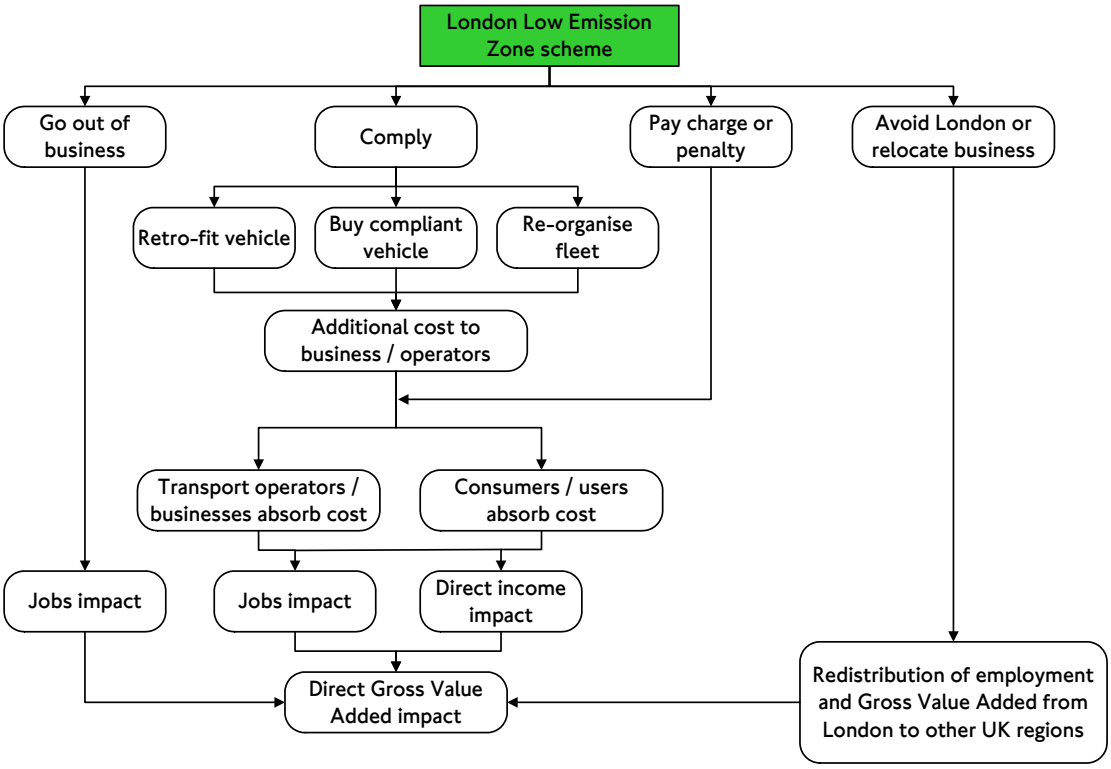
12.2 Business and economy impacts assessment

Overview

As part of TfL's scheme consultation, a business and economy impacts assessment was undertaken by independent consultants to model the economic impacts of the London Low Emission Zone scheme[1]. This section summarises the methodology, assumptions and outputs from this study. The scheme would in principle, bring forward a proportion of operator costs of renewing vehicle fleets and imposes costs on businesses operating non-compliant vehicles in Greater London. The flow chart in Figure 12.1 summaries the chain of options and the potential effects on business in relation to the scheme modelled by the economic impacts assessment.

Economic theory suggests the imposition of regulatory costs on business will, everything else being equal, adversely impact on economic output or Gross Value Added. The extent of any impacts will depend on the options available and the way in which businesses respond to the scheme. However in reality, the costs imposed by the scheme and their consequent impact have to be managed in the context of all other short and long term supply and demand pressures facing businesses in the freight and passenger vehicle operating sectors. These include the recent large rise in diesel prices, higher wage costs and increasing competition from foreign operators – which has been a feature in road freight transport for several years[2].

Figure 12.1 Flowchart illustrating the potential business and economic impacts of the London Low Emission Zone scheme.



Nature and scale of impacts

The nature of freight distribution and origins and destinations of passenger transport mean that the impacts of the scheme will be geographically dispersed across London, regionally, the national economy and abroad. However, the foreign impact is not within the scope of the analysis. The sectors of the economy affected on the 'supply side' are more concentrated (freight and passenger transport services) than on the 'demand side' where many industries from food and drink to tourism may be affected, to some degree.

As well as the direct supply and demand impacts, the business evaluation also considers the wider economy impacts of the scheme. For example, 'induced impacts' or 'second-order impacts' could be generated by increased or decreased business activity in sectors that would be directly or indirectly affected by the scheme. In cases where vehicle owners pass on costs, so that consumers bear a proportion of the cost of the scheme compliance through higher prices for fares, products or services, the effects are modelled on overall output and employment within the economy.

Methodology

The number of vehicles that are directly affected by the scheme is influenced by the age and emissions profile of vehicles travelling in Greater London. These have been considered in Sections 4 and 5 of this report.

The 'compliance costs' associated with the different responses to the scheme include: costs of purchasing new or used compliant vehicles; costs of retrofitting and upgrading existing vehicles; the daily London Low Emission Zone charge; any penalty charges; and costs of other alternatives such as modal shift, business relocation; and closing down business operations. The behavioural responses of vehicle owners and operators are influenced by the conditions of the market in which they operate, and their business processes. These responses are determined by:

- The type of business operators engage in.
- The market conditions in which the vehicle operator's business competes.
- Whether the vehicle operator owns or leases its vehicle.
- The turnover, transport costs, and cash flow characteristics of the business.
- The proportion of transport costs as part of overall costs.
- The characteristics of the fleet, the nature of the vehicles, and the costs associated with different response options.
- The 'do nothing' trend – what the operator would do in the absence of the scheme in terms of vehicle replacement, purchase and upkeep – according to fleet procurement strategy and replacement cycle.

The estimate of business compliance costs, in Transport's for London's Report to the Mayor (April 2007), was between £200 million and £300 million (present value to 2015/16). A better appreciation of compliance costs is becoming available as it is now clear that some Euro I and Euro II heavy goods vehicles and coaches have been manufactured and type approved with Euro III requirements for particulate emissions levels, and so require no action in order to be compliant with the scheme.

Transport for London will be monitoring the scale of compliance costs from the scheme and their assessing consequent impacts on the economy.

The distribution of how the 'compliance costs' get absorbed within the UK economy depends on:

- Who are the direct consumers of transport services; who are the final consumers of transported goods.
- Who pays the compliance cost.
- Where they are located.

'Compliance costs' are incremental costs borne by operators or owners of non-compliant vehicles at the introduction of the scheme. The incremental costs are established by considering a 'do nothing' scenario. Without the London Low Emission Zone scheme, all operators or owners still bear a 'baseline' cost of vehicle replacement, as vehicles are replaced when their economic lives draw to an end. In the 'do nothing' scenario, all vehicles would, over the long term, comply with the scheme standards through existing patterns of vehicle replacement. Without cash-flow constraints, the scheme, would in effect, therefore bring this replacement schedule forward. Thus, 'compliance costs' would be the costs that are incremental to the baseline replacement and maintenance costs.

Key assumptions

In the business and economy impacts assessment, it has been previously estimated by TfL that two thirds of heavy goods vehicles, 75 percent of light goods vehicles, 50 percent of coaches and buses, and 55 percent of minibuses that travel in Greater London would otherwise be compliant with the requirements of the relevant scheme or phase upon introduction of the scheme.

Owners and operators of non-compliant vehicles will consider a range and combination of options to ensure that their vehicles will conform with the scheme:

- Make the vehicle compliant by replacing non-compliant vehicles with new or used compliant vehicles; fitting particulate trap abatement equipment to non-compliant vehicles; or re-engineering non-compliant vehicles.
- Modify operating procedures by only using compliant vehicles in London and using others elsewhere (ie re-deployment of fleet).
- Use routes that avoid the zone.
- Switch to vehicles under 3.5 tonnes.
- Stop trading in London.
- Pay the daily charge or attempt evasion by continuing to use non-compliant vehicles and risk incurring a penalty charge.

The route that non-compliant vehicles operators chose to follow is analysed using TfL's operator cost model which looks at two broad decision-making frameworks:

- Responses gathered in the 2006 TfL Vehicle Operator Survey.
- The 'Whole Life' framework, whereby operators are assumed to follow the most economically cost effective actions over a ten-year period given the initial capital expenditure, subsequent refresh costs and the sum of the operating costs including fuel consumption.

The business and economy impacts assessment develops the outputs from the operator cost model to considers the proportion of the 'compliance costs' that would be absorbed directly by the owners of the vehicles and also the extent that these costs are passed on to the wider London economy through higher fares for passenger transport services, higher product prices, employment costs and fees. This important aspect is based on analysis of businesses by size and in terms of whether they operate in the 'hire or reward' or 'own account' market, taking into consideration market characteristics, including the level of competition in the industry. As an example, it has been assumed that small, 'own account' businesses operating in a competitive market are least likely to pass on their costs of compliance.

The business and economy impacts: sensitivity analysis

Sensitivity analysis has been employed to allow for uncertainty in a number of key assumptions, including estimates of the number of non-compliant vehicles operating in Greater London and variations in vehicle operator responses.

The **high cost scenario** uses DVLA registration data and the results of the 2006 TfL Vehicle Operator Survey to estimate the numbers of vehicles operating within London. Generally these estimates are at the higher end of the range of estimates for vehicle numbers developed during the feasibility study for the scheme. This scenario also assumes that most operators ultimately comply with the scheme through the substitution of compliant vehicles within their fleets rather than paying the daily charge or attempting to evade the scheme.

These assessments indicate that from zero to 5 percent of owners of non-compliant vehicles will either pay the charge or risk evasion. Finally, the high cost scenario assumes operators will increase prices so that costs of compliance can be recovered over a five-year period. At the same time, it is also assumed that only half the expected short-term increases in employment, in vehicle sales, and maintenance in response to the scheme, are sustained in the longer term.

The **low cost scenario** estimates for the numbers of vehicles are taken from the mid-ranges of estimates developed during the feasibility study for the scheme. This scenario also assumes that a higher proportion of owners of non-compliant operators would either pay the charge or risk evasion, and a lower long-term impact of cost increases on the wider economy. All the costs of the scheme are assumed to be passed on from vehicle operators to consumers and are spread across the full evaluation period; that is vehicle operators raise prices so as to recover the costs over the ten-year period of evaluation. Finally, the scenario assumes that indirect impacts from investments in vehicles sales and maintenance are sustained throughout the evaluation period.

Outputs from the business and economy impacts assessment

The eventual impact of the scheme on the national economy depends on how compliance costs are absorbed in terms of changes in economic output and employment. This in turn depends upon how the demand or end use sectors respond to changes in the cost of transport services and products; how householders or consumers responds to higher prices; and the responses from ancillary sectors such as retrofitting of abatement equipment, maintenance and new vehicle sales.

Presented below is the summarised output from the business and economy impacts assessment by the main vehicle market categories affected by the scheme; heavy goods vehicles, light goods vehicles, coach and bus, and minibus.

Heavy goods vehicle operator market

The costs of compliance with the London Low Emission Zone will vary depending on the type of heavy goods vehicle (HVG), size of operator and nature of business whether ‘own account’ or ‘hire or reward’ as well as local market conditions. TfL analysis suggests that the estimated costs of complying with the scheme represent between 2 and 3 percent of typical industry per vehicle HGV ‘standing’ and ‘running’ costs of between £80,000 and £135,000 per year, depending on vehicle type and miles operated[3].

Large and medium sized operators would have greater scope to either avoid the payment of the charge through re-deployment or by passing on costs as an increase in product price or as a variation in contract terms. Additionally, the unit cost of compliance for these operators is low as these fleets tend to be made up of predominantly newer vehicles in accordance with their three- to seven- year replacement cycle, so these operators would be less likely to be affected by the proposed scheme requirements.

Smaller operators, particularly 'hire or reward' carriers with a single vehicle, expect to be affected to the greatest degree by the additional cost of complying with the scheme. This is because these operators tend to have older vehicles and are relatively more cash constrained than larger operators. Other segments of the market have the option to redeploy their fleet so that non-compliant vehicles are routed to avoid London, and given their relatively weak negotiating position in comparison with their customers, it is considered likely that the cost of compliance will largely be absorbed by these operators.

Within Greater London, the geographical distribution of the heavy goods vehicle fleet suggests that the impacts of the scheme would be felt most strongly in outer London, particularly areas with a significant amount of industrial activity, and locations close to the major road network eg M25, M4, A13, and M1. In terms of the geographical distribution of impacts outside Greater London, it is estimated that these would be felt to some extent in all regions of the UK. However, as there is a higher concentration of heavy goods vehicles based in the South East, East of England, the North West and the Midlands, the potential impacts could be greater in these areas.

Light goods vehicle operator market

As with heavy goods vehicle operations, the costs of compliance with the London Low Emission Zone will vary depending on the type of light goods vehicle (LGV), size of operator and nature of business whether 'own account' or 'hire or reward' as well as local market conditions. TfL analysis shows the costs of complying with the scheme represent between two percent and four percent of typical industry per vehicle LGV 'standing' and 'running' costs of between £40,000 and £70,000 per year, depending on vehicle type and miles operated[3].

These vehicles will be affected in phase 3 of the scheme from October 2010. Although it is relatively inexpensive to replace or upgrade an LGV, the size of the population of LGV in comparison to HGVs means that this sector will potentially incur a large proportion of the total cost of compliance with the scheme.

Companies with larger fleets tend to have newer vans and to be able to redeploy fleets. As such this future phase of the scheme would be unlikely to have a significant impact on them. The scheme would have a bigger impact on companies and private operators with smaller fleets and older vehicles. These operators are estimated to incur the highest LGV unit cost of compliance, though this would still be significantly lower than the average cost of compliance for HGV operators. Almost half of all vans are privately owned. The majority of LGV operators are in the service sector, rather

than in the haulage or freight sector, while the largest single industry sector is construction.

While some LGV operators may exit the market or relocate their business or business activities to outside London, the analysis assumes that in the long run the market shares of exiting operators will be subsumed by more efficient existing or new operators in the market. This assumption is based on current trends for increased LGV use in London and the surrounding counties.

Bus and coach operator market

Scheme requirements extended to buses and coaches in phase 2. Buses and coaches over 5 tonnes gross weight came under stricter air quality regulation from July 2008. Bus services within London are tendered by TfL and, by stipulation of the contract, these vehicles need to comply with the relevant emissions standards. Local bus services outside London, by nature of their geographic location, would not be directly affected by the scheme.

The per vehicle cost of compliance for a coach will vary depending on the type of vehicle, on the size of operator, nature of business (whether 'own account' or 'hire or reward') and end use servicing sector. Local market conditions will also dictate the compliance cost.

Large operators already operate with relatively new vehicles on regular high intensity routes. These would be least affected by the scheme requirements. Some London-based smaller coach operators with older fleets operating in niche markets may face a series of large one-off costs. The per-vehicle cost of compliance is estimated to be highest among these operators, and those that are also cash constrained may consider reducing the size of their operations, a move out of London, or in extreme circumstances, closing down operations. As a result there may be a concentration of business among fewer larger operators.

Outside London, smaller operators may benefit from the scheme by picking up good deals in the second hand vehicle market. However some discretionary trips, such as school outings and weekend breaks, may be potentially diverted to other less expensive locations.

Vehicles owned or leased by London boroughs and community transport operators are relatively few in number by comparison. Increasingly these services are leased by local government on contract hire, and so the direct cost would be incurred by the leasing companies. Any indirect costs passed onto boroughs are assumed to be fully absorbed by Government budgets.

Minibus operator market

Scheme regulations extend to minibuses in phase 3 of the scheme from October 2010. The per-vehicle cost of compliance for a minibus will vary depending on the type of vehicle, on the size of operator, nature of business and local market conditions.

It should be noted that there is less data available for minibuses compared to the other vehicle types. Based on the data that is available and model assumptions and analyses, the costs of compliance among minibus operators in the Greater London area is estimated to be low compared with other vehicle types.

'Hire or reward' and the vehicle rental sector account for the largest share of minibus business activity. Due to the high intensity of use and the trend towards contract leasing, vehicles servicing these sectors are younger and most would be compliant in the normal course of events by October 2010. Larger fleet sizes offer options for re-deployment as well as access to cash flow to invest in upgrading and renewing fleets.

Minibus operators classified as 'business own use' do not primarily operate in transport services sector and typically use their vehicles to transport goods, workers or customers in order to provide their main product. These operators would absorb scheme costs and pass on the price that they charge for their core products or services. A small proportion of minibus activity is related to community organisations providing mainly voluntary and charitable services that tend to have older fleets and have a lack of transport alternatives. Cash and fund raising constraints may mean a number of community organisations would potentially face the prospect of having to replace their non-compliant vehicles sooner than expected.

The number of minibuses registered in London is relatively low; however, there are high concentrations in some inner London boroughs, in clusters around Heathrow airport, and around the M25.

Ancillary market impacts

The impact of the scheme will additionally extend to a number of sectors and industries. These ancillary markets include: maintenance, repair, and sales of parts and accessories; used vehicle dealers; new vehicle dealers; and vehicle leasing companies.

Businesses in the maintenance, repair, and sales of motor parts and accessories sector will benefit positively from operator compliance with the scheme as a result of increased demand for retrofitting, maintenance, and parts and accessories eg particulate traps.

Businesses in the used vehicle market are likely to benefit from operator compliance as there would be more churn in the market. The sale price of used vehicles would change because demand for compliant vehicles would increase, whereas demand for non-compliant vehicles would go down in London. This change in prices would result in owners of compliant vehicles benefiting from increased demand for their vehicles, whereas owners of non-compliant vehicles will face lower resale values of their vehicles. This effect may be mitigated in part by the national nature of the resale market and also the benefits for the purchaser of the availability of lower priced vehicles in areas with no scheme similar to the London Low Emission Zone. Future monitoring of the impact of the scheme will aim to examine vehicle price trends to gauge to the extent to the scheme has impacted market prices for second hand vehicles.

Dealers of new vehicles are also likely to benefit from compliance with the scheme in the short run due to accelerated replacement of new vehicles. The effects that the scheme has on the new vehicle market are likely to be spread across the country. This is because a substantial proportion of vehicles that travel in London are registered outside Greater London and surrounding counties, and because new commercial vehicle dealers are more likely to be located outside London.

Leasing companies constitute a majority of the UK demand for new commercial vehicles, and the contract hire sector consists primarily of new vehicles (typical maximum age of a rented or leased vehicle is 6 years).

The demand for leased vehicles is likely to grow because:

- Operators that currently lease their vehicles would be expected to increase market share.
- Operators with currently non-compliant vehicles may choose to lease compliant vehicles rather than purchasing new vehicles.

Direct impact on the economy

The sectors of the economy where Gross Value Added is estimated to experience the greatest percentage impact from the scheme are the 'transport and storage' and 'construction' sectors in and around London, and coach operators to and from London[4].

The impact on the 'transport and storage' sector reflects, as would be expected, the large proportion of affected vehicles that are operated in the sector and also the competitive nature of business activity among smaller operators who tend to have to accept the standard market price for services and would therefore have to absorb the costs associated with the scheme. It is possible that some operators may leave the market if profit margins become too low. However, the business and economy impacts assessment assumes that due to the competitive nature of the road haulage market any market share left by exiting operators would be immediately taken up.

The potential impact on the construction sector has two major components: impact on heavy goods vehicle operators; and the impact on the light goods vehicle market. In the HGV market, owners of non-compliant vehicles within the construction sector are expected to pass the scheme compliance costs on to the final consumers. A very small net employment impact is therefore expected.

In the LGV market, it is likely that some small construction businesses in the London area would suffer losses in the short run. Privately-owned LGVs in the construction sector tend to belong to small enterprises, and as such, the costs associated with compliance would constitute a relatively large proportion of these businesses' cash flows. These businesses operate in competitive markets with the effect that some may potentially be forced to exit the market, as compliance costs erode their operating margins. However, the business and economy assessment assumes that the demand for construction services in the market remains unchanged, largely unaffected by the scheme, so the market shares of the exiting businesses would be taken up by existing firms or new entrants.

Coach users are divided into tourists and commuters and both are likely to incur some of the costs associated with scheme compliance. Given the very small proportional increase in the total cost of an average coach-based holiday to London, it is highly likely that tourists will absorb this small increase in costs and would continue to visit London. No discernable impacts are therefore likely to be experienced by tourist-serving sectors, such as restaurants, hotels and entertainment as a result of the scheme.

Coach commuter demand between London and surrounding counties tends to compete with rail services. It is possible demand could decrease as a result of the increase in commuter coach fares as operators attempt to pass on the cost of scheme compliance. Model estimates of the relatively small decrease in demand however suggest that there are unlikely to be any noticeable employment impacts in the commuter coach sector.

UK households would incur the bulk of the costs of the scheme that get passed down, from higher prices for transport services. These costs, however, would be likely to be spread out over a large area and spending base (beyond London and surrounding counties), and as such constitute a negligible proportion of household spending over the evaluation period. Impacts are therefore unlikely to be discernable on consumer expenditure in the UK or London.

The ancillary markets likely to be affected by the scheme – vehicle leasing, repair and maintenance sectors; abatement equipment suppliers; and new and used vehicle sales sectors – are expected to see an increase in business activity and jobs. Estimates of the increase in economic output among these sectors has been based on the cost of retrofitting vehicles; the cost of buying new and used vehicles; the numbers of new, used and retrofitted vehicles; and the profit margins within the sectors.

Impacts on the wider economy

Wider economy impacts refer to the indirect and induced impacts arising from the scheme – principally from the consequences of the compliance costs. The wider impacts on economic output and employment have been estimated using national input-output multipliers for regional economic growth adjusted for geographical coverage and excess capacity in the sectors.

The business and economy assessment estimates the direct negative impact of the scheme on the economy could be in the region of £300m-£470m (low and high cost scenarios) in present value terms to 2015/16. This comprises the scheme compliance costs and consequent direct economy impacts primarily based on the extent to which businesses absorb or pass on these costs to consumers.

Once the impact of increased activity in ancillary sectors is included, the overall impact on the economy falls to a loss of around £80m-£110m.

It is important to note that this is an estimation of the impact on the economy. A cost benefit analysis would consider compliance costs and other impacts, such as the benefits to public health, set out in section 11.

Table 12.1 summarises the overall sum of the direct, indirect and induced impacts of the scheme on all sectors of the economy. Indirect and induced impacts include the wider effects arising from changes in national and regional economic output from the scheme. Taking these into consideration, the overall economic loss from the direct and wider economy impacts over the 10 years of the evaluation of the scheme could lie in the range of £100m to £270m, with a potential net loss of 140 to 420 full time equivalent jobs. By comparison, and to contextualise these impacts, in 2007 London's economic output (Gross Value Added) was estimated to be around £200bn, with employment totally around 4.7 million workplace jobs[5].

In reality, freight and passenger services are likely to be redistributed from non-compliant vehicle operators to compliant operators with the consequent transfer of jobs. The demand for freight and passenger services is largely unaffected by the scheme so the market share of businesses is expected to transfer from non-compliant to complaint operators, both existing businesses and new entrants.

Table 12.1 Total economic output and employment, low and high cost scenarios, to 2015, 2008 prices.

		Scenario	
		Low Cost	High Cost
Direct impact, present value (£ million)	Loss	-300	-470
	Gain	220	360
	Net	-80	-110
Total GVA (including indirect and induced impacts), present value (£ million)	Loss	-380	-720
	Gain	280	450
	Net	-100	-270
Total employment impact (FTE 2006-2015)	Loss	-570	-1,100
	Gain	430	680
	Net	-140	-420

Source: Business and Economy Impacts Assessment, 2006
Note: Direct impact comprise the scheme compliance costs and consequent direct economy impacts

12.3 Business trends in the freight transport industry

This section reviews recent trends in the key road transport sectors affected by the scheme, profiling longer term background trends in the industry and presenting the principal datasets that will be used by TfL to monitor the actual impacts of the scheme going forward. The market and industry data presented below will be used to monitor trends in the level of business activity, numbers of operators, operator fleet sizes and any discernable impacts on end use sectors. TfL's business and economy impacts assessment suggests the scheme may impact the effected vehicle operator markets in the following ways:

- Moving freight haulage and passenger transport towards greater consolidation;
- Greater importance of large operators;

- Increase in fleet sizes with newer vehicles;
- Movement away from own-account operations to contract hire and leased vehicles; and
- Re-distribution of regional Gross Value Added from certain sectors (eg construction and freight and passenger transport) to others (eg, vehicle sales and repairs and maintenance).

General economic trends in London and the UK

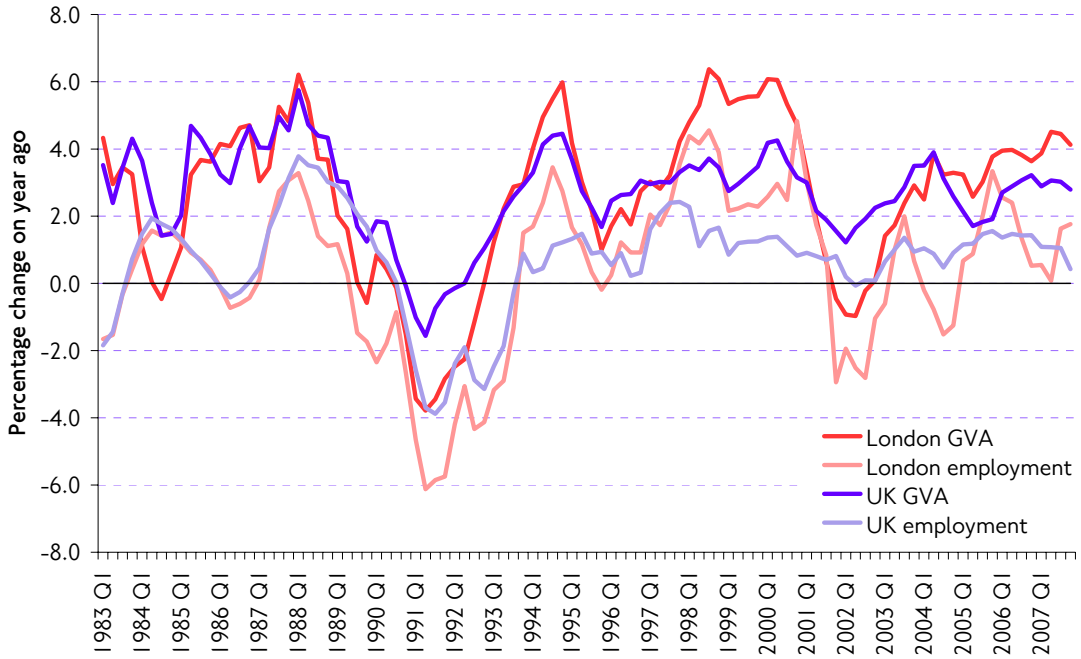
During 2007 London's economic output, Gross Value Added, continued its recent trend of strong growth. Annual output in London grew at 4.1 percent in quarter four of 2007, compared to 2.8 percent in the UK as a whole.

Key features of recent growth and future forecasts are as follows:

- Over the long-term, London's economy tends to grow at the same rate as the economy of the UK as a whole. However, London tends to be a more volatile economy – the peaks and troughs of the red lines as seen in Figure 12.2, compared to the blue lines.
- London's output growth has recovered from the shallow recession at the beginning of 2002 as in 2007 grew well above trend (and above the growth rate of the UK as a whole) at around 4 percent. London's employment growth also picked up during 2005-2007.
- London's Gross Value Added growth rate is projected to weaken to 1.3 percent in 2008, rising to 1.8 percent in 2009 and 2.2 percent by 2010.
- The total number of workforce jobs in London was over 4.7 million in Q4 2007. According to latest macro economic projections London is forecasts to see small contractions in employment in 2008 and 2009, followed by slow growth in 2010[6].
- London household spending will probably grow more slowly than Gross Value Added in 2008 and 2009 and is forecast to match it in 2010.

To contextualise, this variable macroeconomic background is the business and economic climate in which phases 1 and 2 of the London Low Emission zone have been launched.

Figure 12.2 Gross Value Added and employment growth in London and the UK, 1993-2007.



Source: GLA Economics, Quarterly Economic Outlook, Quarter 1 2008.

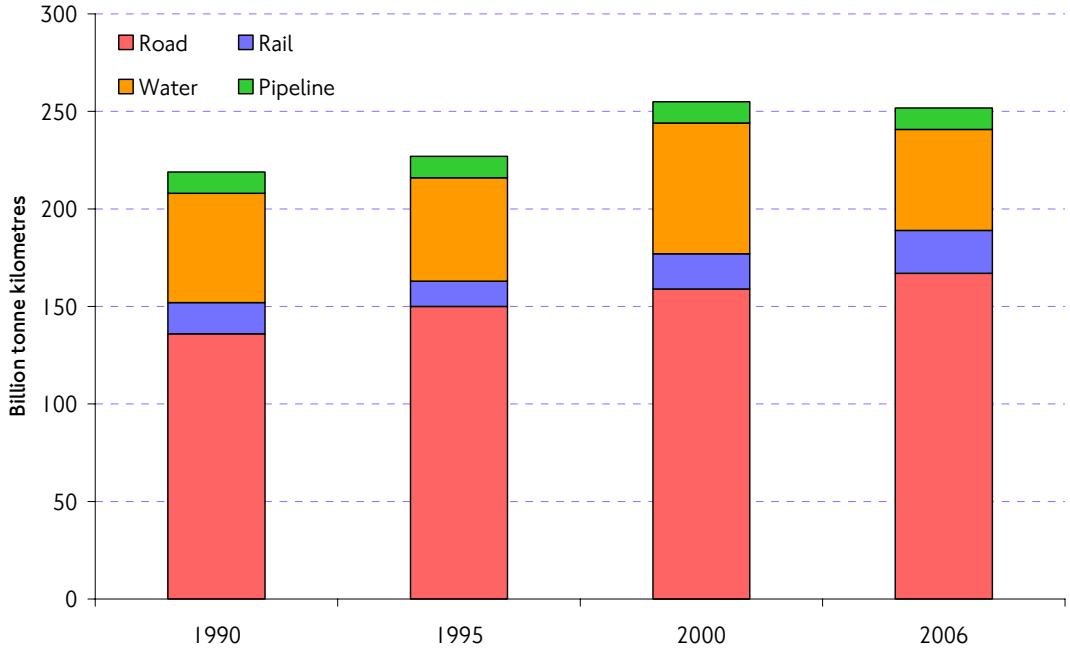
Road freight's contribution to UK economy

Road haulage is vital for economic life as it links producers, suppliers, and customers facilitating production, trade, and competition. Road haulage will be among the sectors most visibly impacted by the scheme.

The Department for Transport samples the movement of British registered goods vehicles' freight activity for all vehicles over 3.5 tonnes (gross vehicle weight), using their Continuing Survey of Road Goods Transport[7]. This is a wide ranging and longstanding national survey widely used across the industry to assess trends in road freight transport.

Figure 12.3 shows freight is moved using several diverse modes of transport including rail, water and pipeline. However, road haulage, due to its flexibility and adaptability in connecting suppliers and consumers, dominates all transport modes – accounting for two thirds of the estimated 252 billion tonnes moved nationally in 2006.

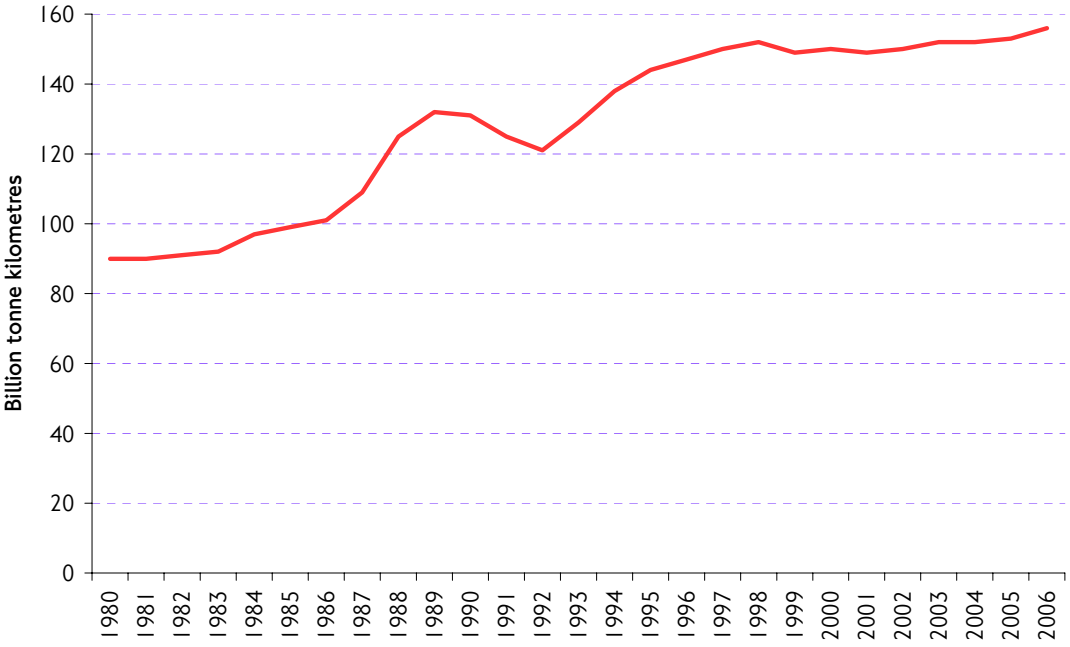
Figure 12.3 Freight moved by mode of transport, Great Britain, 1990-2006.



Source: Transport Statistics GB 2007.

While the London Low Emission Zone initially applied, as from February 2008, to HGVs over 12 tonnes, all lorries over 3.5 tonnes gross weight and buses and coaches over 5 tonnes gross weight came under stricter air quality regulation from July 2008. Large vans and minibuses will need to meet the London Low Emission Zone standards from October 2010.

Figure 12.4 Heavy goods vehicle business activity. Billion tonne kilometres moved, Great Britain, 1980-2006.



Source: Continuing Survey of Road Goods Transport.

Analysis of the Continuing Survey of Road Goods Transport shows that since the 1980s road freight business activity in Great Britain (in terms of tonne kilometres moved) has risen by a steady 2 percent per annum, notwithstanding some cyclical variation, as shown in Figure 12.4. This compares to average annual UK Gross Domestic Product growth of 2.5 percent over the same period. Despite the importance of freight to business and economic activity, its significance in terms of economic output has declined relatively in the last decade.

Table 12.2 illustrates that in the early 1980s, freight activity, as measured in tonne-kilometres, was rising roughly in line with real GDP at around 2 percent per annum. During the economic boom and subsequent downturn between 1987 and 1994, tonne kilometres rose ahead of economic activity with an average annual growth rate of 3.4 percent compared to 1.9 percent growth in GDP. In the most recent decade however economic growth has risen above its long term trend at 2.8 percent per annum but this has coincided with average annual growth in goods vehicle tonne kilometres of 0.7 percent. Table 12.2 provides further details.

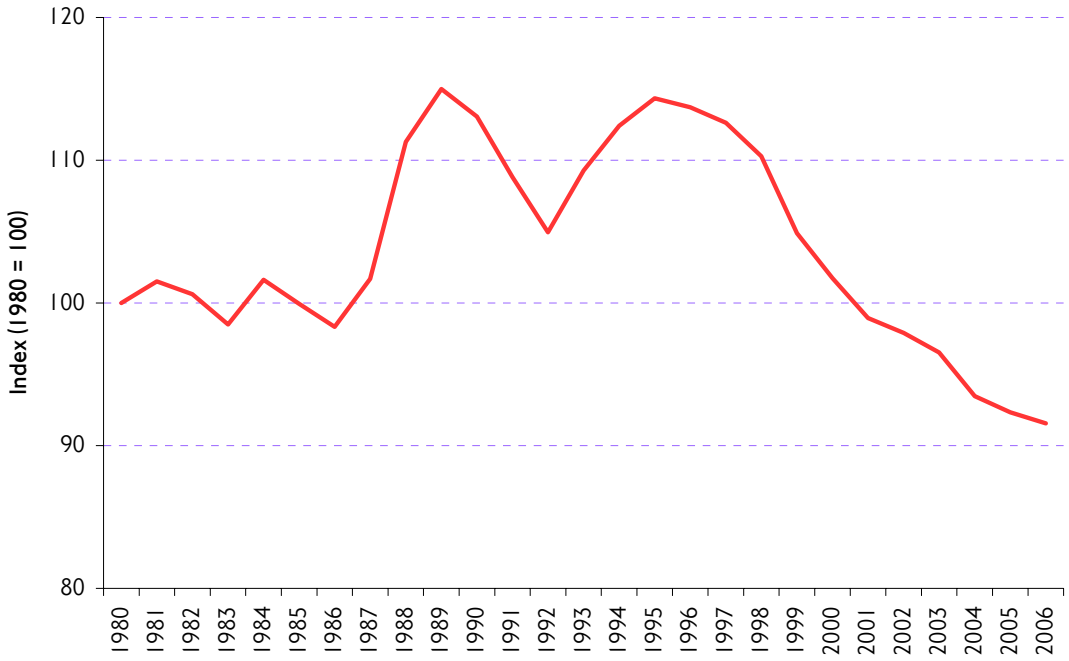
Table 12.2 Average annual growth in goods vehicle tonne kilometres and UK GDP.

	UK HGV tonne km moved	UK Real GDP
1980-1986	1.9%	2.3%
1987-1994	3.4%	1.9%
1995-2006	0.7%	2.8%

Source: Transport Statistics Bulletin 2006 and Office of National Statistics.

These trends have reduced the contribution of freight transport activity to economic growth, as illustrated in Figure 12.5, which shows an index of tonne kilometres per pound (£) of economic output. This 'decoupling' of economic growth and road haulage activity has largely been due to the structural change in the British economy with the persistent decline in the production of manufactured goods and the steady move to a service sector based economy.

Figure 12.5 Heavy goods vehicle tonne kilometres in Great Britain per £ of UK GDP. Index in 1980 = 100.



Source: Department for Transport and Office of National Statistics.

Employment in the road freight sector

The Annual Business Inquiry[8] provides detailed official Office of National Statistics data on the number of employees in employment by sector and location. It is among the most comprehensive sources of employee information, with data available at a relatively fine level of geographic and industrial disaggregation. Publication delays the release of data by up to 12 months and as a consequence the latest available data, released in December 2007, relates to 2006.

However, the 2006 Annual Business Inquiry data was subject to several sources of discontinuity, most significantly a change in the reference survey date from December to September. By no longer capturing seasonal employment gains between September and December the 2006 Annual Business Inquiry understates employment growth in London for 2006 if compared with 2005 estimates. This affects some sectors more than others, for example retail, hotel and restaurant sectors which are greatly influenced by seasonal business activity. The freight distribution sector which supplies goods to these sectors is therefore also impacted by seasonal factors.

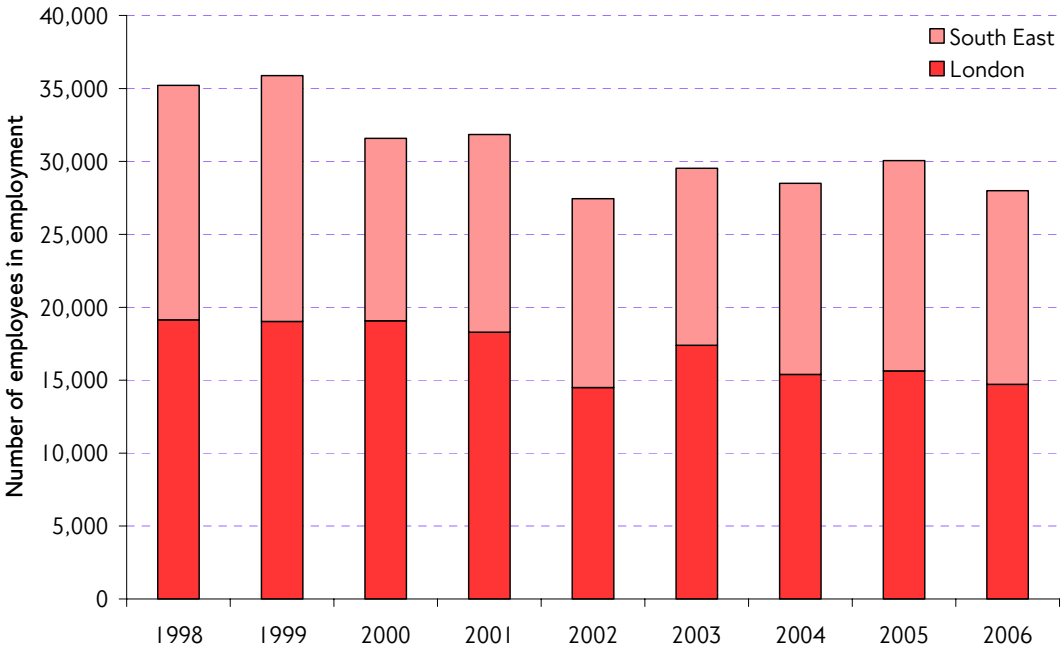
While this discontinuity in the Annual Business Inquiry makes the year on year comparison between 2005 and 2006 infeasible, the 2006 Annual Business Inquiry is nevertheless useful in identifying broad trends in employment in the road freight sector. Thus given the above caveat, Figure 12.6 illustrates that employment in road freight in 2006 totalled 274,384 – above the average of the last eight years of nearly 273,000.

Figure 12.6 Number of employees, road freight, Great Britain. 1998-2005.

Source: Annual Business Enquiry, Office of National Statistics.

In the South Eastern and Metropolitan Traffic Area, which broadly covers Greater London and the South East, employees in road freight transport fell from over 35,000 in the late 1990s to a low point of 27,500 in 2002, with the largest falls in Greater London itself as shown in Figure 12.7. Since 2002, there has been variation in employment levels, although employee numbers have not recovered significantly above 30,000.

Figure 12.7 Number of employees, road freight, Greater London and the South East, 1998-2006.



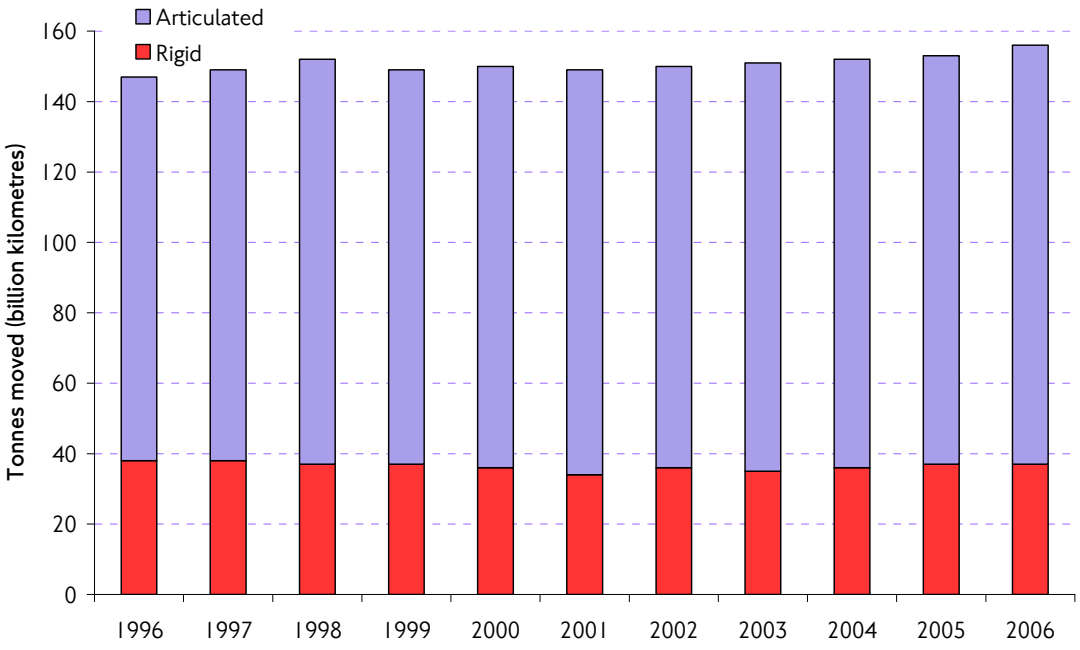
Source: Annual Business Enquiry, Office of National Statistics.

12.4 Key business characteristics in the road freight sector

National trends

Articulated heavy goods vehicles, which tend to be the newest vehicles satisfying the latest regulatory standards, account for three quarters of the freight tonnage-kilometres moved by road. This reflects their economies of scale (Figure 12.8).

Figure 12.8 Goods moved by vehicle type. Billion tonne-kilometres, Great Britain, 1996-2006.



Source: Continuing Survey of Road Goods Transport.

The growth in large articulated goods vehicles has been partly prompted by changes in legislation. In 1995, the maximum permissible gross weight for a heavy goods vehicle was 38 tonnes[9]. The general maximum permissible weight limit was raised to 40 tonnes in 1999 and to 44 tonnes in 2001. The increases in the maximum permissible gross weight for heavy goods vehicles has encouraged economies of scale and a shift in road haulage activity towards larger vehicles. Between 1996 and 2006, goods moved by articulated vehicles over 33 tonnes increased by 21 percent to 113 billion tonne kilometres. In contrast, goods moved by all types of rigid vehicles fell by 3 percent to 37 billion tonne kilometres, over the same period.

Heavy goods vehicles serve a variety of end use sectors, and as expected, articulated vehicles dominate tonnage moved. The demand for 'aggregates or bulk products' such as ores, cement and building materials, which accounts for slightly over a quarter of all tonnes moved, is largely driven by construction activity. The 'food and drink' sector, accounting for a similar proportion of tonnes moved includes agricultural products and is keenly influenced by food retail and supermarket business activity, which in turn is highly correlated with overall consumer spending.

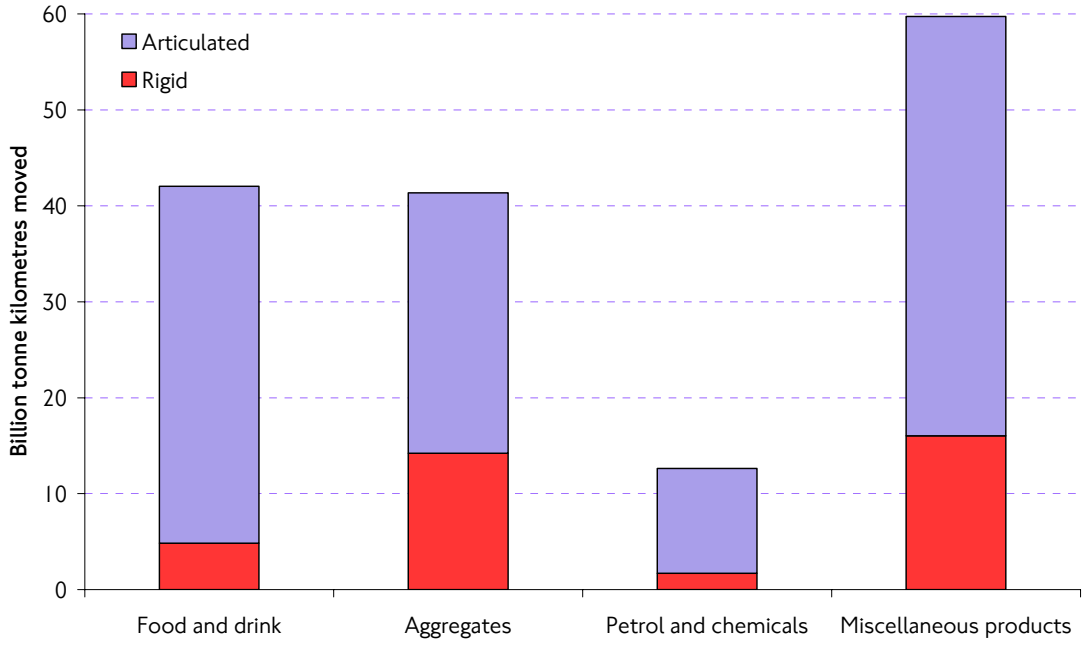
Nearly one in ten tonne kilometres moved services 'petroleum and chemical products' (fuelling forecourts and general manufacturing). The largest end use sector with almost 40 percent of tonnes moved is 'miscellaneous products' which consists a plethora of different industry sub sectors linked to manufacturing and the shipment of miscellaneous articles including post and parcel services.

The wide variety of end use sectors that heavy goods vehicle activity serves means that there are a diverse set of market drivers that influences the demand for heavy goods vehicle business. It also means that any increased costs in freight transport and hire charges will be widely dispersed across a wide range of sectors and industries.

Greater London

The impact of the scheme is expected to be felt most prominently in Greater London. Data from the Continuing Survey of Road Goods Transport on tonnes moved for trips with either an origin, destination or both in London, or where vehicles were registered in London, shows that London's 13.2 billion tonnes moved in 2006 accounts for 8.5 percent of tonnes moved nationally. This is a fairly efficient utilization of the goods vehicle capacity given that Greater London accounts for about 12 percent of national population and reflects the high population density levels within London. Generally, Greater London is a consumer of goods and a producer of services and as a result more goods enter than leave the capital[10]. Trade is dominated by two regions closest to London – the South East and the east of England.

Figure 12.9 Goods moved by end use and vehicle type. Billion tonne kilometres, Greater London, 2006.



Source: Continuing Survey of Road Goods Transport.

In 2006, nearly three quarters of London's 13.2 billion tonnes kilometres was moved by articulated vehicles, as shown in Figure 12.9, although in terms of the numbers of

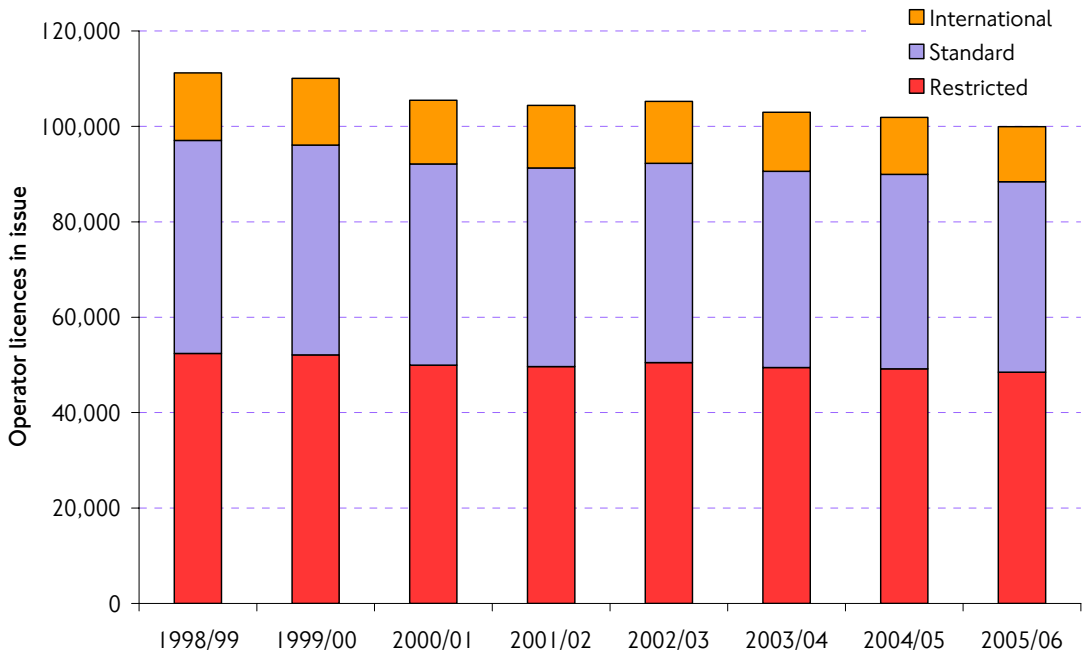
vehicles seen in London articulated and rigid lorries are roughly evenly split. In 2006, Greater London tonnes moved rose by 3.0 percent, in comparison to national growth of 2.0 percent, recovering most of the business activity lost in 2004 when tonnes moved fell by 4.1 percent. Growth was led by articulated vehicles which rose by 8.4 percent year on year while tonnes moved by rigid lorries fell by 9.9 percent in the same period.

12.5 Key operator characteristics in the road freight sector

National trends

In Britain, all operators of goods vehicles over 3.5 tonnes (with some exceptions) must hold an operator's licence which has been issued to them by the Government's Traffic Commissioners[11]. There are three types of licences on issue, based on the nature of business activity: Restricted; Standard and International. Restricted licences allow operators to carry their own goods in the course of their trade or business in Britain and on international journeys. Standard licences authorise operators to carry both their goods in the course of their trade and goods for other people for 'hire or reward'. International licences are Standard licences but operators are also allowed to carry goods for themselves and other people to countries outside Britain.

Figure 12.10 Heavy goods vehicle operator licences in issue, Great Britain, 1998/99-2005/06.

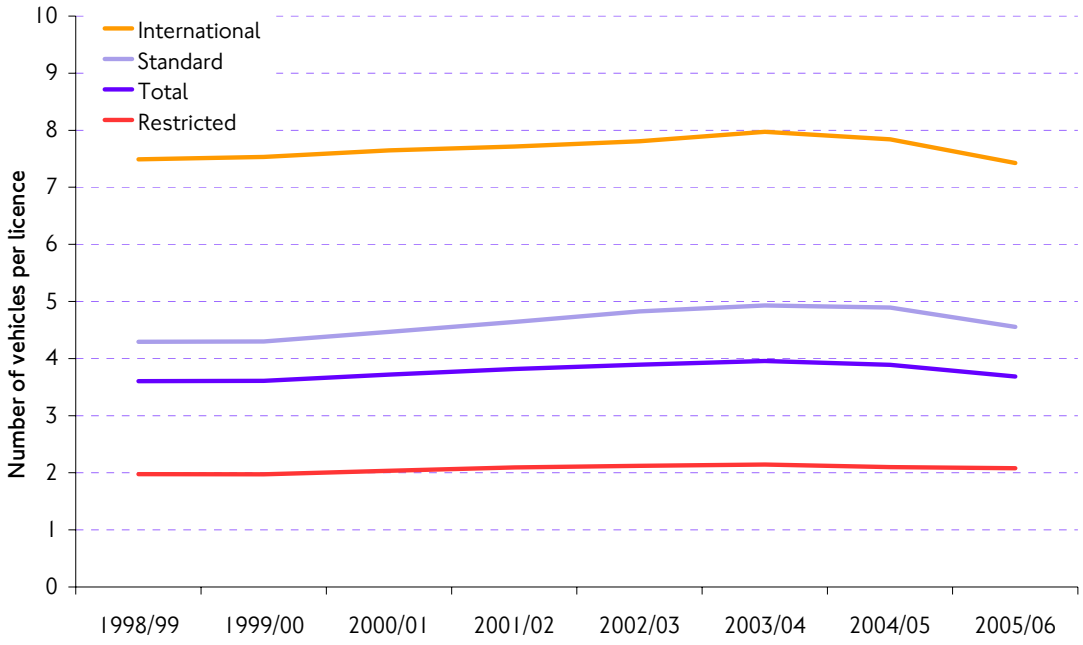


Source: Traffic Commissioners' Annual Reports.

In the last decade, operator licences in issue have declined every year, with the exception of 2002/03 as shown in Figure 12.10. In 2005/06, the last year of available data, operator licences fell to 99,916, a fall of 1.9 percent on the previous year, in line with the long term average annual rate of decline. While all categories of licences have declined, International operator licences, which account for the smallest share (12 percent) of all licences, have fallen the most.

Operators are also required by the Traffic Commissioners to specify the numbers of vehicles registered under each licence. This enables an estimation of the average size of fleets as shown in Figure 12.11. The average size of fleets varies with the type of operator licence. Fleet sizes among International license holders are about 3.5 times bigger (7.4 vehicles per licence) than the fleet sizes of those operating under Restricted licences (2.1 vehicles per licence). This means that while International licence holders account of about one in ten of all operator licences they account for nearly a quarter of all registered vehicles.

Figure 12.11 Average vehicle fleet size by licence type, Great Britain, 1998/99-2005/06.



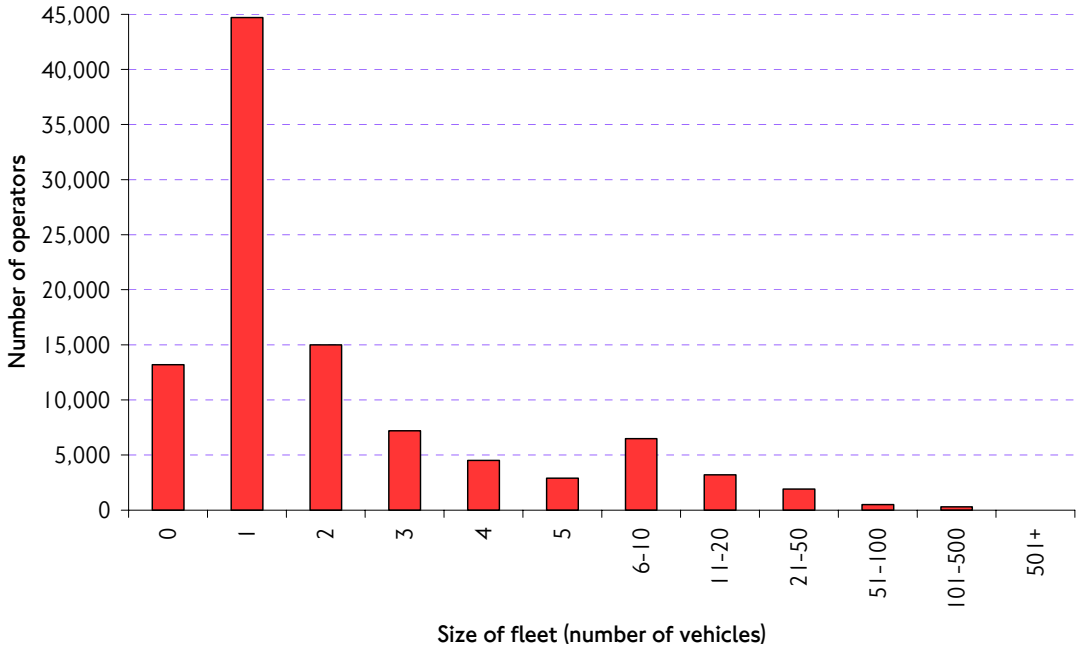
Source: Traffic Commissioners' Annual Reports.

The overall average fleet size across all types of operator licences grew steadily to four vehicles per licence in 2003/04. In the last two years the overall fleet size has declined, however. This decline in overall average fleet size is a result of fewer vehicles operated by International and Standard licence holders. Indeed, the average fleet size among International licence holders fell to 7.4 vehicles per licence in 2005/06, below the levels recorded in 1998/99.

The impact of the scheme may be gauged by changes in average fleet size with fleet sizes increasing if there is consolidation in the industry with small operators and operations being subsumed by larger operators. However, this would contrast with recent background trends.

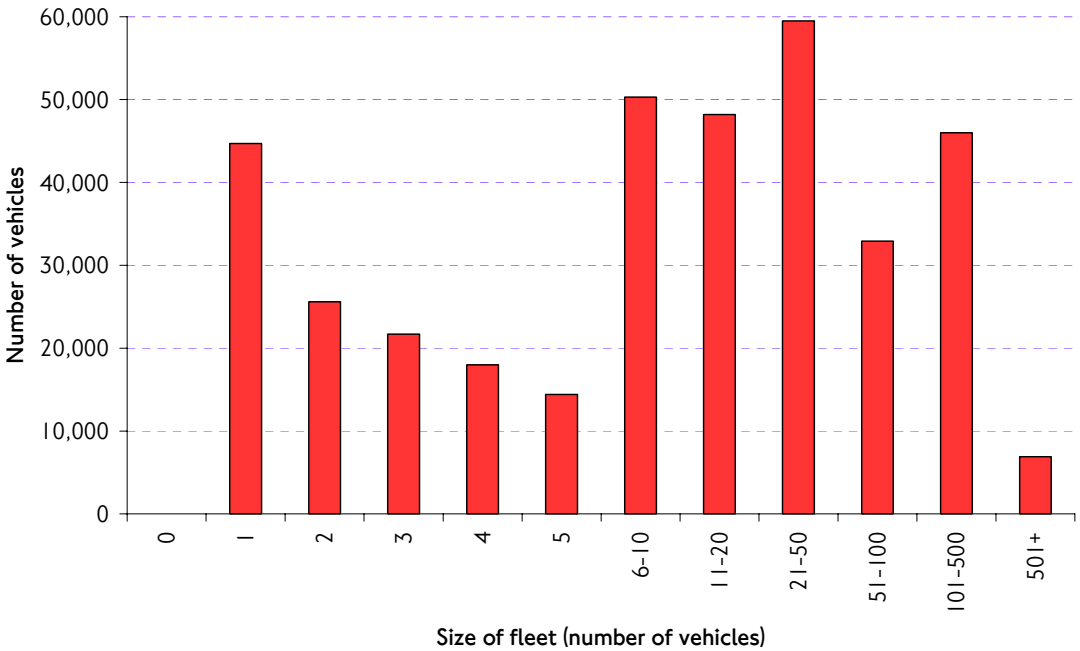
Figure 12.12 shows that the heavy goods vehicles sector's industrial structure is skewed with 45 percent of operators (44,700) operating with one vehicle in 2005/06 according to data from the Vehicle and Operator Services Agency[12]. The number of operators with large fleets – more than 100 vehicles – was small at 275, or 0.3 percent, of all operators. This means that in terms of the vehicle population the large operators account for a disproportionately large number of all vehicles as shown in Figure 12.13.

Figure 12.12 Number of vehicle operators by size of fleet, Great Britain, 2005/06.



Source: Vehicle and Operators Service Agency.

Figure 12.13 Number of vehicles by size of fleet, Great Britain, 2005/06.



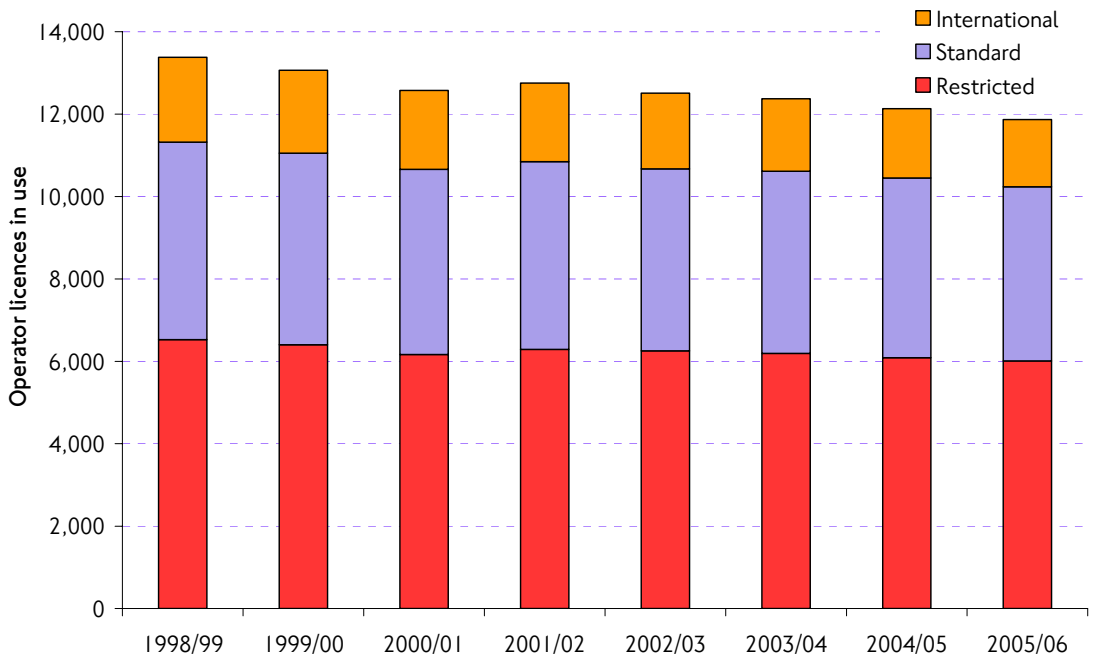
Source: Vehicle and Operator Services Agency.
Note: a zero fleet size occurs where an operator has a licence but does not specify any vehicles on it, for example, if vehicles are only required for short periods and are therefore hired.

South Eastern and Metropolitan Traffic Area

The licensing and regulation of operators, as prescribed by the Goods Vehicles (Licensing of Operators) Act 1995, falls to the independent Traffic Commissioner for the relevant geographical region. The Traffic Area which encompasses the London Low Emission Zone scheme is South Eastern and Metropolitan which also includes Surrey, West Sussex, East Sussex and Kent. In 2005/06, the South Eastern and Metropolitan Traffic Area accounted for 11.9 percent of all licences in issue nationally. This proportion has varied only slightly since 1989/99. The long term trend in operator licences in issue in the South Eastern and Metropolitan Traffic Area very closely reflects the national picture.

In the South Eastern and Metropolitan Traffic Area, heavy goods vehicle operator licences in issue have declined every year since the late 1990s, with the exception of 2001/02 (Figure 12.14). In 2005/06, operator licences in issue totalled to 11,867, a fall of 2.2 percent on the previous year, slightly ahead of the long term average annual rate of decline of 1.7 percent. While all categories of licences have declined, International operator licences, which account for the smallest share (14 percent) of all licences, have fallen the most, averaging an annual rate of decline of 3.3 percent.

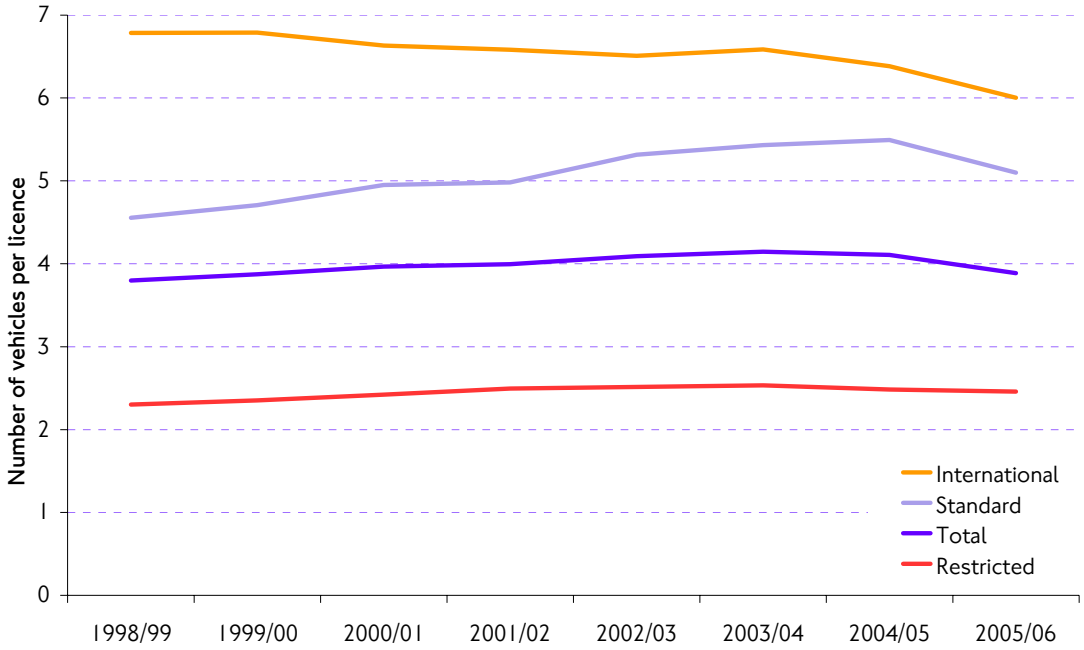
Figure 12.14 Heavy goods vehicle operator licences in issue, South Eastern and Metropolitan Traffic Area, 1998/99-2005/06.



Source: Traffic Commissioners' Annual Reports.

Figure 12.15 shows that in the South Eastern and Metropolitan Traffic Area the overall average fleet size across all types of operator licences has remained relatively stable at around the national level of four vehicles per operator licence since the late 1990s. This has been due to countervailing trends: growth in average fleet size among Standard licences holders, and a decline in average fleet size by holders of International operator licences. In 2005/06, however, average fleet size among standard licence holders also fell resulting in a dip in the overall average fleet size to below four vehicles per licence.

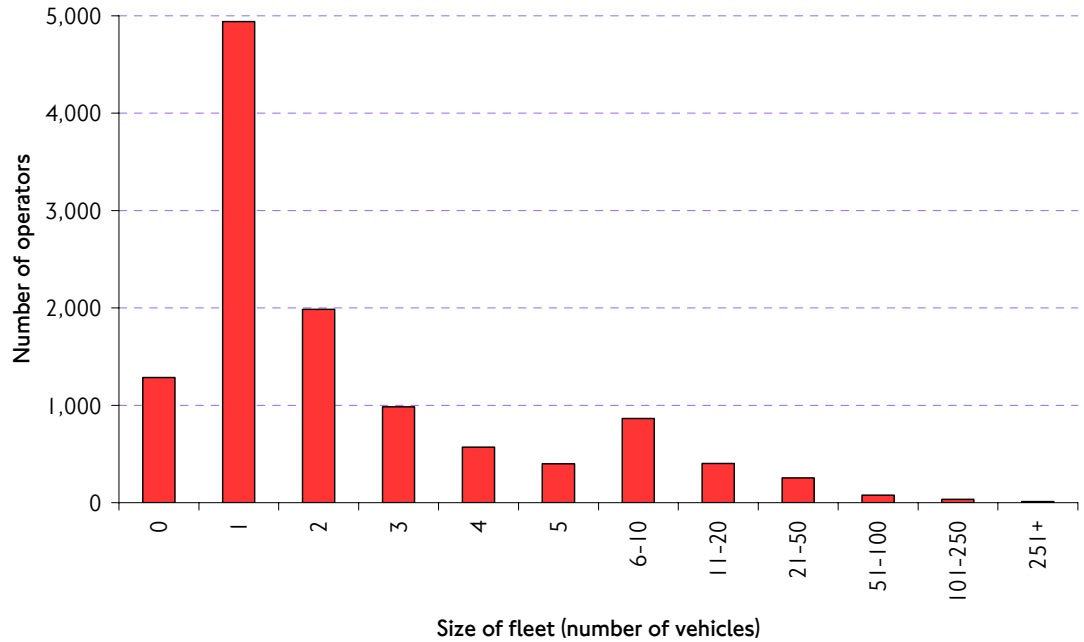
Figure 12.15 Heavy goods vehicle average vehicle fleet size by licence type, South Eastern and Metropolitan Traffic Area, 1998/99-2005/06.



Source: Traffic Commissioners' Annual Reports.

The impact of the London Low Emission Zone may be gauged by changes in average fleet size with fleet sizes increasing if there is consolidation in the industry. This would be in contrast to recent trends in Greater London and the South East.

Figure 12.16 Number of heavy goods vehicle operators by size of fleet, South Eastern and Metropolitan Traffic Area, 2005/06.



Source: Vehicle and Operators Service Agency.

Figure 12.16, shows that in the South Eastern and Metropolitan Traffic Area, the heavy goods vehicles sector's industrial structure is skewed with 42 percent of operators (4,942) operating with one vehicle in 2005/06[12]. The number of operators with large fleets – more than 100 vehicles – was small at 46, or 0.4 percent, of all operators in the region.

12.6 Business trends in the bus and coach market

In the second phase of the London Low Emission Zone implementation, from July 2008, bus and coach operators of passenger vehicles with more than 9 seats and with gross vehicle weight exceeding 5 tonnes were subject to the air quality regulations of the London Low Emission Zone.

Trips and passenger numbers

Official national statistics do not separate bus and coach operations. This is a major limitation in statistical data as the two types of passenger transport provision are treated as one though there are notable differences. Importantly, these differences are particularly relevant when comparing London to the rest of the country.

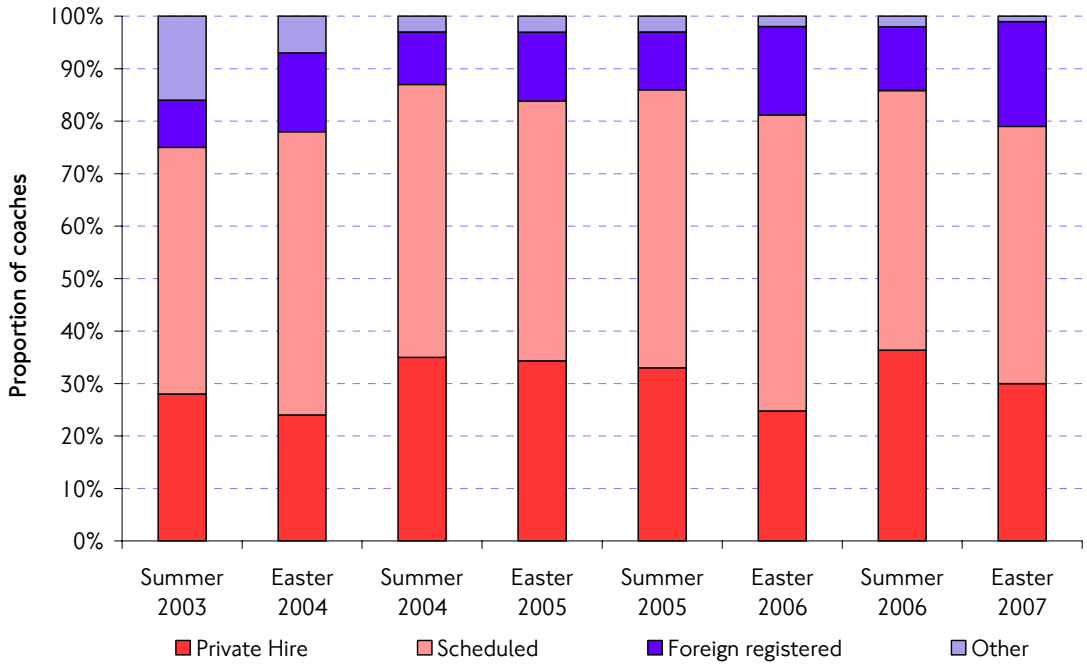
There is a very high level of bus provision in London, which is highly regulated and subsidised, and broadly caters for trips by commuters and local residents. In comparison London coach provision is provided by the private sector. In contrast to buses, the demand for coach services is mainly driven by longer distance domestic and international travel and by tourism.

Nationally the picture is different. The level of bus service provision is much lower than London in relation to population size, and both bus and coach services are largely financed from passenger fares and provided by the private sector.
These differences between bus and coach operations and between the picture in London compared to nationally implies that the impact of the scheme will reflect the specific conditions in London.

Bus operations outside London are not expected to be affected by the scheme, at least in the short term, due to the localised nature of bus trips. In London, in order to comply with disability legislation as well as lower pollution requirements, the majority of the London bus fleet, which is managed by TfL, has been replaced in the last five years and complies with the phase 2, July 2008 London Low Emission Zone requirement. As a result, the secondary impacts on bus business and economic activity arising directly from the scheme are expected to be negligible.

Coach demand at London Victoria totalled nearly 10 million passengers in 2004[13]. Coach passenger demand fell in 2005 but has stabilised at around 8 million passengers in 2006. National Express, a private bus and coach operator, serves London Victoria. Corporate responsibility information from the National Express website shows the company's coach profile by engine standard. All of the company's coaches are Euro II standard or above, with over three quarters Euro III or above[14].

Figure 12.17 Proportion of coaches, by type of service, entering central London between 7:00-19:00, on a random weekday, 2003-2007.



Source: London Travel Report 2007, Central London Coach Survey.

Figure 12.17 categorises all coaches entering or leaving central London between 07:00-19:00 on a random weekday by type of service. Central London is a much smaller area than that covered the scheme, and therefore will only represent a proportional of all coach movements. However, as most coaches in London would tend to enter central London's business and tourist district, it provides a useful insight on the distribution of different types of coach services: private hire, scheduled, foreign registered vehicles, and other.

According to this survey, on average about a half of all coaches are scheduled services (high intensity use) using the newest coaches. Private hire, serving domestic tourists, visitors to various London events throughout the year, business visits etc, account for between a quarter and a third of all coaches in central London, normally higher in summer months due to the greater frequency of visitor events in London. Foreign registered coaches, catering for longer distance travel also tending to employ newer vehicles, account for between 10-20 percent of coaches entering central London.

Generally, coaches are used less intensively than buses and therefore have a long vehicle life-expectancy, typically between 15-20 years. However, coaches travelling to London tend to be newer vehicles. London's role as a leading capital city with the higher standard luxury tourist market means those private coach operators based outside London will tend to employ their newest vehicles to serve the capital in order to maximise returns from their investments. London also serves a disproportionately large number of national and international scheduled services where intensive use requires the utilisation of the newest vehicles. New 'no-frills' coach and minibus operators such as the 'megabus' company, 'easybus' and National Express's 'NX FunFare' have recently started passenger services operating new fleets, offering very

low intercity fares and have consequently increased price competition in the sector. Any future business and economy impact assessment of the scheme will need to take account of these market changes which have coincided with the launch of the London Low Emission Zone.

Bus and coach operator licences in issue in South Eastern and Metropolitan Traffic Area

All commercial operators of public service vehicles that carry passengers by road for payment (hire or reward) must hold an operator licence. There are three main types of licence: Restricted licences; Standard licences; and International licences (Figure 12.18). These vary in the degree of restrictions in the use of buses and coaches with the International licence allowing the greatest freedom in the provision of passenger transport services.

There are approximately 1,000 bus and coach operators registered in the South Eastern and Metropolitan Traffic Area with nearly 17,000 vehicles between them accounting for 12 percent of all operators nationally, but nearly one in five of the national bus and coach fleet. Consequently, fleet sizes in the South Eastern and Metropolitan Traffic Area are higher than the national averages – across all licence types, particularly Standard and International licences.

In the last six years Restricted licence operators have grow by a strong 7.5 percent per annum while International operators have declined by on average 1.3 percent per annum. Standard licence bus and coach operators have shown steady growth of 2.3 percent per year – slightly ahead of overall growth in total public service vehicle operators in the South Eastern and Metropolitan Traffic Area of 1.8 percent per annum.

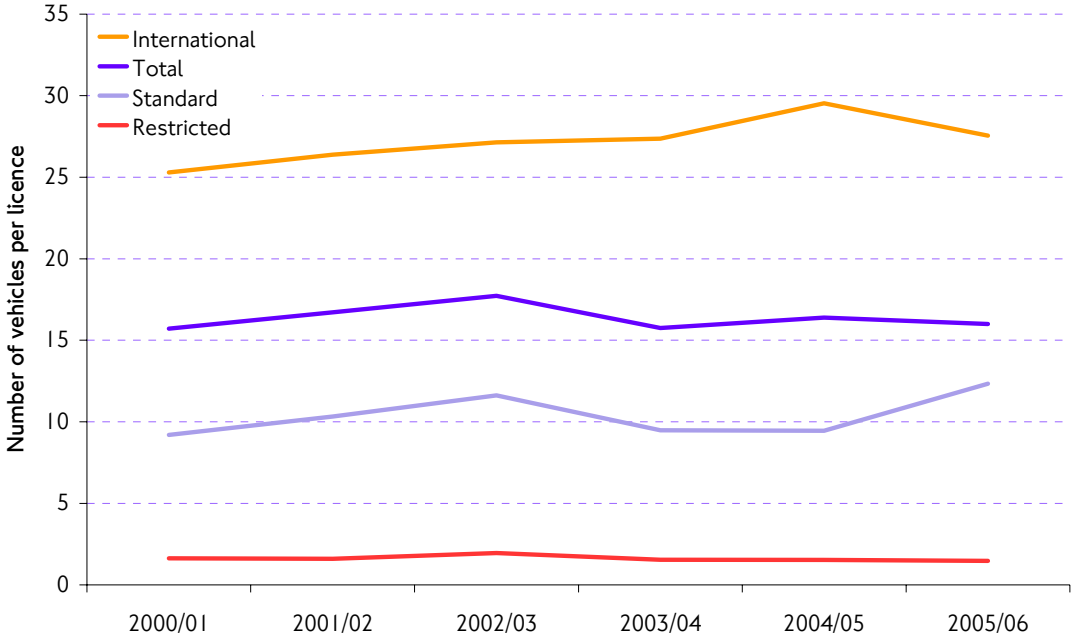
Figure 12.18 Bus and coach operator licences in issue, South Eastern and Metropolitan Traffic Area, 2000/01-2005/06.

Source: Traffic Commissioners' Annual Reports.

Total fleet size in the South Eastern and Metropolitan Traffic Area has grown marginally at an average annual rate of 0.4 percent in the last six years, with some annual variation (Figure 12.19). Fleet size among Standard licence operators have grow by a strong 6.1 percent per annum while Restricted license operator fleet sizes have contracted – falling by on average 2 percent per annum since 2000/01.

The impact of the scheme may be gauged by changes in average fleet size, with fleet sizes increasing if there is consolidation in the industry, with small operators and operations being subsumed by larger operators.

Figure 12.19 Bus and coach average vehicle fleet size by licence type, South Eastern and Metropolitan Traffic Area, 2000/01-2005/06.



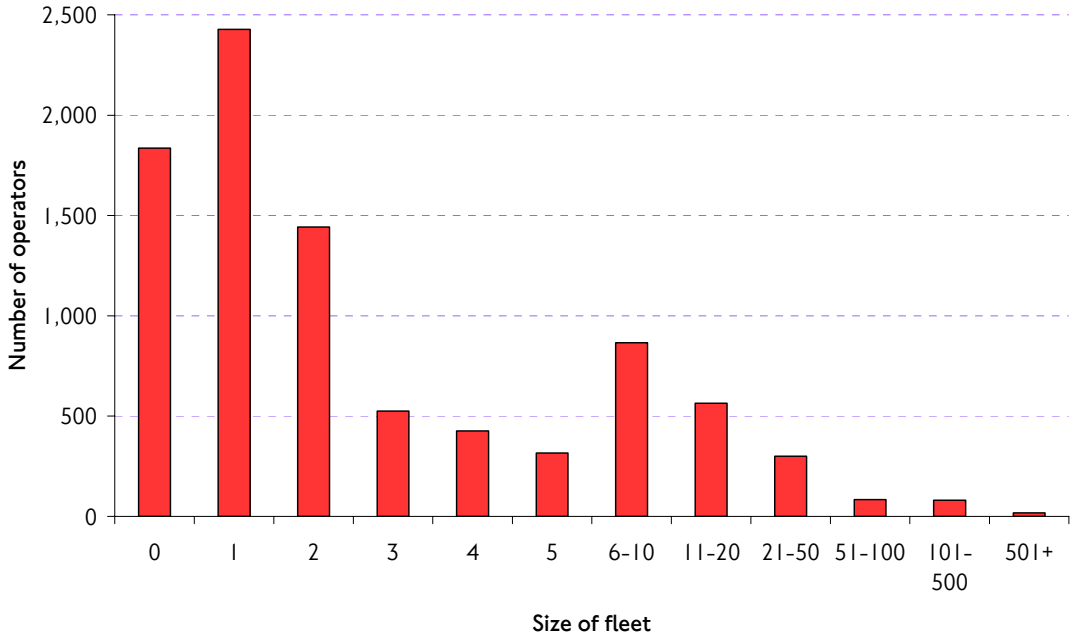
Source: Traffic Commissioners' Annual Reports

Market structure of bus and coach operators

According to data supplied by Vehicle and Operator Services Agency there were 8,889 registered bus and coach operators across the country in 2006/07, the year before the implementation of the scheme. Figure 12.20 shows one in five operators did not have any vehicles registered under licence implying that vehicles are hired, usually for short periods, when required. A quarter operate with one vehicle only while slightly over two thirds (68 percent) have a fleet of between one and ten vehicles.

Although the data does not allow bus and coach operators to be separated it can be assumed that most bus operators will have fleet sizes in excess of ten vehicles. Most of the smaller operators are therefore likely to be coach operators.

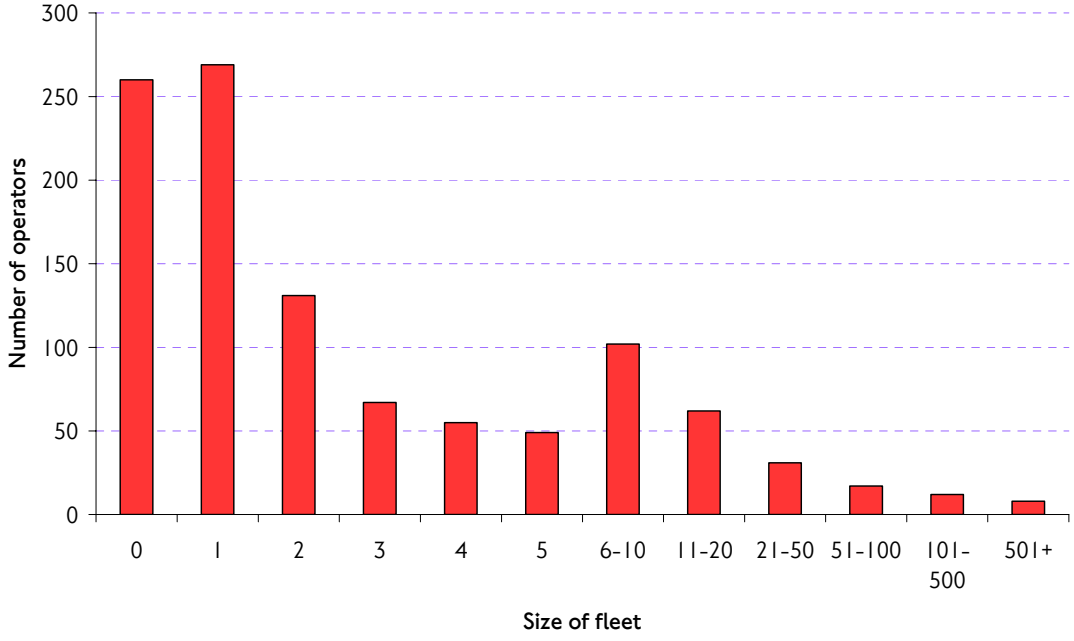
Figure 12.20 Number of bus and coach vehicles (all types) by size of fleet, Great Britain, 2006/07.



Source: Vehicle and Operators Service Agency.

The market structure of the 1063 registered bus and coach operators in the South Eastern and Metropolitan Area in 2006/07 very closely resembles the national picture (Figure 12.21). Almost one in four do not have any vehicles registered under licence, while 25 percent operate one vehicle only. Slightly under two thirds (63 percent) have a fleet of between one and ten vehicles.

Figure 12.21 Number of bus and coach vehicles by size of fleet, South East and Metropolitan Traffic Area, 2006/07.



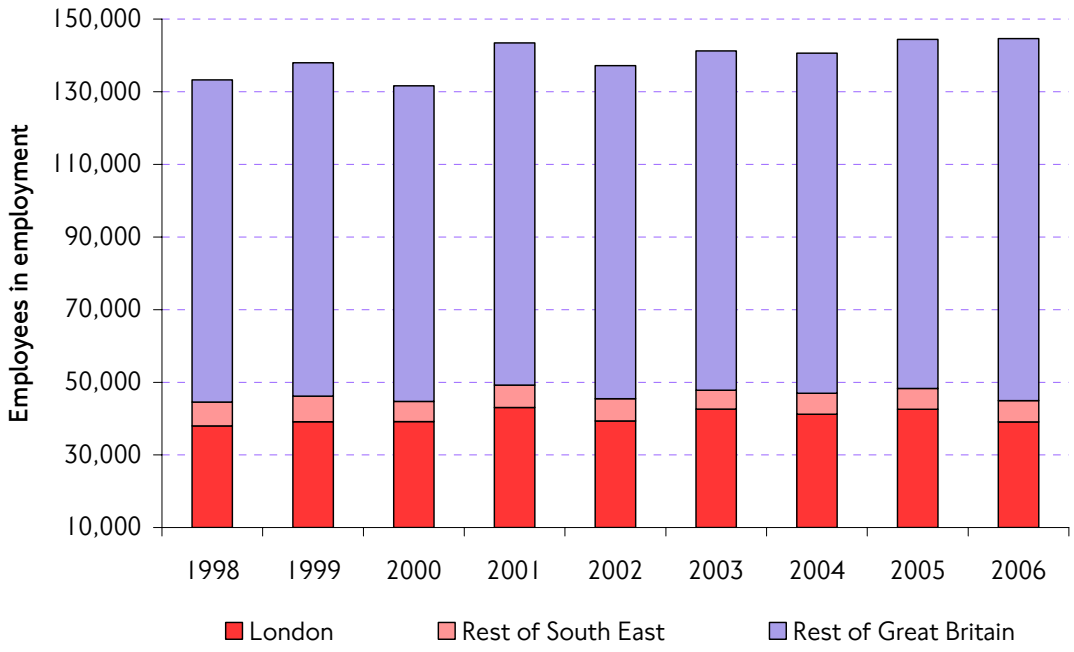
Source: Vehicle and Operators Service Agency.

As with the heavy goods vehicle operators, signs of consolidation in the bus and coach sector would most likely be reflected in fewer smaller operators. It is important to note that the significant proportion (20-25 percent) of operators that do not have any vehicles under licence will therefore escape the direct cost of compliance with the scheme. Changes in hire charges for leased vehicles will depend on several factors including the numbers of non-compliant vehicles held by leasing companies, which is unlikely to be high due to the high intensity of use and low average age of leased vehicles, and the level of price competition in the vehicle leasing sector that will determine to what extent compliance cost are passed on.

Employment in bus and coach sector

The Annual Business Inquiry provides detailed data on the number of employees in the bus and coach sector by location, and provides an additional useful source of independent data to gauge and assess business and economic activity in passenger transport. Given the discontinuity in the 2006 survey dataset, 2005 and 2006 year-on-year comparisons are difficult. Figure 12.22 shows the number of employees in passenger transport in Britain at around 144,500 – above the recent average of nearly 140,000.

Figure 12.22 Number of employees, bus and coach sector, Greater London, rest of the South East and rest of Great Britain, 1998-2006.



Source: Annual Business Enquiry, Office of National Statistics.

Employees in the South Eastern and Metropolitan Traffic Area account for one in three national jobs in passenger transport with employment in London dominating regional totals. Employment in the South Eastern and Metropolitan Traffic Area topped nearly 50,000 in 2001. Since then, while there has been greater variation in employment, employee numbers have not recovered significantly above 40,000.

Small, large and community bus permits in use nationally and in the South Eastern and Metropolitan Traffic Area

From October 2010, minibuses – passenger vehicles with more than 8 seats plus the driver's seat, below five tonnes gross vehicle weight – will be subject to the scheme. Traffic Commissioners' keep records of operators of 'small', 'large' and 'community' buses[15], which includes minibuses, must register for permits if they operate vehicles where a charge is made for transport. Permits are for an indefinite period and allow the owner to run one minibus at a time. These include minibuses operated by local authorities and other designated bodies. Where no charge is made for transport, permits are not required.

Table 12.3 Small, large and community bus permits issued, Great Britain and South Eastern and Metropolitan Traffic Area, 2000/01-2005/06.

	Small		Large		Community		Total	
	SE Met Area	National	SE Met Area	National	SE Met Area	National	SE Met Area	National
2000/01	1020	4299	8	55	0	17	1028	4371
2001/02	1020	3730	36	90	1	10	1057	3830
2002/03	1060	4812	31	97	0	12	1091	4921
2003/04	882	4412	2	111	0	13	884	4536
2004/05	953	4700	44	87	0	4	997	4791
2005/06	571	4076	0	84	0	3	571	4163

Source: Traffic Commissioners' Annual reports

Of the eight regional Traffic Areas nationally, South Eastern and Metropolitan is the largest issuer of 'small', 'large' and 'community' bus permits – accounting for 13 percent of all permits issued nationally, though the region's share has declined from nearly 25 percent in 2000/01.

Table 12.3 shows that in 2005/06, 571 small, large and community bus permits were issued in the South Eastern and Metropolitan Traffic area, a fall of 43 percent on the previous year. This was largely the result of a fall in the number of small bus permits, an acceleration of the downward trend of the previous few years. Small bus permits are mostly used for minibuses, below 5 tonnes (gross vehicle weight), having 9-16 seats plus a (paid) driver where the operator is allowed to charge for transport, but regulations do not allow the general public to be carried. These are operated for charitable or non-profit purposes by mainly voluntary organisations connected with education, religion, social welfare, and recreation. The number of large bus permits, which historically has been very variable, declined to zero in 2005/06. Changes in permits issued in the South Eastern and Metropolitan Traffic area have both reflected and contributed to wider national trends.

Given the historical variability in the numbers of minibus permits these series may prove less useful for monitoring the possible impacts of the scheme. As most

minibuses are operated by the voluntary sector, the cost of complying with the scheme from by 2010 may result in some cuts in service provision for some organisations. However the extent of the impact depends on the budgets and fundraising capacities of the voluntary sector and individual organisations.

12.7 Summary

Economic theory suggests the imposition of regulatory costs such as London Low Emission Zone standards on business will, everything else being equal, have some adverse impact on economic output. The extent of any impact will depend on the costs of compliance, options available to comply and the way in which businesses respond to the scheme.

The monitoring work aims to build on pre-scheme projections of the business and economy impacts of the scheme and market data relating to freight and passenger transport operations. TfL's business and economy impacts assessment quantifies the scale and distribution of the business impacts in terms of economic output and employment, while market data is used to monitor trends in the level of business activity, numbers of operators, operator fleet sizes and any discernable impacts on end use sectors.

The business and economy impacts assessment, conducted during the design stage for the scheme, suggests the overall loss to the economy from the direct and wider impacts of the scheme could lie in the range of £100m to £270m, with a potential net loss of 140 to 420 full time equivalent jobs. By comparison, and to contextualise these estimated costs, in 2007 London's economic output in terms of Gross Value Added totalled around £200bn, with employment of around 4.7 million workplace jobs.

All of the available market data pre-dates the introduction of the scheme due to publication lags. Trends in market data show strong signs of a recent decoupling between economic growth and freight activity, with significantly lower growth in HGV kilometres moved in comparison to economic output. There is a strong background decline in employment in the road freight sector in Greater London and the South East, though road freight employment in Great Britain has been more stable.

Many vehicle operators – road freight, bus and coach – are small businesses operating a single vehicle, though there are a few very large operators. Operator fleet sizes have generally been declining, particularly those operating internationally. This trend is a reflection of competitive pressures in the sectors which pre-date the introduction of the scheme.

The future business and economy monitoring programme (contained in **Appendix 3**) includes a re-calibration of modelling work and a re-estimation of impacts based on observed changes and an improved understanding of operator cost structures and adaptations following the introduction of the scheme. Background changes and trends in UK haulage and bus/coach industries will also be monitored.

13. Preparations for scheme implementation and some early results

13.1 Introduction

This section provides a brief summary of developments since the implementation of the first phase of the scheme on 4 February 2008, covering the period up to end April 2008. It looks at selected aspects of the operation of the scheme, and at how the trends in vehicle compliance have developed across the implementation period of phase 1 of the scheme, following on from the analysis presented in Section 5 of this report.

The implementation of the first phase of the scheme itself progressed smoothly, reflecting extensive preparation by TfL during 2007. Available indicators of vehicle compliance with the requirements of the scheme are highly encouraging. Data for April 2008 suggest that a compliance rate for heavy goods vehicles over 12 tonnes in weight affected by the phase 1 of the scheme of approximately 98 percent has been achieved. Encouraging degrees of 'operator pre-compliance' with the requirements of phase 2 of the scheme, affecting lighter goods vehicles of between 3.5 and 12 tonnes in weight, as well as buses and coaches, are also visible over the early part of 2008.

While it is too early to quantify the emissions and air quality impacts of these recent changes, the signs so far for the success of the scheme are highly encouraging.

13.2 Headlines

Phase 1 of the London Low Emission Zone scheme was introduced as planned on 4 February 2008. The scheme is unique to the UK and is the largest and most ambitious scheme of its kind to be implemented anywhere in the world.

The Low Emission Zone received a great deal of media interest from across the globe. The launch press conference held by Mayor Ken Livingstone was attended by local, national and international media including the BBC, Sky News and Reuters. In the first full week of operation, some 50,000 heavy goods vehicles over 12 tonnes were seen travelling within the zone, of which 91.5 percent complied with the scheme's emissions standards. By the end of April, the compliance rate for the first phase had risen to more than 95 percent. This is a great improvement since January 2007 when the monitoring work started. At that point, the compliance rate of these vehicles was around 75 percent. This reflects the impact the scheme had already had during 2007in changing vehicle operator behaviour.

13.3 Operation of the scheme

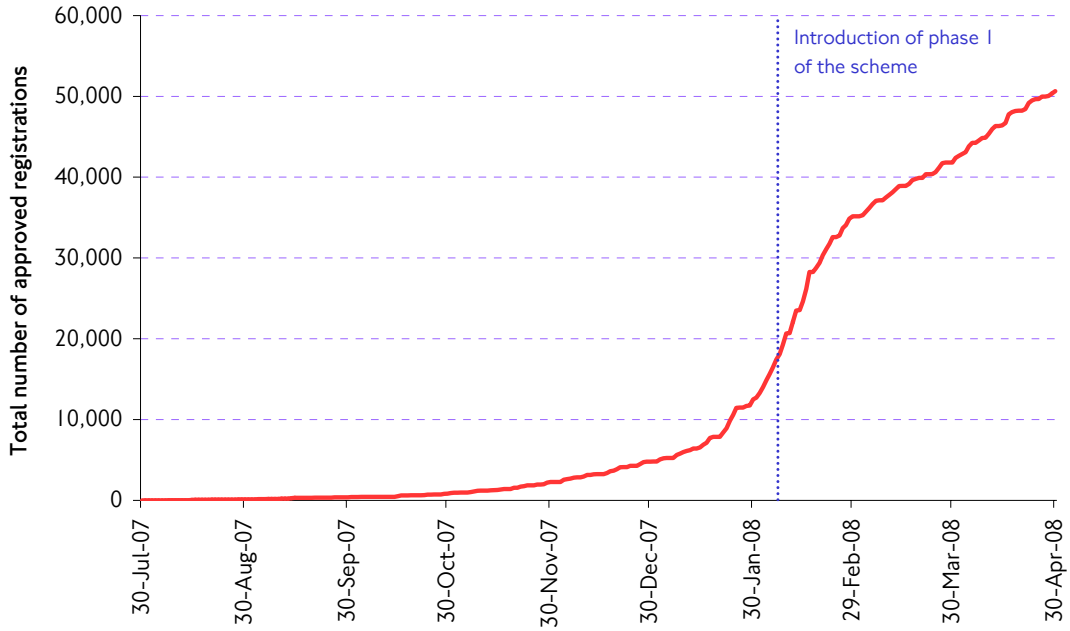
To facilitate a smooth implementation for the scheme, TfL set up its procedures and systems well in advance of the phase 1 start date during 2007. These procedures included elements such as the method of vehicle operator certification, call centre duties, and processes to deal with public complaints and enquiries. Some of the key data reflecting TfL's preparation during this 'run-up' period is illustrated in the following paragraphs.

Vehicle operator registration

The majority of UK operators do not need to register with TfL to be correctly assessed as compliant with the scheme as their vehicle details will already be on the Driver and Vehicle Licensing Agency (DVLA) database. As described in Section 5, TfL uses a sub-set of this database to identify vehicles and assess their compliance with the requirements of the scheme. All foreign and exempt vehicles will need to register with TfL and provide additional evidence as to their scheme compliance status. Operators that have obtained either a Low Emission Certificate (LEC) or Reduced Pollution Certificate (RPC) that effectively changes their Euro emission class do not need to register with TfL as TfL receives this information directly from Vehicle and Operator Services Agency.

Figure 13.1 shows the total numbers of approved vehicle registrations (largely exempted and foreign vehicles) made since July 2007. It is clear that the volumes of registrations started to increase rapidly from the start of 2008. Before the introduction of the scheme, TfL had received over 19,000 registration forms, with around 15,000 vehicles approved. Immediately after phase 1 of the scheme was introduced, a large number of vehicles started to register, but by the start of March, the numbers had steadied to between 1,500 and 2,000 new vehicles each week. By the end of April, over 50,000 of vehicles had been registered for the scheme.

Figure 13.1 Total numbers of approved vehicle registrations with TfL (largely foreign and exempt vehicles).

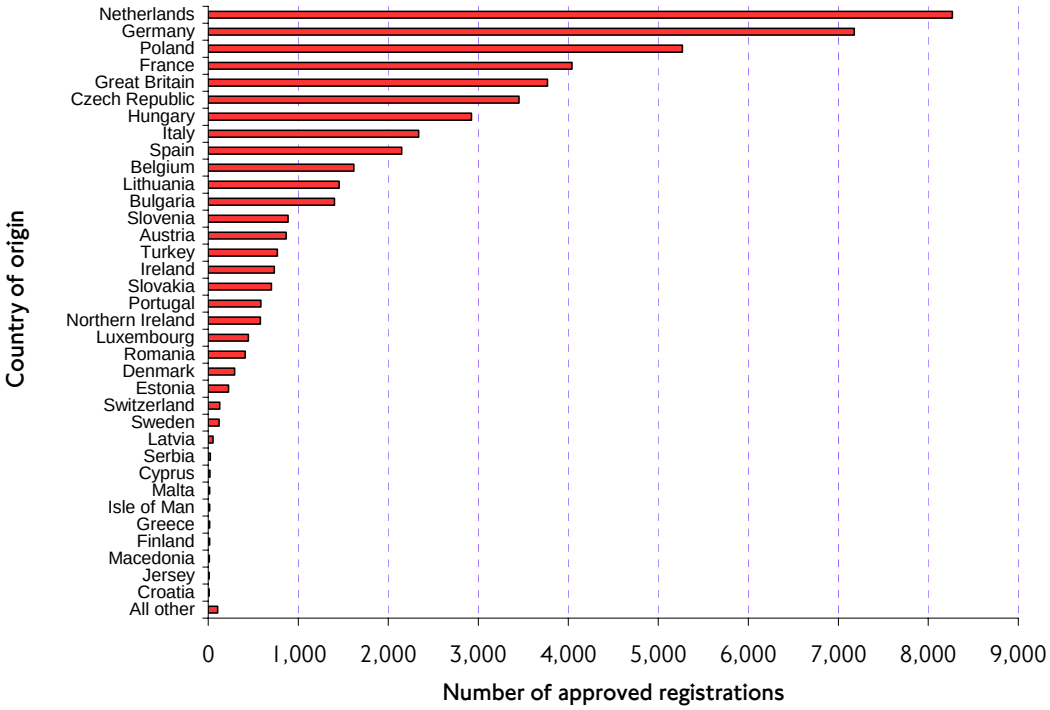


Foreign vehicles

Figure 13.2 provides further information on foreign vehicles, in terms of numbers of vehicles registered with TfL by country of origin from August 2007 to the end of April 2007. The graph shows that the majority of registered vehicles are from the Netherlands, followed by Germany. To date, over 40,000 foreign vehicles have

registered with TfL. The entry for British vehicles reflects vehicles that have registered for other purposes (eg exempt or showmans vehicles).

Figure 13.2 Registrations approved by country of origin.



Modified vehicles

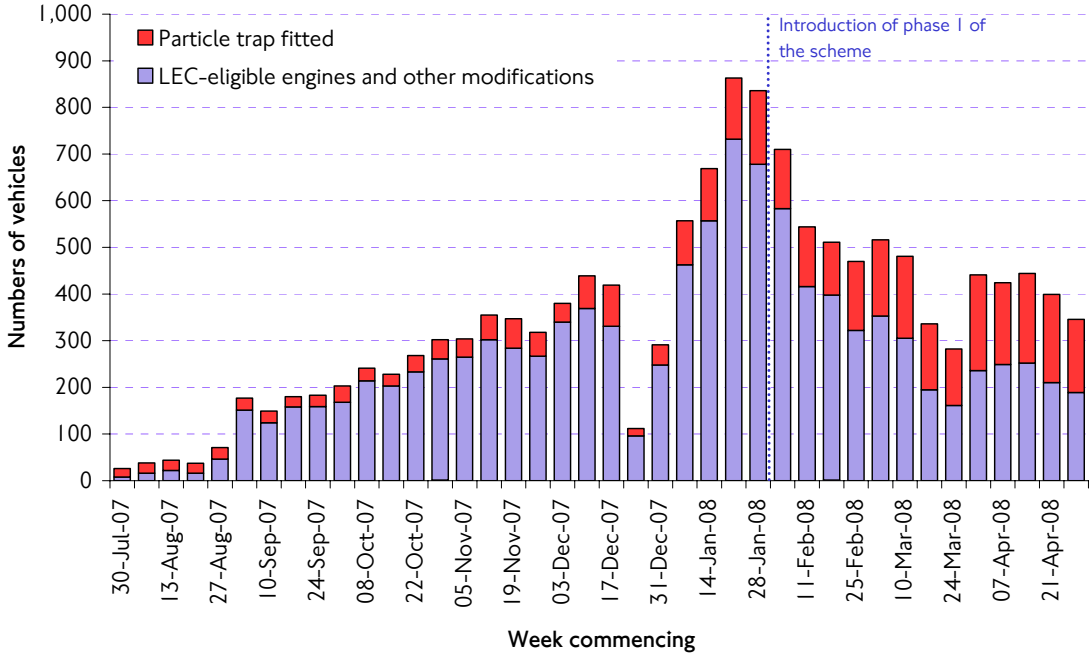
There are four routes by which an operator can be issued with a Low Emissions Certificate or Reduced Pollution Certificate to become compliant with the scheme. These routes are:

- modification or upgrade of their vehicle engine;
- fitment of approved pollution abatement equipment (such as a particle trap) to the vehicle;
- conversion to an approved alternative fuel; or
- provide proof of an 'eligible engine'.

The latter route reflects the fact that a proportion of vehicles manufactured to Euro Standards I and II do, in fact, meet the Euro PM III standard. Vehicles in this category need to take no physical action to comply with the scheme, but are nevertheless required to undergo a Vehicle and Operator Services Agency test to prove this.

Figure 13.3 provides a breakdown by week of the numbers of vehicles issued with these certificates. It clearly shows that the numbers of vehicles issued with a Low Emission Certificate or Reduced Pollution Certificate increased at the start of 2008. Also, a larger proportion of vehicles had particle traps fitted after the scheme was introduced. This could be due to the long lead times to fit a trap, meaning that operators have had to wait for the conversion to be completed, after booking into approved test centres.

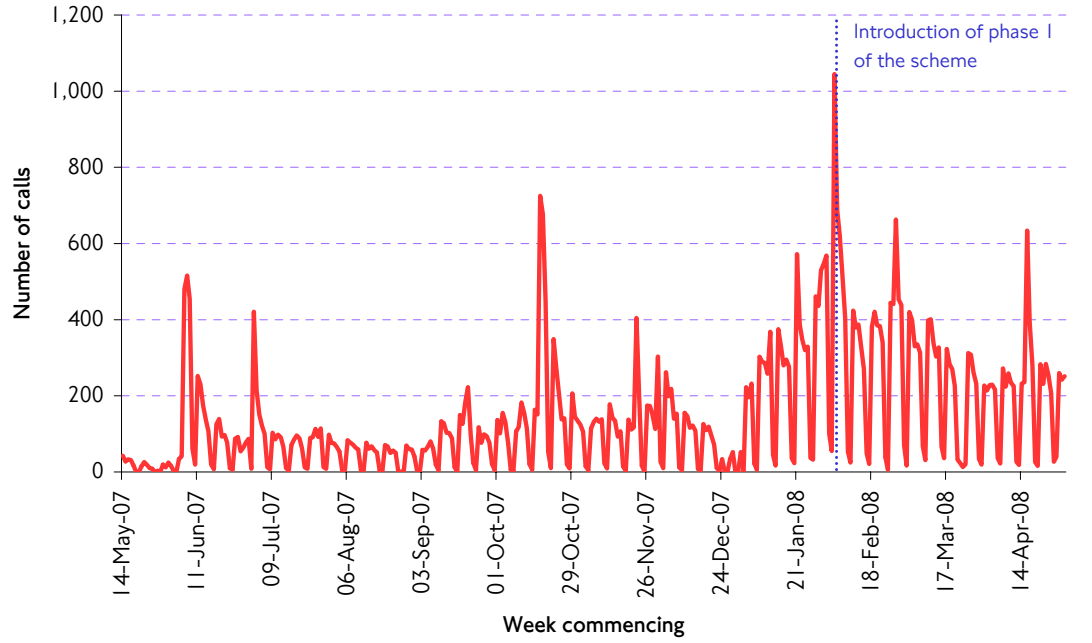
Figure 13.3 Weekly numbers of vehicles that have passed Low Emission Certificate (LEC) and Reduced Pollution Certificate (RPC) tests, up to end April 2008.



Call centre information

The call centre for the scheme started operating from May 2007 to deal with enquiries and provide information. The numbers of calls handled started to increase substantially from October 2007 (Figure 13.4) and in preparation for phase 1 of the scheme, by the start of February 2008, the call centre had handled approximately 30,000 calls, although the numbers varied considerably from day to day.

Figure 13.4 Daily calls handled by the TfL call centre for the London Low Emission Zone.

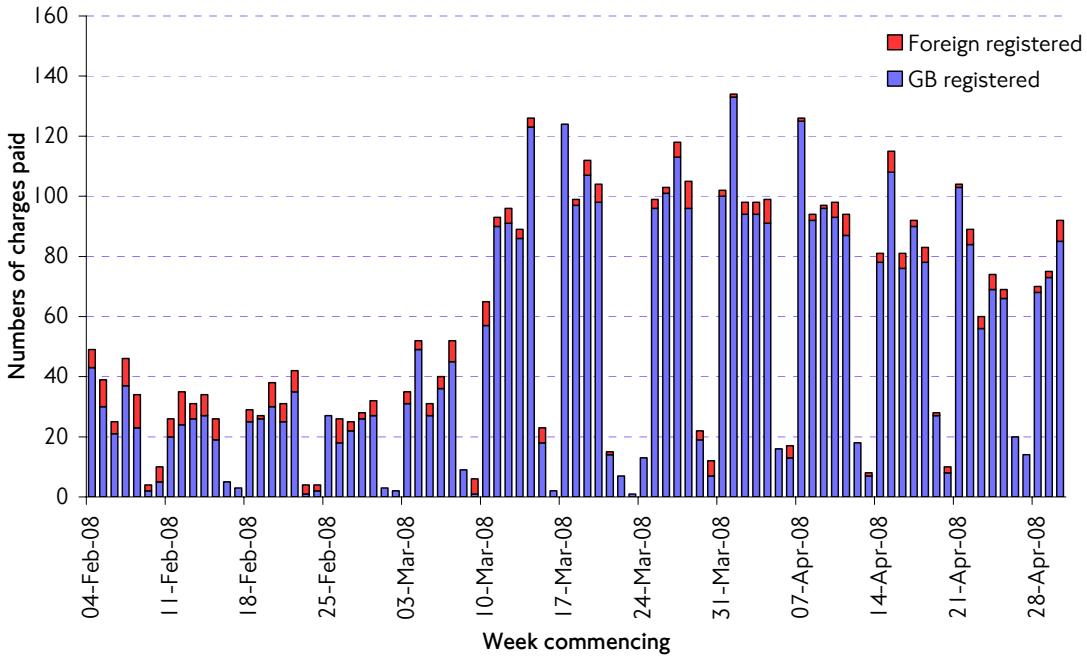


By the end of April 2008, the call centre had handled over 50,000 calls. During weekdays, around 200-400 calls are typically handled, but less than 100 are typically taken during the weekend.

Charge payments

Since the introduction of the scheme, over 4,500 charge payments in respect of the scheme have been received, over 90 percent of which were for GB registered vehicles (Figure 13.5). The majority of these charges were paid through the website (62 percent), with 38 percent of payments made through TfL's call centre.

Figure 13.5 Numbers of charges paid since implementation of phase 1 of the scheme.



Enforcement

Immediately after go-live, there was a period when TfL issued warning letters to non-compliant operators as they were first seen in the zone. These gave operators 28 days to take action to make their vehicles compliant. TfL has issued over 5,000 warning letters to UK operators and 10,000 to foreign vehicle operators. Following this initial 'grace period', TfL has now started to issue penalty charge notices for non-compliant vehicles seen in the zone, and around 4,000 had been issued by 30 April 2008.

13.4 Trends in scheme compliance

Vehicles observed by monitoring cameras

The role and function of camera based monitoring of the emissions characteristics of vehicles has been described in Section 5 of this report. For N3 heavy goods vehicles affected by phase 1 of the scheme, the level of compliance of vehicles seen by the cameras increased substantially during 2007 in anticipation of the introduction of the

scheme and the numbers have continued to increase up until 30 April 2008. Figures 13.6 and 13.7 build on Figures 5.8 and 5.9 to illustrate this continuing improvement, firstly in terms of the numbers of unique vehicles seen and, secondly, in terms of all vehicles recorded by the cameras, ie reflecting vehicle-kilometres operated. Section 5 explains these different 'views' of the London vehicle population in more detail.

Figure 13.6 Trend in scheme compliance during 2007 and into 2008. Unique vehicles, phases 1 and 2 of the scheme, ANPR camera data.

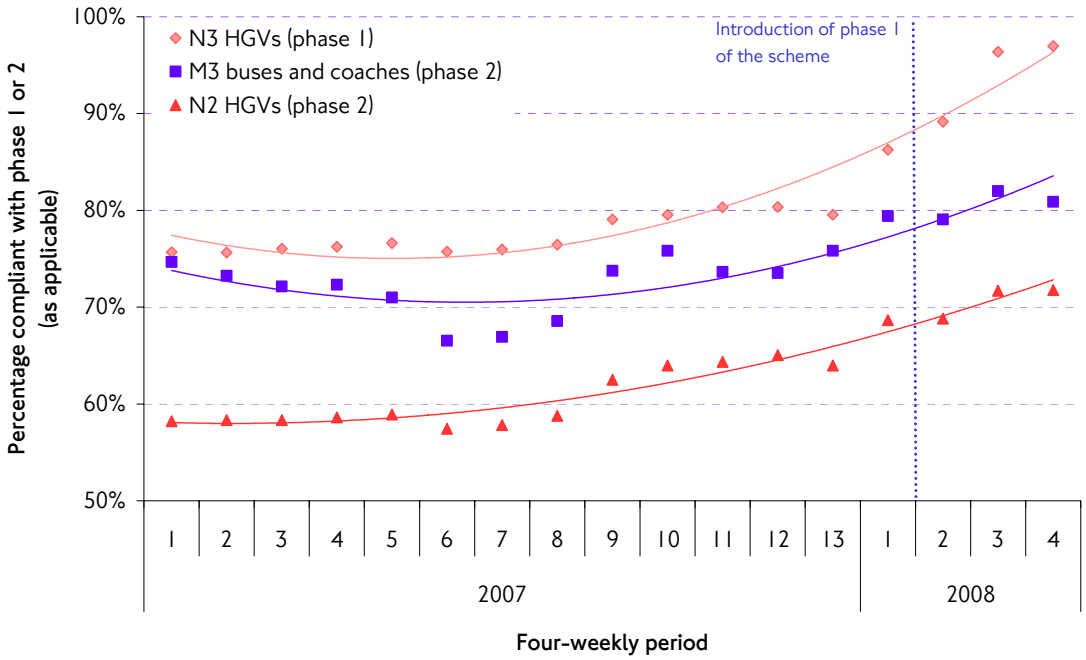


Figure 13.7 Trend in scheme compliance during 2007 and into 2008. Vehicle-kilometre based estimate, phases 1 and 2 of the scheme, ANPR camera data.

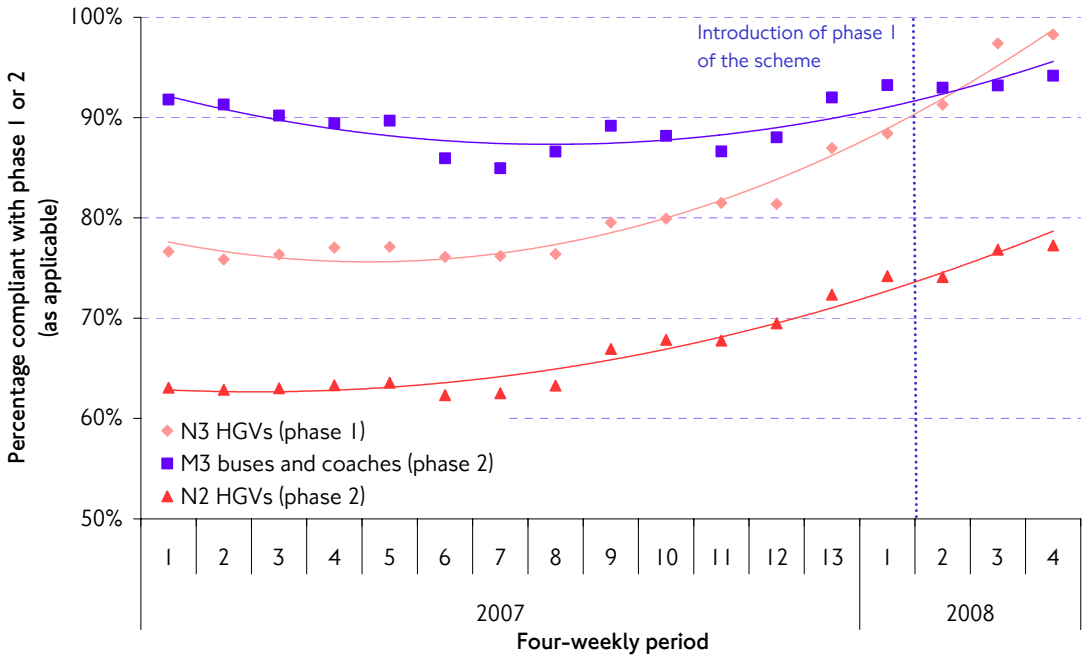


Figure 13.6, looking at unique vehicles, show that the trend towards increased compliance with the requirements of the scheme was fairly gradual for N3 heavy goods vehicles for much of 2007. However, the rate of change significantly increased from the start of 2008, reaching a level above 95 percent by the end of April 2008. The compliance rate of M3 buses and coaches and N2 heavy goods vehicles, which are included in phase 2 of the scheme, has also gradually improved over this period, and is expected to continue to do so throughout 2008.

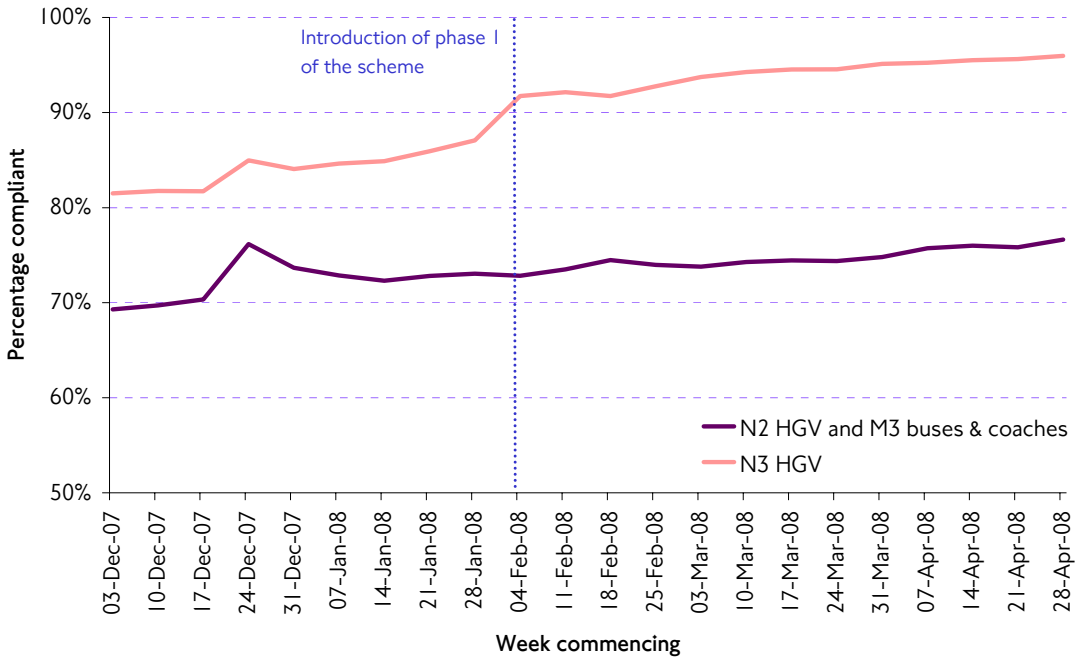
Figure 13.7 shows that when vehicle activity is taken into account, reflecting vehicle-kilometres operated in Greater London, the level of compliance is higher than the unique vehicle based view, implying that the newer (ie compliant) vehicles tend to be used more than the older vehicles. On this basis, the level of compliance among N3 heavy goods vehicles was around 98 percent in April 2008.

Looking at buses and coaches, affected by phase 2 of the scheme from July 2008, it is seen that the level of compliance on a vehicle-kilometre basis is significantly higher than on a unique vehicle basis. This reflects the predominance of the TfL London bus fleet, which is 100 percent compliant with the requirements of the scheme, among these vehicle types in London.

Estimates of compliance can also be obtained using the enforcement camera network. A larger number of vehicles are observed by this system and data is processed on a daily basis. As would be expected, these cameras give estimates of compliance that are closely comparable with those from the monitoring cameras.

Figure 13.8 shows the increasing weekly trend in compliance of unique vehicles observed by the enforcement cameras.

Figure 13.8 Proportion of compliant vehicles from the enforcement camera network.



By the end of April, the compliance rate for phase 1 of the scheme (N3 heavy goods vehicles) was up to 96 percent – compared to an equivalent estimate of 97 percent from the monitoring camera network. Note that the trend in Figure 13.8 appears to have been affected by specific conditions applying over the Christmas and New Year holiday period of 2007/08.

Vehicle registration data

The levels of compliance with the requirements of the scheme now being observed in Greater London can be compared to the compliance of all licensed vehicles in the national fleet, from DVLA registration data. Table 13.1 updates the information provided in Table 5.3 with the latest DVLA update from April 2008. This table shows that the percentage of vehicles that are compliant for phase 1 has continued to increase. However, it is apparent that even after the introduction of the scheme, compliance of N3 heavy goods vehicles is still noticeably lower for registered vehicles at the national level – at a level of 75 percent – compared to more than 95 percent in London as observed from the cameras (see Figures 13.6 and 13.7).

Table 13.1 Compliance status of national vehicle fleet, from DVLA registered vehicles.

Vehicle Type	Category	As of 23 Mar 2007	As of 01 Jun 2007	As of 01 Sep 2007	As of 30 Dec 2007	As of 22 April 08
N3 HGVs	All	293,000	290,000	295,500	295,300	295,000
	Phase 1 compliant	193,000	188,800	201,100	212,300	220,000
	Percentage compliant	65.9%	65.1%	68.1%	71.9%	74.6%
M3 buses and coaches	All	75,300	76,100	75,400	74,800	73,500
	Phase 2 compliant	30,100	29,800	31,400	33,000	33,500
	Percentage compliant	40.0%	39.1%	41.6%	44.1%	45.8%
N2 HGVs	All	241,400	287,400	234,000	234,700	233,000
	Phase 2 compliant	109,600	134,300	112,700	119,700	122,000
	Percentage compliant	45.4%	46.7%	48.2%	51.0%	52.1%

This data can be disaggregated further into those vehicles registered in London. Table 13.2 provides an update to Table 5.4, to include the new DVLA data obtained in April 2008. This table shows that between December 2007 and April 2008, the compliance rate for the N3 heavy goods vehicles that are subject to phase 1 of the scheme and registered in Greater London increased significantly from 70 to 83 percent – a significantly higher rate than in the national fleet. N2 heavy goods vehicles registered in London had a similar level of compliance compared to the national fleet but, as discussed in Section 5, M3 buses and coaches registered in London have a much higher level of compliance, similar to that observed by the cameras in London.

Table 13.2 Compliance status of vehicle fleet registered in Greater London, from DVLA registered vehicles.

Vehicle type	Category	As of 23 Mar 07	As of 01 Jun 07	As of 01 Sep 07	As of 30 Dec 07	As of 22 April 08
N3 HGVs	All	18,400	18,200	17,900	17,700	17,800
	Phase 1 compliant	10,600	10,400	10,700	12,400	14,800
	Percentage compliant	57.9%	56.9%	60.0%	69.7%	82.6%
M3 buses and coaches	All	9,900	9,900	10,000	9,900	9,700
	Phase 2 compliant	7,800	7,300	7,700	8,100	8,200
	Percentage compliant	78.8%	73.8%	77.1%	81.5%	84.3%
N2 HGVs	All	19,800	23,900	18,500	18,500	18,200
	Phase 2 compliant	8,100	10,600	8,300	9,200	9,700
	Percentage compliant	41.0%	44.1%	45.0%	49.5%	53.2%

All of this data suggest that, as intended, the Low Emission Zone scheme is having a strong beneficial and consistent impact on the emissions performance of heavier vehicles operating in Greater London. Recent camera and vehicle licensing data tend to bear out some of the inferences drawn in Section 5 of this report, particularly the 'loose' relationships between the vehicle fleet registered at the national and Greater London levels, and vehicles actually operating 'on the road' in Greater London. These are new and potentially useful findings for future air quality assessment work and policy development.

13.5 Summary

The first phase of the London Low Emission Zone scheme was successfully launched by TfL on 4 February 2008. Thorough preparation and refinement of the operational processes underlying the scheme resulted in a smooth implementation period with no significant operational problems.

Initial data on the impacts of the first phase of the scheme show a clear trend towards near complete compliance with the requirements of the scheme, by those vehicles affected by phase 1, therefore delivering air quality benefits to Londoners. Encouraging degrees of 'operator pre-compliance' with the requirements of phase 2 of the scheme (effective from July 2008) are also visible.

Table 13.3 looks at different 'views' of the population of N3 heavy goods vehicles affected by phase 1 of the scheme (as defined in Section 5.2). It shows estimates of compliance corresponding to the start of 2007, when the monitoring work for the scheme started; the end of 2007, reflecting operator pre-compliance during 2007 with the requirements of the scheme, and latest data from April 2008, reflecting settled post-implementation conditions. The fourth row of the table reflects vehicle-kilometres operated in the London Low Emission Zone by these vehicles and shows, when the limited number of exemptions and daily charge payers are allowed for, a near 100 percent compliance with the requirements of the scheme has been

achieved. The emissions and air quality benefits associated with this change are now therefore being delivered in Greater London, and the beneficial impacts of the first phase of the scheme are also being felt more widely across Great Britain.

Table 13.3 Summary of trend in compliance with phase 1 of the scheme. N3 heavy goods vehicles only. Percentage compliance with requirements of scheme.

	Spring 2007	End 2007	April 2008
National registered vehicle fleet	66	72	75
Greater London registered vehicle fleet	58	70	83
Unique vehicles observed in zone	78	86	96
Vehicle-kilometres operated in zone	**78**	**90**	**98**

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